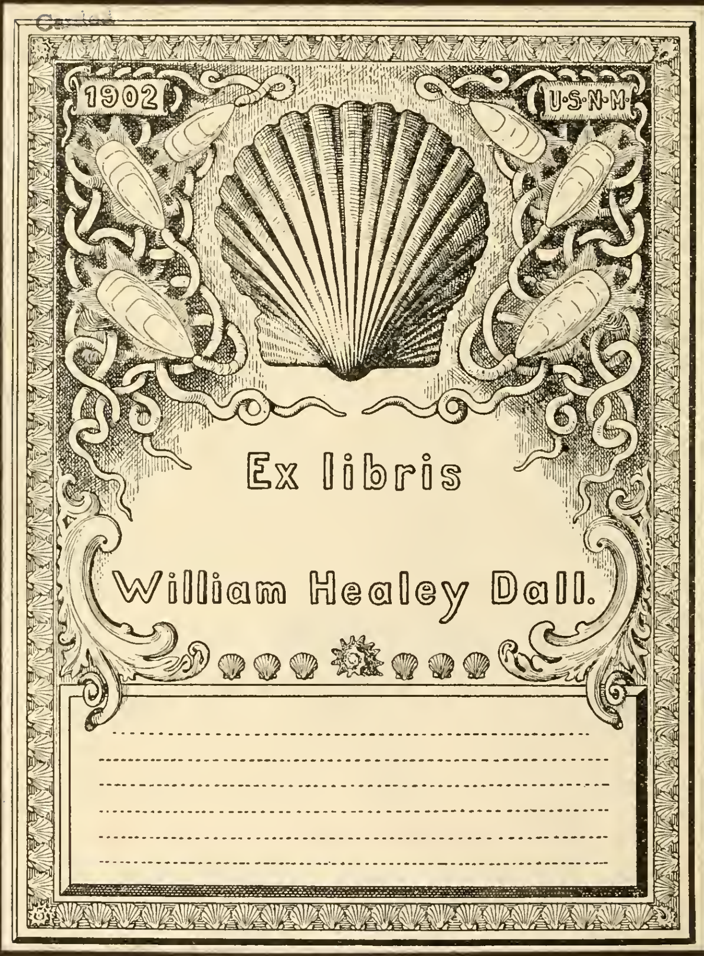
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THE GEOLOGY

OF

ENGLAND AND WALES.

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THE GEOLOGY

OF

ENGLAND AND WALES:

WITH NOTES ON THE

PHYSICAL FEATURES OF THE COUNTRY.

BY

HORACE B. WOODWARD, F.G.S.,

OF THE GEOLOGICAL SURVEY OF ENGLAND AND WALES.

Second Edition.

WITH GEOLOGICAL MAP AND ILLUSTRATIONS.

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PREFACE.

MORE than ten years have elapsed since the former edition of this book was published; in the meanwhile, such large accessions have been made to our knowledge of English and Welsh Geology, that the work has long stood in need of revision. Prompted by the kindly reception of his first attempt, the writer has devoted his leisure during the interval to the preparation of this new edition; but the endeavour to make it a worthy successor has occupied far more time than was anticipated, and its publication has therefore been delayed.

The original plan of the book has not been altered, but the volume has attained a larger size, owing to the many additions, necessary to do justice to the subject. Nor is this increase surprising when it is remembered that, sixty-five years ago, the excellent and in great measure original "Outlines of the Geology of England and Wales," by Conybeare and Phillips, filled 531 pages; and only the first part of that work was published.

The aim of the present work is to afford a book of reference, useful not only to students of the scientific aspects of the subject, but also to engineers and others interested in its practical applications. Thus the volume contains an account of the lithological characters, leading fossils, and economic products of the Stratified rocks, with notes on their method of formation, and references to the chief localities where they may be studied. Details are also given of the Eruptive and Metamorphic rocks, of Metalliferous deposits, Springs and Mineral Waters, together with some remarks on the origin of the Scenery. The object, in short, is to enumerate the principal geological facts of this country; and consequently the work differs from ordinary Text-Books of Geology, whose main purport is to impart a knowledge of the Elements and Principles of the Science as a whole. In the present edition Mr. Rutley has kindly revised his notes on the mineral characters of the Eruptive and Metamorphic rocks; while Mr. E. T. Newton has contributed a new Synopsis of the Animal Kingdom.

Owing to the additions thus made, it has been found necessary to omit a particular account of the geology of the principal lines of Railway, but many of the sections exposed along these routes have been noted in the text; moreover, the Glossary that was appended to the former edition is no longer inserted, as the various terms are now explained in the body of the work.

Differences of opinion still exist on the Nomenclature and Classification of certain strata, and as the International Geological Commission has not yet formulated any definite scheme, the classification in the previous edition has been retained, except in a few cases where a change was needed. As before, alternative groupings are stated, and, wherever possible, old and well-established names of formations are employed, while the synonyms are also mentioned. Numerous tables are given with the view of explaining more clearly the relations of the various divisions of the Stratified rocks.

An attempt has been made to give some historical value to the work by indicating the labours of the many geologists to whose observations our present knowledge is due. Thus the foot-notes are confined almost entirely to original memoirs, and they are with few exceptions the result of personal research.

Without the friendly co-operation and the sympathy of many geologists the work, however, could never have been accomplished, and the writer is under great obligations to some of them for pointing out mistakes and omissions in the former edition, and to others for revising proofs of the present one. He is more especially indebted to Prof. Bonney, Mr. Horace T. Brown, Mr. Champernowne, Mr. Goodchild, Mr. W. Gunn, Mr. P. F. Kendall, Mr. T. M. Hall, Dr. Hicks, Prof. Hughes, Prof. Hull, Mr. Jukes-Browne, Prof. Lebour, Mr. Mellard Reade, Mr. Clement Reid, Mr. Rudler, Mr. Rutley, Mr. Topley, Mr. Ussher, Mr. Whitaker, Mr. Edward Wilson, and Mr. B. B. Woodward. Many serious errors have thus been avoided; but it must be understood, at the same time, that the friends above mentioned are not responsible for any facts or opinions, unless where expressly stated, for their suggestions have not in all cases been adopted.

To the Councils of the Geological Society and of the Geologists' Association, as well as to the respective authors, the writer is indebted for permission to reproduce many illustrations published by those Societies. Dr. Henry Woodward has also kindly lent a number of blocks that have illustrated the pages of the "Geological Magazine." Several views of the Isle of Purbeck have been reproduced from etchings by Mr. Alfred Dawson. Other illustrations have been specially prepared for this new edition, including

the frontispiece, which is an autotype from a photograph taken by Mr. George Barrow. Particular acknowledgment of these and other views and sections is appended to the List of Illustrations; and there also will be found a brief explanation of the Map, the preparation of which was undertaken by Mr. Goodchild.

Some errors and omissions, observed during the preparation of the Index, have been recorded at the end of the volume (p. 612): notices of further shortcomings will be penitently and withal gratefully received by the writer.

HORACE B. WOODWARD.

60, HAMILTON ROAD, HIGHBURY PARK, N.
10th March, 1887.

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EXPLANATION OF MAP.

The Map is coloured to show the superficial extent of the principal geological systems. The Cambrian and Silurian rocks are classified according to Sedgwick, so that under the former term are included the Lower Silurian strata of Murchison, now frequently termed Ordovician. The New Red Sandstone includes the Permian and Triassic strata, and some areas previously regarded as Permian, but now believed to be stained Carboniferous rocks, are coloured in accordance with this view. Some additional areas of Pliocene strata are shown ; the Drift deposits, which cover so large an area of the Eastern, Midland, and Northern counties, are omitted, as they cannot be accurately shown on a map of so small a scale. For the same reason many Eruptive rocks are omitted. The geology is based on the published maps of the Geological Survey.

ILLUSTRATIONS.

The Etchings by Alfred Dawson were published in "A Royal Warren, or Picturesque Rambles in the Isle of Purbeck," by C. E. Robinson, 1882.

ABBREVIATIONS.

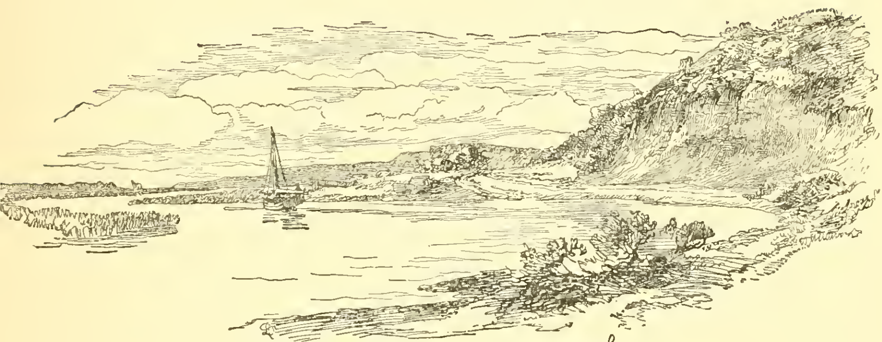
T. G. S.	*Transactions of the Geological Society of London.*
Proc. G. S.	*Proceedings of the Geological Society.*
Q. J.	*Quarterly Journal of the Geological Society.*
P. Geol. Assoc.	*Proceedings of the Geologists' Association.*
G. Mag.	*Geological Magazine.*

All Sections and Tables of Strata are given in descending order, unless otherwise stated.

GEOLOGY

OF

ENGLAND AND WALES.



On the Frome near Stoborough

INTRODUCTION.

GEOLOGY in its widest sense is the History of the Earth. It deals with the nature and origin of the rocks that form the solid ground on which we live, and with the fossil plants and animals whose remains are embedded in the rocks. It inquires into the conditions of climate and scene under which these forms of life existed, and into the character and causes of the physical changes which have occurred in the past, and which have led to the life, climate, and scenery of the present.

The science, in the first instance, is best looked at in a broad, general way. For so intimately is all knowledge linked together through the 'Unity of Nature,' that our investigations lead us by insensible gradations from Astronomy to Geology, and thence through Geography to the various subdivisions of Natural History and to the study of Man himself. And, in the words of Mr. E. A. Freeman, "He who puts together a record of the strata, and he who puts together a record of the political changes of England or of any other land, are in truth only working at different stages of one great story."[1]

In Geology, as in Human History, we desire to go back to the beginning, and here we must discriminate between fact and hypothesis, as we do between actual record and tradition. When we turn to the earliest phases of our Earth's history, or to that branch of the subject termed Cosmogony, we enter the region of hypothesis. Following Laplace, we dimly picture a nebulous mass of intensely heated gaseous matter from which, in process of time, the Solar system was developed. And we conclude that the Earth, like other planets, assumed its present form by gradual cooling, a process which led to various combinations of the elementary substances. At one time a molten sphere surrounded by vapours and gases, the crust at length became solidified; and when the temperature was sufficiently reduced, the earliest oceanic areas were formed by condensation of the steam and alkaline vapours that previously encircled the Earth. Thus the saltness of the sea to some extent dates from the earliest times, although it is partly owing to the saline matter continually carried into it by rivers.[2]

The facts of Geology enable us to discuss the changes which the Earth has undergone since the earliest divisions of land and water were marked out. But until the principles of Geology were established, the ideas concerning the Earth's past history were little more than conjecture. It was clear that various rocks or earths occurred in different areas; clay in one place, slate in another, chalk here and coal there. Organic remains known as fossils were found in them, and their resemblance to living forms was admitted; but for a long time they were thought, either to be freaks of Nature, or the products of a Universal Deluge. Thus fossils were observed by the early Greek and Roman philosophers, and, many centuries later, by other European students. In our own country, in the seventeenth century, Plot, Lhwyd, and Lister gave accounts of the 'petrifactions' known to them; while in the eighteenth century John Woodward published his celebrated "Attempt towards a Natural History of the Fossils of England" (1729), and his collection subsequently formed the nucleus of the Woodwardian Museum.

That most of the rocks are arranged in layers or strata, was

[1] Address, Somerset Arch. Soc. xxvi. 8.

[2] D. Forbes, G. Mag. 1867, p. 438; T. S. Hunt, Q. J. xv. 491. See also J. Murray (Brit. Assoc. 1885), Nature, Oct. 15, 1885, p. 583.

noticed by some early writers; but the sequence was not perceived until about the year 1788, when the Rev. John Michell recorded the general succession of strata in the Midland Counties. We are indebted, however, to William Smith, justly termed the "Father of English Geology," for the first clear definitions of our strata. In 1794 he proved that they were (many of them) continuous over large areas, that they succeeded one another in a certain order, produced similar soils, and presented marked physical features. He gradually learnt that they were characterized by fossils more or less peculiar to them, and he thus established the fact that strata could be identified in distant localities by their organic remains. He also concluded that certain strata had been in succession the bed of the sea, and that the fossils were remains of animals that had lived and died at or near the places where they are now embedded.[1]

In the mean time the philosophic deductions of Hutton (1788), subsequently illustrated by Playfair, and elaborated by Scrope, De la Beche, and Lyell, established the principles of geology, according to which the past may be interpreted by the modern changes of the earth and its inhabitants. Thus Geology has come to be regarded as the Physical Geography of past periods, and we are taught that the changes now going on are but the continuation of the Earth's ancient history.

Our first lessons, then, are to be learnt from the alterations taking place on the Earth's surface in the continual waste of land by rain, rivers, glaciers, and sea; the dispersion and deposition of the material thus removed; from the phenomena of earthquakes and volcanoes, and the rising or sinking of different areas. Further we have to consider the variations of climate at the present time, the distribution of animal and vegetable life, and the circumstances under which various organisms may become buried and preserved.

Utilizing this knowledge we find by the testimony of the rocks, that physical changes like those now affecting every portion of the Earth's surface, have been in operation in past times through similar agents; and that the solid ground on which we live is largely made up of the consolidated mud, sand, and ooze of old sea-bottoms, with the included fossilized remains of the animals and plants of successive periods.

[1] Memoir of William Smith, by John Phillips, p. 141. For a full account of the History of English Geology, and the influence exerted by Buffon, Linnæus, Cuvier, Lamarck and other Continental Naturalists, see W. H. Fitton, Phil. Mag. vols. i. and ii.; A. C. Ramsay, Passages in the History of Geology, 1848 and 1849; and Lyell's Principles of Geology, vol. i.

Although here and there over limited areas we find evidences of great and apparently abrupt physical changes, we can detect no signs of any universal catastrophe: on the contrary, through every epoch we discern a Uniformity in cause not only in the inorganic world, but also in the organic world, accompanied though it be (on the one hand) by evidences of evolution, or the gradual development, in the course of time, of higher and higher forms of life; and (on the other hand) by the local catastrophic action of earthquakes and volcanoes. In these questions we cannot of course limit our observations to the British Islands; nor must we, in concluding that the physical forces have been the same throughout geological time, suppose that their action has been always of similar intensity to that of which we have definite proof in the present. Every volcanic outburst, indeed, is a loss of energy.

Thus while the greater portion, if not the whole, of the present land has been at times submerged beneath the ocean, we cannot prove that all oceanic areas have at times been dry land. This may have been the case, notwithstanding the conclusions of recent investigators, who favour the view that the abysmal regions of the ocean have been the more permanent areas of the earth's surface.[1]

The causes of great physical changes are intimately connected with the internal structure of the earth. The Rev. O. Fisher is of opinion that it consists of a rigid nucleus, nearly approaching the size of the whole globe, covered by a fluid (molten) substratum of no great thickness compared to the radius, upon which a crust of lesser density floats in a state of equilibrium. This crust he concludes to be about twenty-five miles in thickness; and being in this unstable condition, any considerable load added to it will cause a region to sink, or any considerable amount of material removed will cause an area to rise.[2] This hypothesis helps to explain the changes of level revealed in geological history, for it indicates that the great accumulations of sediment may be one cause of the subsidence of an area, and the gradual waste of land and the transfer of the material to other tracts, one cause of the upheaval of land. At the same time we must not neglect the aid of subterranean changes, whether in active volcanic action or in the rupture of the earth's crust on shrinkage and contraction; to which causes the more important instances of elevation and depression were probably due.

[1] J. Murray (Brit. Assoc. 1885), Nature, Oct. 22, 1885, p. 613.

[2] Physics of the Earth's Crust, pp. 18, 269, 275, 286; see also Dr. C. Ricketts (who first drew prominent attention to this subject), G. Mag. 1883, pp. 302, 348.

The study of the materials and general structure of the Earth's crust is sometimes termed Geognosy, while the particular study of the rocks is termed Petrology or Lithology. Into the composition of the Earth's crust about sixty-four elementary substances are known to enter, the most important of which are Oxygen, Hydrogen, Chlorine, Carbon, Sulphur, Silicon, Calcium, Magnesium, Sodium, Potassium, Aluminium and Iron. While changes of various kinds are continually in operation, no new materials are added, with the exception of Meteoric stones and dust. Meteoric dust may include volcanic material, such as that of Krakatoa, as well as Cosmic dust. Meteorites are of interest to the geologist as affording possible evidence that the composition of the Earth's interior is to some extent metallic. It has even been suggested that they were ejected from the earth during its early volcanic phase. Twenty-four of the commoner elements in the Earth's crust have been recognized in them. Those called Siderites yield from 80 to 95 per cent. of iron; while the Siderolites and Aerolites are of a more stony character.[1]

The Rocks forming the earth's crust are arranged into four classes, according to their method of formation:—

1. Aqueous or Sedimentary Rocks (in old times known as Neptunian).—These include most rocks deposited under water, as Gravel, Sand, Clay, Shale, Marl, Limestone, etc.

2. Subaërial or Terrestrial Rocks.—These include deposits formed or accumulated on land areas, as Peat, Coal, and Blown Sand.

The rocks belonging to these two classes are usually stratified or arranged in layers; and they are fossiliferous.

3. Igneous or Eruptive Rocks (formerly termed Plutonian).—These include the rocks which have been intruded in a molten condition as bosses and dykes amidst the stratified rocks; and those which have been poured out as lava-flows or ejected as ashes from volcanic centres. They are, as a rule, crystalline, unstratified, and unfossiliferous, and include Basalt, Diorite, Trachyte, Felstone, Porphyry, and Granite.

4. Metamorphic Rocks.—These include rocks which by contact with igneous rocks, and by excessive pressure and disturbance, have undergone great alteration, so that their original character is much changed and their stratification is frequently obscured. Their structure is often schistose or foliated—the mineral components being arranged in separate layers. Quartzite, Mica-schist, Gneiss, some kinds of Marble, and Slate belong to this class.

David Forbes proposed the name *Ingenite* (signifying created within or below) for the granitic, metamorphic, and igneous rocks; and *Derivate* for all sedimentary, subaqueous, and subaërial accumulations, since directly or indirectly the latter are all derived from the destruction of the former.

There can be no doubt that the Aqueous rocks, as a rule, were formed and deposited on the ocean-bed in the same

[1] L. Fletcher, P. Geol. Assoc. vii. 351.

way as such rocks are now accumulated—the pebble-beds and sands near the shore, the clayey and marly beds further away from land, and the limestones in the deeper water. Gravel, sand and clay are likewise formed and distributed by rivers and glaciers, and all kinds of sediment may be deposited in lakes.

It may be noticed on any sea-coast where there are cliffs, how the ceaseless action of the land-springs and the breakers is ever wearing away the land. Portions of the cliffs are undermined, landslips occur, and the harder rocks that fall down are pounded up by the waves into shingle and sand. The finer matter is often carried to some distance from the shore and laid down at the bottom of the ocean ; while at a very great distance from land, the accumulations may be chiefly organic. Thus in time great deposits are formed.

Again, all rivers bear along with them much material held in suspension or solution, which has been worn away from their banks or carried into them by springs and rivulets, and this they convey to the sea or lake, as the case may be ; the heavier suspended materials naturally sinking first, and the finer or lighter particles being carried to the greater distance.

The general arrangement and characters of the Aqueous, or Sedimentary Rocks will be seen from the accompanying Table :—

Deposits.	*When indurated or compacted.*	*Lithological Constitution or chief Mineral Ingredients.*	*Altered or Metamorphosed.*
Gravel	Breccia or Conglomerate.	Angular, sub-angular, and rolled fragments of quartz, quartzite, sandstone, flint, limestone, etc.	Greywacke and Quartzite.
Shingle and Pebble-beds	Conglomerate & Puddingstone	Pebbles and sub-angular fragments of similar hard rocks.	
Sand	Grit	Coarse grains of quartz, etc., cemented by siliceous, calcareous or ferruginous matter.	
	Sandstone	Fine grains of quartz, etc., cemented by similar material.	
Loam or Brickearth	Mudstone	Clay and much Sand.	Hornstone and Slate.
Clay	Shale	Clay (Hydrated silicate of alumina) and sand.	
Marl	Marlstone	Clay with carbonate of lime : or Argillaceous limestone.	Marble.
Calcareous Mud or Ooze	Limestone	Carbonate of lime (chiefly).	

The term Psammitic (from *psammos*, sand) has been applied to sandy rocks and hard quartzose sandstones; and Pelitic or Pelolithic (from *pelos*, clay) to the muddy and clayey deposits.

The term Greywacke was formerly applied to the older Primary rocks. Any limestone and some other rocks of ornamental character, such as Alabaster, Serpentine, etc., if capable of being polished, are popularly known as Marble.

The Aqueous or Sedimentary and Subaërial Rocks may be again classified, according to their method of formation, as follows:—

1. *Mechanically formed* (Clastic, Fragmental or Detrital Rocks):—Gravel, Sand, Conglomerate, Breccia, Silt (fine sandy mud), Clay, Shale, Loam, Marl, and some Limestones.

2. *Chemically formed*:—Ironstone and Cement-stone Nodules, Septaria,[1] Rock-salt, Alabaster or Gypsum, Tufa, Chert and Flint (in part), Dolomite, and some Limestones.

3. *Organically formed*:—Peat, Lignite, Coal, Chert and Flint (in part), and most Limestones.

In all attempts to classify the rocks, we find that hard lines of separation do not exist, as many agencies work together in their formation. Nor in the matter of names can we be always precise, for the rocks pass one into the other; clay into loam or marl, and these into sandstone or limestone; and we may often hesitate whether to term a rock calcareous sandstone or sandy limestone. As Sedgwick long ago exclaimed, "How impossible it is for us to constrain the vast and complicated operations of Nature by the fetters of a rigid definition!"

Moreover deposits formed by chemical action may be mingled with organic remains and mechanically formed sediment. Coal and other beds formed organically have been modified by chemical action. Some limestones may have resulted from the destruction of older calcareous rocks, having been formed from material carried in suspension in water, and ultimately deposited as a sediment in lake or sea; while others may be due to precipitation from water holding bi-carbonate of lime in solution. Limestones may also be composed in great part of the minute calcareous tests of Foraminifera, or of the shells or comminuted fragments of other organisms; or they may be largely due to the secretion of carbonate of lime by Corals. These rocks may be termed of organic origin. But Darwin has observed that in recent coral formations the quantity of stone converted into impalpable mud by the excavations

[1] These are nodules of argillaceous limestone or clay-ironstone, divided by septa or cracks filled with mineral matter, usually calc-spar.

of boring-animals is very great; besides which numerous fishes subsist by browsing on the living branches of coral.[1]

Again, the siliceous matter in beds of chert and in nodules of flint may be due in the first instances to the accumulation of organisms having siliceous structures, but the formation of the beds and nodules themselves is evidently due to inorganic agency. Both flint and chert are formed in rocks of marine and freshwater origin, by the indirect agency of plants and animals.

Deposits of very varied origin may be commingled in the neighbourhood of active Volcanoes, the ashes from which are frequently carried to great distances, and may be deposited on the ocean-bed as a sedimentary deposit, together with organic and other accumulations.

To turn to the subject of Igneous rocks, we find that although a study of the volcanic phenomena that are presented to our view at the present day throws considerable light on their former history, yet our opportunities of observation are necessarily limited to the rocks now thrown up at the surface. On the other hand, many of the old igneous rocks, belonging to the various geological epochs, have evidently been formed or intruded at a depth below the surface, and have perhaps never appeared in the light of day, until comparatively recent times, when disturbances and denudation have together assisted to reveal them. The volcanic action of the present day, however, that may be witnessed in different parts of the world, enables us to explain the origin of most of our igneous rocks, and to demonstrate the former presence in Britain of centres of eruption.

Igneous rocks are of all ages, and occur as bosses and dykes bursting through and penetrating the stratified rocks. Sometimes they have flowed over a surface upon which other beds were afterwards deposited, so that they are intercalated with these rocks; at other times they have forced their way between already hardened beds, and given a false appearance of contemporaneity.

Rocks, too, which were once deposited under water, have in part or entirely lost their original stratified character, and become altered or metamorphosed. This may result from great mechanical disturbance, and from molecular or purely chemical changes, due to contact with igneous rocks, and the influence of heated waters, and attended perhaps by the loss or addition of certain elements. Igneous rocks may also be metamorphosed. All rocks, indeed, are in

[1] Proc. G. S. ii. 576.

in one sense metamorphic, as all have undergone some changes, however trifling they may be, since their formation; but they are not properly termed metamorphic unless their original structure is much obscured. At the same time, it is a remarkable fact that in many regions we find an alternation of rocks highly metamorphosed with others that have suffered comparatively little change.[1]

The stratified rocks generally contain remains of the plants and animals which existed at the time of their formation. Of the latter the most conspicuous are the hard parts of Mollusca, Crustacea, stony Corals, and Sea-urchins, and the bones and teeth of Fishes, Reptiles and Mammals. These are termed fossils. The rocks are also liable to contain the organic remains of pre-existing periods, just in the same way as fossils are often found mingled with the recent shells in our present shore-deposits. These derived fossils are often spoken of as *Remaniés.* They may frequently be detected by their rolled or fragmentary condition, by being accompanied by a portion of the matrix of the rock in which they were first embedded, or by their occurring in pebbles. The fossils found in the Triassic pebble-bed of Budleigh Salterton furnish a remarkable instance of derived fossils; and it has been questioned whether the parent rocks of some of them are represented in England. The shells found in the "Box stones" at the base of the Crag in Suffolk belong to an earlier Pliocene period, which is not known for certain to be represented in our country. These are examples of "the Fragmentary strata of England."

The fossils proper to a formation furnish us with a key to its age, and the mode of its accumulation, whether by fresh-water, estuarine, or marine agencies. In identifying a deposit by its organic remains, it must, however, be borne in mind that not only do the sedimentary conditions of one period vary in different places, but that the forms of life whose existence depends largely upon the conditions, likewise vary in different localities. "Distinct faunas may be separated by narrow barriers in existing seas; and differences almost as great may occur on the same coast-line without the interposition of any barrier, merely in passing from a sea-bed of rock and weed to one of sand or mud, or to a zone of different depth. It would be unreasonable to expect the same fossils in a limestone as in a sandstone; and even in comparing similar strata we must consider the probability of their

[1] J. J. Bigsby, Edin. New Phil. Journ. (2), April, 1863; and J. C. Ward, Q. J. xxxii. 30. See also 'The Study of Rocks,' by Frank Rutley, 1879.

having been formed at different depths, or in distinct zoological provinces."[1] Further, in studying the fossils of any particular formation, we must expect an admixture of marine forms that could not have existed together in the same depth of water, as forms which frequent shallow water would sometimes be drifted into deeper sea, and animals belonging to the deeper sea are occasionally washed on shore.

Bivalve Mollusca embedded in their natural positions are important guides in ascertaining the depth of water during the deposit of a stratum. So also may be the occurrence of footprints of animals, their tracks or burrows, the impressions of rain-drops, ripple-marks, sun-cracks, or false-bedding. Nevertheless, deposits that originally contained many fossils have sometimes lost all traces of organic remains by chemical agency.[2]

The rocks of England and Wales belong mostly to the Sedimentary or Stratified group, and they constitute a series, of which the subdivisions are distinguished by certain prominent lithological characters, and often by the presence of particular fossils. Moreover, the newer the rocks in which these organic remains are embedded, the more closely are the fossils allied to the forms of life now in existence—a doctrine first taught by Werner. It is true that we have clay, limestone and marl, sandstone, sand and conglomerate, intercalated one with another, at all horizons in this great series; but the sequence of the groups of rocks has been clearly established by observation. The relations of the different strata may be seen in many cliffs, in quarries, brickyards and railway-cuttings;[3] while the order is confirmed by the records of deep mines and wells. When such evidence is wanting in particular districts, the stratigraphical position of the rocks may be determined by tracing out their extension across country, and noticing their relation to the form of the ground; when it will be perceived that the lithological characters of the rocks exercise a marked influence on the scenery, and in ascending a hill the soils, springs, and vegetation may indicate the superposition of distinct strata. Observations of this

[1] See the *Manual of Mollusca*, by S. P. Woodward, p. 410; and J. Morris, P. Geol. Assoc. v. 198.

[2] See remarks on the dissolution of shells from sand, by W. Whitaker, Q. J. xxxiii. 122; and on disappearance of fossils from clays, by Dr. P. M. Duncan, *Ibid.* xxii. 12. See also H. C. Sorby, Address to Geol. Soc. 1879, p. 65.

[3] The term Section in Geology is applied to any artificial excavation, boring or cutting, or natural cliff or bank, in which some geological stratum or set of strata has been exposed or proved.

nature long ago attracted the attention of William Smith; and as early as 1822, the Rev. W. D. Conybeare remarked—

"If we suppose an intelligent traveller taking his departure from our metropolis, to make from that point several successive journeys to various parts of the island, for instance to South Wales, or to North Wales, or to Cumberland, or to Northumberland, he cannot fail to notice (if he pays any attention to the physical geography of the country through which he passes) that before he arrives at the district in which coal is found, he will first pass a tract of clay and sand [Eocene, etc.]; then another of chalk; that he will next observe numerous quarries of the calcareous freestone [Oolites] employed in architecture; that he will afterwards pass a broad zone of red marly sand; and beyond this will find himself in the midst of coal mines and iron furnaces. This order he will find to be invariably the same, whichever of the routes above indicated he pursues; and if he proceeds further, he will perceive that near the limits of the coal-fields he will generally observe hills of the same kind of compact limestone [Carboniferous Limestone], affording grey and dark marbles, and abounding in mines of lead and zinc; and at a yet greater distance, mountainous tracts in which roofing slate abounds [Silurian and Cambrian], and the mines are yet more valuable; and lastly, he will often find, surrounded by these slaty tracts [Devonian, etc.], central groups of granitic rocks." [1]

It is this regular order which enables us to form our tables of strata, showing the oldest known rocks to be the Archæan and Cambrian, and the newest the Alluvial deposits of our rivers and the Beaches along our coasts.

This order is, however, nowhere absolutely complete. We find, as a rule, that the older the rocks, the more wild, rugged, and mountainous is the nature of the ground they occupy; for these rocks have often been elevated to form land for long periods, while around them were forming newer deposits, which indeed were made up to a large extent from their destruction. And throughout all time, while deposits have been forming very much as they do now in limited areas, these areas have many of them changed again and again from dry land to water, and *vice versâ*. The deposits have been upheaved, and partly worn away or denuded; other strata have afterwards been spread over their worn surfaces; and thus, although there is regularity, the series is here and there marked by the local absence of some of its members. Where denudation has taken place before the newer strata were laid down, the deposits are said to be *unconformable*, and this

[1] Outlines of the Geology of England and Wales (1822), p. ii.

feature is a sure indication of a lapse of time. In other instances we find certain strata overlapping the margins of deposits previously formed, so as entirely to conceal them over large tracts. Thus there is much uncertainty in the distribution of the strata, but their order is never inverted except in some rare cases of disturbance, and then, as a rule, only over a small area. The older rocks are often at the surface where the newer have either never been deposited upon them, or have been subsequently denuded. Consequently in coal-mining, it is always easy for a geologist to say that coal *cannot* be found where the rock at the surface is older than the Coal-measures, but it requires much consideration to say where it *might* be found, and if so at what depth, when newer rocks are at the surface. (See Figs. 23 and 24.)

When we come to take the estimated thickness of the known strata, and this is from 80,000 to 100,000 feet, and compare it with what we know of the earth's crust through the deepest boring, which is little over one mile in extent,[1] we at once discern what changes, denudations, and dislocations the crust has undergone, by means of which the older rocks are brought to the surface. For it may be safely assumed that all the beds were originally deposited in an approximately horizontal position, and that any considerable deviation from this, such as is often exhibited by the planes of bedding, is due to subsequent disturbance.

The study of the formation, alteration, and disturbances of the rocks is termed Dynamical Geology.

The 'lie,' or general inclination of the strata is called the *Dip*.

The Strike is the line of outcrop of beds along a level surface; it is the line of greatest upheaval. In England the Secondary and Tertiary beds dip generally to the south-east, consequently the strike is north-east and south-west. In tracing the boundary-line of a formation belonging to a conformable series, as the Carboniferous or Secondary strata, the dip is a constant guide. Where this takes a low angle of 2° or 3°, a very small irregularity in the ground, a gentle hollow, may cause the boundary between two divisions to run a long way from the line of strike; whereas, with a high dip, the lower beds would extend but a short distance even in a deep valley or ravine. The edges of a formation, exposed by denudation, are termed its *outcrop* or *basset*.

While observing the general direction or dip of the beds, care

[1] Boring at Sperenberg, near Berlin, 4172 feet; at Potsdam, Missouri, 5500 feet, *Colliery Guardian*, March 10, 1876; at Homewood, Pennsylvania, 6000 feet! *Athenæum*, Nov. 21, 1885.

must be taken to discriminate between this and '*Slaty cleavage*,' which often intersects the Palæozoic strata at all angles, and is a phenomenon produced by "viscous shearing" or by great lateral pressure subsequent to the consolidation of the beds.[1] Jukes has observed that if the beds undulate while the dip of the cleavage is steady, and if the substance of the slate be very homogeneous, it may easily happen that the stratification is only well shown when it has a given relation to the cleavage; when, for instance, they coincide, or when they are at right angles to each other, or when they cross at some other angle, so that the particular mark of stratification which the kind of slate possesses shall be least obscured by the cleavage.

To determine the true dip when the beds are affected by 'cleavage,' lines of organic remains, and flaggy or gritty bands must be looked for; sometimes this may be done by evidence of what Sedgwick called the 'stripe,' which consists of bands of different colour, whether grey, purple, or green, which run through the slaty rocks and indicate different layers of mineral matter.[2] In rare cases, disturbances seem to have contorted the cleavage planes.

Bedding is the term applied to marked lines of stratification which separate the rock into more or less distinct layers from a few inches to a foot and more in thickness, and probably indicate slight pauses in deposition. *Lamination*, which is most conspicuous in clays and shales, is applied to the splitting of rocks into thin films, which are in many cases the original layers of deposition. Paper-shale is very finely laminated. In some cases we find rapid alternations of sand and clay. *Joints* are produced by shrinkage, and sometimes by disturbance. They are cracks which occur generally at right angles to the bedding; and when enlarged by the action of water, they are converted into fissures. Sometimes joints may occur as irregular divisional planes, simulating false-bedding. These "Rift-joints" may also be due to contraction and shrinkage.[3]

False-bedding or *Oblique lamination* is a feature produced in shallow water by currents and tidal action, whereby beds are heaped up in irregular layers without any approach to horizontality or continuity. Minute false-bedding is seen in Sandstones and Oolites; and more conspicuous wedge-shaped bedding is often seen in the same rocks.

The term *Foliation* is applied to the arrangement of mineral matter in alternate layers of different composition; and is characteristic of metamorphic rocks. (See p. 5.)

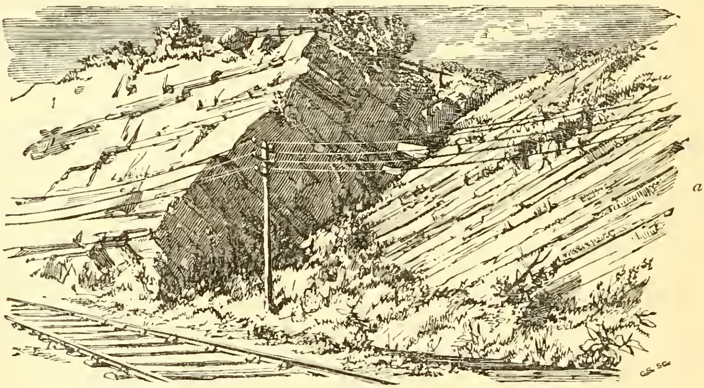
Terminal curvature is applied to the local and superficial disturbance of shaly and slaty rocks whereby the beds (or their cleavage planes) are bent over and present an opposite direction in dip to the beds below. In some instances it is traceable to the action of

[1] See O. Fisher, G. Mag. 1884, p. 276, 1885, p. 174.
[2] T. G. S. (2), iii. 473.
[3] See J. G. Goodchild, G. Mag. 1883, p. 398; and H. C. Sorby, Address to Geol. Soc. 1880.

the weather, and particularly of frosts, while in others the appearances may be caused by the roots of trees; again, many cases seem to require some more powerful disturbing cause, and are suggestive of glacial action. It is of course necessary to distinguish these from any original disturbances which may have affected the beds. (See Fig. 18.)

Faults are disturbances in the strata whereby older rocks, or older beds of the same formation, are brought into abrupt contact with newer. They are fractures in the earth's crust attended by the upheaval of one side of the ground and the downthrow of the other; the amount of the shifting is termed the throw, and the dip or direction underground of the line of disturbance is its hade. The hade is generally in the direction of the downthrow. Care must be taken not to confound faults with unconformities, where a newer set of strata abut on a cliff of older rocks against which they

FIG. 2.—CUTTING NEAR UPHILL (BRISTOL AND EXETER RAILWAY).[1]



b Carboniferous Limestone, faulted against, *a*. Lower Lias.

were deposited. This may, however, be proved by the sedimentary nature of the newer deposit, which would probably exhibit conglomeratic conditions.

Faults generally approach a straight line in the direction they take, although of course they are much modified in their superficial outline by the shape of the ground and the amount of the hade. The material filling a fault is sometimes termed the 'clog' or 'Fault rock'; this of course varies according to the nature of the rocks affected, being either clay, rubble or breccia. In many instances Faults have become the receptacles for mineral matter.

Reversed faults are so termed when the dislocated beds overlap

[1] This woodcut should represent the cutting on the eastern side of the railway, but unfortunately the drawing was not reversed on the block.

one another; that is to say, supposing the hade of a fault to be in an easterly direction, then if the beds are upraised on the east, instead, as would usually be the case, of being thrown down on that side, this would be a reversed fault. Nevertheless it is not always easy or possible to determine in a small section if an apparently reversed fault is really so, for the reversed hade may be merely an irregularity in the hade of an ordinary fault. (See Fig. 2.)

The walls of a fault are sometimes grooved or striated by the friction attending the disturbance which produced it: these features are known as '*slickensides*.' In limestones the groovings are often obscured by a stalactitic coating of carbonate of lime.[1]

One of the largest and most important faults in England and Wales is the Pennine Fault, which commences in the south of Scotland, and runs southwards to near Brough in Westmoreland. On the eastern side Carboniferous rocks, and even Cambrian (Ordovician) strata are brought against the Permian rocks on the west, with a maximum throw estimated at from 6000 to 7000 feet. The fault continues by Kirkby Stephen to near Kirkby Lonsdale, where it was termed the Craven fault by Sedgwick. He observes, "It crosses my native valley of Dent about half a mile below the village, dislocating and setting on edge all the lower limestone beds. These 'edge-beds,' well known to all the quarrymen of the neighbourhood, greatly affect the external features of the country through which they pass."[2] (See Fig. 25.)

The Tynedale fault, known also as the 'Ninety-fathom dyke,' in the Newcastle Coal-field, is so termed because the same beds are sometimes ninety fathoms lower on the northern than on the southern side of the fault; the amount of the downthrow is at other times much greater. On the east side of the Vale of Clwyd the Silurian rocks are faulted against the Bunter Sandstone with a throw of not less than 1200 feet. (See Fig. 3.)

The Radstock slide-fault in the Somersetshire Coal district is a curious example of beds faulted in a nearly horizontal position, for it has thrust the upper portion of the Radstock series over the lower half, back from the direction of the Mendips northward, for a distance of from 50 to 350 yards. It is a reversed fault.

Sometimes in the neighbourhood of a fault the beds exhibit an attenuation. In contrast to this attenuation are what are termed '*wants*' in strata, which consist of interrupted (broken, not nodular) bands of hard rock in a clayey or shaly formation. In the former case the facts might lead to the supposition that the disturbance took place before the beds were thoroughly consolidated, but the experiments made by Mr. L. C. Miall tend to show that most rocks are both elastic and plastic, when subjected to long-continued pressures or strains of low intensity. The 'wants,' on the other hand, would indicate a more sudden strain, the hard bands indicating the tension by separation, whilst the clayey beds, as Mr. R.

[1] G. V. Du Noyer, Geologist, iii. 38.
[2] Q J. viii. 36; T.G.S. (2), iv. 60, 69; Phillips, *Ibid.* iii. 5.

L. Jack has pointed out, do not lose their continuity.[1] The *Cleat* of a coal-seam, is a term applied to interrupted layers of coal separated by shales, and may be caused by fracture.

When one formation succeeds another, and extends over its margin, this is called *Overlap*, and is no doubt due to the sinking of the area of deposition. A good example of this occurs in the Mendip country, where the Lias overlaps the Penarth Beds. (See Fig. 24.) Where, however, one formation stretches over the outcrop of a series of strata, this is an unconformable overlap or *overstep*: and this is the case where the Chalk and Greensand stretch across the outcrops of the Lower Secondary strata in Dorset and Devon.

The strata are sometimes disturbed and bent into folds: the basins or troughs of these undulations are known as *synclinals*, the saddles or ridges are *anticlinals*. When the strata are very rapidly and irregularly folded, they are said to be *contorted*.

The Pennine anticlinal, the Mendip anticlinal and the Weymouth anticlinal are familiar exhibitions of this kind of structure. The Merioneth anticlinal, described by Sedgwick, brings up Arenig, Tremadoc, and older rocks on the south-east side of Snowdon, while the fossiliferous Bala strata of that mountain occupy a synclinal.[2] The structure of the London Basin is also an example of a synclinal.

Sometimes beds are found to be actually folded over or *inverted*. On the northern side of the Mendip Hills the Coal-measures are so much disturbed, faulted, and contorted that the same coal-seam has been penetrated three times in one shaft. The most interesting features in connection with these disturbances are the little masses of Carboniferous Limestone which at Luckington and Vobster occur in the midst of the Coal-district, and beneath which in places coal has been worked. The position of these masses seems to be due to a complicated system of inversion and faulting.

Prof. Phillips has pointed out that in the Abberley district there is an anticlinal of Aymestry rock which has the singular character of being folded or bent on an axal plane dipping to the east, so that the Ludlow rocks overlie the Old Red beds, while on the east the ridge of Wenlock Limestone is seen dipping in the same direction, as if it were a superior stratum.[3]

The rocks are divided into numerous groups, and systems, and minor subdivisions, all of which, when looked at in a large way, are seen to be merely terms of convenience, for the ancient history of the earth, so far as we know it, like the 'Short History of Our Own Times,' shows a sequence of events uninterrupted by any universal physical break. And

[1] G. Mag. 1869, p. 505, 1871, p. 388.

[2] See Phil. Mag. (4), viii. 125; and A. C. Ramsay, Geology of North Wales, Edit. 2, Plate 28, Sec. 3. See also Figs, 20, 21, 24, etc., of the present work.

[3] Mem. Geol. Survey, Vol. ii. Part I. p. 151.

although, when we find one rock deposited on the eroded surface or upturned edges of another of a much older date, we infer a considerable break in time between the two, yet by looking elsewhere, the missing formations may frequently be discovered. While the British Islands, and even England and Wales, are not without breaks in the succession of rocks comprised within their limits, still they present a very full record of the periods embraced in the history of the earth's crust, and so far as we know furnish a more complete account than does any other tract of similar extent. No doubt our islands have been more carefully and thoroughly investigated than other portions of land; but the fulness of the record has given great impulse to the study of Geology, and depends on the succession of the strata, and the rarity of great breaks, studied together with the succession of organic remains. Moreover, the physical history of Britain proves that it has been more subject to great changes of level than many other portions of the Earth's surface.

Nevertheless, it must always be remembered that the geological history of England is not the geological history of the world, any more than the history of the English people is the history of all nations. So long as we base our conclusions on the evidence of changes now in operation, we cannot expect that those which affected England and Wales should have been accompanied by similar changes over a large extent of the earth's surface. Our coal-bearing period was not a coal-bearing period all over the world; nor is it likely, except perhaps in the earliest geological periods, that the organic species found in our rocks existed over wider areas than do the forms now living around our coasts, and in other regions.

In order to establish uniformity in the use of the names applied to the strata, the International Geological Commission has recommended the adoption of terms in the following order, the most comprehensive being placed first: —

Divisions of sedimentary formations.[1]	*Corresponding chronological terms.*
1. Group.	1. Era.
2. System.	2. Period.
3. Series.	3. Epoch.
4. Stage.	4. Age.

According to this scheme, we should speak of the Palæozoic Group or Era, the Silurian System or Period, the Ludlow Series or Epoch, and the Aymestry Stage or Age.

[1] The term Stromatology has sometimes been applied to the history of the stratified rocks.

The term Formation, as defined by Lyell, means an assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we may speak, by way of contrast, of stratified and unstratified formations, and in like manner of freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

The term Cycle has also been applied to the three great divisions in time of Palæozoic, Mesozoic, and Cænozoic.

No particular restriction can be given to the use of the terms Beds, Rocks, Strata, and Deposits. In many cases, however, it is more convenient to use the term Beds than one indicating a particular lithological character, such as Thanet Beds instead of Thanet Sand; but in other cases, such terms as Red Crag, Oxford Clay, and Old Red Sandstone are so generally used that they are preferred.

It is evident that a deposit will be subject to variation according to the conditions of the area in which it was formed; changing just as any marine or freshwater accumulation changes at the present day from sand to shingle or mud. Conglomerates, for instance, may occur at all horizons on or near the margin of a series: as in the case of the Trias.[1] Hence were our marine formations complete, so far as they were originally deposited, we might expect to find evidence of shore accumulations in all cases as well as the deposits of deeper water. The results of denudation, and the limited areas over which many formations are exposed, prevent our seeing more than a portion of each. So that when we speak of one formation representing deep-water conditions, and another shallow-water or terrestrial conditions, it must be remembered that the records only of particular areas in the physical history of each formation are, as a rule, presented to our view. It is generally admitted that no good classification of strata can be made until the sequence of rocks has been ascertained; that "to begin with fossils, before the physical groups are determined, and through them to establish the nomenclature of a system, would be to invert the whole logic of geology, and could produce nothing but confusion and incongruity of language."[2] And yet the history of geological research proves how impossible it is to select any one locality as "typical." The rocks change, and the assemblages of fossils change also. Strictly speaking the names of our formations should be the expression of certain physical conditions; but as these conditions were, in all probability,

[1] See remarks on conglomerates by A. Geikie, Q.J. xxxix. 305.
[2] Sedgwick, Q.J. viii. 7.

seldom begun, continued and ended uniformly over wide areas, we find that a formation based on such considerations cannot always be definitely distinguished.

Even in England the term Gault is generally understood to refer to the *clayey* beds that occur between the Upper and Lower Greensand, but the Gault may not be persistent as a clayey stratum everywhere at this horizon : for instance, at the Blackdown Hills in Devonshire it may be represented in part by sand. It would, however, tend to produce confusion in our geological tables were we to designate a certain part of the Blackdown Greensand as "Gault." Where the Kimeridge and Oxford clays come together without the intervention of the Corallian series, we might identify portions of the clay as probably synchronous with the absent limestones and sands, but it would obviously be absurd to term portions of the clay "Coral Rag." Our minor geological terms must be applied essentially to lithological divisions, for these only can be represented on geological maps.

At the present day much attention is paid to minute palæontological divisions, and to assemblages of fossils or *zones*, to which a name is given according to the occurrence of some prominent species. These zones are most useful in indicating the succession of life, but they are, as a rule, irregular in their limits. The term *Horizon* is used to designate the particular level or position at which a certain stratum or fossil may occur in a formation.

In classifying and correlating different deposits there are many circumstances to be taken into consideration, and it will be seen that, in comparing the formations of countries far apart, it is often impossible to prove contemporaneity, and that the term 'homotaxial,' used by Prof. Huxley, is more convenient to express similar relative position without necessarily meaning identical age.[1]

Although, in the following pages, descriptions of each formation will be given, it must be borne in mind that such descriptions refer only to the main or characteristic lithological features. Hand-specimens might be collected which would be characteristic of each formation, and yet specimens might be brought together of Silurian, Carboniferous, and Lias Limestones, which would seem identical in character ; or of Lias Clay, Oxford Clay, and Kimeridge Clay, which could not be distinguished ; or of Old Red Sandstone, Coal-measure Sandstone, and New Red Sandstone of very similar composition.

The life-history of each formation tells of a plan which

[1] Address to Geol. Soc. 1862 ; see also H. G. Seeley, Ann. Nat. Hist. Dec. 1867.

as yet we can only dimly picture: that there is a succession in the forms of life, as we ascend the geological scale. Higher and higher organisms appear, and yet the lower forms, although generally much modified, remain; while also the very lowest types continue to exist, and range through vast intervals of time, sometimes with but little variation. Different forms were suited to the ever-varying physical conditions. As these conditions altered, some species died out, and others migrated to more favourable areas, to be replaced by new forms; while those species remained which were fitted to endure the change. Varieties may thus have profited largely by the altered circumstances, and would doubtless be perpetuated and multiplied, well illustrating the doctrine which teaches the 'survival of the fittest in the struggle for existence.' Not the least interesting part of Geology is the light thrown on the present geographical distribution of plants and animals, by a study of the physical changes which the earth's surface has undergone in past times.[1]

The study of Fossils, or Palæontology, is thus intimately connected with Zoology and Botany, for the recent forms enable us to judge what were the habits of the extinct, while only by a study of the fossil forms can we expect to explain the origin or development of the living.

In interpreting the climates of the past from the organic remains found in the strata, we must of course be cautious in considering that the genera were adapted to the same climates in which they now flourish, for the variations of species may have enabled them to endure different climates. Until the woolly-haired Elephant and Rhinoceros were found embedded in the ice of Siberia, we had no notion that animals of their kind could withstand the rigours of an arctic climate. And as only the bones and shells and other hard parts of animals are, as a rule, preserved to us in the rocks, we cannot always safely assume that they were adapted to precisely the same conditions as their modern representatives. But of course we have also the evidence of plant-remains, and when we find associated, forms of life whose modern representatives co-exist only under certain conditions, the inferences that may be drawn are fair and legitimate, even if not in all cases absolutely conclusive.

Climate is the result of influences that belong to the world in general, even to the Solar system. And we know, by

[1] Darwin, 'Origin of Species'; A. R. Wallace, Geographical Distribution of Animals; J. Phillips, Life on the Earth, 1860.

inference, that in the course of geological ages the climate of the British area has changed again and again, so that this limited tract has probably witnessed as many variations of climate, and scene, as are now distributed over the face of the globe.

Dr. J. Croll regards changes of climate as due in the main to cosmical causes, in other words, to gradual variations in the excentricity of the earth's orbit. By such means physical agencies that affect climate are brought into operation, and among these, the most important would be the deflection of Ocean currents.[1] Of course, when we realize that the orbit of our earth does vary, and that the Sun itself is travelling around some far-distant and at present undiscovered centre of attraction, we can understand that almost endless combinations might take place which would render the earth's surface warmer or cooler.

Geological changes themselves must have had considerable influence upon climate. The uplifting of mountain masses, the subsidence of large tracts, the denudation of a country, and in fact any changes in the distribution of land and water, must have had considerable effect on the climate. It has been suggested, too, that some displacement of the earth's axis of rotation may have been caused by the elevation of mountains, or the excessive accumulation of ice at particular periods.

Dr. C. W. Siemens, moreover, has advanced the theory that the heat of the sun is maintained by the combustion of gases diffused in the medium through which it moves, and which are drawn in at the polar, and after combustion, returned by centrifugal force from the equatorial parts of the sun into space. Remarking on this theory, Mr. S. V. Wood, jun., observes that it would furnish an explanation of the variation in the Sun's heat, since the quantity of diffused gases may vary in different parts of the medium through which the Sun moves.[2] Hence many causes may have helped directly or indirectly to modify climate.

In regard to Geological time as compared with Historical time, but little can be said with certainty, except that it is 'inconceivably great.'

The total thickness of the known sedimentary strata of the British Isles may be estimated at upwards of 80,000 feet; but we must not unite the thicknesses of the strata at their maxi-

[1] Climate and Time in their Geologieal Relations, 1875.
[2] Q. J. xxxviii. 736; see also J. Evans, Address to Geol. Soc. 1876.

mum, and say that the sum total represents the thickness of our stratified rocks. The varying thicknesses and characters of our formations may be frequently accounted for by considering that the changes in physical conditions did not take place uniformly; but that a clayey, a sandy, or a calcareous formation may have occupied a longer period in its deposition in one locality than in another, while the succeeding deposit may tell of conditions which locally were of shorter duration. We cannot, however, be exact in our measurements, nor is it possible to calculate with certainty the amount of strata unrepresented in our Islands. Sir A. C. Ramsay, indeed, would lead us to believe that the unrepresented strata were as great as, perhaps greater than, those preserved to us.[1] It is true that we know but little of the very earliest or Pre-Cambrian strata; but between them and the Cambrian rocks there is no evidence of any great break. Locally, there is great unconformity between the Cambrian and Silurian strata of Sedgwick, and there is usually a great break between the Coal Measures and overlying New Red rocks; locally there are breaks between the Wealden beds and Lower Greensand, and between the Lower Greensand and Gault; there is a great palæontological and physical break between the Chalk and the Tertiaries; and between our Eocene and Pliocene beds there is a break, which is bridged over by the Miocene deposits of other countries. Of course, there are many minor unconformities, but on the whole the sequence of strata in England and Wales gives a fair idea of the succession of changes which the earth's surface has undergone.

Sir William Thomson has calculated that the sun has probably not illuminated the earth for 100,000,000 years, and almost certainly not for 500,000,000 years. This gives a limit to our estimates of time, which it is desirable not to overstep. The question has naturally arisen whether this estimated period of time is sufficient for all geological changes. Taking 100,000 feet as a full allowance for the total thickness of stratified rocks containing traces of life, Professor Huxley has pointed out that, restricting the time to 100,000,000 years, the deposits may be estimated to have taken place at the rate of $\frac{1}{1000}$ of a foot, or $\frac{1}{83}$ of an inch per annum. And this is a rate which no one can consider too rapid. At the same time, such an estimate is exceedingly vague, for sandstones and limestones would be formed at very different rates. Moreover, the important fact must not be overlooked, that in the very earliest geological periods each bed of sand, clay

[1] Addresses to Geol. Soc. 1863, 1864; see also T. McK. Hughes, Proc. Cambridge Phil. Soc. iii. 247.

shingle, or limestone had actually to be formed; whereas in each succeeding period the fresh deposits were many of them largely made up of the older sedimentary strata; and therefore new deposits *may be* laid down more rapidly at the present day than could have been the case under similar conditions in former times. Mr. T. Mellard Reade has discussed the question of Time from this point of view, dealing with the denudation of the land, which can be estimated, and then calculating the rate at which various rocks are destroyed, and the rate at which material carried away from the land in solution and suspension may be again accumulated. The results, although interesting and suggestive, do not enable us to estimate with accuracy the duration of our geological periods.

Calculations, such as that by which the formation of the Coal-field of South Wales has been estimated at 640,000 years, are, however, not without their use in giving a rough notion of the time occupied in the accumulation of strata; for while we know the relative antiquity of the groups of rocks, we can scarcely help forming crude ideas of their relative duration, derived from the ascertained thickness of the strata, together with their sedimentary character and organic remains. More precise inferences may eventually be made from Astronomical calculations, based on a study of the physical and climatic conditions of each period. This subject has occupied the attention of Dr. Croll, and it may be mentioned that on these grounds it has been inferred that the Glacial period commenced about 200,000 years ago.

Figures, however, when introduced into Geological Time, must be received with much caution, and the safest position, even with regard to the antiquity of Man, is that recommended by Prof. Prestwich. That we must greatly extend our present chronology with respect to the first existence of man cannot be questioned. "Nevertheless, just as, though ignorant of the precise height and size of a mountain-range seen in the distance, we need not wait for trigonometrical measurements to feel satisfied in our minds of the magnitude of the distant peaks, so with this geological epoch, we see and know enough of it to feel how distant it is from our time, and yet we are not in a position at present to solve with accuracy the curious and interesting problem of its precise age."[1]

[1] Phil. Trans. 1864, p. 303. On the subject of Geological Time, see J. Croll, Climate and Time, 1875; J. Phillips, Address Geol. Soc. 1860, p. 26; Sir W. Thomson, Trans. Glasgow Geol. Soc. vol. iii.; T. H. Huxley, Address Geol. Soc. 1869; J. C. Ward, G. Mag. 1869, p. 8; T. McK. Hughes, Proc. Roy. Inst. 1876; C. Lloyd Morgan, G. Mag. 1878, p. 145; and T. M. Reade, Chemical Denudation in Relation to Geological Time, 1879.

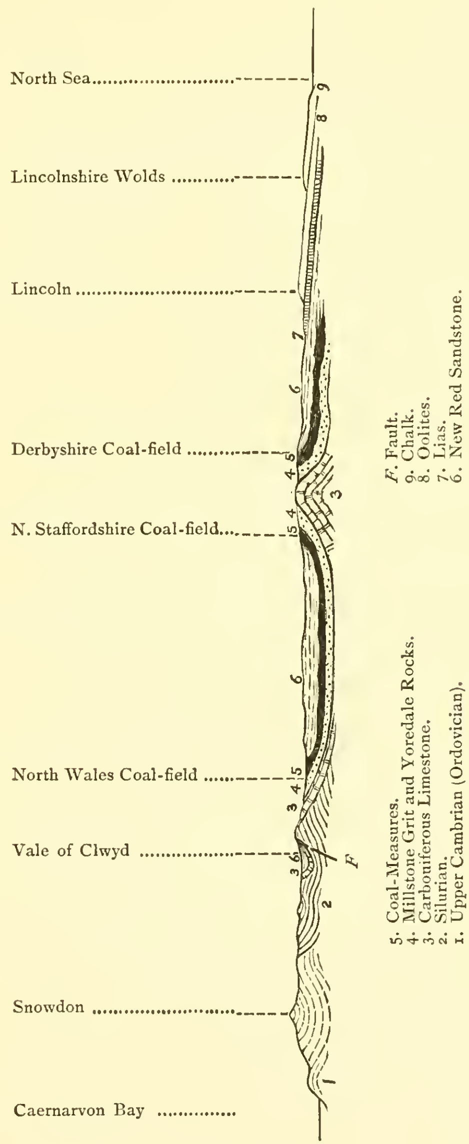
When for the first time in our lives we decide to give some attention to geology, we find that much hard study is necessary before the grand principles of the science are comprehended. Not only must we read one or more of the leading Manuals, but we must go into the field, and examine for ourselves, in quarries, cliffs, and cuttings, the nature and arrangement of the rocks.[1]

Equipped with map, note-book, hammer, compass, clinometer, pocket-lens, and pen-knife; and with also a bag, and small bottle of hydrochloric acid, the geological student would be prepared for work of all kinds. The clinometer will be useful for registering the 'dip' or angle of inclination of the strata. The pocket-lens will be of service in determining whether the rock be crystalline or composed of a mechanical aggregate of rounded or angular fragments. The pen-knife will, by its determination of hardness, indicate a very siliceous from a calcareous rock. Hydrochloric acid (diluted to $\frac{1}{12}$) will be useful in detecting the limestones and marls.

Following in the footsteps of William Smith, the main outlines of the geological structure of our country were sketched by Sedgwick, Webster, Buckland, Conybeare, Fitton, De la Beche, Murchison, Mantell, Lonsdale, and John Phillips. To De la Beche we owe the establishment of our Geological

[1] The principal modern Manuals of Geology are those by A. Geikie (two separate works), J. Geikie, A. H. Green (Physical Geology), A. J. Jukes-Browne (2 vols.), J. Prestwich (2 vols.), H. Seeley and R. Etheridge (2 vols.). See also Text Book of Field Geology, by W. H. Penning, edit. 2, 1879 (Palæontology, by A. J. Jukes-Browne); A. Geikie, Outlines of Field Geology, edit. 3, 1882.

Fig. 3.—General Section across England and Wales.



Survey, whose Maps and other publications describe the country in detail; while the work of the pioneers is followed up by an ever-increasing band of geologists.

Broadly speaking, the northern and western parts of England and the greater part of Wales are formed of the older rocks known as Primary or Palæozoic. These were considerably folded and disturbed, before the newer rocks were laid down. Resting on their upturned edges, or abutting against them, lie the Secondary strata which form a group dipping generally in a south-easterly direction, so that in passing from north-west to south-east we come successively on higher and higher beds, from the Lias, which stretches from Lyme Regis in Dorsetshire to Whitby in Yorkshire, to the Chalk which runs from Dorsetshire and Hampshire to Flamborough Head. The older Tertiary beds repose on the Chalk in the irregular areas known as the London and Hampshire Basins; and they were together much disturbed and denuded before the newer Tertiary or Pliocene strata were laid down on the western borders of the German Ocean. The Quaternary deposits form a distinct group scattered irregularly over the country, and resting indifferently on any of the rocks from the oldest upwards.[1] (See Map and Fig. 3.)

While Cuvier laid the foundation of the Palæontology of Vertebrate animals, and Lamarck that of the Invertebrates, we are in this country indebted to the Sowerbys [2] and Parkinson [3] for the early illustration of our fossils.

The number of British fossils, amounting to about 4450 genera and 16,000 species (according to Mr. Etheridge), may well appal those who would attempt to identify the fossils they collect; but the student, as a rule, must be satisfied with determining the genus of any fossils he may procure, leaving the specific names to those whose special work lies in some department of Palæontology. Access, however, to the splendid Monographs published by the Palæontographical Society, or a comparison of his specimens with those exhibited in the cases of some Museum, will often enable the geologist to determine the species he has obtained.[4]

[1] For the geology of particular counties, see the Geology of the Counties of England and of North and South Wales, by W. J. Harrison, 1882. See also Geological Map of England and Wales, by A. C. Ramsay, which contains a section on which Fig. 3 is based.

[2] The Mineral Conchology of Great Britain, 1818–1829.

[3] Organic Remains of a Former World, 1804–1811.

[4] See also Figures of Characteristic British Fossils, by W. H. Baily, vol. i. Palæozoic, 1867–75; Charts of Characteristic British Fossils (1853), and of British Tertiary Fossils (1868), by J. W. Lowry; and Chart of Fossil Crustacea, by J. W. Salter and Dr. Henry Woodward, 1865; Stratigraphical Geology and Palæontology, by R. Etheridge, 1885.

The deductions of geology rest upon the accumulation of a vast number of facts—facts which in themselves are often dry and tedious. Thus the very detailed work of the Palæontologist — the determination and description of species of organic remains—derives its interest and importance from the light that any fossil or set of fossils may throw upon the past history of the earth, or upon the development of life. The intimate structure of a rock is interesting and important, as it sheds light on the character of the deposit of which it is a fragment, whether formed by volcanic agency, by rain, river, or sea.

Geology has, however, a practical aspect. The habits and industrial pursuits of the people are largely dependent on the nature of the land, and consequently on geology. The mining population is chiefly in the western half of the country, and the agricultural chiefly in the east, if we draw a line between Flamborough Head and Lyme Regis. While the manufactures are chiefly in the northern and midland counties, in proximity to the principal coal- and iron-producing strata.

Among the Economic purposes of Geology are its applications to Engineering, Architecture, Agriculture, and Mining. In regard to drainage and water-supply, in the selection of sites for building, in the formation of canals, and in the making of roads, railway-cuttings, and tunnels, a knowledge of Geology is most useful. So also in the selection of building-stones, where the mechanical structure of the rock has to be taken into consideration.

Our Geological Maps display the superficial exposures of Limestones adapted for building-purposes and lime; of Marls for agricultural purposes; of Clays and Loams used in the manufacture of bricks, tiles, and pottery; of Slates for roofing and other purposes; of Marbles for ornamental purposes; and of Granites used for building, for road-metal, etc.

The prospects of Coal and the supply of Metals are questions towards the solution of which Geology lends great assistance. There are, however, many minor applications of the Science to the Arts and Manufactures, which will be mentioned in the sequel.

When the philosophy of Geology is understood, its history can be appreciated, and without reference to details. We soon learn that the science does not consist in the mere collecting and naming of rocks and fossils; but that it ultimately aims at restoring in imagination the successive changes through which the earth has passed, at picturing the different distribution of land and water in each period, the changes in climate, and the character of the animal and vegetable life that has existed. Finally it deals with the

Table of Geological Formations.

Cænozoic.	Quaternary.	Recent	Terrestrial, Alluvial, Estuarine, and Marine Beds, of Historic, Iron, Bronze, and Neolithic Ages.
		Pleistocene	Terrestrial, Alluvial, Estuarine, Marine, and Glacial Beds, of Palæolithic Age.
	Tertiary.	Pliocene	Cromer Forest Bed Series. Norwich Crag Series. Red Crag. Coralline Crag.
		Oligocene	Hempstead Beds. Bembridge Beds. Osborne Beds. Headon Beds.
		Eocene	Bagshot Beds. London Clay. Oldhaven and Blackheath Beds. Woolwich and Reading Beds. Thanet Beds.
Mesozoic or Secondary.		Cretaceous	Chalk. Upper Greensand. Gault. Lower Greensand. Wealden { Weald Clay. / Hastings Beds. }
		Jurassic	Purbeck Beds. Portland Beds. Kimeridge Clay. Corallian Beds. Oxford Clayand Kellaways Rock. Great Oolite Series. Inferior Oolite Series. Lias.
		New Red Sandstone or Poikilitic	Trias { Rhætic Beds. / Keuper. / Bunter. } Permian or Dyas.
Palæozoic or Primary.		Carboniferous	Coal Measures. Millstone Grit. Carboniferous Limestone Series.
		Old Red Sandstone and Devonian	Upper Old Red Sandstone. Devonian. Lower Old Red Sandstone.
		Silurian	Ludlow Series. Wenlock Series. May Hill Series.
		Cambrian	Bala Series. } Ordovician. Llanvirn Series. } Ordovician. Arenig and Skiddaw Series. } Ordovician. Tremadoc Slate Series. Lingula Flag Series. Menevian Series. Harlech and Longmynd Series.
Azoic?		Archæan	

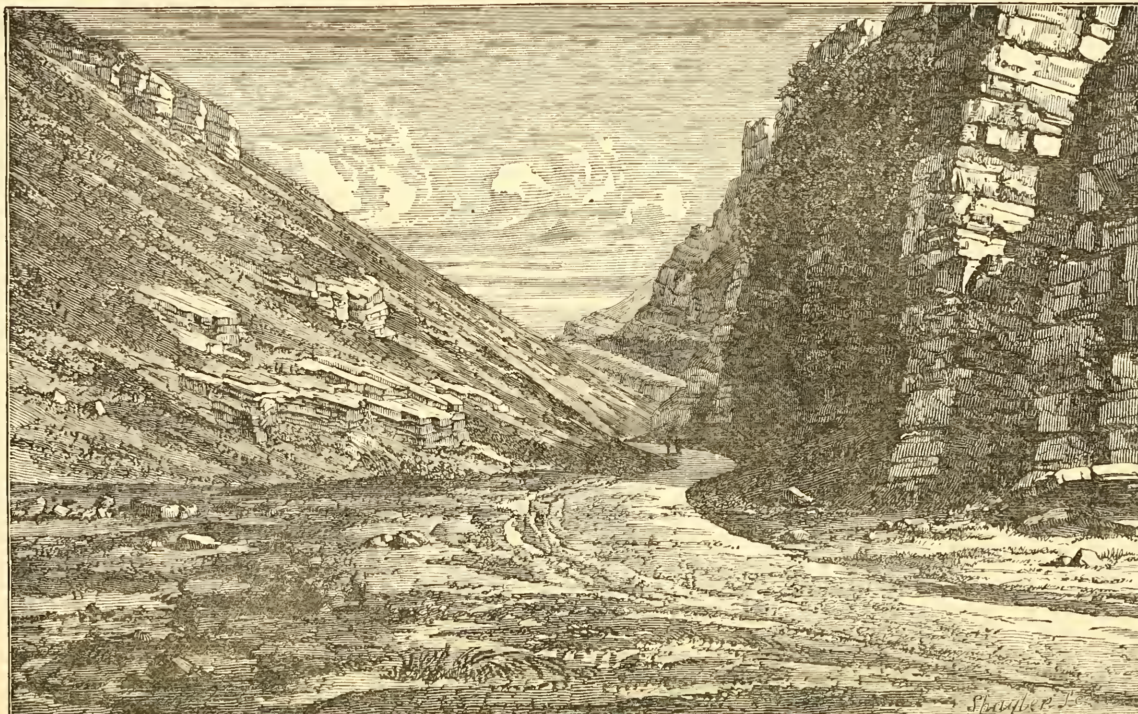
evidence furnished of continuity and a gradual succession of living beings, by the development of higher and higher types, and culminating in the appearance of Man upon the earth.[1]

The subject of the Classification and Nomenclature of the Stratified Rocks is one on which very little agreement is found among geologists. Even the Reports of British Sub-Committees for the International Geological Congress (1885) offer no authoritative and comprehensive scheme, while the most recent writers differ very largely in the use of terms.[2] Under these circumstances it appears best to adhere, wherever possible, to old and well-known names.

The Table on the opposite page shows the classification adopted in this work, the names introduced are those which have a general application in this country, although the divisions are far from equal in value—the further local divisions are given in the sequel.

[1] See Dr. H. Woodward, G. Mag. 1874, p. 289; Dr. P. M. Duncan, Address to Geol. Soc. 1878.

[2] W. T. Blanford, G. Mag. 1884, p. 320; A. J. Jukes-Browne, *Ibid.* p. 525, 1885, p. 293; H. Hicks, *Ibid.* p. 359.

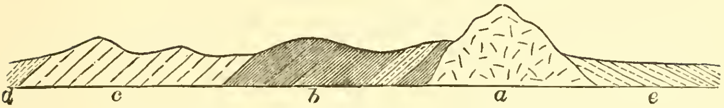


The Cheddar Cliffs, Somersetshire. (*From a Photograph.*)

Part I.

PALÆOZOIC.

FIG. 4.—GENERAL SECTION OF THE MALVERN HILLS.
(Prof. J. Phillips.)



e. New Red Sandstone (Poikilitic).
d. Lower Old Red Sandstone.
c. Silurian.
b. Cambrian.
a. Gneiss (Archæan).

AS early as the year 1756, the rock-formations were divided by Lehman into Primitive and Secondary, the former term being applied to those rocks in which no fossils had been found, and the latter term to the fossiliferous strata. Later on, in 1795 or 1796, Werner introduced the term Transition for a class of rocks intermediate between these old groups.[1] In those early days the arrangement of the rocks was but imperfectly understood.

The term Palæozoic (derived from Greek words signifying 'ancient life') was introduced in 1838 by Sedgwick, and is now generally applied to the oldest stratified rocks that enter into the composition of the earth's crust. They are, in fact, the 'Primary' rocks with which the Geologist has to deal; and although this latter term (introduced by Hutton) is less frequently used, perhaps because we are unable to state positively that the oldest rocks known to us were those first formed, yet it is a simple and by no means inappropriate term.

No doubt the earliest rocks that appeared at the cooled surface of the earth "In the beginning" were of a crystalline nature: more we cannot say. The old notion that granite is

[1] Conybeare and Phillips, Outlines of the Geology of England and Wales, p. vi.

essentially a fundamental and primitive rock is so far modified that we recognize its intrusion from depths below at various epochs in the earth's history. Nevertheless, its formation, so far as we can read it, was always deep-seated ; some granites are among the oldest rocks, and the date of the upthrust of others is indicated by the alteration produced on adjoining strata.

In the Primary or Palæozoic group we may include the earliest known rocks (Archæan[1]) and those formed up to the close of our Coal period. Some authorities still place the Permian rocks in this group, but in their sedimentary character and method of formation, they are so closely allied to the Triassic strata, that these two divisions are best classed together to form the New Red Sandstone or Poikilitic system at the base of the Secondary or Mesozoic group. The following are the Palæozoic systems :—

Carboniferous.
Old Red Sandstone and Devonian.
Silurian.
Cambrian.
Archæan.

The total thickness of the Palæozoic group may be roughly estimated at 70,000 feet, whereas the thickness of all the newer strata in England and Wales probably does not exceed 14,000 feet. And it is well to bear in mind what a vast series of strata these older rocks comprise, for they do not enter so largely as do the Secondary or Quaternary rocks into the superficial structure of the land. In the lower divisions of the Palæozoic rocks the rarity and frequent obscurity of the organic remains, the effects of igneous intrusion and metamorphism, and the faults and contortions, add many difficulties to the study of the strata. The Carboniferous rocks, indeed, are readily recognized, but the exact age of the Devonian strata is a subject still under discussion.

The Palæozoic rocks generally possess a more crystalline and slaty structure than the newer strata ; they occupy more elevated ground, forming the lofty hills and mountains in Cumberland and Wales, the Pennine Chain, the Malvern Hills, and the greater part of Devon and Cornwall. The older rocks, especially, furnish a poor soil, the beds often

[1] Sedgwick originally proposed the term Protozoic for the Pre-Cambrian rocks (Proc. G. S. ii. 684) ; while the term Azoic has also been applied to the older crystalline and unfossiliferous rocks ; but neither term is much used. The term Eozoic has also been employed for the oldest rocks that contain organic remains.

jutting out on the hill-sides. In this respect they offer many more natural exposures than do the Secondary and newer strata, in crags and scarps, and along the sides or bottoms of water-courses. These rocks are the principal repositories, in England and Wales, of metallic wealth and of coal; and although not so tempting to the collector of fossils as many of the newer strata, they must always command great interest, because in them we look for the earliest traces of life on the earth. It has been suggested that life originated in the Polar Regions, on the grounds that the equatorial regions would have been too hot to support life in the earliest geological period.[1]

Concerning the oldest supposed evidences of Palæozoic vegetation, they are generally referred to *Algæ*. Indeed, the Cambrian, Silurian, and Lower Devonian systems form the first botanical epoch of Professor Schimper, to which he gives the name of the "Period of Thalassophytes," because, with few exceptions, only sea-weeds have been recognized in these formations. The term Eophytic has also been applied. The evidence of the existence of plants is based on certain markings on the surface of the rocks, for rarely have any traces of structure, or even of carbonaceous stains, been noticed in connection with any of these supposed *Algæ*. The markings have received specific names, and have been grouped into genera, but it is very doubtful whether there is sufficient evidence to show that they are really impressions of plant-forms, especially in view of the interesting observations of Dr. A. G. Nathorst. He has noticed on the mud of the Baltic shores, markings and impressions produced by the action of flowing water on small obstacles, or on plants, which are identical with some of the markings found on the surface of Palæozoic rocks.[2] Some so-called plant-remains may also be trails and burrows of Annelides. Dr. Nathorst has shown that different animals may produce similar trails, and the same animal different forms of tracks. He regards *Eophyton* as probably the trail of *Medusa*, and *Palæochorda* as trails of Mollusca and Crustacea.[3]

The plants of the Upper Palæozoic rocks are chiefly Cryptogams—Ferns, *Lycopodiaceæ*, and *Equisetaceæ*. These range from the Devonian rocks upwards; but the earliest traces of land-plants have been found in Silurian rocks.

The Palæozoic rocks contain many genera of Corals, such as *Heliolites*, *Favosites*, *Lithostrotion*, *Halysites*, *Cyathophyllum*, and *Calceola*; and of Crinoids, as *Actinocrinus*, *Platycrinus*,

[1] See Address to Norfolk Nat. Soc. 1886, by Major H. W. Feilden.
[2] W. Carruthers, Proc. Geol. Assoc. v. 4. See also G. Mag. 1883, p. 33.
[3] G. Mag. 1882, p. 22. See also T. McK. Hughes, Q.J. xl. 178.

Pentremites, etc. Graptolites are specially characteristic of the Lower Palæozoic rocks (Cambrian and Silurian).

Crustacea, in the form of Trilobites, are also typical of these rocks, and they extend upwards to the middle of the Carboniferous series. The older genera are *Asaphus*, *Agnostus*, *Paradoxides*, and *Trinucleus*; the newer include *Calymene*, *Homalonotus*, *Phacops*, and *Phillipsia*. Besides these, there are other forms of Crustacea, the *Pterygotus* and *Eurypterus* —the former of which sometimes attained a length of five or six feet.

Brachiopoda are very abundant in some of the beds, including *Leptæna*, *Spirifer*, *Orthis*, *Productus*, *Pentamerus*, *Strophomena*; also Mollusca of the genera *Aviculopecten*, *Posidonomya*, *Euomphalus*, *Murchisonia*, *Lituites*, *Orthoceras*, *Goniatites*, etc. The earliest known Insects in Britain make their appearance in the Coal-measures,[1] which have also yielded traces of Myriapods and Arachnides. Fishes make their appearance in the uppermost Silurian rocks—they mostly belong to the Ganoid order. And so abundant do they become in certain portions of the Old Red Sandstone, especially in Scotland, that this period has been termed the "Age of Fishes." Amphibia (Labyrinthodonts) have been met with in the Coal-measures; but no true Reptiles are known to occur in rocks older than the Permian. No Mammals have been found in Palæozoic rocks. (See Synopsis of the Animal Kingdom in *Appendix*.)

The Palæozoic rocks contain a few living genera of Mollusca, such as *Lingula*, *Terebratula*, and *Rhynchonella*. As might be expected, there is no evidence of any fundamental modification or advance in the Foraminifera from the Palæozoic period to the present day.[2]

In these early periods the same groups of animals (Mollusca and Crustacea) appear to have been very widely diffused, suggesting that the physical conditions under which they existed in Palæozoic times were probably much more uniform than they now are.[3] We must also remember that the Palæozoic epoch was probably of enormous duration compared to the succeeding geological periods. At the same time we may mention that in the opinion of Sir R. S. Ball, the globe was affected by enormous tides during its infancy,

[1] On the Insect Fauna of Palæozoic rocks, see H. Goss, P. Geol. Assoc. vi. 271; and S. H. Scudder, G. Mag. 1881, 300.

[2] Dr. W. B. Carpenter, Introd. to Study of Foraminifera (Ray Soc.), 1862; see also R. Etheridge, Address to Geol. Soc. 1881.

[3] Dr. A. Geikie, Text-Book of Geology, ed. 2, p. 21.

and even in early Palæozoic times they may have been very great: hence the destruction of land and the formation of sediment may have been comparatively rapid in those days.[1]

ARCHÆAN.

This term, introduced by J. D. Dana in 1874, is now generally applied to the rocks older than the Cambrian, and which are frequently designated as Pre-Cambrian. These are the oldest rocks exposed at the Earth's surface. Formerly the term Laurentian was applied to the most ancient rocks in the British Islands.

The term Laurentian was given in 1854 by Sir William E. Logan to a series of highly contorted gneissic rocks which occur in Canada, in the country drained by the St. Lawrence, and which are among the oldest known sedimentary rocks in the world. Their thickness has been estimated at 30,000 feet. Zones of altered limestone included in the series have yielded traces of structure supposed to be foraminiferal, and named *Eozoon Canadense* by Sir J. W. Dawson. It is only right to add that the organic nature of Eozoon has been seriously questioned.[2] The occurrence also of Graphite in these rocks has been considered as evidence of vegetation having existed.

The existence of Laurentian rocks in England and Wales, or o English rocks equivalent to the oldest rocks of America, has not been definitely determined; nor is it probable that, in comparing the rocks of these two countries, we can ever do more than state that certain series of strata are homotaxial, or in other words that they occupy the same relative position in regard to the succession of life in the two areas. The oldest rocks in North Britain are unconformably overlaid by the Cambrian rocks. To these rocks Murchison in 1858 applied the term Lewisian or Fundamental Gneiss—the former term being taken from Lewis, the largest island of the Hebrides.

In several localities in England and Wales there is evidence of the presence of rocks of Pre-Cambrian age, and these are now grouped under the general name Archæan. No fossils have as yet been positively identified in any of these

[1] Nature, Dec. 28, 1882.

[2] An Old Chapter in the Geological Record, by Prof. W. King and Prof. T. H. Rowney, 1881.

rocks. Their position is determined by their relation to the overlying Cambrian rocks, the basement beds of which are often conglomeratic, and contain pebbles of the older rocks.[1]

The rocks regarded as Archæan consist chiefly of schists, gneiss, quartzose and granitoid rocks, volcanic agglomerates, breccias, and slates. Some unconformities have been recognized in the series, but as these rocks were, to a large extent, volcanic, and perhaps also terrestrial, the unconformities may not mark any great break in time.[2] The earliest rocks of this period are of a crystalline nature, with veins of eruptive material, which apparently did not find vent at the surface. The rocks have undergone much alteration, and have in some instances been so crumpled, folded, and faulted, that older rocks have been driven over newer rocks by 'overthrust' faults; while in other instances the rocks themselves have been crushed, drawn out and almost reconstructed in a mineralogical sense by a process of 'shearing.'

Little can be said of the physical conditions at this remote epoch, but evidences of possible Glacial action in Pre-Cambrian times have been indicated.[3]

The determination of Archæan rocks in England and Wales is mainly due to the researches of Dr. H. Hicks, Prof. T. McK. Hughes, Dr. C. Callaway, and Prof. T. G. Bonney. Some portions of the evidence have, however, been controverted by Dr. A. Geikie, and it will therefore be desirable to point out the differences of opinion which have been expressed respecting the areas in England and Wales where these, the oldest known rocks, have been identified.[4]

Malvern.—The old gneissic rocks and crystalline schists of Malvern, originally considered to be altered Cambrian strata, were in 1863 described by Dr. H. B. Holl as relics of an old Pre-Cambrian continent.[5] These rocks, which help to form the tiny mountain range or "metamorphic ridge" of Malvern, rise up in the Herefordshire and Worcestershire Beacons, and in the North Hill.[6] (See Fig. 4.) The rocks, which are traversed by intrusive

[1] See paper on "How to Work in the Archæan Rocks," by C. Callaway, G. Mag. 1881, p. 348, etc.

[2] See J. E. Marr, G. Mag. 1883, p. 263.

[3] H. Hicks, G. Mag. 1880, p. 490.

[4] See Prof. T. G. Bonney, On the Archæan Rocks of Great Britain, Brit. Assoc. 1885.

[5] Q. J. xxi. 72; G. Mag. 1865, p. 573.

[6] L. Horner, T. G. S. i. 281; Rev. J. H. Timins, Q. J. xxiii. 352; J. Phillips, Mem. Geol. Survey, ii. Part 1; W. S. Symonds, Records of the Rocks, p. 33.

diorites, comprise granitoid gneisses, hornblendic and micaceous schists, etc. Dr. Callaway has grouped the beds as follows:[1]—

Pebidian	Hornstones of Herefordshire Beacon.
Malvernian . .	Dimetian, with associated quartz-felsites and hälleflintas (Arvonian), passing down into Lewisian.

Abberley Hills.—The Rev. W. S. Symonds has suggested that the 'syenitic' rocks seen near Martley, and also between Berrow Hill and King's Common, along the line of the Abberley Hills, may be of Pre-Cambrian age.

WALES.

In 1838 Sedgwick grouped the "crystalline slates" of Anglesey and the south-west coast of Caernarvonshire as Pre-Cambrian (Protozoic);[2] but they were subsequently regarded as altered Cambrian by Sir A. C. Ramsay. In 1872, however, the Rev. W. S. Symonds recalled attention to the subject, remarking that these crystalline rocks are not simply altered portions of the grits and slates which form the base of the Cambrian rocks in the counties of Merioneth and Caernarvon, and that they should be classed as Pre-Cambrian.[3]

In 1864 Dr. Henry Hicks arrived at the conclusion that in North Pembrokeshire the "intrusive syenite and felstone" (marked on the Geological Survey Map) were portions of an old Pre-Cambrian ridge or island. His earlier views were worked out in conjunction with Mr. J. W. Salter,[4] while his later conclusions have been developed from long-continued personal labour, aided by microscopical investigations carried on by Prof. T. G. Bonney and Mr. Thomas Davies. As the divisions made in the Archæan rocks of St. Davids have been followed out by some observers in other localities, it will be well to describe them in detail.

In 1876 Dr. Hicks proposed to divide the Pre-Cambrian rocks of St. Davids into two distinct series. He introduced the local name of Dimetian for the lower series, *Dimetia* (or *Demetæ*) being the Roman name for a kingdom which included, or for a Celtic tribe which inhabited, this part of Wales; and the name Pebidian for the upper series, *Pebidiauc* (or *Pebidiog*) being the name of the division or hundred in which these rocks are chiefly exposed. In 1871 he introduced a third division intermediate between the two others, which he termed Arvonian, from *Arvonia*, the Roman name from which Caernarvon is derived.[5]

[1] Q. J. xxxvi. (Proc.) 3, and 538.
[2] Proc. G. S. ii. 684.
[3] Records of the Rocks, 1872, p. 28.
[4] G. Mag. 1864, p. 289, 1865, p. 430.
[5] Q. J. xxxiii. 230; xxxiv. 153; xxxv. 285; xl. 507; and G. Mag. 1878, p. 461. See also Harkness and Hicks, Q. J. xxvii. 388, 396.

The prevailing characters in the three formations of Pre-Cambrian rocks made out in Pembrokeshire by Dr. Hicks are thus briefly defined by him:—

Pebidian . .	Micaceous, talcose, and chloritic schists, with slaty and massive green bands containing epidote, serpentine, etc. Tuffs, indurated ashy shales, breccias, silvery schists, porcellanites, conglomerates, and green and purple agglomerates.
Arvonian . .	Breccias, hälleflintas, porphyries, and quartz-felsites.
Dimetian . .	Quartzose rocks, granitoid gneiss, and compact granitoid rocks, with bands of crystalline limestone.

The actual thickness of each division is stated to be "many thousand feet," but it cannot be definitely calculated, although the aggregate estimates exceed 18,000 feet. Older, probably, than the Dimetian, according to Dr. Hicks, is the *Lewisian* (or *Hebridean*) group, the prevailing rocks of which are massive gneisses, in which hornblende and a reddish felspar are the chief ingredients. They are of a dusky red, grey, or dark colour. Sometimes almost a pure hornblende rock is found. The group is met with in parts of the Malvern chain.

The *Dimetian* series, which includes rocks coloured as Granite or Syenite on the Geological Survey Maps near St. Davids, comprises rocks of a granitoid character, usually of a massive, but sometimes of a schistose nature. The rock is largely made up of quartz, with some pinkish or white felspar. The upper portion (*Porthlisky group*) comprises the Lower Moor rock and the highly quartzose rocks of Porthlisky and Porthclais; the lower division (*Bryn-y-garn group*) includes the massive granitoid rocks of Bryn-y-garn, and Brawdy, St. Davids. A peculiar brecciated bed in the Dimetian of St. Davids has been produced in place by weathering along the joint planes.[1]

The *Arvonian* series consists mainly of flows of rhyolitic lavas, alternating with felsitic breccias and hälleflintas. These were formerly grouped as intrusive felstones, porphyries, etc. The series is largely developed in Pembrokeshire. Dr. Hicks remarks that the junction with the Dimetian is abrupt, and may be seen at St. Davids, about a quarter of a mile to the south of the Cathedral, and near Rock House. Excellent sections of Arvonian rocks may be seen in the gorge through which the western Cleddau river flows, and through which the road passes from Haverfordwest to Fishguard. Two divisions are made, the Upper (*Holyhead group*) comprising the schistose and compact quartz rocks of Llanhowell, near St. Davids, and of Holyhead mountain; the Lower (*Treffgarn*

[1] T. McK. Hughes, G. Mag. 1883, p. 306.

group) comprising the breccias, hälleflintas and quartz felsites of Treffgarn Mountain and Roch Castle. The "Treffgarn Rocks" are prominent weathered masses of these rocks.

The hälleflintas were first recognized by Mr. T. Davies (when examining some slides for Dr. Hicks in 1878) as being of the peculiar nature characteristic of the rocks so well known under that name in Sweden. The term, says Dr. Hicks, is used generally for a compact rather flinty-looking rock, which, in chemical composition, does not differ much from one of the more acid varieties of rhyolites, and may be either one of these considerably changed, or an altered sedimentary rock. Mr. Davies regards the hälleflintas as quite distinct from the felstones, as the former contain a larger proportion of silica, and are of very different physical character.

The *Pebidian* group is less altered in character than the Arvonian or Dimetian. According to Dr. Hicks, agglomerates and breccias occur in great thickness in the group, and the fragments are chiefly, except in the lowest beds, of a basic character. Chloritic, talcose, felspathic and micaceous schistose rocks occur also at various horizons, and occasionally purple and green slates. Serpentinous bands are also sometimes found, as well as veins of jasper, epidote, and asbestos. Some of the finer and more quartzose beds assume a gneissose appearance, and others are porcellanitic. Two divisions are made, the Upper (*Treginnis group*) comprising the conglomerates, breccias, schists, and slates, with contemporaneous lava-flows and volcanic ashes, and with limestones and serpentines; and the Lower (*Menai group*) comprising breccias, chloritic, talcose, felspathic and micaceous schistose rocks, also limestones and serpentines. This description of the divisions proposed by Dr. Hicks gives the general characters of the beds recognized in other parts of the country, as well as in Pembrokeshire. The Treginnis group is exposed at Treginnis, on the shore of Ramsey Sound, near St. Davids.

The conglomeratic beds at the base of the Pebidian in Pembrokeshire are largely made up of masses derived from the Arvonian rocks; and Dr. Hicks states that an actual unconformity between the two groups may also be seen at several points. The Cambrian strata rest unconformably upon them.[1]

The conclusions thus made known by Dr. Hicks have, however, been contested by Dr. A. Geikie. Referring first to the gneissic or granitoid rock of Bryn-y-garn, described by Dr. Hicks as a bedded metamorphic rock, Dr. Geikie points out that he found no evidence of foliation; that whether in mass, in hand-specimens, or under the microscope, it presents the ordinary structure of granite. And he observes that at St. Davids, the coast-section and the transverse valley cut by the river Allan permit the actual junction of the granite with the surrounding rocks to be seen at several localities.

[1] Pop. Science Review, 1881, p. 289; Proc. Geol. Assoc. vii. 63; and G. Mag. 1879, p. 435.

This granite he maintains, instead of being a ridge of Pre-Cambrian metamorphic rock, is really a boss of eruptive granite, later in date than the Cambrian strata through which it has been intruded.

Turning to the Arvonian rocks of Dr. Hicks, Dr. Geikie remarks that "Instead of finding evidence that these rocks lie with a discordant strike unconformably against the so-called 'Dimetian' below, and are covered unconformably by Cambrian or 'Pebidian' beds above, Mr. Peach and I discovered that Dr. Hicks had really created a separate stratigraphical 'group' out of the zone of quartz-porphyry bosses and dykes with the accompanying indurated sedimentary rocks that surround the central core of granite." Passing on to the Pebidian rocks, Dr. Geikie agreed with Dr. Hicks that the group marked on the Geological Survey Map as altered Cambrian is almost entirely of volcanic origin, as originally recognized by Sir A. C. Ramsay, and formed principally of tuffs with bands of olivine-diabase and occasional intrusive masses of quartz-porphyry. Dr. Geikie, however, sought in vain for proofs of any unconformity between these rocks and the so-called Arvonian—in fact the volcanic groups (Pebidian) can be seen in many places graduating insensibly into the altered shales which form a great part of the Arvonian. Indeed, the latter group (says Dr. Geikie) consists of portions of the volcanic breccias and tuffs (Pebidian) where these are invaded by quartz-porphyry. Furthermore, Dr. Geikie asserts that the volcanic (Pebidian) group and the overlying Cambrian conglomerate, sandstone, and shales are perfectly conformable—for volcanic beds are even interstratified with the conglomerate and appear above it. Moreover, "On the shore of Ramsey Sound, at the headland of Castell, the red shales and sandstones with *Lingulella primæva*, which lie not far above the conglomerate, are banded with thin seams of sandy tuff, some of the shales being also full of diffused tuffaceous material, as if from slight discharges of fine volcanic dust during the last stages of eruption in the district."[1] (See also under Cambrian, p. 56.)

These differences in the interpretation of this ancient 'Geological Record' are serious, but perhaps not quite so serious as they at first appear. It is admitted that the rocks termed Pebidian underlie the oldest fossiliferous Cambrian strata, and rest on the rocks termed Arvonian. The relative position and the origin of the Dimetian granitoid rock are the main points in question. It may be mentioned, however, that in other areas, where Archæan rocks have been identified, two main divisions are recognized, one of coarsely crystalline rocks (Dimetian), and the other of eruptive rocks (Pebidian).[2]

Mr. W. H. Hudleston, in speaking of these old rocks, has observed that in the more crystalline lower series, as developed near Caernarvon and St. Davids, we see the hypogene conditions of a great mass of rocks, whilst the beds between these crystalline masses and the great Cambrian conglomerate represent a more or

[1] Q. J. xxxix. 261. See also J. F. Blake, Q. J. xl. 294.
[2] C. Callaway, G. Mag. 1885, p. 260.

less contemporaneous outpouring of lavas and ashes, partly subaerial, but, as regards the Pebidian especially, in a great measure remodelled and deposited by water.[1]

In a section in one of the cuttings of the railway which runs from the Dinorwig quarries along the north-eastern shore of Llyn Padarn, the Cambrian basement conglomerate is shown resting in marked unconformity on volcanic tuffs, like the Pebidian rocks of St. Davids. Prof. A. H. Green, who has drawn attention to the section, remarks that the unconformity, strong as it is, does not necessarily indicate any great difference in age between the conglomerate and the breccia on which it lies. These breccias are of volcanic origin, and the irregular and restricted upheavals and disturbances which are always liable to occur where volcanic activity is going on, are quite competent to bring about marked unconformities, which may be purely local.[2]

Dr. Hicks maintains that fragments of the Dimetian rock are to be detected in the basement conglomerate of the Cambrian, a view strongly supported by Mr. T. Davies, and also by Prof. Hughes and Prof. Bonney. Whether Dr. Hicks is right in separating Arvonian from Pebidian is not generally admitted: but that the latter division forms a Volcanic series, on the whole distinct from the overlying true Cambrian rocks, is admitted by most geologists who have studied the complicated regions in which these rocks are displayed.[3] And the desirability of separating the Pebidian from the Cambrian rests rather on the general distinction in character between the rocks, than on any great break in the sequence of events. Dr. Hicks, however, asserts that fragments of Pebidian rocks, metamorphosed and cleaved, have been found in the Cambrian conglomerates. Whether the Dimetian of St. Davids should be regarded as older than the other members of the Pre-Cambrian, as Dr. Hicks maintains, or whether it be regarded as intrusive among these old rocks, is one of the questions which further independent evidence may answer to the satisfaction of all. At present the Doctors disagree.

Pre-Cambrian rocks were recognized in North Wales by Sedgwick. With them Dr. Hicks places the so-called intrusive masses at Caernarvon and Llyn Padarn, and the altered Cambrian of Moel Tryfaen and Tal-y-sarn. He identifies Pre-Cambrian areas at Glynllifon, Craig-y-Dinas, and in the Lleyn promontory, also at Ffestiniog, Dolgelly, and in the Harlech mountains. In the neighbourhood of Bangor and Caernarvon Prof. T. McK. Hughes would thus divide the Pre-Cambrian rocks:[4]—

[1] Q. J. xxxiv. 168. See also E. B. Tawney, G. Mag. 1882, p. 552; and Proc. Bristol Nat. Soc. (2) ii. 113.

[2] Q. J. xli. 74.

[3] See T. McK. Hughes, Q. J. xxxiv. 169; xxxix. 328.

[4] Q. J. G. S. xxxiv. 137; xxxv. 682; Proc. Geol. Assoc. viii. 197. See also Hicks, Q. J. xxxiv. 137; xxxv. 295; xl. 187; G. Mag. 1880, 519; and T. G. Bonney, Q. J. xxxix. 478.

3. *Volcanic series*, consisting of volcanic fragmentary ejectamenta, agglomerates, ash-beds, and slates, occurring near Bangor, and referred to as the *Bangor Beds*. (See Fig. 5 and Fig. 8, p. 54.)
2. *Felsitic series*, consisting chiefly of quartz-felsites, and probably also of volcanic origin, occurring near Llanddeiniolen and Dinorwig, and referred to as the *Dinorwig Beds*.
1. *Granitoid series*, occurring near Caernarvon, and referred to as the *Caernarvon Beds*.

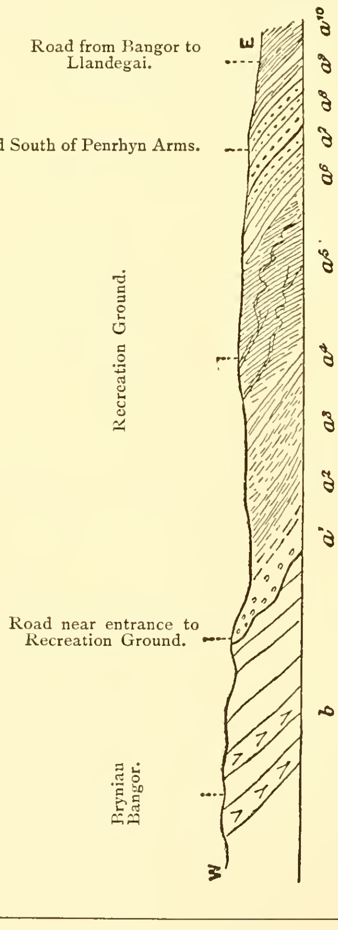


Fig. 5.—Diagram Section E. and W. across Bryniau Bangor, Caernarvonshire. (Prof. T. McK. Hughes.) Length of section about 1 mile.

b Bangor Beds (Upper Pebidian).
a 1 Conglomerate and Sandstone. Basement Bed of Cambrian.
a 2 Sandy mudstone.
a 3 Finer felspathic mudstone.
a 4 Pale green felspathic mudstone.
a 5 Cleaved and contorted felspathic mudstone.
b Archæan.

a 6 Purple and green fine mudstone and slate.
a 7 Fine sandy flags like the Bray Beds, purple, and here and there green, passing up into brown.
a 8 Even-bedded thin grey sandstones.
a 9 Banded flags passing up into
a 10 Black Slates.
a 1 to *a* 10 Lower Cambrian.

The Caernarvon Beds are regarded as equivalent in part of the Dimetian, and are subdivided into—

Upper = Crug Beds, pink and grey, compact and fine-grained felspathic rocks.
Lower = Twt-Hill Beds, consisting of a coarse crystalline aggregate of quartz and felspar.

The Cae-Seri and Tairffynnon breccias belong to the Cambrian Beds. The conglomerates at the base of the Cambrian in Caernarvonshire and Anglesey contain pebbles derived from the Archæan rocks.

Anglesey.—Micaceous and chloritic schists may be seen near Beaumaris, and these, together with gneissic rocks, grits and quartz-rock, constitute a great portion of Anglesey. They are traversed by igneous dykes, and associated with masses of granite and granitoid rocks. The rocks were long ago described by the Rev. J. S. Henslow.[1] The exact age of some of the strata on parts of the north coast of the island is by no means certain. Dr. Hicks regards all the altered "Cambrian" of Anglesey, and its so-called intrusive granite, as Pre-Cambrian.[2] (See p. 55.)

In Anglesey Dr. C. Callaway would identify two Archæan or Pre-Cambrian groups, distinguished as the Slaty and Gneissic formations. In the Slaty series are included the Llangristiolus grits and slates, Llangefni conglomerates and shales, Cerrig-Ceinwen slaty group, Chloritic schists of Mynydd Mechell, Llanfechell grits, Rhosbeirio shales, Amlwch slates and Cemmaes limestones.

The Gneissic or granitoid series comprises hälleflinta, quartz-schist, grey gneiss, schist, and granitoidite. These beds are faulted wherever seen in contact with the slaty series: but their more intense metamorphism points to their greater antiquity.[3]

The correlation of the Slaty series with the Pebidian, and of the Gneissic series with the Dimetian, has been suggested, while certain hälleflintas and quartz-felsites are identified as Arvonian. Sir A. C. Ramsay maintains that the altered rocks of Anglesey are the metamorphosed representatives of the Cambrian.[4]

Holyhead Island and the North and South Stack islets are composed of gneiss, grits, and schists, showing very violent contortions. The rocks may be, in part, Pre-Cambrian.[5] The quartz-schists in Holyhead mountain are regarded as Arvonian by Dr. Hicks. The Lleyn district (the promontory that separates Caernarvon Bay from Cardigan Bay) contains rocks believed to be of Pre-Cambrian age. These are the metamorphosed rocks or schists on the south side of

[1] Trans. Cambr. Phil. Soc. i. 359.

[2] G. Mag. 1878, p. 461; Proc. Geol. Assoc. vii. 70. See also Pop. Science Review, 1881, p. 289; T. G. Bonney, Q. J. xxxix. 476; and Address to Geol. Soc. 1886, p. 87.

[3] Q. J. xxxvii. 210; xl. 567; G. Mag. 1886, p. 117; 1881, p. 348.

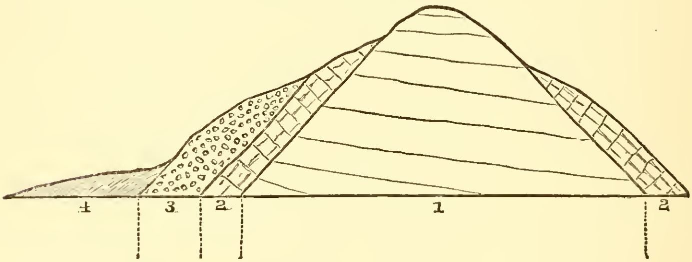
[4] Q. J. xxxvii. 237.

[5] W. S. Symonds, Records of the Rocks, p. 29; see also Murchison's Siluria, ed. 5, p. 35.

Caernarvon Bay, including Bardsey Island and the coast from Bardsey Sound to Porth Nevin.

The Wrekin district of Shropshire.—Some of the older rocks of Shropshire were investigated in 1877 by Mr. S. Allport, who regarded them as belonging to a volcanic series.[1] Dr. C. Callaway subsequently described the Wrekin as a ridge composed of alternations of bedded felspathic lavas and tuffs (Pre-Cambrian), flanked on both sides by quartzites (possibly Pre-Cambrian), which are succeeded by the Hollybush Sandstone (Lingula Flags), the Shineton Shales (Tremadoc), and the Hoar Edge Grits (Lower Caradoc).

FIG. 6.—SECTION ACROSS THE WREKIN, IN SHROPSHIRE.
(Dr. C. Callaway.)



4. Shineton Shales (Tremadoc).
3. Hollybush Sandstone (Lingula Flag Series).
2. Quartzite.
1. Bedded volcanic tuff (Archæan).

The dotted lines represent faults.

These strata appear in places to succeed each other in conformable succession; but it is doubtful if the conformity with the quartzite is real. The Wrekin Volcanic Series (Uriconian or Pebidian) has furnished pebbles to the Longmynd Series. (See Fig. 6 and p. 57.) Dr. Callaway has detected "one good specimen of a worm-burrow, apparently *Arenicolites*," in the quartzite, and this, if Pre-Cambrian, would be the oldest known British fossil.[2] He proposes for it the name *Arenicolites uriconiensis*.[3] Recent discoveries in the Midland counties, however, tend to show that the age of the quartzite is probably Cambrian.

Granitoid rock, and gneiss like that of Malvern, have been observed at Primrose Hill and Ercal Hill at the southern and northern ends of the Wrekin range. Quartzites are exposed on the south-east flank of Caer Caradoc, near Church Stretton, and at Lawley

[1] Q. J. xxxiii. 449.
[2] Q. J. xxxiv. 763; xxxv. 649; G. Mag. 1881, p. 348; 1884, p. 362; 1885, p. 260.
[3] The term Uriconian is derived from the Roman station *Uriconium*, on the site of which stands the village of Wroxeter, S.E. of Shrewsbury.

and Cardington. Quartz-schists are exposed at Rushton. Prof. Bonney remarks, that in the Wrekin we have a portion of an ancient volcanic hill which has ejected rhyolitic lavas and scoria. At Lilleshall Hill rhyolitic agglomerates and other volcanic rocks are met with.

Lickey Hills, Worcestershire.—In this range the principal rock is a quartzite, bearing considerable resemblance to that which flanks the Wrekin. Formerly this rock was regarded as altered Llandovery sandstone, but the investigations of Mr. F. T. S. Houghton and Prof. Lapworth have shown that, while there is a quartz-grit of Llandovery age, the quartzite proper is an older rock. Prof. Lapworth has also discovered that at the south-western end of the range there are felspathic ashy beds, and a felstone, with a general resemblance to the rocks in the Wrekin area.[1]

Hartshill Ridge, Warwickshire.—A ridge of quartzite north-west of Nuneaton (formerly regarded as Millstone Grit) has been shown by Prof. Lapworth to be overlaid by fossiliferous Cambrian rocks. It is underlaid by Archæan rocks, consisting of felspathic mudstones and ashes, with intrusive quartz-felsite.[2] (See p. 66.)

Charnwood Forest, Leicestershire.—The oldest rocks of Charnwood Forest, in the opinion of Dr. H. B. Holl, and others, may be Pre-Cambrian. Apart from the granitic rocks (see sequel), there is a series of slates, grits, breccias, and agglomerates, among which are some porphyroids, probably lavas. Grits occur at Forest-Rock Inn and Bawdon Castle; volcanic breccia at Whitwick and Markfield; and agglomerate at High Towers.

The Rev. E. Hill and Prof. T. G. Bonney, who have more recently investigated the district in detail, observe that the Charnwood Forest rocks seem to fall naturally into three great groups, which, however, are not separated by any very sharp lines of demarcation:[3]—

3. Slates of Swithland and Groby (visible only in the more southern part of the Forest).
   Sharpley and Peldar Tor rocks (tuffs, porphyroids, etc.), with the agglomerates of Cadman (and their equivalents in Bardon Hill), which are probably succeeded by the finer beds of the quarry near Whitwick School House.
   Some portion of this upper division may be represented by the Forest Gate Beds in the north-east; and the upper limit of the group further south seems to be marked by the pebble-beds and quartz grits of the (Woodhouse) Hanging Rocks, the Brande, the Stable Quarry (Bradgate), and Steward's-Hay Spring.

2. Slate-agglomerate.
   Coarse ash-beds of the Monastery, the Hanging Stones, Timberwood Hill, Benscliff, etc.

1. Blackbrook series, ashy beds, flinty slates, banded grits, etc. (Whittle Hill honestone, etc.)

[1] T. G. Bonney, on the Archæan Rocks of Great Britain, Brit. Assoc. 1885.
[2] Proc. Birmingham Phil. Soc. iii. 206.
[3] Q. J. xxxiv. 199; xxxvi. 349. See also James Plant, G. Mag. 1865, p. 233.

Messrs. Hill and Bonney, who at first were struck with the resemblance of some of the Charnwood slaty rocks to the Borrowdale Series of Cumberland, now agree with Dr. Callaway and Dr. Hicks in referring the series to the Pebidian group.[1] The Charnwood rocks were long ago described by Sedgwick and Jukes, and later on by the Rev. W. H. Coleman and Prof. Hull.[2]

At Whittle Hill are obtained the celebrated 'Charley Forest' oil stones or Whittle Hill Hones. These are ground on the spot, and are said to be among the best substitutes for Turkey oilstone. Mr. W. J. Harrison describes the rock as a fine greenish-grey siliceous slate. Slates are quarried for roofing purposes at Swithland. One pit is 150 feet deep. The Groby slate pits are on the road leading to Markfield: here the grain is not so fine as at Swithland. In some instances the slate is of a purplish tint, with yellowish chloritic veins running through it, in other cases it is of a dull greenish-grey. The blue Groby slate has been used in the Albert Memorial, Kensington Gardens.[3]

Devon and Cornwall.—The researches of Mr. J. H. Collins in the Meneage Peninsula, and of Mr. A. R. Hunt along the coasts of South Devon and Cornwall, have revealed evidence of the presence in these areas of rocks which may be of Pre-Cambrian age. The micaceous and chloritic schists of Bolt Head, Prawle Point, and Start Point, in South Devon, are probably Archæan; and so also may be some of the metamorphic rocks of the Lizard region in Cornwall.[4] The Eddystone Lighthouse is built upon a reef of gneiss, and the Shovel Reef, in Plymouth Sound, is in part gneissic; some of these rocks are massive, others more schistose, and they appear to be of the old granitoid kind. Moreover, the hornblendic and other schistose rocks of Cornwall have been separated by Mr. Collins from the Cambrian (Lower Silurian) rocks, and it has been shown by Prof. Bonney that the latter are faulted against the former.[5]

Gneisses also of a type which occurs in the lower part of the Archæan series have been recognized in the Channel Islands by Prof. Bonney and the Rev. E. Hill.[6]

[1] Q. J. xxxi. 421.

[2] Geology of Leicestershire Coal-field, etc. Nature, Nov. 23, etc. 1876.

[3] W. J. Harrison, Sketch of the Geology of Leicestershire, 1877.

[4] T. G. Bonney, Q. J. xxxix. 1; xl. 1, Rep. Brit. Assoc. for 1885; and Address to Geol. Soc. 1886, p. 85.

[5] H. Hicks, Proc. Geol. Assoc. vii. 73; J. H. Collins, Journ. R. Inst. Cornwall, vii.; and Trans. R. G. S. Cornwall, x. 47.

[6] Q. J. xl. 404; xxxix. 24.

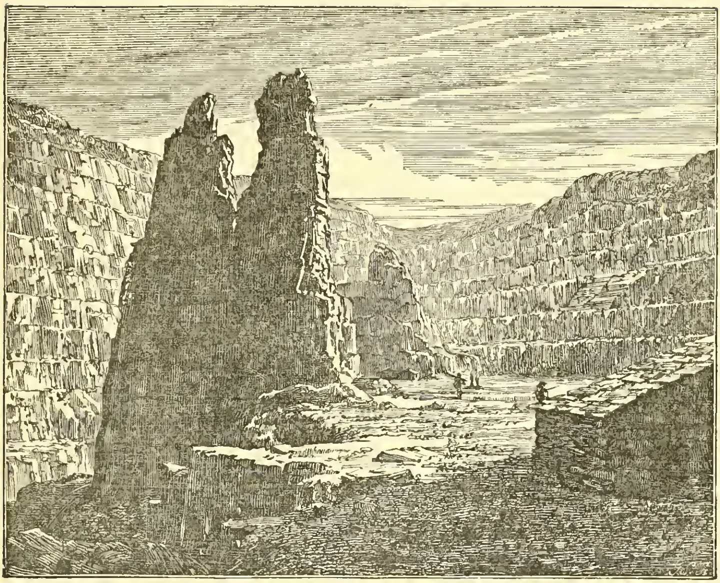


FIG. 7.—PENRHYN SLATE QUARRY. (From a photograph.)

The term Cambrian, proposed by Sedgwick, is derived from Cambria, the old name for Wales, and in its broadest sense it is equivalent in part to the 'Cumbrian' series of the Lake District.

Sedgwick's earlier observations on the Lake District were made during the summers of 1822–1824, but he remarks that we owe our first knowledge of the larger subdivisions of the rocks to Jonathan Otley of Keswick. Thus three groups—1, Skiddaw Slate; 2, Green Slate and Porphyry; and 3, Rocks below the Scar limestone, originally distinguished by Otley in 1820, were adopted by Sedgwick as the basis of his classification. John Phillips mentions a meeting with the celebrated Professor in 1822; he was riding, as usual, with saddle-bags for his specimens, and a miner's boy *en croupe*. John Ruthven, of Kendal, was frequently engaged by Sedgwick to collect fossils for him.[1] The older rocks of North

[1] Sedgwick, T.G.S. (2) iv. 48; Proc. G. S. iv. 224; Phil. Mag. lvi. 257. See also Life of William Smith, p. 104.

Wales were studied by Sedgwick during the summers of 1831 and 1832, and in the following year he gave the name Cambrian to the great mass of the slaty rocks and limestones in North Wales, extending from the Menai Straits to the base of the flagstones and grits of the Berwyns, and which at the time were considered to be older than the Silurian rocks of Murchison.[1]

The subsequent researches of Sedgwick enabled him to fix the boundary-line of the Cambrian and Silurian rocks at the base of the May Hill Series, a line which the further observations of geologists have tended to confirm, as one well marked by a palæontological, and also, in many instances, by a physical break of large extent. Unfortunately, Sedgwick's Upper Cambrian was ultimately found to possess the fossils of Murchison's Lower Silurian. Murchison, however, who had included the Caradoc and Llandeilo beds in his Silurian system, but had misplaced them in his typical section, did not concede these strata to the Cambrian; and finding that his system had no definite base on which to rest, took in from time to time group after group of the underlying series, and had to prove at each step that as yet no break had been found in the series, until at length he annexed part of the lowest Cambrian.[2] Hence arose a painful controversy. And different classifications have been adopted by geologists, some upholding that of Sedgwick; some (including the Directors of the Geological Survey in their publications) adopting that of Murchison; while others again have endeavoured to effect a compromise, and have drawn the line between Cambrian and Silurian, at various horizons, about midway in the debateable ground. Again, some have used the term Cambro-Silurian for the Upper Cambrian, while Prof. C. Lapworth has proposed the term Ordovician for the same division, a term which meets with increasing favour, and appears well fitted to cut the Gordian knot; for although there is no unconformity with the beds below, the Ordovician group contains a new and distinct fauna.[3]

And here it may be mentioned that Joachim Barrande, labouring amongst the older rocks of Bohemia, identified not only the Upper and Lower Silurian rocks of Murchison, but an earlier set of strata, containing a distinct fauna. To this "*First fauna*" he applied the name "Primordial zone," and unhappily grouped it as Silurian, using that term for all the fossiliferous strata older than Devonian. The fossils of the Lower Silurian were grouped as the "*Second fauna*," and those of the Upper Silurian as the "*Third fauna*." These faunas in their collective aspect are distinct.

M. Barrande paid special attention to the subject of "colonies" of fossils. He recognized at certain horizons in Lower Silurian rocks, members of his Upper Silurian fauna. And he concluded that during the Lower Silurian period in Bohemia, certain forms that lived on to Upper Silurian times existed at a distance

[1] Q. J. viii. 149.

[2] See Sedgwick and F. M'Coy, Synopsis of the Classification of the British Palæozoic Rocks; and J. W. Salter, Catalogue of Cambrian and Silurian Fossils, Cambridge. Also T. Sterry Hunt, History of the Names Cambrian and Silurian, G. Mag. 1873, p. 385; T. McK. Hughes, Discussion at Meeting of Geol. Soc. December 2, 1874; Rep. Brit. Assoc. 1875; Q. J. xxxi. 194; Jukes, Pop. Phys. Geology, p. 212; C. Lapworth, G. Mag. 1879, p. 1.

[3] C. Lapworth, G. Mag. 1881, p. 261; Hicks, P. Geol. Assoc. vii. 297.

away, and occasionally migrated when communication between the separate areas was now and again established.[1] Mr. Marr has, however, shown that these re-appearances of faunas can be explained by faults.

It is perhaps needless to observe that the names Cambrian and Silurian are mere terms of convenience in classification: one name might indeed be applied to the whole series of rocks, but as we have no reason to doubt that the history of the earth was a series of regular changes, so the terms of classification, dividing the history into chapters, are necessary to assist the memory and mark out the leading modifications that have taken place over any given area. And the division between Cambrian and Silurian proposed by Sedgwick is one that marks the most important break noticed in the series in England and Wales. Were this classification generally adopted, it would only be an act of justice to the geologist, who first made out the natural divisions of the older Palæozoic rocks, whose early researches have been shown to be in all essential points correct, but whose work has not, until within the last few years, received adequate acknowledgment. The enthusiastic labours of both Murchison and Sedgwick are now duly appreciated. Nor should we neglect to give credit to the more detailed work of the Geological Survey in Wales, done by A. C. Ramsay, W. T. Aveline, A. R. C. Selwyn, and J. B. Jukes; work which entailed great labour and no little hardship, and which, carried out with the utmost zeal and energy, has formed the basis for all subsequent investigations.[2] But, while it is necessary here to give prominence to one form of classification, the alternative groupings of the rocks are likewise given, so that the student can at once understand the views adopted by different authorities.[3]

Table showing the Classification of the older Palæozoic Rocks.

Cambrian (*Sedgwick*).	Upper.	Bala Series.	Hirnant Limestone and Ashgill Shales.	Ordovician (*Lapworth*). Cambro-Silurian (*Jukes*).	Lower Silurian (*Murchison*).
			Caradoc Beds and Coniston Limestone.		
			Llandeilo Flags.		
		Llanvirn Series.			
		Arenig Series.			
	Middle.	Tremadoc Slate Series.		Upper Cambrian (*Hicks*). Primordial Zone (*Barrande*).	
		Lingula Flag Series.	Dolgelly Beds.		
			Ffestiniog Beds.		
			Maentwrog Beds.		
	Lower.	Menevian Series.		Cambrian (*Murchison*). Lower Cambrian (*Hicks*).	
		Harlech and Longmynd Series.			

[1] Défense des Colonies, v. 1881. Apparition et réapparition en Angleterre et en Ecosse des espèces coloniales Siluriennes de la Bohême; see also Lyell, Elements of Geology, edit. 6, p. 569; and A. Geikie, Text-Book of Geology, edit. 2, p. 618.

[2] See Letters, etc., of J. B. Jukes, 1871.

[3] See A. C. Ramsay, Geology of North Wales, edit. 2, p. 1; J. E. Marr, The Classification of the Cambrian and Silurian Rocks, 1883; and Murchison, Siluria, edit. 5, 1872. See also Life of Murchison, by Dr. A. Geikie.

The following Table is intended to show the general relations between the Cambrian rocks of the Lake District and those of Wales.

WALES.	LAKE DISTRICT.
Bala Series.	Coniston Limestone Series.
	Borrowdale Series.
Llanvirn and Arenig Series.	Skiddaw Slates.
Tremadoc Slate Series.	
Lingula Flag Series.	
Menevian Series.	(Not exhibited in the Lake District.)
Harlech and Longmynd Series.	

In the Lower Cambrian rocks we meet with the first definite traces of animal life, and in the oldest group of rocks we find many classes represented, most important among them being Brachiopoda and Crustacea. The earliest stage of this group has, however, at present yielded only Annelides; higher up we meet with Ostracoda and Brachiopoda (*Lingulella*, *Discina*, and *Obolella*), and still higher a more varied fauna—species of *Paradoxides*, *Agnostus*, and *Conocoryphe*, among the Trilobites (Crustacea) being most prevalent. Sponges, Pteropods, and Cystideans also occur. Hence we must probably look to Pre-Cambrian times for the origin of life. The Middle Cambrian rocks introduce many forms of Graptolites, also *Olenus*, *Parabolina*, and *Sphærophthalmus*, among the Trilobites; and *Kutorgina* among the Brachiopods. Phyllopods,[1] Cephalopods,[2] Lamellibranchs, Crinoids, and Asteroids, appear. The Upper Cambrian (Ordovician or Lower Silurian) rocks introduce *Asaphus*, *Angelina*, *Cheirurus*, *Ampyx*, *Ogygia*,

[1] T. R. Jones and H. Woodward, G. Mag. 1884, pp. 348, 393.

[2] For descriptions and figures of Palæozoic Cephalopoda, see Monograph of British Fossil Cephalopoda, by J. F. Blake, Part I. 1872.

Trinucleus, *Calymene*, *Phacops*, *Illænus*, and *Homalonotus* among the Trilobites; *Crania*, *Leptæna*, and *Strophomena*, among the Brachiopods; *Murchisonia* and *Euomphalus* among the Gasteropods. Corals also appear.[1]

The Cambrian rocks constitute a great series of grits and slates, with subordinate beds of limestone; and they contain many interbedded and intrusive igneous rocks.

Their total maximum thickness is estimated at upwards of 35,000 feet in Wales, and at about 20,000 feet in the Lake District, but in the latter area the base is not seen. It must also be remembered that, owing to the disturbances and changes the beds have undergone, such estimates are very hypothetical.

The Cambrian rocks have, on the whole, been formed in shallow seas, but there are some evidences of tolerably deep water. The nearest land-areas lay probably to the north. We have some records of the weather in the "fossilized sunshine and showers," preserved to us in the suncracks and rain-pittings; and Dr. Hicks is of opinion that in the earlier stages of the Cambrian period the climate was probably very cold, gradually becoming milder, until in time warm currents or seas of moderately high temperature prevailed, as indicated by the growth of corals.[2] The Mollusca and the Trilobites indicate marine conditions, and the sandy and muddy sediments indicate the nearness of land.

The later stages of this period were characterized by much volcanic activity, and Sir Andrew Ramsay has remarked that our terrestrial scenery, so far as we can restore it, then consisted of groups of volcanic islands. Some of the volcanoes may have rivalled Etna in height, but no traces of any terrestrial flora have been found. In North Wales the ashy series of beds thickens more and more in an easterly direction, suggesting that prevalent westerly winds had a tendency during eruptions to blow the volcanic dust and lapilli eastwards.[3]

[1] Hicks, Q. J. xxxi. 190.
[2] G. Mag. 1876, pp. 160, 250.
[3] Phys. Geol. and Geogr. Gt. Britain, ed. 5. pp. 80–82.

CAMBRIAN.

WALES AND WEST OF ENGLAND.

LOWER CAMBRIAN.

The Lower Cambrian rocks are often subdivided geographically, or according to the several tracts over which they are exposed. Two well-marked series are, however, now established :—

2. Menevian Series.
1. Harlech and Longmynd Series.

Together they comprise two palæontological divisions, being marked by the presence of *Paradoxides* and Annelides. They are arranged as follows :[1]—

Paradoxidian	2. Menevian Series.	
	1. Harlech and Longmynd Series.	
		2. Solva Group.
Annelidian		1. Caerfai Group.

The thickness of the Lower Cambrian rocks varies in different areas, the estimates being from about 4000 to upwards of 8000 feet.[2]

HARLECH AND LONGMYND SERIES.

This series, named by Sedgwick, includes the Harlech, Longmynd, and Llanberis Beds; and the Caerfai and Solva Beds, which have been more recently distinguished, in South Wales. The subdivisions have not been correlated with precision.

The rocks consist of a series of grey, purple, and red flaggy sandstones, conglomerates and shaly beds, having a thickness estimated at from 3500 to 4000 feet in South Wales, and supposed to be over 8000 feet in North Wales. Remains of Sponges, Annelides, Pteropods, Polyzoa, Brachiopods, such as *Lingulella* and *Obolella*; also of Entomostraca, and Trilobites of the genera *Conocoryphe*, *Paradoxides*, *Microdiscus* and *Plutonia*, have been determined in these strata, mainly through the researches of Dr. Hicks. The earliest British Brachiopod (*Lingulella primæva* or

[1] C. Lapworth, G. Mag. 1881, p. 321.

[2] For remarks on the deposition of the Lower Cambrian beds, see E. Hull, Q. J. xxxviii. 210.

ferruginea) was obtained by him from the lower beds of this group as early as 1867.[1]

These indicate the marine origin of the strata in which they occur. Sir A. C. Ramsay has suggested that some of the red or purple beds, which are unfossiliferous, may have been deposited in inland waters, or in lacustrine areas subject to occasional influxes of the sea.[2]

Harlech Grits.

A large tract of ground between Barmouth and Harlech, extending eastwards to Craig-y-Penmaen in Merionethshire, is composed of greenish grits (the Harlech Grits and Barmouth Sandstones), interstratified here and there with green and purple slates. The series is stated by Sir A. C. Ramsay to be more than 6000 feet in thickness. The beds are pierced by dykes of igneous rock.

Evidence of sun-cracks and rain-drops has been detected on the surfaces of some of the beds. The only organic remains are Annelide tracks and borings.

The junction of the Harlech Grits with the Menevian strata is well seen at Aber-rhamffroch, also in the Waterfall Valley, near Maentwrog, and in the Mawddach Valley, Dolgelly: the beds are conformable. The slates have been worked for economic purposes in places.

Llanberis Grits and Slates.

This series, named by Sedgwick, includes the famous slates (Caernarvon or Bangor slates) of Penrhyn and Llanberis: it comprises about 1300 feet of purple and green grits, resting on blue, purple, and green slates; while below are bands of slate, grit, and conglomerate. Altogether the series attains a thickness of about 3000 feet. The best sections are in the Passes of Llanberis and Nant Francon.[3] The beds contain some igneous dykes, while the cleavage is very intense and distinct from the bedding. Sedgwick observed that in the fine quarries of Nant Francon and Llanberis, the cleavage planes strike exactly with the beds, but are inclined at a greater angle.[4]

North Wales is the chief slate-producing country in the world; some beds were worked as early as the twelfth century.

At Penrhyn the slaty series comprises:—

Green slates.
Purple slates.
Blue and purplish-blue slates.
Purple and red slates.

[1] Davidson, G. Mag. 1868, p. 306.
[2] Q. J. xxvii. 197, 241.
[3] Ramsay, Geology of North Wales, edit. 2, p. 173.
[4] Proc. G. S. iv. 215. See also diagram of Mr. Assheton Smith's quarries, Llanberis, Q. J. iii. 138.

Here and there bands of grit are met with, while conglomerates occur at the base.

The large slate quarry of Penrhyn is probably familiar to all visitors to North Wales. The summit of the quarry is about 500 feet above the base, and the slates are worked out in terraces, each about 40 to 45 feet in height. The beds of good slate are about 200 feet in thickness, and are of a rich purple colour with green spots.[1] The outstanding mass in the woodcut represents a dyke of unprofitable rock. (See Fig. 7, p. 47.)

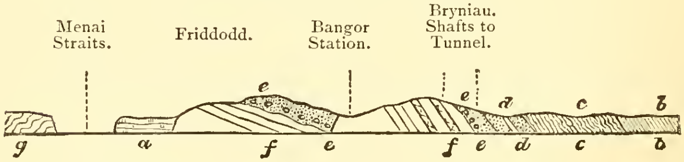
The beds have yielded no fossils save some burrows of marine worms, and very doubtful traces of Fucoids, termed *Chondrites*.[2]

The bluish varieties of slate owe their colour to protoxide of iron; the red and purple varieties to peroxide of iron. The green banding of the slates, and the production of the large uniform masses of green, are considered by Mr. G. Maw to be not only due to independent causes, but probably to have occurred at different times. The ordinary form of variegation of the slates consists of nuclei chemically or mechanically formed and environed by pale green slate, the bleaching of which has been due to the abstraction of the greater part of the colouring oxides of iron. This banding and blotching of the slate was formed probably before the slate was cleaved, and some of the purple slate has been changed into green at the junction of the greenstone dykes. An analysis of the slate at the Glyn Quarries, Llanberis, showed 60 to 66 per cent. of silica, 13 to 21 per cent. of alumina, with peroxide and protoxide of iron, etc.[3] Dr. Sorby has attributed the pale blotches of slate to concretions lying in the planes of bedding.[4] Slate has been worked also at Cilgwyn, and Nantlle.[5]

Bangor.—Near Bangor, according to Prof. Hughes, the Cambrian

Fig. 8.—Section near Bangor.

(Prof. T. McK. Hughes.)



a. Carboniferous Limestone.

Cambrian. { b. Black slate. c. Banded slate. d. Greenish grit and subordinate purple and green slate. e. Grit and conglomerate. }

Bangor Beds (Archæan). { f. Greenish slates, hornstones, breccias, &c. g. Schists. }

[1] D. Sharpe, Q. J. ii. 283.
[2] Salter, Q. J. xii. 246; Ramsay, Geol. N. Wales, ed. 2, p. 336.
[3] Q. J. xxiv. 381; Geol. Mag. 1868, p. 123.
[4] Edin. Phil. Journ. July, 1853, p. 3.
[5] D. C. Davies, A Treatise on Slate and Slate Quarrying, 1878.

beds consist of grits, conglomerate, mudstone, and slate. The conglomerate contains pebbles of quartz, quartzite, lydian stone, jasper, mica-schist, etc., and rests unconformably on the Archæan rocks, from which the fragments have been derived. The general succession of Cambrian rocks in this neighbourhood appears to be as follows[1] (see Fig. 8, and Fig. 5, p. 42):—

3. Black and purple Slates.
2. Brown Sandstones, often fossiliferous.
1. Basement-conglomerate series, consisting sometimes of a quartz conglomerate, sometimes of a felsite conglomerate, and sometimes of quartzose or felspathic grits: varying according to the character of that part of the underlying series on which it rests.

The Quartz-conglomerate of Twt Hill, Caernarvon, about which much controversy has been raised, and which is seen in juxtaposition to the Archæan granitoid rocks, has been shown by Prof. Hughes to form the base of the Cambrian series.[2] Symptoms of unconformity were noted by Mr. G. Maw in the lowest Cambrian Beds at Llyn Padarn, near Llanberis. This irregularity is (in the opinion of Prof. Hughes) due to lateral pressure acting on beds of unequal texture and character. The coarser and more sandy beds were crumpled and protruded into the finer beds, which were compressed and cleaved.[3]

Anglesey.—The exact equivalents of all the older rocks of this Island have not yet been definitely determined. Two slate groups have been described by Prof. Hughes, the upper belonging to the Silurian system, and a lower in which Arenig, Tremadoc, and even older beds may be recognized. Below are the basement beds of the Cambrian, consisting of conglomerates, grits, and sandstones.[4] The Baron Hill grit near Beaumaris probably belongs to the basement conglomerate.

The Clymwr and Llanfihangel or Treiorwerth conglomerates, with intervening Cwaen shales, have been described by Dr. Callaway —they fringe the granitoid and slaty rock (Archæan) of Tywyn; and are overlaid by grits with *Orthis Carausii* and other fossils of Upper Cambrian or Ordovician age. He doubts whether any Lower Cambrian rocks are present in Anglesey.[5] (See also p. 43.)

Caerfai and Solva Beds.

In South Wales two divisions have been made in the Harlech series by Dr. Hicks (1881), and named respectively the Solva and Caerfai groups, from localities near St. Davids, in Pembrokeshire,

[1] Q. J. xxxv. 688; and R. D. Roberts, G. Mag. 1882, pp. 114, 152.
[2] G. Mag. 1881, pp. 194, 439. See also papers by T. G. Bonney and F. T. S. Houghton, Q. J. xxxv. 309, 321; G. Mag. 1882, p. 21; Q. J. xxxix. 478; and H. Hicks, Q. J. xl. 197.
[3] Q. J. xxxiv. 143, 764.
[4] Q. J. xxxviii. 27; see also Proc. Cambridge Phil. Soc. iii. 341.
[5] Q. J. xl. pp. 572, 581.

where the rocks are exhibited.[1] In descending order the beds are grouped as follows :—

2. Solva Beds.	*Upper.*—Grey flags, 150 feet, with *Obolella sagittalis*, *Paradoxides aurora*, *Conocoryphe bufo*.
	Middle.—Coloured gritty and flaggy rocks, 1500 feet, with *Paradoxides Solvensis*, *Agnostus Cambrensis*, *Eophyton*.
	Lower.—Yellowish flags and grits, 150 feet, with *Paradoxides Harknessii*, *Plutonia Sedgwickii*, *Eophyton*.
1. Caerfai Beds.	*Upper.*—Massive purple sandstones, 1000 feet, with Annelides.
	Middle.—Red shales, 50 feet, with *Lingulella primæva*, *Discina Caerfaiensis*, *Leperditia Cambrensis*.
	Lower.—Green flaggy sandstones and conglomerates, 520 feet, with Fucoids and Annelides.

The Annelides are represented by *Arenicolites* and *Scolites*. Notwithstanding the fossils mentioned, the rocks, as a rule, are very barren.

Dr. Hicks considers that the older (Pre-Cambrian) rocks form a distinct group, and that the Cambrian conglomerates overlap them irregularly. These conglomerates, in his opinion, are almost entirely made up of pebbles derived from the underlying rocks.[2] The Lower Cambrian rocks are well shown in the Caerbwdy Valley, and along the coast towards Nun's Chapel. In the Caerbwdy Valley, the thickness of the more conglomeratic portion of the basal beds is about 60 feet, and some of the pebbles attain a foot in diameter.[3]

Dr. A. Geikie has thus divided the Lower Cambrian (Harlech) rocks of St. Davids, exposed on the north side of St. Bride's Bay in Pembrokeshire :[4]—

	Purple and green grits and shales	Solva and Caerfai groups of Dr. Hicks.
	Purple grits	
	Red shales (with *Lingulella primæva*).	
	Greenish shales	
	Quartzite conglomerate	
Contemporaneous volcanic group.	Porthlisky schists	Pebidian of Dr. Hicks.
	Agglomerate, tuff, and diabase	

In this grouping, as before noted, Dr. Geikie's conclusions are at variance with those of Dr. Hicks. (See p. 39.) The conglomerate has been taken as marking the base of the Cambrian system, but Dr. Geikie believes that no abrupt break can be traced between the volcanic group and the conglomerate. The latter forms a band composed of rolled pebbles of quartz and quartzite, whose average size is probably less than that of a walnut, though occasionally as large as a man's head. The band varies in thickness from a few feet to upwards of one hundred feet. The conglomerate appears to mark the decline of the submarine volcanic activity. Dr. Geikie

[1] Q. J. xxvii. 396. See also Proc. Geol. Assoc. vii. 282; Pop. Science Review, 1881; and C. Lapworth, G. Mag. 1881, p. 321.

[2] Q. J. xxxiii. 230.

[3] Q. J. xl. 520.

[4] Q. J. xxxix. 268. See also Hicks, Q. J. xl. 526.

adds that these rock-groups, which had been laid down continuously, were subjected to disturbance, the principal effect of which was to throw them into an arch, and to bend over this arch into an isocline (or inverted anticlinal), with a general inclination towards the north-west. The strata likewise underwent a wide-spread foliation, which, in accordance with the structure and composition of the rocks affected, was chiefly developed in certain kinds of material. Subsequent to these changes the south-eastern side of the fold was invaded by the rise of a mass of granite with quartz-porphyries. Accompanying and outlasting this intrusion, a process of metamorphism went on, the effect of which has been to change fine felsitic tuffs or shales into hard flinty translucent masses, and to superinduce in them a finely-crystalline structure with the development of porphyritic-felspar crystals and veins and threads of crystalline quartz.[1]

The cathedral of St. Davids is in some parts built of Cambrian sandstone.

Longmynd Beds.

These rocks, so named by Sedgwick, from the Longmynd hills in Shropshire, which rise to heights of 1000 and 1600 feet, consist of green and purple grits, conglomerates, and slates. They are developed at the Longmynd and in the neighbourhood of Shrewsbury, where they are overlaid by Tremadoc Beds. Their thickness has been estimated at 8000 feet. At one time they were considered to be the oldest or "Bottom Rocks." Murchison in 1834 used the term Longmynd and Gwastaden Rocks, the latter name being taken from a locality in Brecknockshire.[2]

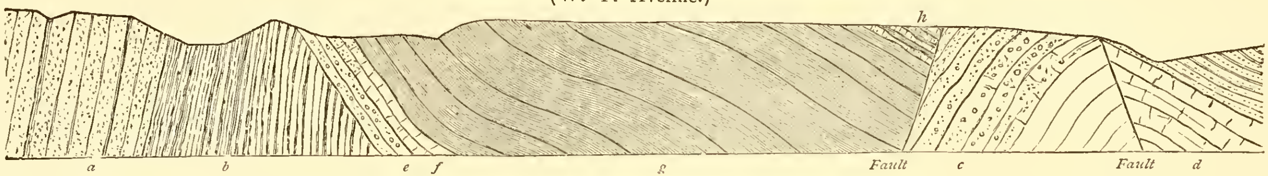
The beds contain Annelide burrows, belonging to two species, according to Mr. Salter, who named them *Arenicolites didymus* and *A. sparsus*. The burrows, as well as ripple-marks, sun-cracks, and rain-prints, have been observed in the beds near Church Stretton, between Caer Caradoc and Stiper Stones in Shropshire.[3] Mr. Salter also discovered portions of a Trilobite at Callow Hill, Little Stretton, which he named *Palæopyge Ramsayi*.

The Longmynd group is sometimes divided into an upper and a lower portion, the former supposed to be equivalent to the Harlech Grits, and the latter to the Llanberis Slates. But there is no evidence, however, at present to show that the Llanberis Slates are older than the Harlech Grits, for the difference in their lithological characters may easily be explained, as stated by Sir C. Lyell, by looking upon them as deposits of fine mud thrown down in the same sea, on the borders of which the sands of the Harlech Grits were accumulating.[4]

[1] Q. J. xxxix. 324.
[2] Proc. G. S. ii. 14.
[3] Q. J. xiii. 192. See also Horizontal Sections, No. 33 (Geol. Survey), and J. D. La Touche, Geology of Shropshire, 1884.
[4] H. Hicks, P. Geol. Assoc. iii. 102.

FIG. 9.—SECTION OF THE EASTERN SLOPE OF THE LONGMYND, NEAR CHURCH STRETTON, IN SHROPSHIRE.

(W. T. Aveline.)

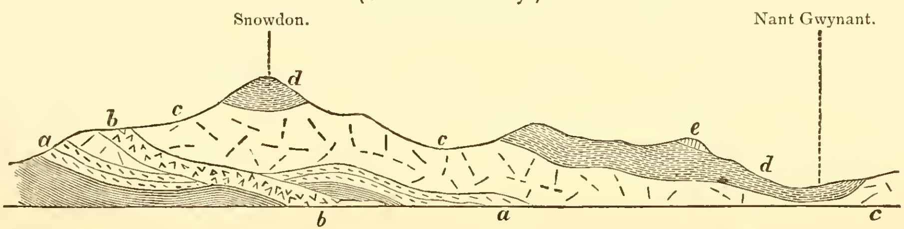


d. Variegated fossiliferous sandstone. } Bala and Llandeilo Series.
c. Conglomerate.
b. Hard Shales. } Longmynd Series.
a. Hard Sandstone.

h. Wenlock Limestone.
g. Wenlock Shale.
f. Pentamerus-limestone. } May Hill Series.
e. Conglomerate.

FIG. 10.—SECTION OF SNOWDON.

(Sir A. C. Ramsay.)



e. Columnar Felspathic Rock.
d. Volcanic Ashes, sometimes calcareous and fossiliferous = Bala Limestone.

c. Felspathic Porphyry (Lava beds).
b. Greenstone (intrusive).
a. Fossiliferous Grits overlying slaty beds.

The Rev. W. S. Symonds remarks that the Cambrian beds of the Longmynds are continued into the smaller range of the Haughmond Hills near Shrewsbury, and that the exudation of mineral pitch or bitumen from these old rocks is very remarkable.[1] This bitumen may have been derived from Coal-measures which formerly occurred over these rocks.

MENEVIAN SERIES.

The term Menevian, from Menævia, the old Roman name of the district of St. Davids, was proposed by Mr. J. W. Salter and Dr. Hicks (in 1865) for a series of black and grey slates and blue and grey flags with thick beds of sandstone, which underlie the true Lingula Flags, and attain a thickness of 600 feet or more. They overlie the Harlech rocks conformably around the Merionethshire anticlinal; the junction may be seen about half a mile east of Barmouth.

The Menevian Beds contain many species of Trilobites, amongst which the large *Paradoxides Davidis*, sometimes nearly two feet in length, is conspicuous. It was discovered by Mr. J. W. Salter in 1863. Hence the term Paradoxidian applied in part to this group. (See p. 52.) Among other fossils are *Agnostus scutalis*, *A. Davidis*, *Conocoryphe coronata*, *Microdiscus punctatus*, *Erinnys venulosa*, *Protospongia fenestrata*, and *Theca corrugata*. Most of the characteristic fossils are as yet unknown in the beds above. One Cystidean makes its appearance.

The Menevian beds are developed at St. Davids in South Wales, and in the neighbourhood of Maentwrog, Dolgelly, Tyddyngwladis, and Tafarn Helig, in North Wales. They have not yet been distinguished in the Longmynd area. At St. Davids the beds are very fossiliferous, and so closely related palæontologically to the Harlech or Longmynd group that Dr. Hicks (in 1867) proposed to class the two groups together as Lower Cambrian.

The following divisions have been made:[2]—

Menevian.	*Upper.*—Sandstones and shales, with *Orthis Hicksii*, *Obolella sagittalis*. 100 feet.
	Middle.—Black flags, with *Paradoxides Davidis*, *Agnostus scutalis*. 350 feet.
	Lower.—Grey flags, with *Paradoxides Hicksii*, *Obolella sagittalis*, *Agnostus Barrandei*, *Conocoryphe coronata*. 300 feet.

An interesting account of phosphates in these and other Cambrian rocks has been given by Dr. Hicks; and he states his opinion that much of the material may have been derived from Trilobites.[3]

[1] Records of the Rocks, p. 49.

[2] Harkness and Hicks, Q. J. xxvii. 396. See also P. Geol. Assoc. iii. 99, where the Middle and Upper divisions are grouped as one by Dr. Hicks; and C. Lapworth, G. Mag. 1881, p. 321. Also G. Mag. 1868, p. 306, Q. J. xxv. 51, and xxxi. 168.

[3] Q. J. xxxi. 376.

MIDDLE CAMBRIAN (*Sedgwick*).

UPPER CAMBRIAN (*Hicks*).

This group is divided as follows:—

2. Tremadoc Slate Series.
1. Lingula Flag Series.

Being marked by the preponderance of *Olenus*, it has been termed the Olenidian division by Prof. C. Lapworth.[1]

The following subdivisions have locally been made in the group:—

		North Wales.	Malvern.	Shropshire.
Tremadoc Slate Series.		*Upper*		
		Lower	Dictyonema Shales.	
Lingula Flag Series.		Dolgelly Beds	Malvern Black Shales	Shineton Shales.
		Ffestiniog Beds	Hollybush Sandstone.	
		Maentwrog Beds.		

The total thickness of the Middle Cambrian rocks has been estimated at about 6000 feet. The Rev. J. C. Ward was of opinion that portions of the Skiddaw Slates might be paralleled with the Lingula Flag Series and Tremadoc rocks (see p. 78).

LINGULA FLAG SERIES.

These beds were named by Mr. E. Davis in consequence of his discovery in 1845 of *Lingula* (*Lingulella*) *Davisii* in these rocks near Tremadoc. They consist of slaty and shaly beds with grits and hard sandstones, often much altered by the igneous rocks intruded among the strata. Where well developed they attain a thickness of from 5000 to 6000 feet; but half this estimate is sometimes considered sufficient. They were separated from the Tremadoc rocks in 1847 by Sedgwick, under the name of the Ffestiniog group.

The fossils are noted in the accounts of the subdivisions of the strata, but it may be mentioned that a 'pod-shrimp' (*Hymenocaris*) and many Trilobites make their appearance in them.

Many dykes and intrusive bosses of igneous rock penetrate the beds: some may be seen in the Ffestiniog Slate Quarries.

The Lingula beds are well developed in Caernarvonshire and Merionethshire, occurring near Bangor and Portmadoc, and ranging from the mouth of the Barmouth estuary to the north-east;

[1] G. Mag. 1881, p. 260.

thence circling round the Cambrian grits by Ffestiniog, they pass out to sea on the south side of Traeth Bach. They may be studied at St. Davids in South Wales, where they rest conformably upon the Menevian beds, and attain a thickness estimated by Dr. Hicks at 2000 feet. In Shropshire they are represented by the Shineton Shales; and in the Malvern area by the Hollybush Sandstone and Malvern Shales.

The gold lode of Dol-y-frwynog occurs in a talcose schist associated with igneous rocks on the horizon of the Lingula Flags.

In the maps of the Geological Survey, all the beds (excepting the Igneous rocks) from the Lingula Flags to the Lower Llandovery strata have received one colour; for though an order of succession can be made out by the help of fossils, yet practically most of the formations pass so gradually into each other that it was found impossible to define their limits on the map.[1]

In Wales the beds have been divided as follows:—

Lingula Flag Series	3. Dolgelly Beds.
	2. Ffestiniog Beds.
	1. Maentwrog Beds.

Maentwrog Beds.

The name Maentwrog Beds was proposed by Mr. T. Belt in 1867, for the grey, yellow, and bluish-coloured slates and flags with bands of sandstone, characterized by typical forms of *Olenus*, and sometimes termed the Olenus Beds, which are exhibited in great perfection at and around the village of Maentwrog, in Merionethshire.[2] The Maentwrog group is specially characterized by its dark blue, jointed, ferruginous slates. It attains a thickness of about 2500 feet.

Two divisions have been made:—

Maentwrog Beds	*Upper.*	Dark dull blue slates, with *Agnostus pisiformis*, *Olenus cataractes.* 1200 feet.
		Fine-grained grey flags, with *A. pisiformis*, *O. truncatus.* 600 feet.
	Lower.	Bluish-grey and black slates, alternating with grey and yellow flags: the slates contain *Olenus gibbosus*, *Agnostus nodosus*, *A. pisiformis*, var. *obesus.* 300 feet.
		Fine-grained grey and yellow pyritic flags. 400 feet.

On the whole, the fauna is very restricted. Phyllopoda make their appearance. Mr. John Plant obtained many fossils from the slates of Tyddyngwladis and Cwm Eisen.[3]

The Maentwrog beds extend from a little above Barmouth to Llanelltyd. They are well developed in the Waterfall Valley and in the valley running from Tafarn-helig to Caen-y-coed.

[1] A. C. Ramsay, Geol. N. Wales, edit. 2, p. 343.
[2] G. Mag. 1867, p. 538.
[3] Q. J. xxii. 505.

The lower beds may be studied on the range between the Eden and Mawddach, and near Dolmelynllyn. The upper beds are exposed near Dolgoed, Hafod-fraith, and Llanelltyd. The beds are also to be seen at St. Davids and Solva in South Wales.

The slates are sometimes worked for economic purposes, as at Caen-y-coed, and Llanelltyd, but they are not of much commercial importance. The gold-mines of Hafod-y-morfa, Cefn-deuddwr, have been opened in these beds. Cwm-eisen gold-mine is in hard flags of this group and Menevian beds—the metal occurs in a quartz vein, which is much disturbed. The Rev. W. S. Symonds observes, "From what I know of these gold-mines, I have no faith in Welsh gold, inasmuch as the precious metal occurs only on the surface, and dies out when followed into the heart of the rock." He notes the proximity of igneous rocks.[1] Ores of copper, lead, and zinc occur in small quantities.

Ffestiniog Beds.

Mr. Belt proposed (1867) to restrict the name of Ffestiniog group (of Sedgwick) to the hard sandy and micaceous flags containing *Lingulella Davisii*, and *Hymenocaris vermicauda*, which lie conformably upon the Maentwrog beds. The group is about 2000 feet in thickness.

Two divisions have been made in this group:[2]—

<table>
<tr><td rowspan="2">Ffestiniog Beds.</td><td>Upper.</td><td>Tough bluish-grey flags, with Lingulella Davisii (small variety), Hymenocaris vermicauda, Bellerophon Cambriensis, Olenus micrurus. 50 feet.</td></tr>
<tr><td>Lower.</td><td>Brown, grey, and yellow flags, with Lingulella Davisii, H. vermicauda, Cruziana, Buthotrephis (a Fucus). 2000 feet.</td></tr>
</table>

The beds occur in the neighbourhood of Maentwrog and Dolgelly. The river Mawddach cuts through the whole of the beds between Rhiwfelyn and Hafod-fraith. They cross the Wnion near Glyn Maldon, and then by Gwern-y-barcud and Tyn-y-craig, range to Coed-y-garth, and into the estuary of the Mawddach. They occur at Ramsey Island, near St. Davids. The lower beds occur near Penmaen-pool, Mynydd-gader, and on Moel Hafod-Owen. At the last-named locality Mr. John Plant has obtained many fossils.[3] The upper beds may be studied at Gwern-y-barcud.

The Hollybush Sandstone of Malvern is placed on the horizon of the Ffestiniog beds.

Good building-stones and flags are worked in the Ffestiniog Beds; and copper-ore has been obtained at Glasdir. Mr. Belt says the numerous quartz veins intersecting the beds near Dol-y-frwynog all contain a little gold, but have nowhere on this horizon been worked with profit.

[1] Records of the Rocks, p. 67.
[2] G. Mag. 1867, p. 540.
[3] Q. J. xxii. 505.

Dolgelly Beds.

The term Dolgelly group was proposed by Mr. Belt (1867) for the soft blue and black slates of the neighbourhood of Dolgelly. Their thickness is estimated at 600 feet.

The beds have been divided as follows:[1]—

Dolgelly Beds.	*Upper.*	Soft black slates (Moel Grün Slates), with *Conocoryphe abdita*, *Agnostus trisectus*, *Olenus* (*Peltura*) *scarabæoides*, *Ctenopyge pecten*, *Sphærophthalmus bisulcatus*, *Orthis lenticularis*. 300 feet.
	Lower.	Hard blue slates (Rhiwfelyn Slates) with *Olenus* (*Parabolina*) *spinulosus*, *Orthis lenticularis*, *Agnostus*, *Lingulella*, and *Protospongia*. 300 feet (?).

Mr. Belt states that the slates in the Upper Dolgelly beds give a black streak, and that with the exception of a thin layer of black slate in the Ffestiniog group, there are no other beds in the Dolgelly district so characterized. These beds generally contain numerous grains of pisolitic iron-ore.

A very fine section of the beds is exposed along a brook falling into the Mawddach at Rhiwfelyn. The beds are developed at Dolgelly and near Tremadoc. In South Wales the series comprises bluish and grey flags; and the black iron-stained slates of Leweston, Haverfordwest, with *Olenus spinulosus*, may belong to this series. The Black shales at Malvern represent the Upper Dolgelly Beds.

TREMADOC SLATE SERIES.

This formation, so termed by Sedgwick in 1846, from the town of Tremadoc in Caernarvonshire, consists of blue and grey earthy slates, flags, and sandstones, having a thickness of about 1000 feet. They rest conformably upon the Lingula Flags, and are exhibited in many places in Caernarvonshire and Merionethshire. In 1866 Messrs. Salter and Hicks indicated their presence near St. Davids.

Two divisions are made in this group:[2]—

Tremadoc Beds.	2. *Upper.*—With *Asaphus* (*Asaphellus*) *Homfrayi*, *Conocoryphe depressa*. Tremadoc, Shineton?
	1. *Lower.*—Dictyonema Beds, with *Dictyonema socialis*. Tremadoc, Shineton, Malvern.

Other fossils include *Ogygia scutatrix*, *Asaphus affinis*, *Angelina Sedgwickii*, *Conocoryphe depressa*, *Niobe*, and *Olenus*. In this formation Cephalopoda first make their appearance, such as *Orthoceras* and *Cyrtoceras*; Graptolites, Crinoids, Asteroids, and Lamellibranchs appear. *Lingulella Davisii* is met with, together with *Obolella* and *Orthis*, also *Conularia*. The oldest British Starfish,

[1] G. Mag. 1867, p. 541; see also C. Lapworth, G. Mag. 1881, p. 320; John Plant, Q. J. xxii. 506.

[2] C. Lapworth, G. Mag. 1881, p. 320.

Palasterina Ramseyensis, was obtained from these beds in Ramsey Island.

Mr. Belt has remarked that in the Tremadoc rocks we appear to have the return of a fauna driven from our area at the close of the Lower Cambrian period.[1]

Near Tremadoc and Moel-y-gest, the beds are fossiliferous; but where exposed in the cliffs of Ogof-ddu, near Criccieth, the strata appear to be barren.

Dr. Hicks has made two divisions in the Tremadoc slates near St. Davids—the lower beds consisting of grey flaggy sandstones, about 200 feet in thickness. The upper division consists of iron-stained flags and dark earthy slates, about 800 feet in thickness. The beds occur at Ramsey Island and St. Davids. These two divisions form the Lower Tremadoc group of Salter and Belt.

Slates have been worked in places. Beds of pisolitic ironstone occur in the Tremadoc Beds at Bettws-garmon.

LINGULA FLAG SERIES AND TREMADOC SLATE SERIES.

MALVERN AREA.

The following succession of beds may be traced near White-leaved Oak, south of Malvern :—

Tremadoc Slate Series.	3. Dictyonema Shales......	Malvern Shales.
Lingula Flag Series ...	2. Malvern Black Shales...	
	1. Hollybush Sandstone.	

Hollybush Sandstone.

This bed, so named by John Phillips, consists of greenish-grey or brown sandstone, with quartz-conglomerate at the base, resting unconformably upon the gneiss of Malvern, and attaining a thickness of from 200 to 600 feet (see Fig. 4, p. 31). It yields Annelides *Scolecoderma* (*Trachyderma*) *antiquissima*, and Dr. H. B. Holl found the Brachiopoda *Lingula* and *Kutorgina* (*Obolella*) *cingulata*.[2]

The Hollybush Sandstone may be studied on Raggedstone Hill, overlooking the Hollybush valley, Malvern. Dr. Hicks places it on the horizon of the Ffestiniog beds.

Malvern Shales.

Above the Hollybush Sandstone comes the 'Black Shale' of Malvern. This deposit consists of thinly laminated black carbonaceous and pale greenish shale, from 500 to 1000 feet in thickness,

[1] G. Mag. 1868, p. 8. [2] Q. J. xxi. 89.

including some bands of trap, composed of felspar and hornblende. The eruptive rock is an ancient lava, consolidated for the most part underground, or under the sea. The great deposit of shale must have been formed in calmer and probably deeper water than the Hollybush Sandstone, there having been, doubtless, a continual subsidence of the sea-bed, interrupted by occasional volcanic outbursts.[1]

The Black Shale has yielded, among the Trilobites, species of *Conocoryphe*, *Olenus*, *Sphærophthalmus*, *Agnostus*; and among the Brachiopods, *Lingula* and *Kutorgina* (*Obolella*) *cingulata*.

The upper portions of the Malvern Shales are of a lighter colour, and were called the Dictyonema Shales by Dr. Holl, on account of their being characterized by the presence of *D. socialis*. He states that this Hydrozoan occurs in North Wales immediately above the Lingula Flags. The beds are grouped with the Dolgelly and Lower Tremadoc rocks. (See Fig. 14.)

SHROPSHIRE.

Shineton Shales, etc.—In Shropshire the dark blue micaceous shales which extend from near Evenwood by Cressage and Shineton, on the Severn, to within a mile of Wellington, and which underlie the Hoar Edge Grits (Caradoc), are grouped by Dr. C. Callaway with the upper part of the Malvern Shales and the Lower Tremadoc Beds. They contain *Lingulella Nicholsoni*, *Asaphellus Homfrayi*, and species of *Asaphus*, *Olenus*, *Agnostus*, etc., which, however, are mostly new species, according to Dr. Callaway. He terms these beds the Shineton Shales. (See Fig. 6, p. 44.)

About 25 miles south-west of Shineton, there is a small exposure of shales at Pedwardine, near Brampton Bryan, containing *Dictyonema socialis* and *Lingulella Nicholsoni*, which Dr. Callaway would correlate with the Malvern *Dictyonema*-shales.[2] Furthermore, forming a continuous band between the Shineton Shales and the quartzite which rests upon the Wrekin, is a series of thin-bedded, micaceous, green sandstones, which Dr. Callaway identifies with the Hollybush Sandstone. The Brachiopod *Kutorgina cingulata* (= *Obolella Phillipsii*) occurs plentifully in a quarry near Neves Castle. The sandstone is also found at Lilleshall, five miles north-east of the Wrekin.

MIDLAND COUNTIES.

At the Lower Lickey ridge there are quartzites—used for road-metal—which, according to Prof. C. Lapworth, are covered unconformably by the Llandovery Beds.[3] (See Fig. 33.) Mr.

[1] See J. Phillips, Mem. Geol. Survey, vol. ii. part 1, pp. 51, 54.
[2] Q. J. xxxiii. 655; G. Mag 1878, p. 333.
[3] G. Mag. 1882, p. 563; see also W. J. Harrison, Midland Naturalist, viii. 70; and H. H. Howell, Geol. Warwickshire Coal-field.

W. J. Harrison and he have recognized similar quartzites between Nuneaton and Atherstone, which are overlaid by shales. These are regarded as Cambrian, and grouped as follows:—

2. Red, grey, and black shales, with hornblendic trap, nearly 2000 feet.
1. Thick-bedded quartzite, about 1000 feet.

This quartzite, known as the Hartshill stone, was formerly regarded by the Geological Survey as Millstone Grit. In the shales (Stockingford Shales) previously grouped as Lower Carboniferous, Prof. Lapworth has found *Lingulella ferruginea*, *Agnostus pisiformis*, *Kutorgina cingulata*, etc. The beds, which attain a thickness of nearly 2000 feet, are well exposed in the railway-cutting between Stockingford and Nuneaton. At Dosthill, south of Tamworth, shales are also exposed, and these are remarkable for the abundance of worm-tracks. They are named the Dosthill Shales by Mr. Harrison.

CORNWALL.

Hard siliceous slaty rocks, schists, and killas, possibly of Lower Cambrian age, have been described by Mr. J. H. Collins under the name of the Ponsanooth Beds, from their occurrence at Ponsanooth, north-west of Penryn, and between Falmouth and Truro. Their character appears to be variable. On the coast, south-west of Pentewan, they consist of hard siliceous rocks; and they include a number of altered beds, hitherto termed "greenstones," such as the beds largely worked for road-stone near Tresavean Mine, in Gwennap. The black rocks of the Lelant cliffs, and the greater part of the north coast between St. Agnes and St. Ives, are composed of these old rocks. Their thickness is estimated at 12,000 feet.[1]

UPPER CAMBRIAN.

ORDOVICIAN.

LOWER SILURIAN.

We now come to the Upper Cambrian rocks of Sedgwick, the Lower Silurian of Murchison, the Siluro-Cambrian or Cambro-Silurian of some authors; a group representing the Second Fauna of Barrande, and including the rocks from the base of the Arenig series to the base of the Llandovery Beds.

For this series Prof. C. Lapworth in 1879 proposed the term Ordovician, from the name of the British tribe *Ordovices*.[2] This term is sometimes corrupted into Ordovian.

[1] Journ. Roy. Inst. Cornwall, vii. (1881).

[2] G. Mag. 1879, p. 13. The term is adopted by Dr. C. Callaway. *Ibid.* 1880, p. 118.

The beds are not unconformable to the Tremadoc Slate rocks that preceded them, but there is a considerable change in the organic remains, or, in other words, a palæontological break between the groups. The rocks are developed in Wales and in the Lake District, and comprise slates, flags, sandstones and limestones, characterized by considerable accumulations of volcanic material.

This group includes three Series (or four if the Llandeilo Flags be placed as distinct from the Bala Series), and the strata may be tabulated as follows :—

	Wales, etc.	*Lake District, etc.*	
Bala Series.	Hirnant Limestone.	Ashgill Shales.	Coniston Limestone Series.
	Caradoc Beds.	Coniston Limestone.	
		Dufton Shales.	
	Llandeilo Flags.	Borrowdale and Skiddaw Series (representing also older strata.)	
	Llanvirn Series.		
	Arenig Series.		

The thickness of these Upper Cambrian or Ordovician rocks varies much in different districts, in consequence of the unequal distribution of interbedded volcanic rocks, especially in the higher divisions. The estimates for the total thickness thus vary from nearly 12,000 to upwards of 25,000 feet.[1]

WALES, ETC.

ARENIG SERIES.

The rocks of this series were described by Sedgwick in 1852, the name being taken from the Arenig mountains of Merionethshire. They were previously included in Sedgwick's Snowdonian series.

The rocks consist for the most part of black slates with shales and sandstones, including the quartzose Stiper Stones of Shropshire. The thickness of the Arenig rocks is about 1000 feet and upwards in North Wales, and about 2500 feet in the neighbourhood of St. Davids, South Wales. They rest conformably on the Tremadoc rocks.

The beds were at one time divided into three stages, but the uppermost being now distinguished as the Llanvirn Series, the following divisions remain :—

Arenig Series.	*Upper.*	Slates, Flags, and bands of Grit (Garth Grit). About 1500 feet (maximum).
	Lower.	Fine black slates (Garth Slates), shales and flags (formerly grouped as Upper Tremadoc). About 1000 feet.

[1] Hicks, Q. J. xxxi 192.

The Upper beds are developed at Arenig, and in Caernarvonshire, Shropshire, and at St. Davids. The Lower beds are exhibited at Portmadoc, St. Davids and Ramsey Island.

Among the fossils, Graptolites are abundant; in the lower portion about 22 species have been found, including *Didymograptus* and *Dendrograptus*, and in the upper, *Tetragraptus* and *Diplograptus* occur. Dr. Hicks observes that the deep-sea conditions prevalent at the time were no doubt favourable to the growth and development of Graptolites.[1] In the upper beds, the Grit of Garth Hill and Ty Obry, east of Tremadoc, in North Wales, has yielded no fossils, but other beds have yielded *Ogygia bullina*, *O. peltata*, *Trinucleus Gibbsii*, *Æglina grandis*, *Ampyx Salteri* and *Calymene*.

The lower beds have yielded *Asaphus Homfrayi*, *Ogygia scutatrix*, *Trinucleus Sedgwickii*, *Conularia Homfrayi*, *Theca*, *Obolella plicata*, *Lingula*, *Orthis remota*, etc.[2]

Between Shrewsbury and Montgomery are the Shelve and Corndon areas of older rocks, to the east of which are the Stiper Stones. The quartzose rocks called Stiper Stones in Shropshire belong to the Arenig series: they extend for ten miles, from Pontesbury, near Shrewsbury, to Snead, near Bishop's Castle, and were by Murchison originally considered as the base of the Silurian System (1833–4). They form a celebrated ridge of rocks which jut out upon a lofty moorland, at heights varying from 1500 to 1600 feet above the sea. They consist of outstanding masses of a thick band of siliceous sandstones, in parts veined, altered and fractured, and occasionally passing into crystalline quartz-rock. *Lingula* and also Annelide-burrows (*Scolithus linearis*) have been found in the Stiper Stones.[3]

Dr. Hicks observes that in Shropshire the order of the beds is almost similar to that observed in North Wales, and the Stiper Stones are doubtless, as first suggested by Mr. Salter, the equivalents of the Arenig grit beds in Caernarvonshire. Hitherto the black beds under the Stiper Stones have proved almost barren of organic remains, and they cannot be correlated with other series except by position; but in the beds immediately upon the Stiper Stones the fauna is exceedingly like that in the Upper Arenig group at St. Davids, and contains, like it, the genera *Illænus* and *Illænopsis*, in addition to most of the genera in the beds at Ty Obry, in Caernarvonshire.[4]

Slates are worked in the Arenig series, as at the Crown Slate quarry near Dolgelly, Maengwynedd quarry near Cader Berwyn, and on the north side of Whitesand Bay. In the Shelve district lead-mines were worked shortly after the time of the Roman invasion.

[1] See also J. Hopkinson, G. Mag. 1872, p. 467.
[2] See Hicks, P. Geol. Assoc. iii. 99; Q.J. xxix. 42, xxxi. 175, 192.
[3] See J. W. Salter, Q. J. xiii. 200; Murchison, Siluria, edit. 5, 1872, p. 37.
[4] Q. J. xxxi. 175.

LLANVIRN SERIES.

This series was defined by Dr. Hicks in 1881, the name being taken from Llanvirn near St. Davids. The beds were formerly grouped with the Arenig series and Llandeilo Flags.

The Llanvirn series consists of dark slates and shales, with contemporaneous beds of volcanic tuff. It has an average thickness of about 2000 feet. The fauna is rich in Trilobites, amongst which the genus *Placoparia* is unknown elsewhere in Britain. Several genera appear for the first time, such as *Illænus*, *Barrandea*, *Phacops*, and *Acidaspis*. The Graptolites *Diplograptus* and *Didymograptus Murchisoni* are found, as well as large Cephalopods, Gasteropods, Brachiopods, and Lamellibranchs. Dr. Hicks divides the beds as follows:[1]—

Llanvirn Series.	*Upper.*	Fine black slates interstratified with beds of ash and tuff, containing *Didymograptus Murchisoni*.
	Lower.	—Dark grey flags and slates with *Placoparia*, etc.

The lower portion of the so-called Llandeilo Flags at Abereiddy Bay belongs to the Llanvirn Series. Graptolites were discovered in these beds by Sir A. C. Ramsay in 1841. The *Didymograptus*-Shales found near Narberth, Haverfordwest, by Messrs. Marr and Roberts, may probably be grouped with this series.[2] The beds are also represented near Shelve, in Shropshire, and near Caernarvon.

At Tai-hirion near Arenig, and Ty Obry near Portmadoc, there are beds formerly grouped as Upper Arenig, and which should now be placed with the Llanvirn Series, according to Dr. Hicks's classification. The fossils, however, according to Mr. J. E. Marr, are more closely related to those of the Arenig Series. The fine-grained slates of Ty Obry (Ty Obry beds) have yielded *Æglina caliginosa*, *Calymene parvifrons*, *Dionide atra*, *Dendrograptus*, etc. At Tai-hirion *Calymene parvifrons*, *Ogygia Selwynii* and other fossils have been obtained.

Near Caernarvon, Mr. Marr has collected Graptolites and other fossils from rocks which probably belong to the Llanvirn Series; and near Llangwyllog church in Anglesey, Prof. Hughes has obtained evidence of similar fossiliferous strata.[3] Other fossils from this series are *Phacops Llanvirnensis*, *Illænus Hughesii*, *Calymene Hopkinsoni*, *Trinucleus Etheridgii*, *T. Ramsayi*, *Pleurotomaria*, *Bellerophon perturbatus*, *Orthoceras*, *Lingula attenuata*, *etc.*

[1] Hicks, Pop. Science Review, 1881, p. 289.

[2] Q. J. xli. 477.

[3] Hicks, Q. J. xxxi. 175, 192; J. E. Marr, Classification of the Cambrian and Silurian Rocks, p. 35, and Q. J. xxxii. 134; Ramsay, Geol. N. Wales, edit. 2, p. 357, etc.

BALA SERIES.

LLANDEILO FLAGS.

The name is taken from the town of Llandeilo in Caermarthenshire, where the rocks were described by Murchison in 1834. The beds were first clearly defined by Sir A. C. Ramsay in 1842.

They consist of bluish-grey and black micaceous and calcareous flags, with black shales or slates at the base. Associated with them are beds of limestone and many igneous rocks. The total thickness of the series is estimated at from 3300 to 4000 feet, including sometimes 2500 feet of lavas.

Two divisions have been made as follows, a third and lowermost division determined by Dr. Hicks in Pembrokeshire being now placed by him with the Llanvirn Series:[1]—

Llandeilo Flags.	*Upper.*	Black slates, flags, and flaggy sandstones, with interbedded igneous rocks. 2000 feet.
	Lower.	Calcareous shales, flags, and black slates, with limestone. About 1000 feet.

The Llandeilo Flags contain the earliest limestone of importance, a marine band occurring in the lower division. Trilobites were recorded from Llandeilo as early as 1698 by Lhwyd, and the name Trilobite Schists was originally applied to these rocks by Murchison. Actinozoa are found in these rocks; also Sponges of the group *Receptaculitidæ* represented by the genus *Ischadites*. *Phyllopora* (formerly *Retepora*) is also found. The Upper Beds, which are developed at Builth and St. Davids, yield *Ogygia Buchii*, *Calymene duplicata*, *Cheirurus Sedgwickii*, *Trinucleus fimbriatus*, *Ampyx nudus*, *Barrandea Cordai*, *Lingula Ramsayi*, *Bellerophon perturbatus*, etc.

The Lower Beds, seen at Llandeilo, Builth, Lampeter Velfrey, Musclewick Bay, and Aber-eiddy, contain *Asaphus tyrannus*, *Trinucleus Lloydii*, *T. favus*, *Calymene Cambrensis*, *Lingula attenuata*, *Orthis striatula*, *Halysites catenularius*, etc.

In North Wales the Llandeilo Flags are represented by black shales near Tremadoc, and in Anglesey by the mudstones of Llanfaelrhys, beds which in both cases yield Graptolites. Near Builth, the Builth Flags of Murchison rise in a boss in the midst of the Silurian rocks, which lie unconformably upon them. Cader Idris is formed of Llandeilo Flags with their included felspathic ashes, etc.[2] In Shropshire the beds are represented by flagstones overlying the Stiper Stones.

In South Wales the beds are well shown on the north shore of Aber-eiddy Bay, near St. Davids. The lower beds, comprising

[1] Q. J. xxxi. 172, 192; G. Mag. 1876, p. 156; Pop. Science Review, 1881.
[2] An early description of Cader Idris was given by A. Aikin, T.G.S. (2) ii. 273.

black calcareous shales and flags, followed by limestone, rest conformably on the Llanvirn series. The upper beds comprise black slates, flags, and flaggy sandstones. The black limestone of Llan Mill, and Lampeter Velfrey, Haverfordwest, which is interstratified with black shales, and contains *Asaphus tyrannus*, etc., is regarded as Llandeilo limestone.[1] Mr. Salter thought that some of the fossils from the Budleigh Salterton pebble-bed (New Red Series) might belong to the Llandeilo rocks.[2] (See sequel.)

In South Wales there are slate-quarries in Aber-eiddy Bay; and in North Wales slates are worked at the Hendre Dhu or Prince Llewellyn quarry, at Dolgarth or Pennant Vale quarry, Dinas Lake, Snowdon slate quarry on Bwlch Cwmllan, near Beddgelert, between Bettws-y-Coed and Capel Curig, at Dolwyddelan, and in the Corys (or Corris) and Ffestiniog districts.

BALA OR CARADOC BEDS.

The Caradoc Sandstone was first noticed by Murchison in 1833, and in 1834 he described the strata under the name of Horderley and May Hill Sandstone. Subsequently, in the Silurian System (1839), they were termed Caradoc Sandstone from the circumstance of their being typically developed in the neighbourhood of Caer Caradoc, in Shropshire, a hill which rises to a height of 1200 feet. In 1838 Sedgwick described the Bala rocks from the Bala district in Merionethshire, and regarded them as forming the upper part of his Cambrian system. Salter, in 1853, from an examination of the fossils, concluded that the Bala Beds were generally identical with the Caradoc Sandstone.[3]

The Caradoc and Bala beds consist of sandstones, flags, shales, slates, and limestones, with interbedded volcanic rocks. They constitute the Upper Caradoc group of John Phillips (1842); and a portion of the Snowdonian group of Sedgwick.

Dr. Hicks has divided the beds as follows:[4]—

Bala Beds.	*Upper.*—Shales, flags, and limestones.	4000 to 12,000 feet.
	Lower.—Sandstones, shales, grits, calcareous bands, and interbedded ash.	

The beds vary in thickness considerably in different districts in consequence of the uneven distribution of interbedded volcanic rocks. They rest conformably on the Llandeilo rocks. They are developed at Bala, Snowdon, Anglesey, Caradoc, Horderley, Norbury, Haverfordwest, Llandeilo, etc.

The Bala Beds are particularly rich in Trilobites and Brachiopods, but they include many other forms of life. Among these are

[1] J. E. Marr and T. Roberts, Q. J. xli. 477.
[2] G. Mag. 1864, p. 6.
[3] A. C. Ramsay, Geol. N. Wales, edit. 2, p. 6. See also Sedgwick, Q. J. viii. 47; and D. Sharpe, Proc. G. S. iv. 10.
[4] Q. J. xxxi. 192.

Asaphus Powisii, *Calymene brevicapitata*, *Ampyx tumidus*, *Phacops Brongniartii*, *Lichas laxatus*, *Trinucleus concentricus*, *Illænus Bowmanni*, *Beyrichia complicata*, *Lingula ovata*, *Orthis vespertilio*, *O. elegantula*, *O. porcata*, *O. Actoniæ*, *O. calligramma*, *Strophomena depressa*, *S. expansa*, *S. grandis*, *Leptæna sericea*, *Modiolopsis*, *Holopea concinna*, *Bellerophon perturbatus*, *Orthoceras vagans*. Starfishes of the genus *Palæaster* are found at Bala, Cystideans also occur. The Coral *Favosites fibrosa* is met with in the upper beds. *Orthis alternata* characterizes a zone near the base of the series.

Graptolites are abundant, chiefly *Diplograptidæ and Dicranograptidæ*, and these, as Prof. Lapworth has pointed out, are distinct from the forms met with in the Arenig series.

The Polyzoan *Pinnatopora Sedgwickii* (*Glauconome disticha*, in part) has been described by Mr. G. W. Shrubsole from the Bala Beds of Glyn Ceiriog, in Denbighshire, and is regarded as the oldest known representative of its class.[1]

The typical Bala beds lie in the Bala district, between Dinas-Mowddwy, Bettws-gwerful-goch, and Bettws-y-Coed. They consist of black and blue slates, and grey and brown sandstones; the Bala limestone, generally very impure, lying about the middle, and averaging from 20 to 30 feet in thickness. Between the limestone and the lower eruptive rocks of the Arenigs and Llyn Conwy, two, and sometimes three thin and imperfect beds of volcanic ashes represent the whole of the vast volcanic accumulations of Moel Hebog, Snowdon, and Carnedd Llewelyn. The middle part of the Bala beds, including the limestone, is most fossiliferous, the black slates below, and the slaty and sandy interstratifications above, being comparatively barren.[2]

Sir A. C. Ramsay states that north of Moelwyn and the Manods the slaty rocks dip north and north-west, plunging under the felstones and calcareous ashes of Dolwyddelan and of the equivalent traps of the Snowdon region south and south-east of Llyn Gwynant and Llyn-y-ddinas. The slates are associated with numerous dykes of hornblendic greenstone, which for the most part lie more or less between the beds, and are proved to be intrusive by the alteration of the strata in contact with them both above and below. Towards the upper part near the felstones, the strata are often sandy, and yield numerous fossils of the ordinary Bala species. The same author adds that both physically and palæontologically the proof is clear that these are equivalents of the Bala beds, and of the Caradoc sandstone of Shropshire, and that the calcareous ashes of Dolwyddelan are the actual representatives of the Bala limestone; and this leads to the startling conclusion that all the vast masses of ashes that crown the felstones of Snowdon and Moel-Hebog are but an enlarged development of the same strata. *Orthis flabellulum* occurs in shales near the little Inn on the summit of Snowdon. (See Fig. 10, p. 58.)

[1] Proc. Chester Soc. Nat. Sc. 1884, p. 98.

[2] Ramsay, Geology of North Wales, edit. 2, pp. 12, 123.

The Snowdonian slates, as exhibited in the pass of Nant Francon, are full of fossils, occurring in five or six bands between the beds of ash and felspathic trap. The species include *Strophomena expansa*, *Orthis flabellulum*, and *Bellerophon*.[1]

North of Moel-Siabod (according to Sir Andrew Ramsay) the Bala beds assume a markedly different character from that which they possess between Dinas-Mowddwy and Dolwyddelan, for they contain a much greater number of interbedded felstones and volcanic ashes, which range northward to Conway, and thence south-westwards along the higher Caernarvonshire mountains. Carnedd-Llewelyn, Carnedd-Dafydd, Y-Glyder-fawr, Snowdon, and Moel-Hebog are the chief mountains in this, the wildest and grandest part of North Wales. And these, like the ranges of Cader Idris, the Arans, and the Moelwyn, consist in a great degree of volcanic products. These volcanic rocks belong to two sections of the [Cambrian] period, for the felstone-porphyries and felspathic ashes, and perhaps even the intrusive greenstones of Merionethshire, were formed during the deposition of the Llandeilo strata, while the same species of thick-bedded traps and ashes on Snowdon and the surrounding mountains are high in the Bala or Caradoc series (see Fig. 10). In both cases they form the highest mountain ranges in Wales, not from upheavals caused by the *intrusion* of igneous masses in special areas, but simply from the circumstance that long after their formation, and after the volcanoes had become extinct (having been already much denuded and lying deep below thousands of feet of newer strata), the whole of the rocks of the area have been disturbed; and the hard igneous masses now rise so high because they have better withstood degradation than the slaty rocks with which they are interbedded. The ranges formed of the lower porphyries, etc., of Cader Idris, Aran Mowddwy, Arenig, and Moelwyn, lie in the Arenig beds midway up in the strata of the great Merionethshire anticlinal, while the peaks of the still newer series of igneous rocks that form the range of Moel-Hebog, Snowdon, and Carnedd-Llewelyn, actually lie in the middle of a basin. The whole form but minor parts of an old mountain system, of which Wales is only a fragment.[2]

The shales and andesitic ashes of the Berwyns are grouped with the Lower Bala and Borrowdale Series by Mr. J. E. Marr.[3]

North-west of Bala, the Rhiwlas limestone, a grey limestone 30 to 40 feet thick has been considered to be the equivalent of the Bala limestone. It has yielded many fossils, but these, according to recent researches, suggest a higher horizon. In Montgomeryshire, the Meifod slaty beds, which belong to the upper part of the Bala beds, have also yielded many fossils. In Denbighshire many specimens, including *Orthis alternata*, have been obtained from Cerrig-y-Druidion.

[1] J. W. Salter, Q. J. ix. 177.
[2] A. C. Ramsay, Geol. N. Wales, edit. 2, pp. 130, 131, 141.
[3] Q. J. xxxvi. 278.

In the neighbourhood of Haverfordwest the following divisions in the Bala Series have been made by Messrs. J. E. Marr and T. Roberts:[1]—

Trinucleus seticornis Beds.
- *Slade Beds.*—Gritty green shales, seen at Lower Slade, with *Trinucleus seticornis*, *Phyllopora Hisingerii*, etc.
- *Redhill Beds.*—Bluish-grey shales, seen near Redhill Farm, with *Phacops Brongniartii*, etc.
- *Sholeshook Limestone.*—Greenish impure limestone and calcareous shales of Sholeshook and Prendergast, with *Trinucleus seticornis*, *Phacops Brongniartii*, *Heliolites interstinctus*, etc. *Staurocephalus globiceps* occurs here and also in the Rhiwlas limestone, with which it is compared.

Robeston Wathen Limestone.—Black limestone and black shales of Robeston Wathen, with *Halysites catenularius*, *Orthis elegantula*, etc. The bed is compared with the Bala and Coniston Limestones.

Dicranograptus Shales.—These beds succeed the Llandeilo limestone of Llandewi Velfrey, and consist of black shales, with bands of grit, and are usually crowded with Graptolites of the "tuning-fork" type, including *Dicranograptus ramosus*, *Climacograptus bicornis*, etc. The uppermost portion of these shales is spoken of as the zone of *Orthis argentea*, being characterized by that Brachiopod.

In describing the great masses of "gnarled" shales or schists of Anglesey, Prof. Hughes has suggested that they may be of the age of the Bala volcanic series. They comprise greenish shales with gritty and serpentinous bands, some much gnarled, others little altered.[2]

In Shropshire the Caradoc rocks have been thus divided:[3]—

Onny Shales.—Seen on the banks of the Onny, near Cheney Longville.

Cheney Longville Flags.—Seen near the village of that name, near Winstanstow, south of Church Stretton.

Chatwall or Horderley Sandstone.—Shelly sandstones seen at Chatwall, north-east of Caradoc and Horderley. *Orthis alternata.*

Harnage Shales.—Exposed near Harnage. *Trinucleus concentricus* (Trinucleus Shales), *Beyrichia complicata*, *Orthis testudinaria*, *Diplograptus*, *Favosites fibrosus*, etc.

Hoar Edge Grits.—Seen along Hoar Edge. *Strophomena expansa*, *Orthis vespertilio*, *O. flabellulum*.

These beds are overlaid unconformably by the May Hill Sandstone. (See p. 44, and Fig. 9, p. 58.) Shales, with *Trinucleus concentricus*, etc., occur at Bausley Hill (Breidden Hills), north-east of Welshpool; and these are underlaid by volcanic beds, and by the unfossiliferous Criggion Shales.[4]

In the Craven district, an indefinite area that lies between Settle and Ingleton, the Silurian rocks rest unconformably on rocks of Bala age. These latter comprise an upper series of limestones, shales, mudstones, and ashy grits, containing fossils of Bala types; and

[1] Q. J. xli. 478. [2] Q. J. xxxvi. 239.
[3] C. Callaway Q. J. xxxiii. 655; J. D. La Touche, Geol. Shropshire, p. 12; J. W. Salter and W. T. Aveline, Q. J. xiii. 211; Murchison, Siluria, edit. 5, p. 66.
[4] W. W. Watts, Q. J. xli. 533.

a lower series of slates, mudstones, grits, and beds of arkose, with a prevailing greenish-grey tint throughout, and devoid of fossils. Notwithstanding their superficial resemblance to the Borrowdale Series, these lower beds of the Ingleton area are not directly of volcanic formation; and the term "Green Slates" was first applied to beds developed to the west of Ingleton. At Chapel-le-dale they are about 10,000 feet in thickness, and they are regarded by Prof. Hughes as of marine origin. In many respects these beds belong more closely to the Welsh type of Bala rocks than to that of the Borrowdale Series. (See p. 79.)

Hirnant Limestone.

This limestone is locally developed in the valley of Hirnant, south-east of Bala, and in a tortuous tract between Bala and Dinas-Mowddwy. It was noted by Sedgwick in 1832. It is described as a black impure pisolitic and fossiliferous limestone, containing a few species of *Orthis* (*O. Hirnantensis*, *O. sagittifera*, etc.), *Arca* and *Modiolopsis*, and stems of Encrinites. It occurs locally near the junction of the Bala and the Llandovery Beds, and was considered of Upper Bala age by Sedgwick.

In Hirnant beds at Bwlch Hannerob, north of Aberhirnant, Mr. Thomas Ruddy obtained *Orthis Hirnantensis*, *O. sagittifera*, *O. elegantula*, *O. biforata*, *Lingula ovata*, *Favosites fibrosus*, *Homalonotus bisulcatus*, etc. The beds here consist of grits and shales, and are from 50 to 300 feet in thickness. In other places there occur concretionary lumps of limestone associated with the grits. Mr. Ruddy believes that the Hirnant grits and limestone are identical with beds that have been grouped as Lower Llandovery Grits.[1]

It may also be mentioned that in Pembrokeshire and Cardiganshire, where the Llandovery group attains a great thickness, it appears to rest conformably on the Bala Beds. Direct proofs of unconformity are wanting in the neighbourhood of Corwen in Merionethshire, and in Denbighshire.[2] These instances of conformity may be due to accidental concordance in bedding, because, as a rule, the Silurian beds rest irregularly on the Ordovician or Upper Cambrian rocks.

CORNWALL.

Gorran Haven Beds.—The grey quartzites of Veryan Bay, and other places south of Mevagissey, between St. Austell and Falmouth, have been considered by Sedgwick (1851) and M'Coy to be of Upper Bala age; the fossils from Carn Goran (Gorran Haven) being *Orthis calligramma*, *O. scotica*, *Calymene brevicapitata*, *C. parvifrons*, *Homalonotus bisulcatus*, etc. They were first made known by the collections of Mr. C. W. Peach.[3] Mr. Salter

[1] Q. J. xxxv. 201.
[2] H. Hicks, P. Geol. Assoc. vii. 295.
[3] Q. J. viii. 13. 12th Report Cornwall Polyt. Soc. p. 66.

recognized the rocks and fossils as similar to beds developed in Normandy.[1] *Orthis Budleighensis* also occurs, and this, together with pebbles of similar quartzites, have been found in the Triassic pebble-bed of Budleigh Salterton, and in the Drift of the Midland counties.[2]

These rocks have been more recently studied by Mr. J. H. Collins, who describes them as a great series of dark grey or blue schists and conglomerates, estimated to have a thickness of 23,000 feet. In his opinion they extend much further into West Cornwall than has been supposed, since they may be traced southward to St. Keverne, and westward to Penzance and Mousehole. They comprise thick beds of quartzite, and also thin lenticular masses of black limestone, siliceous slate, etc. Conglomerates may be seen at Nare Head. Quartzites yielding fossils have been found in the Meneage peninsula, south of Helford river. The limestones which contain fragments of Encrinites and species of *Orthoceras* are found north of Porthalla, at Gerran's Bay, Caerhayes, and Gorran Haven.[3] Graptolites have been found by Mr. Peach in the dark slates of Black Head.

Economic Products, etc. of the Bala or Caradoc Beds.

Murchison observed that in the Caradoc sandstone, remains of fossils are often so abundant as to render some of the beds sufficiently calcareous to be burnt for lime: these beds are known to the workmen as 'Jacob's Stones.' Sandstone is quarried at Soudley, Horderley, and Long Lane near Craven Arms. There are limestone quarries at Esquire Hall, near Bishop's Castle.

Some valuable deposits of phosphate of lime (phosphorite) have been discovered at the top of the Bala Limestone in the Berwyn Mountains, near Dinas Mowddwy, between Llangynog and Bala, and near Llanfyllin in Montgomeryshire, North Wales. Mr. D. C. Davies has described the bed as varying from 9 to 18 inches in thickness, it is composed of nodules, some of which still preserve their organic structure.[4] (See also p. 59.) Beds of jasper also occur at Dinas-Mowddwy, and other places.

Mr. W. Keeping observed nodules showing cone-in-cone structure on the coast between Aberystwith and Borth. They occur in Bala (?) or Lower Llandovery rocks.[5]

Welsh oilstone is obtained from Bethgellert, and the vicinity of Llyn Idwal, Snowdon, and sometimes called Idwal stone. From Snowdon the 'Cutler's green stone' is also obtained. Hones or oilstones generally consist of a fine-grained and compact slate-rock; they are sometimes called Whet-slates or Whet-stones.

[1] G. Mag. 1864, p. 9. See also Jukes, Roy. Geol. Soc. Ireland, 1867.
[2] T. Davidson, G. Mag. 1880, p. 339, and Supplement to Devonian Brachiopoda, Palæontograph. Soc.; T. G. Bonney, G. Mag. 1880, p. 406.
[3] Journ. Roy. Inst. Cornwall, vol. vii. (1881).
[4] P. G. Assoc. iv. 566; G. Mag. 1867, p. 251; Q. J. xxxi. 357.
[5] G. Mag. 1878, p. 532.

CAMBRIAN.

LAKE DISTRICT, ETC.

While we are chiefly indebted to Sedgwick[1] for the earliest interpretations of the structure of the Lake District, the older rocks which enter most largely into its composition were in later years studied in great detail by James Clifton Ward,[2] whose enthusiastic and successful labours were unfortunately terminated at an early age. The work on the Geological Survey among the older rocks of the Lake District was performed partly by Mr. Ward, and partly by Mr. W. T. Aveline, Prof. Hughes, Mr. J. G. Goodchild, and others. The rocks include the following divisions (see p. 50) :—

3. Coniston Limestone Series. { Ashgill Shales. Coniston Limestone. Dufton Shales.
2. Borrowdale Series.
1. Skiddaw Slates.

They may represent rocks that in Wales range from the period of the Lingula Flag Series to the top of the Bala Series.

SKIDDAW SLATES.

The slates of Skiddaw are the oldest rocks in the Lake District. They comprise shales and mudstones, usually much cleaved, and of a dark bluish or black colour, and they contain flaggy beds with veins of quartz. The term Skiddaw Slates was originally used by J. Otley, because the slates rise up in the mountain of Skiddaw. The fine black slates show the cleavage best, while the Rev. J. C. Ward has remarked on the difficulty, and sometimes the impossibility, of determining the original bedding. In the series he observed ripple-marked flags, grits, and conglomerate. One band of conglomerate occurs high up in the series, but it did not, in his

[1] See his Geology of the Lake District, in Three Letters addressed to W. Wordsworth, 1843.

[2] Geology of the Northern Part of the Lake District, 1876 ; Q. J. xxxii. 12 ; G. Mag. 1879, p. 50. See also numerous papers by R. Harkness ; Dr. H. A. Nicholson, Geology of Cumberland and Westmorland, 1868.

opinion, mark an unconformity. The flaggy beds exhibit little or no cleavage.

The Skiddaw Slates may be divided as follows, according to Mr. Ward:[1]—

Skiddaw Slates.	4. Skiddaw Slate proper (black clay-slate of Skiddaw).	=	(Llanvirn Series) and Arenig Slates.
	3. Coarse Grit.	=	Arenig Grit.
	2. Black iron-stained slates.	=	Tremadoc Slates.
	1. Thick-bedded sandy and gritty series (of Grasmoor and Whiteside).	=	Lingula Flag Series.

The beds are developed, as their name implies, on Skiddaw, also on Saddleback, Cawsey Pike, Grasmoor Fells, near Egremont, Cockermouth, Loweswater, Buttermere, and Crummock Lake: they form the mountain of Black Combe, etc., and they occur over a large area in the Isle of Man.[2] They are seen also at the foot of the Cross Fell escarpment. (See Fig. 25.) They attain a thickness of from 10,000 to 12,000 feet, but nowhere is the base exhibited.

The Graptolites discovered by Joseph Graham, Ruthven, and Harkness, form the most remarkable fossils of the Skiddaw Slates; these include the genera *Dichograptus*, *Didymograptus*, *Diplograptus*, *Tetragraptus*, and *Phyllograptus*, and *Graptolites sagittarius*.

A Phyllopod (*Caryocaris Wrightii*) and some Trilobites occur, the latter including *Phacops Nicholsoni* (which has been taken to indicate a zone), *Æglina binodosa*, *Agnostus Morei*, etc.; also *Lingula brevis*; and *Palæochorda major*, *Scolites*, and other markings like Annelide burrows. Fossils may be found in many places near Keswick, at Outerside, Barff, etc., and in the 'screes' on the slopes of Black Combe, etc. Our knowledge of the fauna is largely owing to the researches of Prof. R. Harkness and Prof. H. A. Nicholson,[3] and especially to Mr. W. Kinsey Dover, Mr. J. Postlethwaite, and others residing in the district.[4]

The rocks indicate shallow-water and shore conditions, with land most likely in the west, according to Mr. Ward. Some possible plant-remains have been identified under the name of *Buthotrephis*, *Eophyton*, and *Chondrites*.

Mr. Ward has remarked, that as we approach the granite area of Skiddaw, the slate becomes spotty, crystals of Chiastolite appear, and the rock becomes a Chiastolite Slate.[5] This passes into a harder, more thickly-bedded, foliated and massive rock, Spotted (or Andalusite) Schist; and this again into a kind of Mica Schist of generally a grey or brown colour, which occurs immediately around the granite.[6]

[1] G. Mag. 1879, pp. 50, 122; 1880, p. 1.
[2] Q. J. xxii. 488.
[3] Q. J. xix. 313; xxiv. 125; G. Mag. 1869, p. 498.
[4] Trans. Cumberland Assoc. No. x. p. 71.
[5] Noticed by Sedgwick, Q. J. ii. 106.
[6] Geology of the N. Part of the English Lake District, p. 9.

Many years ago Daniel Sharpe noticed that the slate was apparently hardened by proximity to the granite in quarries at Thornthwaite Gill in Ralphland, and on Rosgill Moor. There, however, appears to be no connection between the cleavage and metamorphism.[1]

The peculiar 'cone-in-cone' structure is often met with in these rocks. Ores of Iron, Copper, Cobalt, and Lead occur in places. The quartz-veins of Carrock-fell, north of Keswick, are noted for rare minerals.[2] Slate-pencils have been largely manufactured near Shap. Mr. Sharpe observed that slate-pencils were cut from a slate which is soft enough not to scratch, and which can be split down the planes of secondary cleavage with nearly the same facility as along the true cleavage. The latter character is not common. Slate-pencils are made at Knock Fell, Ashlake Pike, etc. There are two quarries near the village of Shap. The slate seldom forms good workable material for roofing, as it splits up into small flaky pieces or pencil-like fragments. It is generally of very uniform texture, soft, fine-grained, and very fissile, and has been occasionally employed in the vicinity of Keswick and Hesket Newmarket for roofing houses; but for this use it is not very suitable, as it easily perishes in the atmosphere. The best slate has been procured at Bowscale Fell. In consequence of its want of durability, the mountains of this slate, as John Phillips remarked, have smoother contours, more uniform slopes, and a more verdant surface than those of the Borrowdale series (Green Slates and Porphyries). Hence the smooth slopes of Skiddaw and the rude crags of Scafell.

Fig. 11.—Generalized Section across the Lake District. (J. G. Goodchild.)

N. The Solway.

S. Ingleton Coal-field.

7. New Red Rocks.
6. Upper Carboniferous, including the true Coal Measures.
5. Lower Carboniferous, including the Carboniferous Limestone.
4. Kirkby Moor Flags, Bannisdale Slates, Coniston Grits and Flags, and the Pale Slates, with the Graptolitic Mudstones at the base. } Silurian.
3 and 3*a*. Borrowdale Series (Volcanic Rocks), surmounted by the Coniston Limestone Series ×. } Cambrian.
2. Skiddaw Slates.
1*a*. Shap Granite.
1. Granite of the Caldbeck Fell area.

BORROWDALE SERIES.

In Cumberland and Westmoreland, mainly overlying the Skiddaw Slates, comes a great thickness of volcanic rocks, termed the Green Slates and Porphyries by Otley and Sedgwick, and the Volcanic Series of Borrowdale by Prof. Harkness and Dr. Nicholson (1872). The latter term, derived from Borrowdale, where the

[1] Q. J. v. 115, 128. See also Bonney, Address to Geol. Soc. 1886, p. 87.

[2] Harkness, Q. J. xix. 124.

rocks are well exhibited, is now generally adopted. The rocks were originally known as the Chloritic Slate and Porphyry. They are overlaid by the Coniston Limestone.

Mr. Aveline states that, as a whole, the beds consist of lavas and consolidated or altered ashes and breccias, which have been ejected from volcanic vents, and vary in lithological character from thick-bedded coarse breccia to an ash so fine in texture that, when well cleaved, it yields good slates. Hence the name 'Green Slates and Porphyries,'—the term porphyries being applied to the lavas or, locally, even to the altered ashes, in which a porphyritic structure has been developed. The total thickness is estimated at from 7000 to 12,000 feet. No fossils have been found in the beds. They probably represent beds from the Llanvirn Series, up to the middle Bala beds.

The Rev. J. C. Ward stated that alternations of Skiddaw Slate with submarine volcanic deposits occur at the base; and that there are indications of a gradual passage from submarine volcanic conditions to those of terrestrial and wholly subaërial volcanoes.[1] (See sequel.) Mr. W. T. Aveline has also pointed out a conformable junction to be seen near Bootle.[2] Mr. J. R. Dakyns,[3] however, regards the Borrowdale Series and Skiddaw Slates as unconformable, and so does Prof. H. A. Nicholson.[4] The shales overlying the Borrowdale Series, which also contain volcanic rocks, present evidences of local unconformity, inasmuch as they successively overstep various members of that Series, as the junction is followed in a south-westerly direction from Coniston.

The Borrowdale series occupies the area south of Keswick and south-east of Buttermere, forming, as remarked by Prof. Phillips, a long range of mountains parallel to the Skiddaw slates, and those highly picturesque and romantic valleys wherein the lakes of Ulleswater, Haweswater, Thirlmere, and Wastwater spread their beautiful waters. The beds may be seen in the Vale of St. John, and Matterdale. Scafell and Helvellyn are formed of them, and they may be seen at Bleaberry Fell and Falcon Crag, near Keswick. In proceeding from Borrowdale, through Langdale to Ambleside, and through Tilberthwaite to Coniston Waterhead, this great and complex series of rocks may be examined in an interesting variety of positions. By a short deviation from Borrowdale, over Sty Head, toward Wastwater, or from Langdale, over Hard Knott, to Eskdale, the granite which breaks into the midst of the series, and sends off porphyritic branches, accompanied by metamorphosed slates, may be well studied. The base of the whole mass, as seen on Derwentwater, about Barrow, is a red or purple mottled argillaceous rock usually regarded as a breccia. The mottled aspect of some of

[1] G. Mag. 1879, p. 50; see also the Geology of the Northern Part of the Lake District.

[2] G. Mag. 1869, p. 382; 1882, p. 441.

[3] G. Mag. 1869, pp. 56, 116.

[4] G. Mag. 1869, pp. 105, 167; P. Geol. Assoc. iii. 106.

these rocks has earned them the title of "rain-spot" slates (as at White Moss Quarry, near Ambleside).[1]

The Bowder Stone in Borrowdale is a tumbled mass of rock belonging to the Borrowdale Series.

The occurrence of the Borrowdale Series between Ingleton and Settle has been noticed by Sedgwick, Phillips, and Prof. Hughes.[2] The Volcanic rocks on this horizon, in the area at the foot of the Cross Fell escarpment, consist of submarine tuffs, interbedded throughout a great thickness of strata with beds of the same lithological character, and containing the same fossils as the Skiddaw Slates. Mr. J. G. Goodchild regards these beds, which he terms the Milburn Rocks, as the submarine representatives of the mainly subaërial volcanic accumulations of the Borrowdale Series proper.

The "Green Slates" are much used for building at Keswick and other places. They are quarried in Borrowdale (north of the Bowder Stone), at Honister Crag, Goat Crag, Castle Crag, Wallow Crag, and Falcon Crag. In many places the slate is of excellent quality for roofing. Some of the beds contain gritstone or greywacke, provincially called "calliard." Good slates are obtained at Tilberthwaite, and these are coarse fragmentary rocks.

As John Phillips remarked, in consequence of the superior hardness of the rocks, the mountains formed of the Borrowdale Series assume bolder forms, present more lofty and rugged peaks, and more inaccessible precipices, than the softer slates of Skiddaw.

An interesting example of minutely faulted slate belonging to the Borrowdale Series has been figured by Mr. J. J. H. Teall.[3]

CONISTON LIMESTONE SERIES.

This series forms the Lower Coniston Group, the Upper Group belonging to the Silurian System. It consists of slaty beds in which limestone is more or less prominently developed; and it includes, in several places, a variable thickness of volcanic beds. The series may be locally divided as follows:—

Coniston Limestone Series.	Ashgill Shales. Coniston Limestone. Dufton Shales.

The total thickness is variable. While in some localities it may not be more than 500 feet, Mr. J. G. Goodchild informs me that under Roman Fell, north-east of Appleby, the limestones and shales are interstratified with a great thickness of alternating felspathic mudstones, tuffs, and ashy grits, of various degrees of fineness, and with occasional beds of lava, which altogether must attain a thickness of not less than 1500 feet. Certain shales at Style-End Grassing were originally grouped with the Borrow-

[1] J. Phillips, in Black's Guide to the Lake District, 1866, p. 239.
[2] See also Nicholson, G. Mag. 1869, p. 213.
[3] G. Mag. 1884, p. 1.

dale Series by Prof. Harkness and Dr. Nicholson; they belong properly to the Coniston Limestone Series, and may be classed with the Dufton Shales. These Shales, as before mentioned, overstep members of the Borrowdale Series, thus bearing out the view that the Coniston Limestone and Borrowdale Series are to some extent unconformable in the Lake District.[1]

Dufton Shales.

These beds consist of dark flaggy shales, sometimes having ashy beds intercalated among them, and with bands of nodular limestone near their base. They attain a thickness of 300 feet, and may be seen at Swindale Beck, near Knock; Pusgill and Dufton-Town dykes, near Dufton; Harthwaite Gill, near Keisley; and at the Smelt Mill, near Hilton. The fossils include *Strophomena expansa*, *Leptæna sericea*, *Orthis vespertilio*, *Discina corona*, *Calymene Blumenbachii*, *Trinucleus concentricus*, *Homalonotus bisulcatus*, *Agnostus*, and *Illænus Bowmanni*. In addition *Holopea*, *Bellerophon* and *Orthoceras* have been noted, as well as two species of Corals, stems of Crinoids, etc. The shales are locally known as the Swindale Shales, Pusgill Shales, etc.

On a somewhat lower horizon at Style-End Grassing, between Long Sleddale and Kentmere, there is a band of shales, separated from the Coniston Limestone by some thickness of volcanic rocks, etc. The fossils of these Style-End Grassing beds are of Bala types, such as *Calymene Blumenbachii*, *Orthis vespertilio*, and *Petraia æquisulcata*.[2]

CONISTON LIMESTONE.

This formation, named by Sedgwick from Coniston in Lancashire, consists of hard grey calcareous shales and slates, containing nodules or thin bands of dark blue crystalline limestone of variable character. In some places the beds of limestone, in others the shales predominate. On the whole there is nowhere so great a development of limestone as is met with in the Bala beds, with which the Coniston Limestone is paralleled. The Coniston Limestone (and shales) attain a thickness of about 200 feet.

Among the fossils are *Heliolites interstincta*, *Halysites catenularius*, *Petraia* (*Streptelasma ?*) *æquisulcata*, *Favosites fibrosa*, *Trinucleus seticornis*, *Cheirurus juvenis*, *Sphærexochus*, *Lichas laxatus*, *Illænus Bowmanni*, *I. Davisii*, *Phacops conophthalmus*, and *P. macroura* (both of which species have been taken to mark zones), *Strophomena antiquata*, *S. depressa*, *Orthis calligramma*, *O. flabellulum*, *O. actoniæ*, *O. vespertilio*, *Leptæna sericea*, *Orthoceras vagans*.

While fossils are, as a rule, abundant, they are not often well

[1] W. T. Aveline, G. Mag. 1872, p. 441.

[2] Harkness and Nicholson, Q. J. xxi. 248; xxii. 480; xxxiii. 461; Proc. Geol. Assoc. iii. 109.

preserved. Some of the best specimens have been obtained from Keisley, north-east of Appleby, and here the Limestone, which is better developed than at any other locality, is a white and pink crystalline limestone.

The Coniston Limestone stretches from Millom on the estuary of the Duddon to near Ambleside and Wastdale Crag. It occurs also in the Furness district, where the formation was called Ireleth limestone by Sedgwick. It may be studied on the western side of Troutbeck, in Westmoreland, in the valley of Long Sleddale, near Kendal, and in Ravenstonedale.

The formation is well exposed and highly fossiliferous in the upper part of Helm Gill, and above Gawthorp near Dent, also in Sarly Beck, north-east of Sedbergh in Yorkshire. Organic remains have been obtained from a quarry by the road leading from Coniston Waterhead to Ambleside, about two miles from Coniston, and also at Sunny Brow, south-west of Ambleside.[1]

Speaking of the Coniston Limestone, Mr. J. Bolton remarks that it is a hard, compact, dark blue rock. It is not much used as a building-stone, being subject to rapid decay by atmospheric influence, neither is it of much use for burning into lime.[2] It burns to a dark-coloured lime, which has been used for agricultural purposes and for cement. Hæmatite occurs in the Coniston Limestone of Millom.[3]

Ashgill Shales.

This uppermost division of the Coniston Limestone Series was so named by Sedgwick and Salter, from Ashgill, three miles south-west of Coniston.[4] It consists of grey and green calcareous mudstones, sometimes affected by cleavage, with grey crystalline limestone in the lower part. The beds attain a thickness of about 200 feet.

Among the fossils are *Trinucleus concentricus*, *Phacops apiculatus* and *P. mucronatus* (two species which have been taken to mark a zone), *Orthis protensa*, *O. biforata*, *and Strophomena Siluriana*.

The beds have been traced from Coniston at intervals through the southern part of the Lake District to the borders of Yorkshire. Besides Ashgill, they may be seen at Rebecca Hill Quarry, north of Dalton-in-Furness; at Pull Beck, on the west side of Windermere; at Skelgill, and at Applethwaite Common, east of Troutbeck in Westmoreland. Near Sedbergh the *Trinucleus* and *Strophomena* shales observed by Prof. Hughes, belong to this series; and further north he has traced them on the east of the river Lune, in Spengill and Fairy Gill.[5]

[1] See Sedgwick, Q. J. i. 444; Hughes, G. Mag. 1867, p. 354; Harkness and Nicholson, Q. J. xxi. 248, xxxiii. 467; J. E. Marr, Q. J. xxxiv. 872.

[2] Geological Fragments, p. 49.

[3] J. D. Kendall, Q. J. xxxii. 180.

[4] Salter, Catalogue of Cambrian and Silurian Fossils, Cambridge, p. 72.

[5] Geol. Mag. 1867, p. 351; see also Harkness and Nicholson, Q. J. xxxiii. 469; and J. E. Marr, Q. J. xxxiv. 873.

SILURIAN.

UPPER SILURIAN. (Murchison and Geol. Survey.)

The term Silurian System, with which the name of Sir Roderick I. Murchison will ever be connected, was given in 1835 from the country of the ancient Britons known as Silures; a tract extending over the south-eastern portion of Wales and adjoining parts of England. Murchison commenced his labours in this field in 1831. And later on he tells us that, "When Ostorius, the Roman general, conquered Caractacus, he boasted that he had blotted out the very name of Silures from the face of the earth. A British geologist had, therefore, some pride in restoring to currency the word Silurian, as connected with great glory in the annals of his country."[1] The term was not altogether appropriate, as it indicates but a small portion of the area over which Silurian rocks are developed, and it is, for the reason stated previously, here confined to the rocks between the Bala Series and the Lower Old Red Sandstone. The beds rest unconformably upon the Cambrian rocks.[2]

The total thickness of the system may be as much as 14,000 feet in the north-west of England, while it varies from 3000 to 6000 feet in Wales, for the beds themselves are subject to much local change. They comprise slates, shales, and grits, with important beds of Coral- and Encrinital-limestone. It has been observed that all the Silurian limestones are local phenomena; where the Woolhope limestone is well developed, as at Presteign, there the Wenlock limestone is very feebly represented. At Wenlock the limestone forms a grand terrace, but the Aymestry limestone has almost vanished. At Leintwardine the Aymestry limestone is a grand rock, and the Wenlock limestone is but poorly developed.

The organic remains of the Silurian rocks indicate their marine origin, and show that the beds were deposited in a continuously but slowly subsiding area, and in water never of very great depth. There are no evidences of volcanic action during this period in England and Wales.

[1] P. Geol. Soc. iii. 640. See also Silurian System, 1839. Q. J. viii. 173.

[2] See Horizontal Sections, Geol. Survey, Sheets 33 and 34.

The following Table exhibits the main divisions of the Silurian strata :—

Wales and West of England.		Lake District, Etc.
Upper Ludlow.		Kirkby Moor Flags.
Aymestry Limestone.		Bannisdale Slates.
Lower Ludlow.		
Wenlock Limestone and Shale. Woolhope Beds.	Denbighshire Grits and Flags.	Coniston Grits and Flags.
Tarannon Shales. Upper Llandovery. } Lower Llandovery. }	Corwen Grits.	Pale Shales or Slates. } Stockdale Graptolitic Mudstones } Shales. Austwick Conglomerate (Basement-beds of Silurian).

Upper Cambrian (Ordovician or Lower Silurian).

The fossils of the Silurian System as here defined belong to the "Third Fauna" of Barrande. They include the earliest traces of Land Plants, also Sponges, and Graptolites, of which the genus *Monograptus* is conspicuous. Many Corals occur of the genera *Favosites*, *Heliolites*, and *Petraia* ; Crinoids (Encrinites) ; Phyllopods, including *Discinocaris* and *Ceratiocaris* ; Trilobites, of the genera *Acidaspis*, *Encrinurus*, *Phacops*, *Homalonotus*, etc., as well as the Crustacea *Pterygotus* and *Eurypterus*. The Brachiopods include *Atrypa*, *Leptæna*, *Orthis*, *Pentamerus*, *Rhynchonella*, and *Strophomena* ; the Lamellibranchs include *Cardiola* and *Pternea* ; among the Gasteropods are *Euomphalus*, *Murchisonia*, and *Pleurotomaria* (a form still existing) ;[1] and the Cephalopods include *Orthoceras* and *Lituites*. The earliest traces of Fishes are found, and these include *Scaphaspis*, *Cephalaspis*, *Pteraspis*, and *Onchus*.[2]

[1] See Dr. H. Woodward, G. Mag. 1885, p. 433.

[2] See the *Thesaurus Siluricus*, by Dr. J. J. Bigsby, 1868 ; a work which contains lists of the older fossils, up to the close of the Silurian period.

SILURIAN.

I. WALES AND WEST OF ENGLAND.

The Silurian rocks of Wales, etc., are divided as follows :—

Ludlow Series.	Ledbury Shales.	(Passage Beds.)	Downtonian Series.[1]
	Downton Sandstone.		
	Upper Ludlow Beds.		
	Aymestry Limestone.		
	Lower Ludlow Beds		Salopian Series.[1]
Wenlock Series.	Wenlock Limestone.	Denbighshire Flags and Grits.	
	Wenlock Shale.		
	Woolhope Beds.		
May Hill Series.	Tarannon Shales.		Valentian Series.[1]
	Upper Llandovery.		
	Lower Llandovery.		

On the eastern borders of Wales, and in the adjoining English counties, the Silurian rocks are developed near Usk, May Hill, Woolhope, Malvern, Abberley, and Tortworth;[2] and from the central part of South Wales, near Llandeilo and Llandovery, the rocks stretch by Builth to Ludlow and Wenlock, and again by Montgomery to the neighbourhood of Conway. They appear also near Dudley.

At one time the division between Upper Cambrian (Lower Silurian) and Silurian proper (Upper Silurian) was taken between the Upper and Lower Llandovery rocks. These rocks are now, however, grouped together, as they are very intimately associated. Sir A. C. Ramsay remarks that in mineral character the Lower Llandovery rocks so strongly resemble the Upper Llandovery rocks, that up to 1856 no geologist had been able to distinguish between them. Even then, when the section at Noeth Grug showed a lower group beneath the Pentamerus beds, it was a task of great difficulty to separate them.[3] The stratigraphical evidence, according to Prof. Hughes, shows that Llandovery rocks rest unconformably on beds older than any Llandovery rocks, but it does not seem to be shown by reference to any localities that Upper Llandovery is unconformable to Lower Llandovery. Nor is there any trustworthy list showing what fossils are peculiar to Upper and what to Lower Llandovery; and while palæontologists cannot separate the fossils of the two formations into well-marked groups, stratigraphical geologists con-

[1] These terms have been suggested by Prof. Lapworth : the name of Valentian being derived from Valentia, a Roman division of the south of Scotland.

[2] These districts were described in detail by John Phillips, Mem. Geol. Survey, vol. ii. part I.

[3] Geology of North Wales, edit. 2, p. 5.

fess the difficulty of separating them in the field. Therefore they are best grouped together in the May Hill Series, which includes also the Tarannon Shales.[1]

Sir Andrew Ramsay has pointed out that physically the break between the Llandovery beds and the strata below is complete. In Shropshire and at Builth the unconformity is visible, and in the Malvern area the beds lie on Upper Lingula flags. The Upper Llandovery beds on the banks of the Onny lie on the higher part of the Caradoc Sandstone, and as they strike northward, gradually overstep the higher strata, till, on the banks of the Severn, near Buildwas Abbey, they rest on the lower beds of the same formation. A few miles from Wenlock Edge they lie on the nearly vertical edges of the Longmynd rocks, and also on various members of the Cambrian system, between Church Stretton and Chirbury. (See Fig. 9, p 58.) In South Wales, between Builth and Newbridge, they lie equally unconformably on the Llandeilo flags; and 14 miles off at Noeth Grug they rest on the Lower Llandovery beds; but, again, they rapidly creep across these to the south-west, and in the river Sawdde the Llandovery beds lie directly on the Llandeilo flags. There is no unconformity so complete as this yet observed in other members of the strata from the Llandeilo flags upward.[2]

The Silurian strata are not exposed west of Llanarthney in Caermarthenshire, being concealed by the Upper Old Red Sandstone and Carboniferous strata, which overlap them and rest on the Cambrian rocks.

MAY HILL SERIES.

This term is adopted from that used by Murchison in 1834 for the older rocks of May Hill, between Newent and Mitcheldean, on the borders of Herefordshire and Gloucestershire.

The May Hill Sandstone, which is included in the series, was originally grouped with the Caradoc Sandstone by Murchison, and afterwards distinguished as Upper Caradoc by John Phillips, who had observed the difference in organic remains between the two Sandstones. Still later the distinctness of the May Hill Sandstone from the Caradoc Beds was shown by Sedgwick and M'Coy.[3]

The series comprises the following divisions:—

3. Tarannon Shales.
2. Upper Llandovery Beds.
1. Lower Llandovery Beds.

[1] Brit. Assoc. 1875; Trans. Cambr. Phil. Soc. iii. 255. See also Hicks, G. Mag. 1876, p. 159.

[2] Ramsay, Geology of North Wales, edit. 2, p. 5.

[3] Q. J. ix. 215; see also J. W. Salter, G. Mag. 1867, p. 201.

LLANDOVERY BEDS.

The name was given by Murchison, because the strata are well developed near Llandovery, in Caermarthenshire. The beds consist of sandstone, grit and conglomerate, slate and shale, attaining a thickness estimated at 2500 feet, though frequently it is much less.

Lower Llandovery Beds.

These rocks consist of hard grey grits and conglomerates, with beds of slate and shale, and attain a thickness of from 600 to 1000 or even 1500 feet.

Among the fossils are *Petraia uniserialis*, *Halysites catenularius*, *Calymene Blumenbachii*, *Orthis elegantula*, *Strophomena*, *Pentamerus* (*Stricklandinia*) *lens*, *Meristella crassa*, etc. Casts of *Pentamerus oblongus* are occasionally met with in the rocks.

To the west of Builth and near Llandovery the beds appear to be most fossiliferous. Fossils have also been recorded from Pen-y-Craig in Caermarthenshire; from Llangyniew, Mathyrafal, and Meifod, in Montgomeryshire; and from the Quaker's Burial Ground in Pembrokeshire.

The Lower Llandovery strata appear south-east of Bala Lake, and are developed over a great part of South Wales, near Rhayader, Garth, north-west of Builth, etc. The junction with the Upper Llandovery beds is seen near Noeth Grug, north-east of Llandovery. These rocks extend over a good deal of country on the borders of Cardigan Bay, between Aberystwith and Cardigan, and are exposed at Haverfordwest. To the south of Haverfordwest shelly sandstones are exhibited, which overlie conglomerates that form the base of the Silurian system.[1]

Upper Llandovery Beds or May Hill Sandstone.

These rocks consist of grey and yellowish sandstones, grits, and conglomerate, attaining a thickness of about 800 feet. Sometimes a calcareous band is met with: as, for instance, the Norbury Limestone and Hollies Limestone, in Shropshire. From the abundance of *Pentamerus*, these strata are termed the Pentamerus-beds, or zone of *P. oblongus*.

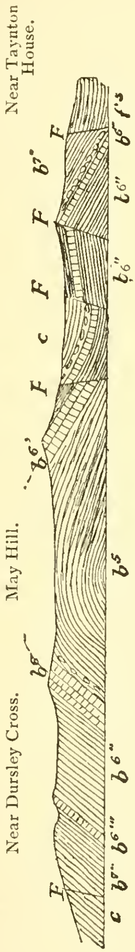
The May Hill Sandstone yields species of Corals, *Favosites*, *Heliolites interstincta*, *Petraia rugosa*, *P. elongata*, and *P. bina*. Also Annelides, Trilobites, and Mollusca, the Brachiopoda being most abundant. Amongst the species are *Pentamerus oblongus*, *Atrypa reticularis*, *Orthis protensa*, *Strophomena compressa*, *S. antiquata*, *Murchisonia*, *Bellerophon trilobatus*, *Encrinurus punctatus*, etc.

[1] J. E. Marr and T. Roberts, Q. J. xli. 489.

Remains of *Pterygotus* have been found in these rocks at Eastnor Park, near Ledbury; these are the earliest known traces of this Crustacean.[1] (See Fig. 14.)

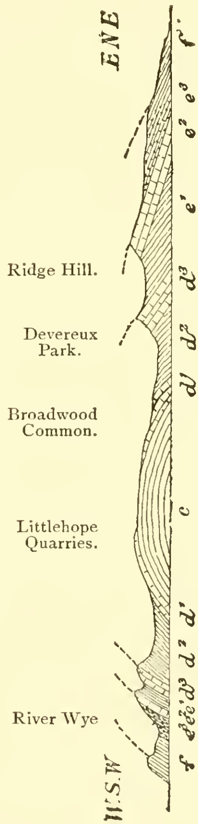
FIG. 12.—SECTION ACROSS MAY HILL, IN GLOUCESTERSHIRE.[2] (Sir A. C. Ramsay.)

S.W. Length about 3 miles. N.E.



f^5 Keuper.
c Lower Old Red Sandstone.
$b^{7''}$ Ludlow Beds } Silurian.
$b^{6'''}$ Wenlock Limestone. } Silurian.
$b^{6''}$ Wenlock Shale. } Silurian.
$b^{6'}$ Woolhope Beds. } Silurian.
b^5 Upper Llandovery (May Hill Sandstone). } Silurian.
F Faults.

FIG. 13.—SECTION ACROSS WOOLHOPE VALLEY, IN HEREFORDSHIRE.[3]
(Prof. John Phillips.) Length about 5 miles.



f Lower Old Red Sandstone (base of).
e^3 Upper Ludlow. } Silurian.
e^2 Aymestry Limestone. } Silurian.
e^1 Lower Ludlow. } Silurian.
d^3 Wenlock Limestone. } Silurian.
d^2 Wenlock Shale. } Silurian.
d^1 Woolhope Beds. } Silurian.
c Upper Llandovery (May Hill Sandstone). } Silurian.

[1] W. S. Symonds, in Dr. H. Woodward's British Fossil Crustacea (Palæontograph. Soc.), 1872, p. 92.

[2] This section is taken from a Programme of Excursion to Ledbury, etc., Geol. Assoc. 1879; see also Sedgwick, Q. J. ix. 219; and Horizontal Sections, Sheet 13 (Geol. Survey).

[3] From Horizontal Sections, Sheet 13 (Geol. Survey); reproduced from section published by Geol. Assoc., in Programme, 1879; see also H. E. Strickland, Q.J. viii. 383.

In South Wales these beds first appear in Marloes Bay, and, at intervals, range across Pembrokeshire; but further north and east they disappear for a space, being overlapped by the Old Red Sandstone. They re-appear south of Llandeilo and, varying from a few feet to 1000 feet in thickness, they range north-east in a narrow strip through parts of Caermarthenshire, Brecknockshire, and Radnorshire, lying indifferently upon Lower Llandovery, Caradoc, or Llandeilo Beds. Near Builth, where they are only a few feet thick, they rest unconformably upon the Llandeilo Flags and their associated igneous rocks. They are also found near Presteign, where they are locally called 'Corton grit.' They occur at Nash Scar, and in Shropshire they lie unconformably on the Caradoc Sandstone, between Cardington and Coalbrook Dale. In the Longmynd country they also lie quite unconformably (in the form of a calcareous conglomerate) on Cambrian rocks, and beyond this in Wales they are not known anywhere at the western base of the [Silurian] strata between Radnorshire and the mouth of the Conway.[1] The Upper Llandovery Beds are well known at May Hill and Huntley Hill in Gloucestershire. (See Fig. 12.) They consist of sandstone and shale, with conglomerate. They occur also at Charfield Green and Stone, near Tortworth in Gloucestershire, where fossils have been obtained; and here they comprise red micaceous sandstone and grit, with subordinate beds of shales, and sometimes limestone. At Malvern they consist of grey and purple laminated sandstones and shales, about 500 feet thick, resting on grey and purple sandstones and conglomerates, about 600 feet thick.[2] (See Fig. 14.) Here and in the Abberley Hills many fossils have been collected.

In North Wales the Llandovery Beds are represented by the *Corwen Grits* described by Prof. Hughes in 1876. These grits, which take their name from Corwen, in Merionethshire, consist of fine sandstones and grits, sometimes containing quartz pebbles. They yield species of *Favosites*, *Petraia*, *Orthis*, etc. The beds may be seen near Corwen and Penyglog. In places they are worked for road-metal. At Nant Llechlog there is a white saccharoid sandstone. The beds rest unconformably on the Bala Beds, and are overlaid by "Pale Slates" (Tarannon Shales). Certain mudstones at Llansantffraid appear locally to represent the Corwen Grits.[3] The May Hill group may also be represented near Treiorwerth in Anglesey.[4] Fossils have been collected from the neighbourhood of Presteign, in Radnorshire; Builth, in Brecknockshire; Llandovery, Llangadoc, and Pen-y-lan, in Caermarthenshire; and Marloes Bay and Wooltack, in Pembrokeshire.

In the Dee Valley, the Cerrig-y-druidion grits are grouped by Mr. J. E. Marr with the Corwen Grits and May Hill Group.[5] They

[1] Ramsay, Geol. N. Wales, edit. 2, p. 18.
[2] Phillips, Mem. Geol. Surv. vol. ii. part 1.
[3] Q. J. xxxiii. 207.
[4] T. M'K. Hughes, Q. J. xxxvi. 239.
[5] Q. J. xxxvi. 278.

comprise calcareous grey grits, false-bedded and ripple-marked, with numerous clay-galls, and they rest unconformably on the Bala beds.

Fossils have been obtained at Walsall, Chirbury, Norbury, Church Stretton, and at the Bogmine, near Shelve, in Shropshire. In this county, according to Messrs. Salter and Aveline, the Upper Llandovery beds comprise the following strata (See Fig. 9, p. 58):[1]—

Purple shales (Tarannon Shales), 200 to 400 feet thick.
Thin limestone bands, interstratified with ochreous sandstone and argillaceous shales (Pentamerus beds).
Conglomerates and sandstones, 100 feet.

The Upper Llandovery rocks are developed in the Lower Lickey Hills in Worcestershire, and in Staffordshire. At the Lickey, low heathy hills occur chiefly composed of quartz-rocks, lithologically identical in character with those masses on the flanks of the Caradoc and Wrekin; the main portion of these rocks is of Cambrian age, but they are overlaid by quartz-grits and sandstone of Llandovery age. (See pp. 45 and 65.)[2] The fossils from the sandstones of the Bromsgrove Lickey include *Pentamerus oblongus*, *P. lens*, *Orthis calligramma*, etc. The older Lickey quartzite, as observed by Dr. Buckland, furnished a large proportion of the pebbles in the New Red Sandstone and Drift;[3] these pebbles occur over a large area, so that this exposure alone would not have furnished the material, and no doubt, as Mr. W. J. Harrison has suggested, the beds formerly extended over a much larger area, and, where not denuded, are concealed by overlying strata.[4]

Tarannon Shales.

These beds comprise smooth pale-blue, purple, and greenish-grey slates and shales 1000 to 1500 feet in thickness.

They were first noticed by Sedgwick, under the name of 'paste rock.' They were named by the Geological Survey from their development by the river Tarannon near Llanidloes, in Montgomeryshire, where they were mapped by Mr. Aveline. These shales form the lowest part of the Silurian rocks of North Wales, and from beneath the Denbighshire grits they are exposed in a narrow and nearly unbroken line from the mouth of the Conway to near Builth in Radnorshire, where they are strikingly unconformable to the various underlying members of the Cambrian strata.[5]

They extend southwards to near Llandovery, where their thick-

[1] Q. J. x. 63; see also H. Hicks, P. Geol. Assoc. vii. 295.
[2] A. Aikin, T.G.S. i. 208; Murchison, Siluria, edit. 5.
[3] T. G. S. v. 507.
[4] Proc. Birmingham Phil. Soc. iii. 157. See also J. B. Jukes, South Staffordshire Coal-field, edit. 2, p. 111.
[5] Ramsay, Geol. N. Wales, edit. 2, pp. 4, 14, 18, 281.

ness is much diminished. They rest conformably upon the Upper Llandovery rocks. Few fossils have been found in the beds, and none of these are peculiar to them, all belonging to species that occur in the Wenlock Series; hence they are intimately associated with that Series, and were at one time designated as Woolhope Shales.[1]

Near Conway Castle, Graptolites have been found by Prof. Lapworth, including species of *Monograptus*, etc., and Corals have been met with near Meifod and Llanfyllin.

The Tarannon shales may be taken to include representatives of the Pale Slates or Shales and the Graptolitic Mudstones of the Lake District.

According to Mr. W. Keeping central and west-central Wales is made up almost entirely of a great series of imperfect slates and greywackes belonging to the following group:—

Cardiganshire Group.	2. Metalliferous-slate group.	2000 feet.
	1. Aberystwith grits (Sedgwick).	1000 feet.

The rock-beds are remarkably folded and contorted, with frequent inversions; hence there is some doubt about the relative positions of these strata. The included fossil remains, especially the Graptolites, prove the Aberystwith Grits and Metalliferous slates to belong to the same general geological horizon above the Bala group and on the parallel of the Coniston Mudstones of the Lake District. The grits contain *Monograptus Sedgwickii*, *Phacops elegans*, etc.; the slates have yielded *Rastrites peregrinus*, etc. The beds may be seen at Cefn Hendre, Devil's Bridge, Morben, near Machynlleth, etc. Above the Cardiganshire group come the Plynlimmon grits (1000 feet), forming a line of high country in the centre of Wales, including Plynlimmon. These grits are probably an arenaceous development of the Tarannon Shales, and the Cwm-Elan conglomerates and Rhayader Pale Slates belong to the same series. Mr. Keeping thinks that in the district there is evidence of a passage upwards from the Bala to the Llandovery groups, and from these into the Tarannon Shales and Denbighshire Grit series.[2] Some plant-like remains occur in the Aberystwith Grits, and under the name of *Nematolites* Mr. Keeping has described curious irregular branching structures of widespread occurrence. (See p. 33.) The grits of Llangrannog are on the same horizon as the Aberystwith Grits.[3]

In North Wales, above the Corwen Grits, there are representatives of the "Pale Slates," above which are the striped flaggy slates of Penyglog, in which Prof. Hughes has found *Monograptus priodon*, *Orthoceras primævum*, etc. These latter, together with

[1] Symonds, Records of the Rocks, p. 151.

[2] Q. J. xxxvii. 146.

[3] G. Mag. 1882, p. 486. The terms Aberystwith and Plynlimmon groups were used by Sedgwick, Q. J. iii. 151. See also J. E. Marr, Cambrian and Silurian Rocks, p. 48.

certain Grits above, he refers to the Denbighshire Flag- and Grit-series.[1] Mr. J. E. Marr places the Penyglog Flags at the base of this series. (See p. 95.) In the upper part of the Clwyd Valley, near Glynbach, Prof. Hughes has noted the following succession of beds beneath the representatives of the Coniston Flags and Denbighshire Grits:[2]—

Tarannon Series.	Wavy-banded Sandstone Pale Slates. Sandstones. Pale Slates with Graptolites (*Monograptus*).	Pale Slates and Graptolitic Mudstones.

In the area of the Breidden Hills, between Welshpool and Shrewsbury, the purple shales which overlie the Pentamerus-beds are about 200 feet thick.[3] The Tarannon Shales have been noted in the Dee Valley, and there, according to Mr. Marr, they are more cleaved than is usually the case with the corresponding beds of the Lake District.[4]

Slates belonging to this group have been worked in some localities.

WENLOCK SERIES.

The Wenlock Series is divided as follows:—

3. Wenlock Limestone. 2. Wenlock Shale. 1. Woolhope Beds.	Denbighshire Grits. Denbighshire Flags.

The term Wenlock Series, used by Murchison in 1833, is derived from Wenlock Edge, in Shropshire.

DENBIGHSHIRE GRITS AND FLAGS.

Under the name Denbighshire Sandstones these beds were described in 1841 by J. E. Bowman; later on their position was determined by Sedgwick. The name is derived from the development of the beds in Denbighshire.

This formation consists of a series of shales, flagstones, sandstones, and grits, attaining a maximum thickness of at least 3000 feet. According to Sir A. C. Ramsay, they form but a local variety of the Wenlock Series; and apparently, where the grits thin away and disappear, instead of being overlapped by the shale, they

[1] Q. J. xxxiii. 209.
[2] Q. J. xxxv. 697.
[3] W. W. Watts, Q. J. xli. 539.
[4] Q. J. xxxvi. 282.

rather pass by lithological gradations into strata of a shaly character. In some areas fossils are absent or very scarce in the grits, a few fragments of Encrinites or of bivalve Mollusca alone showing that they are fossiliferous. In other places, however, fossils are plentiful, as near Conway, at Plas Madoc, near Pentre Voelas, Craig-hir, etc.

Amongst the fossils may be mentioned *Phacops Downingiæ*, *P. caudatus*, *Calymene Blumenbachii*, *Rhynchonella nucula*, *Strophomena*, *Leptæna*, *Cardiola interrupta*, *Euomphalus*, *Murchisonia*, *Bellerophon expansus*, *Orthoceras primævum*, etc. *Monograptus* (*Graptolithus*) *priodon* also occurs; and Land-plants, the oldest yet known, have been found by Dr. H. Hicks in grits exposed in a slate-quarry at Pen-y-glog, near Corwen.[1] These are the Penyglog Grits described by Prof. Hughes.[2]

The following local divisions have been made:—

2. Denbighshire Grits.	Dinas Bran Beds and Llansannan Shales. Penyglog Grits.
1. Denbighshire Flags.	Penyglog Flags.

The Denbighshire grits and flags succeed the Tarannon shales, and, interstratified with slaty shales, they form the base of the Wenlock Series. They run from north to south, in a long sinuous and sometimes broad strip, from the mouth of the Conway to Melenydd. East of Bala Lake they lie in a trough, from two to four miles wide, and the Tarannon shales and older rocks of the Berwyn hills rise from underneath their eastern boundary. North of the Berwyn hills, between Llangollen and Corwen, the Denbighshire grits, more shaly in character, overlie the Tarannon shales; and in the valley of the Vyrnwy, and eastward by Welshpool and the Long-mountain, and round the older rocks of the Shelve and Corndon country, the sandy character of the base of the formation disappears. It may, indeed, be stated that in the Long-mountain, north of Montgomery, the Wenlock Series exhibits a transition from the calcareous development in Shropshire to the arenaceous type of Denbighshire.[3] In Radnorshire, ten or twelve miles north of Builth, the Denbighshire grits die out, but their equivalents in a more shaly form are believed by Mr. Aveline to strike into South Wales.[4] Many fossils have been found in the Llansannan Shales.

In the Clwyd Valley, above the Pale Slates and Graptolitic Mudstones, Prof. Hughes notes the following beds:—

Grey gritty, and concretionary Sandstones.	Denbighshire Grits.
Sandy Mudstones and grey banded Sandstone. Flaggy Shales and Sandstone.	Denbighshire Flags.

In the flaggy beds at Pontyrddol, near St. Asaph, and on Moel Fodia, the following fossils were obtained:—*Favosites fibrosus*,

[1] Q. J. xxxvii. 482; xxxviii. 97.
[2] Q. J xxxiii. 207.
[3] W. W. Watts, Q. J. xli. 537.
[4] Ramsay, Geol. N. Wales, edit. 2, p. 14.

Atrypa reticularis, *Chonetes lata*, *Rhynchonella navicula*, *Orthis elegantula*, *Strophomena depressa*, *Cardiola interrupta*, and *Orthoceras primævum*.

The Denbigh grits are exposed on the top of Ffriddfawr. The entire series is estimated to have a thickness of about 4000 feet. The Penyglog Grits of Corwen and the Austwick Grits of Yorkshire belong to the same series.[1] In the Dee Valley Mr. J. E. Marr notes the following succession:—

			Lake District.
Denbighshire Flags.	3. Dinas-Bran Beds	=	Upper Coldwell Beds.
	2. Penyglog Grits	=	Middle and Lower Coldwell Beds.
	1. Penyglog Flags	=	Brathay Flags.

In (1) the Flags or banded slates of Penyglog quarry and Maeshir, *Monograptus priodon*, *Retiolites Geinitzianus*, *Cyrtograptus Murchisoni*, and *Orthoceras* have been obtained. The gritty beds (2) are seen above Penyglog quarry. The highest beds (3) are exposed on the hill near Llangollen, upon which Dinas-Bran Castle stands. They have been correlated with the Llansannan Shales by the Geological Survey. They contain *Favosites fibrosus*, *Rhynchonella navicula*, *Cucullella coarctata*, *Orthoceras tenuicinctum*, etc.[2]

The Penyglog Flags are probably on the same horizon as the Pencerrig beds of Builth, which contain *Cyrtograptus Murchisoni*.

At Rhymney quarry near Cardiff there are about 70 feet of sandstones (Rhymney Grit), containing a bed with *Ctenodonta subæqualis* (*Ctenodonta*-sandstone). These beds are described by Prof. W. J. Sollas as belonging to the Lower Wenlock Beds.[3]

WOOLHOPE BEDS.

The term Woolhope Beds was given by Murchison from the occurrence of these strata at Woolhope, near Hereford.

The Woolhope Limestone is regarded as forming a subordinate part of the Wenlock formation, and has been termed the Lower Wenlock Limestone. This formation, which rests on the Tarannon Shales and Upper Llandovery rocks, as seen in Shropshire and parts of North Wales, consists of dark grey shale, with subordinate and thin nodular masses of limestone and calcareous sandstone. The formation is rich in Trilobites, Brachiopoda, and also in Cephalopoda: these include *Homalonotus delphinocephalus*, *Encrinurus punctatus*, *Acidaspis Brightii*, *Illænus Barriensis*, *Phacops caudatus*, *Spirifera elevata*, *S. plicatella*, *Orthis elegantula*, *Strophomena euglypha*, *Leptæna transversalis*, *Atrypa reticularis*,

[1] Hughes, Q. J. xxxv. 694.
[2] Q. J. xxxvi. 283. See also Marr, Cambrian and Silurian Rocks, p. 41.
[3] Q. J. xxxv. 488.

Orthoceras angulatum, etc. A few Corals occur, as *Cyathophyllum*, *Heliolites*, *Petraia*, etc.

In describing the Woolhope area, the Rev. W. S. Symonds observes that the term "valley of elevation" does not convey an adequate idea of its interesting geological structure. The central dome of Haughwood is occupied by the May Hill rocks; around these rocks, the Woolhope Limestone forms a circle dipping away on all sides beneath the Wenlock Shale and Limestone, and these again disappear beneath the Ludlow rocks and Old Red Sandstone. (See Fig. 13.) The Woolhope Limestone is quarried at Scutterdine, near Mordiford, Woolhope, Westington, and Rudge End.[1]

The Woolhope Limestone at Malvern is a rough, impure limestone, with occasional beds of sandstone intercalated, having altogether a thickness of about 150 feet. It may be studied north of Crumpend Hill, at Ballard's quarry, near the Wych, and in the valley of Netherton, near Eastnor. (See Fig. 14.) Around May Hill the beds are thin. (See Fig. 12.) At Littlehope the limestone is extensively burnt for lime.

In Radnorshire the Woolhope Limestone is well developed at Nash Scar near Presteign, where it has been extensively quarried.

Woolhope Limestone, known as the Barr or Hay Head Limestone, is exposed at the surface at Hay Head near Great Barr, east of Walsall. There large specimens of *Illænus Barriensis* (the "Barr Trilobite") have been found.

WENLOCK SHALE.

This formation consists of shales, with flags and sandstones, and was termed the Wenlock Shale by Murchison.

It is the thickest and most persistent member of the Wenlock Series, and occurs above the Woolhope Limestone. The latter being absent in many tracts, it is not then easy to separate the Woolhope shaly beds from the Wenlock Shale. The Wenlock Shale is well exposed near Coalbrook Dale and the Iron Bridge, and may thence be followed all along the escarpment of Wenlock Edge. It was formerly known as the Dudley Shale.

The Wenlock Shale contains Graptolites, *Monograptus priodon*, etc., several species of *Orthis*, *Leptæna*, and *Rhynchonella*, *Spirifera plicatella*, *Obolus Davidsoni*, also *Euomphalus*, *Bellerophon Wenlockensis*, *Ceratiocaris*, *Theca anceps*, *Orthoceras*, *Encrinurus punctatus*, *Calymene*, *Sphærexochus*, and *Phacops longicaudatus*. Crinoids also are not uncommon.

Mr. G. R. Vine has described many Tubicolar Annelides from the Wenlock Shales and Limestone. They belong to the genera *Cornulites*, *Conchicolites*, *Ortonia*, *Spirorbis*, *Tentaculites*, etc. Many species of Polyzoa have also been obtained, including the genera

[1] Records of the Rocks, p. 166; see also Murchison, Siluria, edit. 5, p. 107.

Fenestella, *Stomatopora*, *Ceriopora*, and *Thamniscus*.[1] Fossils have been found at Castel Dinas Bran.

In Shropshire, as stated by Mr. G. Maw, there is an insensible gradation between the Wenlock Limestone and the Wenlock Shale, the shales under the limestone containing scattered concretionary courses of nodular limestone. Mr. Maw has termed this intermediate zone the *Tickwood Beds*, which may be roughly estimated at from 300 to 500 feet in thickness. The beds are exposed in the deep road-cutting near the railway bridge between Tickwood and Farley Dingle; also east of Benthall Edge, opposite Ironbridge; and in the adjacent cutting on the Severn Valley Railway: they are highly fossiliferous. The Shales beneath would be from 1800 to 1900 feet in thickness, and comparatively barren in organic remains; but near the base is a fossiliferous zone of shales 80 to 100 feet in thickness, termed the *Buildwas Beds*. These beds are exposed on the east bank of the Severn, a short distance above Buildwas Bridge; also south of Harley. The portions of the Wenlock shales above these Buildwas Beds, and below the Tickwood Beds, being the barren shales of Coalbrook Dale and Ape Dale, 1100 to 1200 feet in thickness, are termed the Coalbrook Dale Beds; and the beds below the Buildwas Beds, the barren shales of Buildwas Park, 500 to 600 feet in thickness, are termed the "Basement Beds." We have thus the following local divisions:[2]—

Wenlock Shales	Upper —	Tickwood Beds.
	Middle —	Coalbrook Dale Beds.
	Lower —	Buildwas Beds.
		Basement Beds.

In North Wales the Wenlock Shales are developed between Conway and Abergele, and here they are overlaid by the basement beds of the Carboniferous System—a structure which represents one of the greatest unconformities in the British Isles.[3] They occur near Llangollen, Welshpool, Montgomery,[4] and Builth, and as far south as Llanarthney, between Llandeilo and Caermarthen. From Wenlock Edge they extend towards Presteign and New Radnor. In the Woolhope district the beds may also be studied. (See Fig. 13.) At Malvern, the Wenlock Shale, consisting of dark blue or grey sandy shale, with thin bands of limestone-nodules, is estimated by Prof. Phillips to have a thickness of 640 feet. (See Fig. 14.) On the east side of May Hill the beds have been well exposed, and numerous fossils have been obtained. They have also been exposed in many places in the Usk district, and also to the west of Tortworth, in Gloucestershire. (See Fig. 12.)

In the Llangollen country the Wenlock Shale has been worked for roofing slates in the Valley of Glyn Ceiriog.[5] In the Vale

[1] Q. J. xxxviii. 44, 377.
[2] T. Davidson and G. Maw, Geol. Mag. 1881, p. 103; T. Davidson, Silurian Brachiopoda, vol. v. (Supplement), p. 71.
[3] See A. Strahan, Geology of Rhyl, etc. (Geol. Survey).
[4] See W. W. Watts, Q. J. xli. 536.
[5] Symonds, Records of the Rocks, p. 170.

of Clwyd trials for slates have been made, but owing to their bad quality, the quarries have been abandoned.

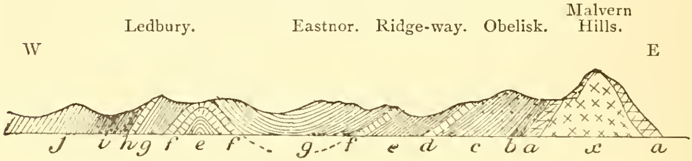
In the boring at Ware in Hertfordshire, Wenlock Shale occurred beneath the Gault, at a depth of 800 feet. The proximity of Silurian rocks in this area had been predicted by Prof. Hull in 1861.[1]

WENLOCK LIMESTONE.

The Wenlock Limestone, so termed by Murchison from its development at Wenlock Edge, consists of thick beds of concretionary or nodular limestone of a light grey colour, containing numerous fossils and separated by beds of shale. It rests conformably upon the Wenlock Shale, and attains a thickness of about 300 feet.

In parts of Wenlock Edge, near Much Wenlock, the rock is more

FIG. 14.—SECTION FROM LEDBURY TO THE MALVERN HILLS.[2]
(Prof. John Phillips.) Length about 4 miles.



j. Lower Old Red Sandstone.
i. Upper Ludlow.
h. Aymestry Limestone.
g. Lower Ludlow.
f. Wenlock Limestone.
e. Wenlock Shale.
d. Woolhope Beds.
c. Upper Llandovery Sandstone and Conglomerate.
b. Hollybush Sandstone and Black Shales with Olenus.
a. Felspathic Rocks. } Archæan.
x. Gneissic Rocks. }

crystalline; and where varied colours prevail, the matrix being charged with Encrinites and Corals, it forms a pretty marble, though the slabs are of no great dimensions. Dull grey, dark blue, and even pink varieties of this limestone are met with. At Ledbury there is an oolitic limestone known as the Ledbury Marble.

Some of the beds, consisting of impure earthy limestone and shale, contain large concretionary masses of good limestone, called 'wool-packs' or 'ballstones': some of them near Wenlock have, according to Murchison, a diameter of 80 feet, and they are quarried out, leaving large cavities. Although very thick near Wenlock, the limestone thins out so rapidly in its range to the south-west, that even in the interior of the Ludlow promontory it is represented by thin courses made up of small concretions only, and near Aymestry it is merely represented by a few concretions, varying in size from two inches to two feet, but still full of beautiful and

[1] Coal-fields, edit. 2; R. Etheridge, G. Mag. 1879, p. 287; J. E. Marr, Classification of the Cambrian and Silurian Rocks, p. 72; J. Hopkinson, Trans. Watford Nat. Hist. Soc. ii. 241.

[2] From Horizontal Sections, Sheet 13 (Geol. Survey); reproduced from section published by Geol. Assoc., in Programme, 1879. See Proc. G. A. vi. 235.

characteristic Corals. It thins out entirely in Radnorshire, and is very feebly represented in Brecon, Caermarthen, and Pembroke; for its place is only marked in the cliffs of Marloes Bay, west of Milford Haven, by some fossils and a small quantity of impure limestone in grey and sandy shale.[1]

The Wenlock Limestone is well developed at Malvern (280 feet), Woolhope, May Hill (220 feet), Tortworth, and Usk. (See Figs. 4, 12, 13, and 14.) Among the most noted localities, however, are the Castle Hill and Wren's Nest at Dudley, where the limestone (Dudley Limestone) has been largely quarried, and is locally known as the "White lime." Here it forms two bands of concretionary and flaggy limestone, the upper twenty to thirty feet thick, and the lower thirty-five to forty feet, separated by about ninety feet of shale. The Wenlock Limestone is also to be seen at Walsall. The occurrence of Wenlock Beds at Pen-y-lan east of Cardiff was made known by the Rev. Norman Glass; their total thickness, including Wenlock Shale, at Pen-y-lan and Rhymney, is estimated at 580 feet by Prof. Sollas.[2]

The Wenlock Limestone is a noted repository for fossils. Among these are Sponges, *Stromatopora striatella*, *Ischadites*, etc.; and Graptolites, *Dictyonema retiformis*, etc. More abundant are the Corals, *Omphyma turbinata*, *Heliolites interstincta*, *Halysites catenularius* (the "Chain Coral"), *Favosites Gothlandica*, *Cyathophyllum angustum*. The Echinoderms include *Actinocrinus pulcher*, *Cyathocrinus pyriformis*, *Crotalocrinus rugosus*, *Taxocrinus tesseracontadactylus*, *Pseudocrinites quadrifasciatus*, *Periechocrinus moniliformis*, etc. The Crustacea include the Cirripede *Turrilepas Wrightianus*, and the Trilobites, *Acidaspis crenatus*, *Encrinurus punctatus* and *E. variolaris* (known as the "Strawberry-headed" Trilobites), *Calymene Blumenbachii* (the "Dudley Locust"), *Lichas anglicus*, *Phacops Downingiæ*, *P. caudatus*, *Proetus Stokesii*, *Sphærexochus mirus*, and *Homalonotus delphinocephalus*. *Pterygotus problematicus* has also been found.

The Polyzoa include many species of *Fenestella*, besides other forms.[3] The Brachiopods include *Strophomena euglypha*, *S. rhomboidalis*, *Pentamerus galeatus*, *Spirifera elevata*, *S. plicatella*, *Orthis elegantula*, *Atrypa reticularis*, *Athyris compressa*, *Meristella circe*, *Retzia Barrandei*, *Rhynchonella borealis*, *R. Stricklandi*, *R. Wilsoni*, and *Lingula Lewisii*. The spiral appendages of many Brachiopoda (*Spirifera*, *Athyris*, *Atrypa*, etc.) have been worked out by the Rev. Norman Glass.[4]

The Lamellibranchs include *Avicula mira*, *A. ampliata*, *Grammysia cingulata*, *Orthonota amygdalina*, *Pterinea lineata*, etc. Fossil pearls have been somewhat doubtfully identified. The Gasteropods include *Euomphalus funatus*, *E. rugosus*, *Holopella obsoleta*, *Murchisonia Lloydii*. The Pteropods include *Conularia Sowerbyi*. The Heteropods include *Bellerophon dilatatus*, and *B. Wenlockensis*. The

[1] Murchison, Siluria, edit. 5, p. 115. See also Prestwich, T. G. S. (2), v. 413.
[2] Geologist, iv. 168; Q. J. xxxv. 475.
[3] See G. W. Shrubsole, Q. J. xxxvi. 241.
[4] See T. Davidson, Silurian Brachiopoda (Palæontograph. Soc.).

Cephalopods include *Orthoceras annulatum*, *Phragmoceras ventricosum*, and many other species.

Some Annelides are also met with; these are *Cornulites serpularius*, *Tentaculites ornatus*, etc. Dr. G. J. Hinde has discovered many specimens of Annelide jaws in the Wenlock and Ludlow Beds, which had hitherto escaped observation, no doubt, as he remarks, from the fact that the largest specimen did not exceed one-fifth of an inch in length.[1]

Among the localities for fossils are Wenlock Edge, Benthall Edge, and Gliddon Hill. In the Woolhope district fossils may be obtained at Checkley Common south of Stoke Edith, at Warslaw and Dormington. At Whitfield near Tortworth, in Gloucestershire, and in the May Hill and Usk districts fossils are plentiful. Some of the finest corals originally described by Lonsdale in the 'Silurian System,' were collected by the Rev. T. T. Lewis, in the gorge of the river Lugg, above Aymestry.

The Dudley Quarries have been spoken of as the most famous in the world for Silurian fossils; and the collections made by the late John Gray of Dudley, and by Capt. T. W. Fletcher of Lawnswood, are deservedly well known. Large slabs of limestone from the Wren's Nest, Dudley, containing specimens beautifully weathered out, of Annelides, Corals, Polyzoa, Brachiopoda, Encrinites, Cystideans, and Trilobites, are generally to be seen in Museums.

The Wenlock Limestone is considered to have been a deep-sea formation, and to have been very tranquilly deposited.[2] Dr. S. P. Woodward has remarked that "In our Silurian Coral-reef of the Wenlock Edge and Dudley there may be masses of branching coral a yard across, and convex *Stromatoporæ* (*Hydrocorallines*) of nearly equal size. But the coral-beds are separated by clay partings, and never attain a great thickness."[3]

Murchison mentions that formerly there were lead-mines in the Wenlock Limestone at Much Wenlock.

The limestone is largely quarried for smelting purposes and for lime-burning at Hurst Hill, near Sedgley, at Lincoln Hill and Iron Bridge, at May Hill, along Blaisdon Edge, and other localities previously mentioned. The 'ballstones' of Wenlock have been quarried out as the best flux for the smelting of iron.

An analysis of the Wenlock Limestone at the Wren's Nest, Dudley, showed the following composition:[4]—

Carbonate of lime	74·64
,, magnesia	2·51
,, protoxide of iron	1·63
Alumina	·75
Phosphoric acid	·35
Insoluble matter	20·03
(Loss in analysis)	·09
	100·00

[1] Q. J. xxxvi. 368.
[2] See J. W. Salter, in Jukes' South Staffordshire Coal-field, edit. 2, p. 116.
[3] G. Mag. 1864, p. 42.
[4] Proc. Dudley Geol. Soc. iii. 114.

LUDLOW SERIES.

The term Ludlow Beds was given by Murchison in 1833, because the town of Ludlow in Shropshire stands on these strata, near their junction with the Lower Old Red Sandstone.

The Ludlow formation may be regarded as a natural continuation of the Wenlock beds, for the inferior strata contain calcareous nodules, which differ from those of the Wenlock deposit only in being usually of a blacker colour, and which have often been formed round an Orthoceras, a Trilobite, or other fossil as a nucleus. Prof. Lapworth would include the Lower Ludlow beds with the Wenlock beds, under the general name Salopian (see p. 86), a grouping suggested in 1865 by Mr. C. Ketley.[1] The thickness of the Ludlow formation is about 7000 feet at Malvern, but as much as 1200 or 1400 feet elsewhere. The Series may be divided as follows:—

5. Ledbury Shales. } Passage Beds between Silurian and
4. Downton Sandstones. } Lower Old Red Sandstone.
3. Upper Ludlow Beds.
2. Aymestry Limestone.
1. Lower Ludlow Beds.

Lower Ludlow Beds.

This formation consists of grey and greenish-grey sandy shales, micaceous sandstone and flags. Some of the upper beds are calcareous, and contain small concretions of impure limestone. The shales have been locally termed 'mudstones,' from their tendency when wet to dissolve into mud. Their thickness has been estimated at 750 feet at Malvern.

The uppermost strata (according to Murchison) become somewhat more sandy, constituting thick flagstones, termed 'pendle' by the workmen. They have attracted much attention at a spot near Leintwardine, and have yielded many remains of Crustacea and Starfishes. These beds form the support of the Aymestry limestone, from which they are usually separated by soft soapy beds, in parts an imperfect fuller's earth. It is the decomposition of this unctuous fuller's earth (provincially Walker's earth or Die earth) beneath heavy masses of the limestone which rest upon it, that has occasioned numerous landslips both near Ludlow and in neighbouring parts of Herefordshire.[2]

Among the fossils are Sponges, *Ischadites*, *Cliona*, etc.; Graptolites, *Monograptus Leintwardinensis*, etc.; Corals of the genera *Favosites*, *Heliolites*, etc.; Echinoderms, including the Starfishes, *Protaster Miltoni*, *Palæocoma Colvini*, and *Palasterina primæva*, as

[1] See Murchison, Siluria, edit. 5, p. 122.
[2] Murchison, Siluria, edit. 5, p. 124.

well as *Actinocrinus pulcher*, etc.; Annelides, *Cornulites serpularius*, *Spirorbis Lewisii*; Crustacea, *Pterygotus arcuatus*, *Eurypterus punctatus*, *Slimonia punctata*, *Hemiaspis Salweyi*, *Ceratiocaris Ludensis*, *C. robustus*, *C. Murchisoni*; and the Trilobites *Phacops Stokesii*, as well as other species that occur in the strata below and above. The Brachiopoda include *Pentamerus galeatus*, *Discina rugata*, *Atrypa reticularis*, *Lingula lata*. The Lamellibranchs include *Ambonychia acuticostata*, *Cardiola striata*, *C. interrupta*, *Orthonota navicula*, etc.; Gasteropods include *Acroculia euomphaloides*, *Murchisonia Lloydii*, *Pleurotomaria quadristriata*; Pteropods, *Theca Forbesii*, etc.; Heteropods, *Bellerophon expansus*, etc.; Cephalopods, *Orthoceras Ludense*, *O. perelegans*, *Phragmoceras ventricosum*, *Lituites giganteus*, etc.

Most interesting are the remains of Fishes, as these are the earliest traces of vertebrate remains known in this country. They belong to *Scaphaspis Ludensis* (originally termed *Pteraspis*), and were discovered in 1859 by Mr. J. E. Lee, in shale below the Aymestry Limestone, at Church Hill quarry, near Leintwardine, in Herefordshire. This locality near Leintwardine is noted for its fossils; Starfishes, Crustacea, and other remains having been obtained there. Many fossils have also been procured from Sedgley, near Dudley.

The Lower Ludlow beds were exposed in the cuttings of the railway between Wenlock and Presthorpe, and also under Shelderton Hill. They occupy the escarpments and contiguous valleys of the Ludlow rocks which range from Shropshire by Presteign to Radnor Forest, and also large undulating tracts of the western parts of Shropshire and bordering parts of Montgomeryshire. From the neighbourhood of Kington, the beds extend, together with higher members of the Ludlow Series, to the banks of the Wye, and there is a fine exposure in the escarpment at the western end of the Forest of Mynydd Epynt, in Brecknockshire.[1] The beds are well known in the districts of Usk, Tortworth (east of Berkeley), Woolhope, and Malvern. (See Figs. 13 and 14.) Near Cardiff, at Pen-y-lan and Rhymney, the thickness of the Ludlow Beds has been estimated at 364 feet.[2] The beds also occur west of Abergele.[3]

The Lower Ludlow beds form a tract of low ground between the ridges formed by the Wenlock and Aymestry Limestones. The dark nature of the shales has led to useless trials for coal near Malvern. Fuller's earth occurs at Hales End, in that neighbourhood.

Aymestry Limestone.

This formation was named by Murchison from the village of Aymestry, north-west of Leominster, in Herefordshire.

The Aymestry (or Ludlow) Limestone is a dark-grey or blue

[1] Murchison, Siluria, edit. 5, p. 126.
[2] W. J. Sollas, Q. J. xxxv. 475.
[3] J. E. Bowman, T. G. S. (2), vi. 195.

earthy limestone, often well-bedded in layers of from one to five feet in thickness, but sometimes of a concretionary nature. It is inconstant in occurrence, and generally contains numerous layers of shells and corals, whilst associated with it are beds of shale. The thickness has been estimated at from 30 to 40 feet, but frequently it is much less.

The fossils include *Actinocrinus pulcher*, *Palæaster Ruthveni*, *Phacops caudatus*, *Calymene Blumenbachii*, *Ceratiocaris inornatus*, etc. More abundant are *Pentamerus Knightii*, *Rhynchonella Wilsoni*, *Lingula Lewisii*, *Strophomena euglypha*, *Atrypa reticularis*, etc. Other fossils are *Bellerophon dilatatus* and *Pterinea Sowerbyi*. The Corals include species of *Cyathophyllum*, *Favosites*, *Heliolites*, *Petraia*, etc.

Most of the Aymestry fossils are found also in the Wenlock Limestone. Salter regarded the Aymestry Limestone as only a calcareous condition of the Lower Ludlow formation.[1] The relative position and fossil contents of the Aymestry Limestone were first worked out by the Rev. T. T. Lewis, of whom Murchison has spoken as "my most efficient coadjutor in all the regions of Siluria."[2]

At Aymestry the limestone occupies both banks of the river Lugg, but it has been chiefly quarried on the right bank, close to the village. It is developed in Shropshire and Staffordshire as well as in Herefordshire. Fossils are to be obtained near Ludlow, Leintwardine, at Sedgley near Dudley, near Broseley, Dean, and Much Wenlock. South-west of Aymestry, near Presteign, the limestone thins out; but it is represented at Abberley, Malvern, Woolhope, May Hill, and Usk. At Malvern the limestone has been exposed at Hales End quarry. (See Figs. 12, 13, and 14.)

The Aymestry Limestone forms bold ridges and scarps of rock where well developed, near Ludlow and Ledbury. At Palmer's Cairn, or Churn Bank, south-west of Ludlow, there is a landslip produced by the limestone, which is much jointed, breaking away and slipping over the subjacent Lower Ludlow shales. (See p. 101.)

The limestone is extensively burnt for lime. That at Sedgley (Sedgley Limestone), which is a dark blue or black limestone, forms an excellent hydraulic cement, and here it is locally known as the "Brown lime."

Upper Ludlow Beds.

These beds consist of flaggy arenaceous and micaceous shales and mudstones, greenish-grey sandstones, and layers of thin shelly limestone. Ripple-marks are occasionally to be seen on the surfaces of the beds. Their thickness near Ledbury is about 140 feet. The lower beds sometimes contain calcareous shelly layers, with *Rhynchonella navicula*.

The upper beds include the well-known Ludlow Bone-bed,

[1] Catalogue of Cambrian and Silurian Fossils, p. 161. See also R. Lightbody, Q. J. xix. 368.

[2] Siluria, edit. 5, p. 129.

discovered by the Rev. T. T. Lewis and Dr. Lloyd. It comprises a layer, from one inch to a foot in thickness, called "Gingerbread," which is largely made up of remains of Fishes, Crustacea, and other fossils, as well as coprolites. Some of the fish-remains are of a mahogany tint or a brilliant black; the Mollusca are many of them phosphatized.[1] The fish-remains include *Auchenaspis Salteri*, *Cephalaspis ornatus*, *C. Murchisoni*, *Plectrodus mirabilis*, *Thelodus parvidens*, *Pteraspis Banksii*, and *Scaphaspis Ludensis*. The Crustacea include *Astacoderma*, *Ceratiocaris*, *Eurypterus*, *Pterygotus* (and its egg-packets known as *Parka decipiens*), *Slimonia*, *Stylonurus*, *Hemiaspis*, etc.

The Ludlow Bone-bed has been noticed not only in the neighbourhood of Ludlow, but at Bradnor Hill, near Kington, and at Linley, in Shropshire.

Among other fossils from the Upper Ludlow Beds are remains of Land-plants, belonging to the genera *Actinophyllum* and *Chondrites*. Some Sponges, Corals, and Echinoderms are also to be found. Among Trilobites are *Calymene Blumenbachii*, *Encrinurus punctatus*, *Homalonotus Knightii*, *Phacops Downingiæ*, etc. The Brachiopods include *Discina rugata*, *Orthis elegantula* and var. *orbicularis*, *Chonetes striatella*, *Lingula lata*; Lamellibranchs include *Avicula antiqua*, *Modiolopsis lævis*; Gasteropods include *Euomphalus carinatus*, *Murchisonia Lloydii*, *Pleurotomaria crenulata*, etc. Several species of *Bellerophon* occur, also *Lituites giganteus*, *Orthoceras bullatum*, etc. The Annelides *Serpulites longissimus* and *Cornulites serpularius* are also met with.

The beds are exposed at Ludlow, Ledbury, Woolhope, Malvern, Hagley and Abberley, May Hill, near Usk, etc. (See Figs. 12, 13, 14, and 15.) They are extensively quarried for building purposes.

Downton Sandstones.

The Upper Ludlow Beds are capped by sandstones which have been quarried near Downton Castle, in Herefordshire, not far from Ludlow. For these beds the name Downton Castle Stone was used by Murchison. They consist of red, grey, and yellow micaceous sandstones, and attain a thickness of from 80 to 100 feet. Together with the Ledbury Shales, they form the Passage-beds between the Silurian system and the Old Red Sandstone, and in some respects may be said to belong as much to one formation as to the other.

These passage-beds were first observed by Murchison at Hay, in Brecknockshire, and in 1834 he grouped them under the name of 'Tilestone,' at the base of the Old Red Sandstone. The term Tilestone was subsequently abandoned by Murchison, for although

[1] Murchison, Siluria, edit. 5, p. 133; Dr. J. Harley, Q. J. xvii. 542; H. E. Strickland, Q. J. viii. 383, ix. 8. The term Coprolites means, literally, petrified dung or fæces; it is, however, often applied simply to phosphatic nodules.

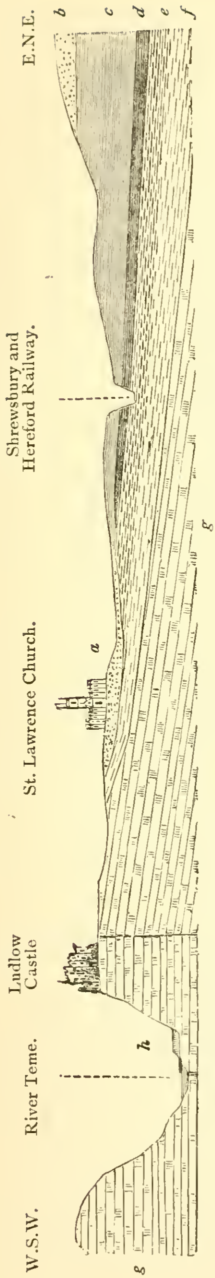


FIG. 15.—SECTION ACROSS LUDLOW.[5] (T. Curley.)

h. Alluvium.
a. Yellow gravel and clay with large boulders.
b. Gravel composed of fragments of Old Red Sandstone.
c. Lower Old Red Sandstone.
d. Olive Shales
e. Greenish Sandstone } Ledbury Shales.
f. Downton Sandstone.
g. Upper Ludlow Beds.

it was in local use in Caermarthenshire and Brecknockshire, yet there is not a stone capable of being formed into a *tile* from the Downton Sandstone to the Cornstones of Wall Hills; but there are thin muddy marls over the Downton beds, which would have been tilestones had they been sufficiently hardened, and which are doubtless equivalents of the true tilestones.[1] The Passage-beds have been observed also in Pembrokeshire, as well as in Gloucestershire, Worcestershire, and Shropshire. Murchison has stated that the tilestones are visible all along the eastern frontier of the Silurian rocks, and scarcely exceed 40 or 50 feet in thickness.

The term Downton Sandstone (used by John Phillips) is now applied to the lower portion of the Passage-beds, the Ledbury Shales constituting the upper portion.

Among the fossils of the Downton Sandstones are Land-plants, *Actinophyllum*, *Chondrites*, and Lycopodiaceous seeds; Annelides, *Cornulites* and *Serpulites;* Crustacea, *Beyrichia*, *Ceratiocaris*, *Pterygotus Ludensis*, *P. problematicus*, *Eurypterus*, etc.; Mollusca, *Lingula cornea*, *Platyschisma helicites*, etc.; and Fishes, *Onchus tenuistriatus*, *Cyathaspis*, *Pteraspis*, etc. The organic remains indicate shallow-water conditions.

Fossils may be found near Builth, at Bradnor Hill, near Kington, in Radnorshire, and near Trimpley in Worcestershire,[2] etc. The beds have been exposed at Hagley Park,[3] also near Ledbury, and near Ludlow.[4]

[1] W. S. Symonds, Q. J. xvi. 196.
[2] R. W. Banks, Q. J. xii. 93; G. E. Roberts, Geologist, ii. 117.
[3] H. E. Strickland, Q. J. viii. 381.
[4] A. Marston, G. Mag. 1870, p. 408; W. S. Symonds, Q. J. xvi. 193.
[5] Q. J. xix. 178, fig. 2.

At Malvern the Downton sandstones are about 100 feet in thickness; there they consist of red, grey, and yellow sandstones and marls. In the Woolhope district the Passage-beds have been exposed at Perton, near Stoke Edith;[1] and here *Pterygotus* and *Eurypterus* were found in the olive (Ledbury) shales. (See Figs. 12, 13, 14 and 15.)

The Downton beds are quarried near Downton Castle, and at Dymock near Ledbury. They are represented by red sandstones at Usk.

The Passage-beds may be seen in the banks of Linley Brook, near Broseley in Shropshire, where an upper Bone-bed occurs above the Ludlow Bone-bed.[2] At one time the junction of Upper Ludlow and Lower Old Red Sandstone was well exposed near Callaughton.[3]

Prof. Hull regards the Foreland group of Devonshire as constituting the passage-beds between the Silurian and Devonian, equivalent in fact to the Dingle Beds or Glengariff Grits of Ireland, to the Downton Sandstones, and to the purple and reddish sandstones, shales, and conglomerates of the Ridge of Trichrug, underlying the so-called "Old Red Sandstone" near Llandovery. These passage-beds he speaks of as the Devono-Silurian formation.[4] The Torquay and Fowey grits may also be placed on the same horizon. (See sequel.)

Ledbury Shales.

This group, which was named by Mr. J. W. Salter from the town of Ledbury, rests conformably upon the Downton Sandstones, and merges gradually upwards into the Lower Old Red Sandstone. Part of it might perhaps be grouped with that formation.[5] It comprises red, grey, and purple marls, shales, and sandstones, having at Malvern a thickness of 300 feet.

The section exposed at the railway-tunnel near Ledbury was described by Rev. W. S. Symonds as follows:[6]—

Lower Old Red Sandstone.	Red marls with grey and reddish sandstone, *Pterygotus*, *Pteraspis*, and *Cephalaspis*.
Ledbury Shales	Grey marl passing into red and grey marl and bluish-grey rock (Auchenaspis-grits), with *Auchenaspis*, *Cephalaspis*, *Onchus*, *Pterygotus*, *Lingula cornea*, etc. 20 feet.
	Purple shales and thin sandstones, *Lingula*. 34 feet.
	Grey shales and grit, with *Cephalaspis* and *Pterygotus*. 8 feet.
	Red and mottled marls, and thin sandstones with *Lingula*, *Pteraspis*. 210 feet.
	Downton sandstone. 9 feet.

[1] P. B. Brodie, Q. J. xxv. 236; xxvii. 256.
[2] G. E. Roberts and J. Randall, Q. J. xix. 229.
[3] Prestwich, T. G. S. (2), v. 422.
[4] G. Mag. 1878, p. 530.
[5] See J. E. Marr, Cambrian and Silurian Rocks, p. 47.
[6] Q. J. xvi. 193; xvii. 152; Records of the Rocks, p. 202.

Mr. A. Marston has described sections of these beds consisting of olive shales, which were exposed on the Shrewsbury and Hereford Railway at the Tin Mills, near Downton, and near Onibury.[1] These shales rest on grey micaceous sandstones (Downton Sandstone). (See Fig. 15.)

SILURIAN.

2.—LAKE DISTRICT, ETC.

The Silurian rocks of the Lake District, etc., have been divided as follows:—

	Kirkby Moor Flags.	
	Bannisdale Slates.	
Upper Coniston Group.	Coniston Grits.	
	Coniston Flags.	
	Stockdale Shales.	Pale Shales or Slates.
		Graptolitic Mudstones.
	Basement Bed (Austwick Conglomerate, etc.).	

The relations of the rocks were first determined by Sedgwick; while the detailed work of the Geological Survey was carried out chiefly by Mr. W. T. Aveline, Prof. Hughes, and Messrs. J. G. Goodchild and E. J. Hebert.[2]

Basement Bed of the Silurian.

At Austwick, near Settle, in the Craven district, a calcareous conglomerate occurs at the base of the Silurian system, resting unconformably on the Bala Beds. This basement-bed, as before mentioned, is regarded by Prof. Hughes as the equivalent of the Corwen Grits.[3] (See p. 85.) The bed occurs beneath the Graptolitic Mudstones near Sedbergh, and is about 15 feet thick.

Certain calcareous and gritty bands forming the base of the Silurian rocks occur at Skelgill, at Pullbeck near Ambleside, and

[1] G. Mag. 1870, p. 409.
[2] See also Dr. H. A. Nicholson, Essay on the Geology of Cumberland and Westmorland, 1868; Sedgwick, Geol. Lake District (Letters to Wordsworth), 1843; and various papers by Prof. R. Harkness.
[3] Proc. Cambridge Phil. Soc. iii. 67; G. Mag. 1867, p. 352.

at Appletreeworth Beck near Coniston. Prof. Hughes has pointed out that the Graptolitic Mudstones and their basement beds rest on different parts of the Cambrian series; at Skelgill on the Coniston limestone bands, and near Coniston on the Ashgill Shales.[1]

Mr. J. E. Marr has remarked that "Not only is there a palæontological break between the Ashgill Shales and what has been taken as the basement bed of the Silurian; but whereas in the Ashgill Shales and underlying beds we get a group of fossils agreeing in all respects with those of the Cambrian series of other districts, in the beds above the Ashgill Shales we find a well-marked Silurian fauna, which will probably be largely added to in future."[2] *Favosites fibrosus*, *Strophomena*, *Orthis*, and *Meristella crassa* occur in this Basement-bed.

STOCKDALE SHALES.

The Stockdale Shales were so termed by Mr. W. T. Aveline, from their occurrence at Stockdale, east of Ambleside, between Shap Fells and Windermere.

The beds consist of pale-grey and purple shales, passing down into black mudstones and shales with Graptolites, and containing calcareous grit or conglomerate at the base. They are subdivided as follows:—

2. Pale Shales (= Tarannon Shales). 10 to 450 feet.
1. Graptolitic Mudstones. 30 feet.

The Graptolitic Mudstones were described in 1868 by Prof. Harkness and Dr. H. A. Nicholson.[3] They were formerly included with the Coniston Flags, and termed the Coniston Mudstones. Subsequently the name "Skelgill Beds" was applied to them by Messrs. Nicholson and Lapworth, from the farm of High Skelgill, near Ambleside, where the rocks are well exposed.[4]

In the Lake District certain black shales are seen beneath the Graptolitic Mudstones at Spengill, Ashgill, etc. (See p. 83.) Mr. J. E. Marr has obtained one Crinoid and a species of *Strophomena* from them.[5]

The Graptolitic Mudstones are dark-coloured and often black mudstones, sometimes anthracitic, alternating with grey and greenish shales, and graduating upwards into the Pale Shales or Slates. The dark mudstones are full of Graptolites. The beds are seen at Spengill, Skelgill, Long Sleddale, Torver Beck and Swindale Beck; near Knock; and again in the neighbourhood of Sedbergh, in Yorkshire. They yield the Graptolites *Diplograptus*, *Rastrites*

[1] Q. J. xxxiii. 483.
[2] Q. J. xxxiv. 880. See also Q. J. xxxvi. 281.
[3] Q. J. xxiv. 297.
[4] Brit. Assoc. 1875. See also Q. J. xxxiii. 471; P. Geol. Assoc. iii. 111.
[5] Q. J. xxxiv. 877.

peregrinus, *Monograptus argenteus* (Argenteus-mudstones); also *Phacops Musheni?*, *Encrinurus variolaris*, *Cheirurus bimucronatus*, *Trinucleus fimbriatus*, *Leptæna quinquecostata*, *Endoceras proteiforme*, *Orthoceras*, and *Sphæronites punctatus*.

While some of the Graptolites, excepting *Monograptus*, are of Upper Cambrian or Ordovician types, yet the more highly organized fossils link the beds to the Silurian system, with which also they are physically connected. Mr. W. T. Aveline has observed that the beds rest unconformably on the Coniston Limestone;[1] and in the Sedbergh district they rest on the *Trinucleus* and *Strophomena* (Ashgill) Shales. The beds were, however, placed with the Upper Cambrian or Ordovician by Messrs. Harkness and Nicholson, exclusively on palæontological grounds.

Dr. Nicholson and Prof. Lapworth have described certain pale-green fine-grained slates developed at Swindale Beck near Knock, under the name of Knock Beds. They resemble the Tarannon Shales, and occur beneath the Coniston (Broughton Moor) Flags. Species of *Orthis* and *Discina* and *Monograptus priodon* are met with in the beds. They were regarded by Prof. Harkness and Dr. Nicholson as the base of the (Upper) Silurian of the Lake District, but the beds graduate downwards into the Graptolitic Mudstones.[2]

The Stockdale Shales being comparatively soft, their occurrence is generally marked by a low tract of ground.

Certain soft shales, formerly worked up into slate-pencils, occur at the old Pencil Mill at Cronkley, in Teesdale. These resemble the Stockdale Shales, according to Messrs. W. Gunn and C. T. Clough, and are probably Silurian in age.[3] Silurian shales (of doubtful age) have also been noted near the head of the Rede-water in Northumberland.[4] Silurian rocks, consisting mainly of shales, with beds of grit and conglomerate, occur in the Cheviot district. They rise up in places to form high ground, and are highly inclined and sometimes vertical, being much folded. (See Fig. 16.) *Graptolites* have been met with in the beds, and they may belong to the Wenlock or Upper Coniston Series.

Representatives of the Graptolitic Mudstones are recognized in the Dee Valley by Mr. J. E. Marr.[5]

[1] G. Mag. 1872, p. 442.
[2] Brit. Assoc. 1875; Q. J. xxxiii. 477.
[3] Q. J. xxxiv. 27; J. R. Dakyns, Geol. and Polyt. Soc. W. Riding, 1877.
[4] G. A. Lebour, Geology of Northumberland, p. 46. See also J. Nicol, Q. J. iv. 195.
[5] Q. J. xxxvi. 278.

CONISTON GRITS AND FLAGS.

The Coniston Grits and Flags were so named by Sedgwick, from Coniston, in Lancashire. They consist of hard siliceous sandstone or grit, flags and conglomerate, with thin bands of slate, which are placed on the horizon of the Denbighshire Grits and Flags. The upper part, especially, contains beds of grit or tough sandstone, interstratified with shivery mudstone; the lower comprises flaggy beds and finely-striped dark blue mudstones, which are more fossiliferous.

The thickness of this group is estimated at between 6000 and 7000 feet in the Sedbergh and Howgill districts; but it may be more in the Lake District proper, for there is no continuous section, and the beds are much disturbed and faulted. The strata rest conformably upon the Pale Shales and Graptolitic Mudstones, and are divided as follows:—

2. Coniston Grits, about 4200 feet.
1. Coniston Flags, about 2000 feet.

Among the fossils of the Coniston Flags are many species of Graptolites, *Monograptus priodon*, *M. colonus*, *M. Sedgwickii*, and *Retiolites Geinitzianus*. Other fossils are *Favosites fibrosus*, *Cardiola interrupta*, *Orthoceras primævum*, *O. subundulatum*, *Lituites giganteus*, and *Phacops obtusicaudatus*. The Coniston Grits contain fewer fossils, including Graptolites, *Monograptus Roemeri*, etc.; also *Cardiola interrupta*, *Pterinea tenuistriata*, *Orthoceras Ludense*, *O. primævum*, *Rhynchonella navicula*, *Acidaspis*, *Phacops Downingiæ*, *Ceratiocaris Murchisoni*, *Spirorbis Lewisii*, and Encrinites.

In the Windermere district the beds have been divided as follows by Mr. J. E. Marr:—

Windermere District.			*Sedbergh District.*
Coniston Grits.			Upper Coniston Grits.
Coniston Flags.	Coldwell Beds.	Upper	Beds S.W. of Helm Knot, beds of High Hollins, etc.
		Middle, Lower	Beds N. of Helm Knot.
	Brathay Flags.		Flags of Frostrow Fell, etc.

An excellent section of these beds in seen in the neighbourhood of the Coldwell and Brathay quarries, south-west of Ambleside.

The Brathay Flags (of Sedgwick) consist of blue, well-cleaved, and finely-laminated flags, of uniform lithological character throughout, and of fine texture. They yield *Monograptus priodon*, *Retiolites Geinitzianus*, *Favosites aspera*, etc., and are regarded as the zone of *Cyrtograptus Murchisoni*. The Lower Coldwell Beds consist of coarse grey grits of no great thickness, and are apparently unfossiliferous. The Middle Coldwell Beds (of Sedgwick)[1] comprise calcareous, flaggy grits, with *Phacops obtusicaudatus*, *Strophomena depressa*, *Cardiola interrupta*, and several species of *Orthoceras*. The

[1] See also Aveline, Explanation of 98 N.E. (Geol. Surv.), p. 8.

Upper Coldwell Beds comprise a series of gritty flags with *Monograptus colonus*, *Actinocrinus pulcher*, *Ceratiocaris Murchisoni*, *Phacops obtusicaudatus*, *Orthoceras tenuicinctum*, etc.[1]

The term Furness Grits was formerly used by Sedgwick for the Coniston Grits;[2] and the term Windermere Rocks used by Daniel Sharpe included the rocks now known as the Upper Coniston group, and was generally equivalent to the Blawith Slate of J. G. Marshall.[3]

Fossils have been found in the Coniston Grits at Helmside near Dent, in the cleaved flags of Ireleth and Broughton Moor, near Ambleside, and on Torver Moor.[4] At Horton-in-Ribblesdale, north of Settle, the beds are known as the Horton flags. Here fossils are uncommon, with the exception of species of *Orthoceras* and *Monograptus*.[5] In the vale of Troutbeck the Coniston Flags have been very extensively worked; and at Applethwaite Common they are succeeded by higher strata belonging to the same series, to which Sedgwick gave the name "Sheerbate Flags."[6]

The Sheerbate Flags just mentioned (the Shear bed of D. Sharpe) have been described by John Phillips and Sedgwick. The former geologist, referring to the thick slate dug near Horton-in-Ribblesdale, remarks that in consequence of the oblique intersection of the laminæ of stratification and cleavage, these slates generally break with edges bevelled on one side, and are called "Sheerbate stone." Sedgwick observes that "bate" is the term applied to laminæ of cleavage.[7] The Sheerbate beds are worked on Torver Moor. As Prof. Hughes has remarked, where the bedding and cleavage nearly coincide, the beds form good flags; where the cleavage makes a considerable angle with the bedding, they split along the cleavage.[8]

Sedgwick classed the Horton flagstone with that at Coniston, and grouped with them the stone at the flag-quarries of Studfield, Dryrigg, and Moughton Fell. In the Dryrigg quarries calcareous or ferruginous concretions disfigure the flagstones; and not unfrequently they are in the condition of a light porous mass (commonly called "rotten-stone"), from which the calcareous matter has almost entirely disappeared.[9]

BANNISDALE SLATES.

This division takes its name from a dale between Windermere and Shap, some distance east of Ambleside.[10]

The Bannisdale Slates are described by Mr. Aveline as consisting of sandy mudstones divided by thin bands of hard sandstone and occasional beds of grit. The beds sometimes exhibit false-bedding and ripple-marks. The sandy mudstones are much jointed and roughly cleaved, never making good slates, but often large rough slabs, which are quarried for paving- or building-stones.

[1] Marr, Q. J. xxxiv. 882. [2] Q. J. ii. 106. [3] Proc. G. S. iii. 603.
[4] See Explanations of Sheets 98 N.E. and S.E. (Geol. Survey).
[5] West Yorkshire, by J. W. Davies and F. A. Lees, edit. 2, p. 27.
[6] Harkness and Nicholson, Q. J. xxiv. 298, 300, 521.
[7] T. G. S. (2), iii. 16, 472. [8] G. Mag. 1867, p. 356. [9] Q. J. viii. 51.
[10] W. T. Aveline and T. M'K. Hughes, in Explanation of Sheets 98 N.E. and S.E. (Geol. Survey).

The total thickness of the formation is about 5200 feet. The boundary-line between the Bannisdale Slates and Coniston Grits is very indefinite, owing to the alternation of slaty and gritty beds near the junction.

In the neighbourhood of Kirkby Lonsdale the beds are thus divided by Prof. Hughes:—

3. Calcareous beds with *Rhynchonella navicula* (= Aymestry Limestone).
2. Dark grey sandstone and shale with Starfishes (= Lower Ludlow).
1. Dark blue flags (= Upper Wenlock).

Fossils are scarce: they include *Bellerophon expansus*, *Pterinea tenuistriata*, *Orthonota undata*, *Rhynchonella navicula*, *Protaster*, and *Phacops Downingiæ*.

The lowest beds are seen at several localities in the neighbourhood of Kirkby Lonsdale. Fossils have been found at Tebay Fells, and in the valley of the Lune below Howgill.

The Bannisdale Slates represent in part the Upper Ireleth Slate Group of Sedgwick, named from Kirkby Ireleth, near Ulverston.[1]

KIRKBY MOOR FLAGS.

This division is named from Kirkby Moor, near Kendal, in Westmoreland, and is equivalent to the Kendal Group of Sedgwick. It includes grey calcareous flagstones and grits, sometimes in thick beds, locally stained of a reddish colour, of coarse texture, and often exhibiting a massive concretionary structure. It also contains bands of coarse slate and tilestone. The estimated thickness of these beds is 2000 feet.

The Kirkby Moor Flags are placed on the horizon of the Upper Ludlow series; they pass downwards into the Bannisdale Slate group. They extend from near Kendal by Benson Knot, through Kirkby Moor to the Lune, but they do not appear to the east of that river. From their occurrence at Hay Fell they are sometimes termed the Hay Fell Flags. Fossils are abundant in some localities. They include *Phacops caudatus* and *P. Downingiæ*, *Ceratiocaris inornatus*, *Lingula cornea*, *Orthis orbicularis*, *O. lunata*, *Orbicula*, *Pterinea demissa*, *Avicula Danbyi*, *Orthonotus amygdalinus*, *Murchisonia torquata*, *Orthoceras Kendalense*, etc. The most common and characteristic species are stated by Mr. Aveline to be *Holopella gregaria* and *H. conica*. *Chonetes lata* may also be mentioned.

The uppermost beds are seen at Helm Hill, near Oxenholme, and consist of hard grey and purple sandstone. The Kirkby Moor Flags are overlaid unconformably by the Old Red Conglomerate, which belongs to the highest division of the Old Red Sandstone, and really constitutes the base of the Carboniferous System.

[1] Q. J. ii. 106.

OLD RED SANDSTONE AND DEVONIAN.

The precise correlation of the strata which intervene between the Silurian and the Carboniferous rocks has for a long time been one of the vexed questions of Geology. On most geological maps three large areas of country are similarly coloured to represent the rocks formed during this interval. In one area, including parts of the counties of Monmouth, Hereford, Brecknock, etc., the rocks are termed Old Red Sandstone; in two other areas, including part of North Devon and the greater part of Cornwall and South Devon, the rocks are termed Devonian.

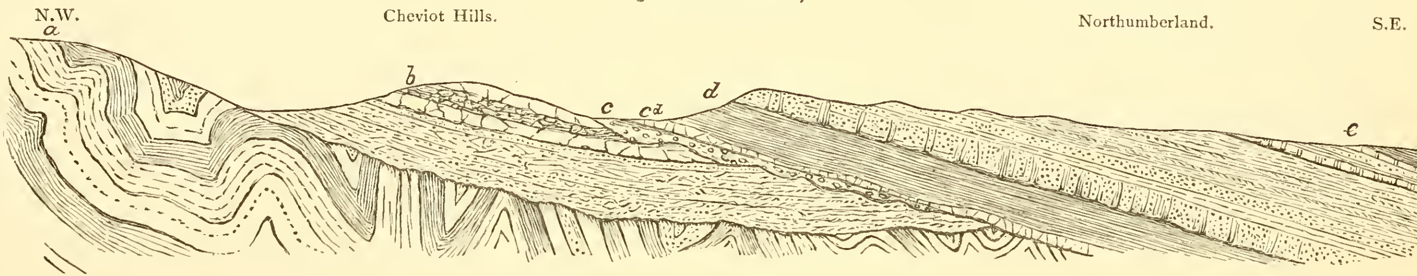
The relations between the Old Red Sandstone and the underlying Silurian and overlying Carboniferous rocks have been long established. In both instances a perfect conformity exists. But only in recent years has it been fully realized that there is a great unconformity between the Upper and the Lower Old Red Sandstone.

On the other hand, the Devonian rocks, which were rescued from the chaos of "Greywacke" by Sedgwick and Murchison, were shown by Lonsdale to contain fossils of a character intermediate between those of the Silurian and Carboniferous rocks; and hence the Devonian rocks were supposed to be equivalent to the Old Red Sandstone.

The term Old Red Sandstone has, in Britain, been restricted to those deposits of red sandstone, etc., in which few, if any, marine fossils occur, and which, both from their lithological characters and organic remains, appear to have been laid down in inland areas of deposit. The Devonian rocks comprise slates and limestones, as well as red sandstones, and in the former rocks the fossils are of a decidedly marine type. Hence, in considering the physical conditions under which the strata were deposited, it has always been a puzzle to understand how these different types of strata were contemporaneously deposited, because they are not separated geographically by a very wide interval. If we regard the Old Red Sandstone as entirely formed in fresh waters, we require a considerable barrier to separate the purely marine area of the Devonian slates and limestones from the lacustrine sands of the Old Red period; and such a barrier (if it ever existed) must be drawn somewhere between the Mendip and Quantock Hills, and there is no physical evidence to support it.

The stratigraphical relations of the Old Red Sandstone with the rocks above and below, have been pointed out; those

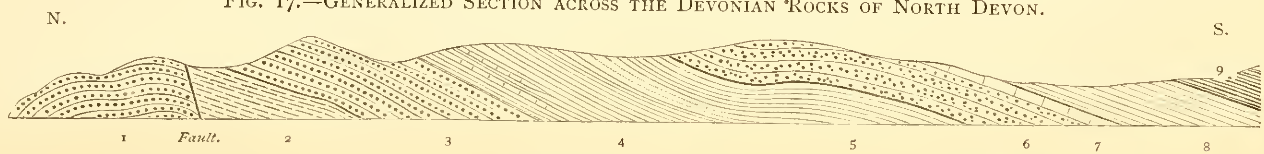
Fig. 16.—Generalized Section across the Cheviot Hills, on the Western Border of Northumberland. (J. G. Goodchild.)



c. Upper Old Red Sandstone and Conglomerate.
b. Lower Old Red Sandstone (Cheviot Series).
a. Silurian rocks (Wenlock Series?).

e. Yoredale Series.
d. Carboniferous Limestone and Calciferous Sandstone Series.
cd. Contemporaneous trap in the Upper Old Red Sandstone.

Fig. 17.—Generalized Section across the Devonian Rocks of North Devon.



3. Hangman Grits.
2. Lynton Slates.
1. Foreland Sandstones.

6. Pickwell Down Sandstones.
5. Morte Slates.
4. Ilfracombe Beds.

9. Culm Measures.
8. Pilton Beds.
7. Baggy and Marwood Beds.

of the Devonian rocks are more complex. The Upper Devonian strata in North Devon shade off into the Lower Carboniferous rocks; but in South Devon, owing to the many disturbances in the rocks, there is no evidence of this passage. Indeed, there is evidence to show that the Culm Measures overlap the Upper Devonian strata, and rest in places directly on the Middle Devonian Limestone. It appears, however, highly probable that the lowermost Devonian rocks represent the passage-beds between the Lower Old Red Sandstone and Silurian, if they do not actually include rocks of undoubtedly Silurian age. The evidence on which these remarks are based will be noted further on, but it may be stated now that the following grouping seems the most in accordance with the ascertained facts:[1]—

Devonshire and Cornwall.	*South Wales, etc.*
Upper Devonian.	Lower Carboniferous and Upper Old Red Sandstone.
Middle Devonian.	(Break.)
Lower Devonian.	Lower Old Red Sandstone, Passage Beds, and uppermost Silurian.

The conclusion to be drawn is that in the Devonshire area there is a conformable sequence of strata, and that the Middle Devonian (marine) beds bridge over the interval between the Upper and Lower Old Red Sandstone in South Wales, etc.

Prof. Hull has, indeed, suggested that the Cornstone Group (Lower Old Red Sandstone) of South Wales, etc., represented not merely the Lower Devonian, but also the Middle Devonian, thus making the series complete in that area. And he maintained that the beds were formed in an estuary, quoting the opinion of Prof. Dewalque that the Cornstone beds might be marine.[2] This view, of course, is more or less conjectural, and for the present we may be content with linking the English and Welsh Lower Old Red Sandstone with the Silurian rocks, and the Upper Old Red Sandstone with the Carboniferous. The same view was suggested as early as 1839 by Thomas Weaver.[3] Hence now-a-days, as in the time of Hugh Miller (1841), the Old Red Sandstone has come to be regarded "as a sort of debateable tract, entitled to no independent status," or as a "common which should be divided as proprietors used to divide commons in Scotland half a century ago, by giving a portion to each of the bordering territories."[4]

The grouping now adopted must be regarded as provisional. The

[1] See also R. A. C. Godwin-Austen, Brit. Assoc. 1870.

[2] Q. J. xxxviii. 200, 205. See also Q. J. xxxvi. 259-273, and G. Mag. 1881, p. 508.

[3] Phil. Mag. 1839, p. 118.

[4] The Old Red Sandstone, p. 19.

Upper Devonian Sandstones (Pickwell Down Sandstones, etc.) may with little doubt be grouped with the Upper Old Red Sandstone; the arenaceous beds of the Lower Devonian in North Devon (Hangman Grits) yield some marine mollusca, and cannot perhaps in this respect be so satisfactorily correlated with the Lower Old Red Sandstone; but it must be remembered that the Silurian rocks merge gradually upwards into the Lower Old Red Sandstone, and the Lower Devonian Beds of South Devon and Cornwall have yielded some fish-remains of similar genera to those found in the Lower Old Red Sandstone.

The Devonian fauna, broadly speaking, includes many species of Corals, belonging to the genera *Favosites*, *Cyathophyllum*, *Petraia*, *Calceola*, etc.; Polyzoa, including *Fenestella;* Brachiopoda of the genera *Athyris*, *Chonetes*, *Orthis*, *Spirifera*, *Stringocephalus*, and *Uncites;* Lamellibranchs of the genera *Pterinea* and *Curtonotus;* and Cephalopods of the genera *Clymenia* and *Goniatites*. Among Trilobites, the genera *Homalonotus*, *Phacops*, etc., are met with.[1] Graptolites of the genus *Dictyograptus* have been recorded from Devonian rocks, but not in this country.[2]

The Upper and Lower Old Red Sandstone contain comparatively few fossils, and these are chiefly Plants, Crustacea, and Fishes.[3]

OLD RED SANDSTONE.

The name Old Red Sandstone was given in contradistinction from the term New Red Sandstone, the latter group overlying the Carboniferous strata; while the former group, regarded as a connected series, underlaid the same strata. The term Old Red Sandstone was used by Conybeare in 1822, but the rocks were first claimed by Murchison as a distinct system in 1839.[4]

The Old Red Sandstone consists of red and grey micaceous and mottled sandstones, sometimes false-bedded, quartzose conglomerates, slaty micaceous marls, and shales. Its name, however, bespeaks its most prominent character. In some localities bands of nodular or concretionary limestone called

[1] See The Palæozoic Fossils of Cornwall, Devon, etc., by John Phillips, 1841.
[2] Dr. O. Herrmann, G. Mag. 1885, p. 407.
[3] See J. Powrie and E. Ray Lankester, The Fishes of the Old Red Sandstone (Palæontograph. Soc.). See also the *Thesaurus Devonico-Carboniferus*, by Dr. J. J. Bigsby, 1878.
[4] Silurian System.

'cornstones' occur; and ripple-marks are met with on the surfaces of some of the beds of sandstone. The maximum thickness of the series may be taken at about 10,000 feet, but in many places it would appear that an estimate of from 3000 to 5000 feet is sufficient.

The Old Red Sandstone extends from near Bridgenorth in Shropshire, southwards, through a considerable portion of Herefordshire, Monmouthshire, and Brecknockshire, into Glamorganshire, Caermarthen, and Pembroke.

Over the greater part of this area the Geological Survey Map was constructed by Sir Henry T. De la Beche, W. T. Aveline, and Trevor E. James.

In the Forest of Dean the thickness of the Old Red Sandstone has been estimated at 8000 feet; and Mr. H. Maclauchlan, who surveyed much of the country geologically, remarked on the difficulty of separating the Old from the New Red Sandstone.[1]

Three divisions of the Old Red Sandstone have sometimes been adopted, as follows: 1. Cornstone or Marl Series; 2. Flagstone Series; and 3. Conglomerate Series.[2]

For a threefold division of the Old Red Sandstone Murchison was responsible (although he at first included the 'Tilestone Group'), for he had so divided the beds in Scotland, where, since the date of the writings of Hugh Miller, a charm has become attached to the name Old Red Sandstone. Dr. A. Geikie, however, has stated that he was never able to resist the suspicion that, plausible though the argument from fossil evidence appears, the threefold subdivision was unconsciously suggested by the seemingly well-established threefold arrangement of the true Devonian rocks, and by the natural desire to establish a closer analogy between these rocks and the Old Red Sandstone. His own work in the centre and south of Scotland proves the Old Red Sandstone to consist of two great divisions,—a lower passing down conformably into the Silurian rocks, and an upper graduating into the Carboniferous rocks, with a complete discordance between the two divisions.[3]

In Ireland, too, a similar division of the Old Red Sandstone has been made, of which the lower portion comprises the well-known Dingle Beds or Glengariff Grits. Moreover, Jukes in 1857 had become convinced that the Old Red Sandstone of South Wales was made up of two series, although he thought they were conformable near Abergavenny, but towards Llandeilo there was either unconformity or a number of faults along the strike.[4] Indeed, the marked overlap of the higher beds of the Old Red Sandstone (which pass up into the Carboniferous series), so well shown on our geological maps, suggests a discordancy in the middle of

[1] Proc. G. S. i. 421.

[2] Phillips, Manual of Geology, 1855, p. 141; Symonds, Records of the Rocks, p. 212.

[3] Trans. R. Soc. Edin. xxviii. 347.

[4] Letters, etc., 1871, p. 508. See also G. H. Kinahan, Geology of Ireland, p. 50.

the Sandstone group: for these higher beds of the sandstone stretch across the Silurian outcrops westwards on to the older rocks near Caermarthen.

That the Old Red Sandstone of this country comprises in reality only two divisions is now the opinion most usually held. Prof. Hughes, in 1875, suggested a twofold classification of the beds. Those which followed the Silurian without a break he termed the Sawdde beds, from the river Sawdde, a tributary of the Towy, which joins that river south of Llangadock in Caermarthenshire, along which the best continuous section is seen. The Upper Old Red Sandstone is here represented by the quartz-conglomerates which rest upon the Sawdde beds and underlie the brown sandstones of the Vans. This upper division may be regarded as the variable basement-series of the Carboniferous, and the equivalent of the thin conglomerates, etc., known as the Old Red Sandstone or Conglomerate in North Wales and in the North of England.[1]

The section in the Sawdde valley attracted the attention of De la Beche during the progress of the Geological Survey, for as he remarks, "Some embarrassment was experienced as to a really good line of demarcation between the Silurian rocks and Old Red Sandstone in South Wales and Herefordshire."[2]

That the Old Red Sandstone was essentially a deposit formed in large lacustrine areas is a view originally suggested by Dr. John Fleming. The subject was discussed by Mr. Godwin-Austen,[3] and has more recently been elaborated by Dr. A. Geikie in describing the limits of the old 'Welsh Lake.'[4] Whether the lacustrine areas were entirely fresh-water may be open to question, for the organic remains of the Lower Old Red Sandstone had, many of them, lived on from Silurian times. It is, however, quite possible that the lacustrine area in which the Lower Old Red Sandstone was formed may have been originally part of the open sea, subsequently isolated like the Caspian.[5]

Until the beds are mapped out in further detail, it is not possible to define the boundary between the Upper and Lower Old Red Sandstone, nor to indicate the areas over which they were respectively deposited. The Rev. J. C. Ward expressed the opinion that there may have been glaciers in 'Old Red' times, which scooped out the lakes.[6]

[1] Brit. Assoc. 1875, Sections, p. 70; Q. J. xxxviii. 209.
[2] Mem. Geol. Surv. vol. i. pp. 23, 46, 69.
[3] Q. J. xii. 51. [4] Trans. Roy. Soc. Edin. xxviii. 346.
[5] See Ramsay, Physical Geology and Geography of Great Britain, edit. 5, p. 106.
[6] G. Mag. 1870, p. 15. See also Hughes, Geol. and Polyt. Soc. W. Riding, 1867.

LOWER OLD RED SANDSTONE.

This division, sometimes known as the Cornstone Series, consists of pale and dark grey, yellow and red sandstones, red and variegated marls, shales and mudstone conglomerates, with cornstones in the lower part. Its thickness varies from 1500 to 2500 feet.

The Rev. W. S. Symonds included the Brownstone Series with the Cornstone Group, but I am informed by Prof. Hughes that it belongs properly to the Upper Old Red Sandstone.[1] As before mentioned (p. 118), the Lower Old Red Sandstone has been designated the Sawdde (or Sawddian) Beds by Prof. Hughes. These beds rest on the Upper Ludlow and Passage Beds at Pont-ar-lleche, and in the vale of Gwinfe, and other places.

The cornstones, as originally described by Buckland, are marl or marlstone, filled with concretions of compact limestone, presenting the fracture and colour of Carboniferous Limestone, varying in size from that of a pea to blocks of many tons, and sometimes spreading out into thick and compact beds, to the almost total exclusion of the marl.[2] They thus occur in lenticular masses, commonly but a few feet in thickness, and extending from about a hundred yards to two or three miles in length.

Remains of Crustacea, such as *Pterygotus* (the 'Seraphim' of Scotch quarrymen) and *Stylonurus Symondsii;* also the curious fishes *Pteraspis rostratus*, *Scaphaspis Lloydii*, *Cephalaspis Lyellii*, *Onchus major*, *Zenaspis Salweyi*, etc., have been found in the Cornstone Series. The fish-remains in the Cornstones are for the most part fragmentary. *Lingula cornea*, which is met with in the Downton Sandstones, passes up into beds that have been grouped with the Old Red Sandstone; its upward limits have, however, not been defined.[3]

The Lower Old Red Sandstone may be studied in the Forest of Hayes, Long Mountain; in Clun Forest, between Montgomery and Knighton; and in the neighbourhood of Old Radnor. It extends from near Much Wenlock to Kington, and Brecknock.

We are informed by the Rev. W. S. Symonds, that "it was at Whitbach, about three miles north-east of Ludlow, that Dr. Lloyd first discovered the shield of a Ganoid fish, which is still in the Ludlow Museum, and bears the name of *Scaphaspis Lloydii*." Many fossil fishes have been obtained there and at Bouldon, by Mr. Symonds, and Mr. Marston, of Ludlow; and there, also, have been found the egg-packets of *Pterygotus*, formerly known under the name of "*Parka decipiens*." *Zenaspis Salweyi*[4] was first discovered

[1] Records of the Rocks, p. 212; see also J. Phillips, Manual of Geology, 1855, p. 141.

[2] Buckland, T. G. S. v. 512; De la Beche, Mem. Geol. Surv. i. 52.

[3] See Godwin-Austen, Q. J. xii. 53.

[4] See Dr. H. Woodward's Monograph of the Brit. Fossil Crustacea, Order *Merostomata* (Pal. Soc.).

in the Cornstones at Hinston and Acton Beauchamp, near Bromyard, by Mr. Humphrey Salwey of Ludlow.

According to Murchison, the upper beds of the Old Red Sandstone, near the Brown Clee, and Titterstone Clee Hills, show a thin band of conglomerate; then follow, in descending order, red or green marls, with two or more zones of impure limestone called cornstone; to these succeed micaceous flagstones, marls, and cornstone.[1]

The quarries in the lower beds at Leysters Pole, north-east of Leominster, and around Puddlestone, have yielded many fossil fishes; and Mr. Symonds observes, that when first struck out from the rock, the enamelled plates of *Scaphaspis* and *Pteraspis* glisten with purple and blue, due to the presence of phosphate of iron.

At Dinmore Hill, between Hereford and Leominster, the Lower Old Red Sandstone may be well studied, but Hereford itself is an excellent centre for observations, and large quarries have been opened in the sandstones at Lugwardine.[2] Near Malvern and Abberley the Old Red Sandstone rests on the Ledbury Shales and Ludlow Rocks. Sandstones are well exposed at Cradley, near Malvern, and cornstones at Heitington, near Bewdley. Near Ledbury the beds are seen at Bush Pitch, the Wall Hills, Canon Frome, and Bosbury, where sandstones and cornstones, with fish-remains, occur. (See Figs. 4, 12, 13, 14, and 15.)

At Pontrilas Mr. Symonds has obtained remains of fishes from the sandstones; and he observes that above these strata are the Cornstones of the High Common of Ewyas Harold; and it is this hard Cornstone that arrested the denudation which has been so rife in this district, and that occupies the plateaux of many hills in this part of Herefordshire and Monmouthshire.

Marly and sandy beds cap the hills of Rowlestone, which, in the opinion of Mr. Symonds, are the equivalents of the building-stones of Cradley, before mentioned. At Rowlestone these beds contain *Stylonurus Symondsii*, *Cephalaspis*, and a giant Isopod, named by Dr. H. Woodward *Præarcturus gigas*. Near Hay these beds overlie the lower Cornstones, and underlie an upper Cornstone series, below the Brownstones of the Black Mountains.

Near Abergavenny cornstones are exposed in the railway-cuttings between that town and Llangvihangel. These, according to Mr. Symonds, are the lowest beds exposed in the district, and the upper Cornstone group forms the hills named the Deri and the Rolben below the Sugar Loaf, and also the wooded escarpments that lie below the Blorenge. Higher up the Brownstones set in, and these unfossiliferous deposits constitute the upper strata of the Sugar Loaf, and the Scyrrid Fawr in Monmouthshire; while in the Blorenge they are overlaid by higher beds of the Old Red Sandstone. Mr. Symonds observes that "at the summit of the Cornstone group there is probably a break in the stratigraphical

[1] Proc. G. S. i. 473.
[2] W. S. Symonds, Edin. New Phil. Journ. April, 1859, p. 232.

succession, for the Brownstones overlap the Rowlestone beds both on the Scyridd, and the Sugar Loaf. It is on this line of break that denudation appears to have been arrested throughout a large area of the Cornstone hills of Herefordshire and Monmouthshire."[1]

The Old Red Sandstone may be traced near Berkeley in Gloucestershire, where, according to Mr. T. Weaver, the beds pass downwards into the Ludlow rocks.[2] There appears, however, to be evidence of overlap of the upper beds of Old Red Sandstone on to the Llandovery rocks. The Lower Old Red Sandstone and Ludlow beds are also conformable in the neighbourhood of Rhymney, near Cardiff.[3]

In the Cheviot District, resting unconformably on the Silurian rocks, there is a great series of felspathic tuffs, ashy grits, and lavas (porphyrites), together with chocolate-coloured sandstones and conglomerates, which constitute the Cheviot Series, and may be grouped with the Lower Old Red Sandstone. The eruptive rocks (which are from 1500 to 2000 feet thick) form the highest points in the Cheviot Hills, which extend from the head of the Tyne in Northumberland and of the Liddel in Roxburghshire, to Yeavering Bell, near Wooler, in Northumberland, a distance of thirty miles. Of these heights Cheviot itself is a broad-topped hill, 2767 feet above sea-level. The Cheviot Series is much denuded, and overlaid unconformably by conglomerates and sandstones belonging to the Upper Old Red Sandstone. (See Fig. 16.) Prof. James Geikie has stated that the chief focus of eruption was near Cheviot, and that the volcanic deposits were mostly subaqueous.[4]

Economic products, etc.

The Cornstone beds, which occur extensively between Monmouth and Abergavenny, were in former days extensively burnt for lime. The beds have also been worked at Credenhill near Hereford.

Many of the sandstones are used for building-purposes, and these, as well as the cornstones, are sometimes used for mending roads. Some beds known as 'firestones' have been employed for making hearths. The sandstone is sometimes known as the Hereford Sandstone, and the Three Elms Stone, near that city, has been much quarried for building purposes. The sandstone is also quarried near Ledbury and Malvern. The Cradley sandstones have been largely employed at Malvern for building-purposes.

The Old Red Sandstone yields in places a strong loamy soil, which is fertile and largely devoted to pasture: many orchards are situated upon it, and a few hop-yards. In some places, however, the soil is wet and boggy, and consequently unproductive. The Cornstones form the richest land in Herefordshire.

[1] Records of the Rocks, p. 234.
[2] T. G. S. (2), i. 317.
[3] W. J. Sollas, Q. J. xxxv. 488.
[4] The Cheviot Hills, by J. Geikie, Good Words, 1876.

DEVONIAN.

The term Devonian was adopted by Sedgwick and Murchison in 1838. This determination was based on the researches of William Lonsdale, who, from a study of the fossils found in the Plymouth and Torbay Limestones, had in the previous year concluded that the strata constitute a natural history group intermediate between the Silurian rocks and the Carboniferous Limestone.[1] Hence it was that the greater portion of the rocks of North and South Devon and of Cornwall came to be regarded as the marine equivalents of the Old Red Sandstone.

The Devonian rocks of West Somerset, Devon, and Cornwall consist of a series of slaty rocks, grits, sandstones, and limestones, with interbedded eruptive rocks, together attaining a thickness estimated at from 10,000 to 12,000 feet.

Apart from the labours of Sedgwick and Murchison, we are largely indebted to Sir Henry T. De la Beche and John Phillips for our knowledge of the strata and fossils of Devon and Cornwall. To De la Beche we owe the establishment of the Geological Survey, the earliest publications of which institution were the maps and reports on Cornwall, Devon, and West Somerset.[2] The labours of other observers will be noted further on. But, as before mentioned, recent researches tend to the belief that in the Devonian rocks we have not only representatives of Upper and Lower Old Red Sandstone, but of the strata which bridge over the unconformity which separates these divisions. Hence in the uppermost Devonian beds we find strata of Lower Carboniferous age, while the lowermost beds may perhaps be linked with the Silurian rocks. Under such circumstances we cannot do better than consider the beds separately as Devonian, while at the same time pointing out some of the ascertained facts and some of the conclusions which they foreshadow.

The following general grouping may be adopted :—

Upper Devonian.	Pilton, Baggy, and Marwood Beds.	Lower Carboniferous.
	Pickwell Down and Cockington Sandstones.	Upper Old Red Sandstone.
Middle Devonian.	Morte, Berry Park, and Dartmouth Slates. Ilfracombe, Torquay, and Plymouth Limestones (Great Devon Limestone) and Lower Slates.	Devonian (Eifelian).[3]

[1] T. G. S. (2), v. 724, 727 ; Q. J. viii. 3.

[2] See also Mem. Geol. Survey, vol. i.

[3] This is a general term applicable to the Middle Devonian series, being derived from the Eifel district near Coblentz in Germany. The Lower Devonian beds are sometimes grouped under the name Coblentzian.

Lower Devonian.	Hangman, Lincombe, and Looe Grits. Lynton and Meadfoot Beds.	Lower Old Red Sandstone and Silurian.

For convenience of description we may arrange our account of the beds in the south-west of England under the following headings: —

1. North Devon and West Somerset.
2. Torquay.
3. Plymouth.
4. Cornwall.

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1. NORTH DEVON AND WEST SOMERSET.

In this area the beds are best displayed in the picturesque coast sections between Barnstaple Bay, Lynton, and Minehead.

The general sequence is clear; but, owing to the contortions which affect the beds, there are no reliable estimates of their thicknesses, and the figures mentioned must be taken as little more than conjectural. Mr. Ussher has remarked that the Upper Devonian rocks are perhaps from 2000 to 3000 feet thick; the Middle Devonian rocks are probably much thicker; while the base of the Lower Devonian rocks is not seen.[1]

Of late years much has been written about the Devonian rocks. Concerning those in North Devon and West Somerset we are especially indebted to Mr. R. Etheridge,[2] Mr. T. M. Hall,[3] and Mr. W. A. E. Ussher;[4] while Prof. Hull, taking a broad view of the deposits, has submitted tables for classifying and correlating them with other divisions elsewhere.[5]

In North Devon and West Somerset the following series of beds has been determined:—

Upper Devonian	Pilton Beds	Pilton and Barnstaple Beds.
		Braunton Beds.
		Croyde Beds.
	Baggy and Marwood Beds.	
	Pickwell Down Sandstones.	
Middle Devonian	Morte Slates.	
	Ilfracombe Beds.	
Lower Devonian	Hangman Grits.	
	Lynton Slates.	
	Foreland Sandstones.	

The diagram (Fig. 17, p. 114) is intended to give a general view of the relations of the strata, and it is based on sections by Mr. A. Champernowne and Mr. W. A. E. Ussher.[6]

[1] P. Geol. Assoc. viii. 443.
[2] Q. J. xxiii. 568.
[3] Q. J. xxiii. 371.
[4] Proc. Somerset Arch. Soc. xxv; Geol. Mag. 1881, p. 441.
[5] Q. J. xxxviii. 255.
[6] Q. J. xxxv. 534, 540.

LOWER DEVONIAN.

Foreland Sandstones.

The term Foreland Sandstone was applied to these beds by the Rev. D. Williams;[1] hence the term Foreland Group is sometimes used. The term Lynton (or Linton) group was used by John Phillips (1841).

The Foreland or Lynton Sandstones comprise hard purple, buff, red and grey fine-grained and flaggy grits, which are in places quartzose and slightly conglomeratic, and sometimes contain slaty beds. Plant-remains have been observed by Mr. Godwin-Austen, who spoke of the group as the Countesbury Series, comparing it with the Lower Old Red Sandstone of South Wales, etc.[2]

The base of this group is not seen in North Devon, and its thickness cannot therefore be estimated. But Mr. A. Champernowne suggested to me that the beds may be the same as the Hangman Grits, repeated by a fault; while Sedgwick and Murchison regarded these beds as identical.[3] For although seen in proximity to the Lynton Slates, the Foreland Sandstones have never actually been traced beneath them, except in situations which may be explained by inversion, combined with overthrust faulting.

The Foreland Sandstones are developed in the fine cliffs at the Foreland and at Countesbury, east of Lynton, at Oare, Porlock, Grabbist Hill, and North Hill, near Minehead, and probably at the northern end of the Quantock Hills. No equivalent of these Sandstones has been met with in South Devon, unless they be same as the Hangman Grits.

Lynton Slates.

The term Lynton Slates was used by the Rev. D. Williams. This division consists of grey gritty shales, schists, and even-bedded grits, about 1500 feet in thickness.

The fossils include *Chonetes Hardrensis*, *Orthis arcuata*, *O. granulosa*, *Spirifera lævicosta*, *S. hysterica*, *Megalodon cucullatum*, *Bellerophon striatus*, *Fenestella antiqua*, *Favosites cervicornis*, *Actinocrinus tenuistriatus*, etc.

Mr. Etheridge has separated the upper part of the Lynton Slates (in ascending order) into the beds of the Valley of Rocks, the Lee Beds (from Lee, a hamlet west of Linton), and the Woodabay Beds.[4]

[1] Proc. G. S. iii. 116. See also T. Weaver, *Ibid.* ii. 589.
[2] Q. J. xxii. 3.
[3] T. G. S. (2), v. plate li. See also Symonds, Records of the Rocks, p. 266.
[4] Manual of Geology, 1885, p. 173.

In the Lyn Valley, according to Mr. Ussher, the Valley of Rocks owes its features in part to the even-bedding and jointing of the grits in the Lynton Slates, and to the associated schists, which are full of calcareous films; and in part to the low dip of the strata.

The Lynton Slates extend from Lynmouth to Woodabay, where they are overlaid by the Hangman Sandstones. The slate rocks overhanging Watersmeet, east of Lynton, are extremely rich in fossils, some beds, as Mr. Etheridge has pointed out, being entirely composed of *Orthis arcuata*.

Hangman Grits.

This group derives its name from the Little Hangman Hill near Combe Martin. It consists of hard red and grey spotted grits, quartzose sandstones, and shales. According to Mr. Ussher, the upper beds are very coarse quartzose grits, with silvery red-stained shales sometimes intercalated; the lower beds are generally grey flaggy or slaty grits, which pass down insensibly into the Lynton Slates. The Hangman Grits attain a thickness of about 1500 feet. Fossils are rare. In the upper gritty beds casts of *Myalina*, *Cucullæa*, etc., have been met with; also *Favosites cervicornis*.

The Hangman Grits may be studied on the coast west of Lynton, where they overlie the Lynton Slates, at Woodabay, and in the picturesque defile of Heddon's Mouth. The rocks were termed the Martinhoe Beds by John Phillips, from their occurrence near that village, and they were termed the Trentishoe Beds (or Trentishoe flinty slate) by the Rev. D. Williams.

The resemblance between the Hangman Grits and the Lynton Sandstone, to which attention has been called, was remarked by Mr. Etheridge. The Rev. H. H. Winwood has also made known the occurrence of fossils in the sandstones of Alfoxton and Holford, in the Quantock Hills, which correlate them with the Hangman Grits; and he concluded that the sandstones at the base of this range of hills may be of the same age.[1] The Hangman Grits are developed at Will's Neck, the highest point in the Quantock Hills, and they occur at Dunkerry Beacon in the Exmoor Hills. At this latter locality they were termed the Dunkerry Sandstone by the Rev. D. Williams.

Iron ore occurs along the junction of the Hangman Grits and Lynton Slates at West Challacombe.

MIDDLE DEVONIAN.

Ilfracombe Beds.

These beds, to which the term Ilfracombe Group was applied by John Phillips, are well developed in the neighbourhood of the town from which they take their name. They consist of "calcareous

[1] Proc. Bath Nat. Hist. Club, ii. 427.

slates," or bluish-grey and silvery slates and shales with impersistent bands of limestone. They sometimes contain beds of grit, and are here and there veined with quartz. The total thickness of the beds has been estimated at 4000 feet. They rest conformably upon the Hangman Grits.

It may be remarked that in South Devon, limestone is conspicuously developed in great masses or reefs, in places passing into slates; these together form the equivalent of the Ilfracombe Beds. In North Devon the limestone occupies but a subordinate position.

The fossils of the Ilfracombe Beds are many and varied. Mr. R. H. Valpy has collected about fifty species.[1] They include *Stromatopora concentrica*, *Cyathophyllum cæspitosum*, *Favosites cervicornis*, *Heliolites porosa*, *Cyathocrinus macrodactylus*, *Tentaculites scalaris*, *Atrypa reticularis*, *Rhynchonella pleurodon*, *R. pugnus*, *Spirifera disjuncta*, *Merista plebeia*, *Streptorhynchus crenistria*, *S. umbraculum*, *Phacops lævis*, etc. *Stringocephalus Burtini* gives name to the Stringocephalus Limestone.

The beds have been divided by Mr. Etheridge and named after the localities in which they are best represented. Thus, resting on the Hangman Grits, we find the Combe Martin Beds (Combe Martin Limestone, etc.), and succeeding these are the Watermouth Beds, Widmouth Beds, Rillage Beds, Hagginton Beds (with Tentaculite Beds at the base, containing *Tentaculites scalaris*), Helesborough Beds, and Ilfracombe Beds.[2] All these may be looked upon as local geographical divisions of the Ilfracombe Beds. Moreover, in West Challacombe Bay, north of Combe Martin, there is a series of grits and shales, between the well-defined top of the Hangman Grits, and the lowest limestone of the Ilfracombe Beds, which, in the opinion of Mr. Champernowne, may correspond with the Lower Slates of South Devon.

The beds extend westwards to Lee Bay. Eastwards they are represented in the Quantock Hills, and near Withycombe. At these localities Corals have been obtained from limestone-bands by Mr. J. D. Pring and Mr. S. G. Perceval.[3]

In the Quantock Hills the beds contain much grit, and at East Brendon the rocks are raddled with iron-ore.

The bands of limestone, although they form so small a proportion of the series, are worked in many places for lime. There are quarries at Ilfracombe, at Combe Martin and Challacombe, as well as near Asholt, on the Quantock Hills. Near Asholt the limestone is much iron-stained, and here Mr. Ussher has traced it over a considerable area. At Combe Martin argentiferous galena has been worked since the year 1294. In some places, as at Kentisbury, contemporaneous igneous rocks have been noticed by Mr. Etheridge; the beds are worked for road-metal.

[1] Notes on the Geology of Ilfracombe, etc., edit. 2. See also R. Etheridge, Q. J. xxiii. 605. The Rev. W. Mules, of Ilfracombe, also laboured most enthusiastically among the Devonian rocks.

[2] Manual of Geology, p. 172.

[3] G. Mag. 1866, p. 184.

Morte Slates.

This division, termed the Morte Slates by the Rev. D. Williams, derives its name from Morte Point, on the north-west coast of Devon. The term Mortehoe Group, from the village of that name, was used by John Phillips.

The Morte Slates, or "grey slates," comprise pale greenish-grey and silvery grey glossy slates, much veined with quartz, and having a thickness estimated at from 3000 to 4000 feet. No fossils have been found; nor have any limestone bands been recognized in them. The beds rest on the Ilfracombe Beds at Lee Bay, and the subdivisions which can be traced are noted by Mr. Etheridge (in ascending order) as the Lee, Rockham Bay, and Mortehoe Beds. The Morte Slates pass downwards into the Ilfracombe Beds, and in Mr. Ussher's opinion they are simply an upper unfossiliferous portion of this lower division, since it is impossible to fix any definite boundary between them.[1] Simonsbath is situated in the valley of the Barle between the Ilfracombe and Morte Beds. Eastwards they extend to near Wiveliscombe, where they are exposed at the Oakhampton Slate quarry, north of that town. The slaty beds of Hestercombe, north of Taunton, are probably on the horizon of the Morte Slates. The valuable spathose iron-ore of the Brendon Hills occurs in these beds.

UPPER DEVONIAN.

Pickwell Down Sandstones.

These beds, which derive their name from Pickwell Down on the borders of Morte Bay, consist in the upper part of red or lilac slates, resting on red, brown, purple, and green grits, and red micaceous sandstones. They pass downwards, according to Mr. Ussher, into the Morte Slates on Exmoor, by intercalation with buff and greenish slates. The thickness of the Pickwell Down Sandstones has been estimated at about 3000 feet.

The beds extend from Pickwell Down and Woolacombe (Wollacombe Sandstone of the Rev. D. Williams), by Molland and Haddon Downs, to Main Down, near Wiveliscombe.

In many respects the beds resemble the Upper Old Red Sandstone. No fossils have been found in them.

The upper part of the Pickwell Down Sandstones has been distinguished by Mr. Etheridge under the name of the Vention Series, from Vention, west of Pickwell, on Morte Bay. This division consists of red slates. The name Upcot Flags was given by Prof. Hull to the beds east of Upcot, north of Braunton.

[1] G. Mag 1879, p. 94.

They comprise yellowish and greenish flags and shales, which pass downwards into purple sandy shales and grits. The Drayton and Slade Beds, so termed by Prof. Hull, take their name from farmsteads north of the Barle, north-west of Dulverton.[1] The beds here exposed were originally described by Jukes as greenish-yellow, rather soft, earthy sandstones, often splitting into flags.[2] They belong to the Pickwell Down Sandstones.

Hæmatite occurs here and there in the Pickwell Down Sandstones.

Baggy and Marwood Beds.

These beds take their names from Baggy Point, south of Morte Bay, and Marwood, north of Barnstaple.

They consist in the upper part of micaceous flaggy sandstones and grits, characterized, according to Mr. T. M. Hall, by *Cucullæa trapezium*—hence these beds are known as the Cucullæa zone or grit. Imprints of rain-drops are met with on the surfaces of the beds. The lower part of the series is made up of green and grey slates with *Lingula squamiformis*. Mr. Ussher informs me that the relative positions of these fossiliferous zones are reversed as the beds are traced eastwards.

Among other fossils are *Avicula Damnoniensis*, *Rhynchonella laticosta*, *Strophalosia productoides*, *Spirifera disjuncta*, etc.

In the sandstones of Sloly Quarry, east of Marwood, remains of *Lepidodendron* or *Knorria*, *Calamites*, and *Adiantites* have been found; plants which foreshadow the vegetation of the Carboniferous period.

The total thickness of the series is not known.

By Mr. Etheridge the beds of Marwood are placed at the base, and the Baggy beds at the top of the series.[3] The Marwood beds were taken as the uppermost Devonian by Sedgwick and Murchison, and were classed as the Barnstaple or Petherwin Group.[4] Mr. J. W. Salter grouped the Marwood Beds with the Upper Old Red Sandstone.[5]

Pilton Beds.

The Pilton Beds, to which the name Pilton Group was applied by John Phillips, take their name from Pilton, near Barnstaple. The beds consist of greenish-grey slates and shales, with beds of calcareous sandstone or gritty beds, and occasional nodular bands of limestone. The thickness is not known.

[1] G. Mag. 1878, p. 532; 1879, p. 94.

[2] Additional Notes on the Grouping of the Rocks in North Devon and West Somerset, p. 5.

[3] Manual of Geology, p. 171. The Brushford Beds, mentioned by Mr. Etheridge, belong to the Pilton Beds.

[4] Q. J. viii. 3.

[5] Q. J. xix. 478.

Among the fossils are *Phacops latifrons* (hence the name Trilobite Slates, used for these beds by the Rev. D. Williams), *Cyathocrinus pinnatus*, *C. variabilis*, *Euomphalus serpens*, *Strophomena analoga*, *Strophalosia productoides*, *S. caperata*, *Streptorhynchus crenistria*, *Spirifera disjuncta*, *Rhynchonella pleurodon*, *Chonetes Hardrensis*, *Productus prælongus*, *Avicula damnoniensis*, *Bellerophon decussatus*, *Fenestella antiqua*, *Petraia celtica*, etc. With the Pilton Beds are included in ascending order, the Croyde Beds (of Croyde Bay), the Braunton Beds (of Braunton, north-west of Barnstaple), the Pilton Beds, and the Barnstaple Beds.

Besides the above-mentioned localities there are quarries at Goodleigh, and at Brushford, near Dulverton, where the beds may be examined. Top Orchard Quarry, a mile and a quarter north of Barnstaple, is a well-known locality for fossils.

South of Barnstaple the Pilton beds appear to pass gradually upwards into the Culm-measures, but owing to the absence of sections, as remarked by Mr. Ussher, they make a most unsatisfactory junction with these newer rocks, frequently exhibiting contrary dips in their vicinity, which are probably due to inverted anticlinals. Moreover, where the junction should occur, the line coincides with a strip of old Alluvial land. Near Dulverton Station the distinction between the Pilton and Culm-measure slates appears to be purely palæontological, and south of Clayhanger and Stawley there is every reason to conclude that their junction is perfectly conformable; but at Morebath fault-junctions complicate the relations of the beds.[1]

The slates in Lundy Isle may perhaps be on the horizon of the highest Devonian beds, but their precise age is uncertain.[2]

It will be remembered that Mr. Jukes regarded the red sandstones of the northern portion of the Quantock Hills, those of Dunster, Minehead, and Porlock, as of Old Red Sandstone age. The slates of Lynton, Ilfracombe, etc., he grouped with the Carboniferous Slate; while the sandstones of Pickwell Down, Haddon Down, and Main Down, he regarded as probably a repetition of Old Red Sandstone brought up by a concealed fault; and he considered that the overlying slates of Marwood, Braunton, and Pilton again represented the Carboniferous Slate which passed gradually upwards into the Culm-measures.[3] Mr. A. Champernowne observes, "Neither by fault, nor inverted junction along the line indicated by Jukes, is there any wholesale reduplication of the North Devon Series. The fault I had already taken to be disproved by Mr. Etheridge's paper;"[4] and no evidence of it was found by Mr. Ussher in his more detailed mapping of the area.

[1] G. Mag. 1881, p. 447.

[2] T. M. Hall, Trans. Devon Assoc. 1871.

[3] Q. J. xxii. 320; Additional Notes on the Grouping of the Rocks of North Devon and West Somerset, 1867; Notes on Parts of South Devon and Cornwall, (R. Geol. Soc. Ireland), 1868. Reprint, p. 39.

[4] G. Mag. 1879, p. 125.

2. TORQUAY.

The slaty rocks, grits, sandstones, and associated limestones of South Devon and Cornwall are so much broken up and disturbed, compared to the equivalent beds in North Devon, that no such continuous sequence can be traced. Large masses of granite and many other rocks of igneous origin, intersect or protrude through the 'killas' or clay-slate of Cornwall and Devon; while, as Mr. Ussher has remarked in reference to this southern area, "at many recurrent periods, the eruptive forces burst into activity, eating their way through the sediments already thrown down, and showering their ashes and cinders and scoriæ upon those in process of deposition."

The Torquay district has been examined and described by many geologists, including De la Beche,[1] Godwin-Austen,[2] and Dr. H. B. Holl.[3] More recently Mr. Arthur Champernowne, of Dartington Hall, has surveyed in great detail a large area around Totnes, and the minute acquaintance he has made with the eruptive as well as the stratified rocks and their organic remains, entitles his views to the utmost respect.[4] So many faults and flexures affect the beds that it is no wonder that the opinions concerning the general succession have been at variance.

The Culm-measures in places near Chudleigh appear to rest conformably on the Devonian Limestone,[5] but this may be simply a local conformity in stratification, for the observations of Mr. Champernowne agree with those of Mr. Godwin-Austen and Dr. Holl, in pointing to a considerable break between the formation of the highest Devonian beds in this part of South Devon and the Culm-measures.

The promontory of Torquay and Babbacombe well shows the great disturbances to which the Devonian beds have been subjected. The cliffs are for the most part abrupt and they must be studied by the aid of a boat. In the quarry at Hope's Nose nearly horizontal beds of Devonian Limestone may be seen resting on the upturned edges of similar rock, in such a manner that a first glance would seem to show an undoubted case of unconformity. This feature, however, is the result of a fault acting on the disturbed beds of limestone, and whose hade is inclined inwards from the face of the quarry. The contortions throughout the Torquay district are very great, and the faults are numerous. In some instances the beds are clearly reversed, as Mr. Champernowne has pointed out.[6]

The mass of limestone that extends from Lyndridge to near Kingsteignton dips to the south-east at angles of from 20° to 30°. The boundary-line with the Culm-

[1] Report on the Geology of Cornwall, etc., 1839.
[2] T. G. S. (2), vi. 433. [3] Q. J. xxiv. 400.
[4] G. Mag. 1878, p. 193; 1879, p. 125; P. Geol. Assoc. viii. 442, 458.
[5] C. Reid, G. Mag. 1877, pp. 454, 457.
[6] Trans. Devon Assoc. for 1874. See also G. Mag. 1877, p. 453, and 1884, p. 524.

measures to the north, runs along the bottom of the valley, and no junction-sections are to be seen. The Culm-measures at Combe, Ileston, and Whiteway Farms, dip to the south-east as if they would pass under the Devonian Limestone. Hence, if the beds be not actually inverted, there must be a considerable fault running along the valley between Lyndridge Hill and Ideford. An inversion might help us to account for the mass of limestone stretching from Oldchard Well to Ugbrooke House, near Chudleigh, and which is situated in the midst of Culm-measures. The Devonian slates exhibit contortions in many places. (See Fig. 18.)

The researches of Mr. Champernowne have led him to divide the beds in South Devon as follows: but it should be understood that there are no hard lines between the divisions, and that the Berry Park Slates might be included as Upper Devonian, and the Lower Slates as Lower Devonian:[1]—

	Torquay.	*North Devon* (See p. 123.)
Upper Devonian.	Cockington Beds.	Pickwell Down Sandstones.
Middle Devonian	Berry Park Slates; and Ashprington Series. Great Devon Limestone. (Dartmouth Slates.) Lower Slates.	Morte Slates and Ilfracombe Beds.
Lower Devonian.	Torquay Grits: Lincombe and Warberry Grits.	Hangman Grits.
	Torquay Grits: Meadfoot Beds.	Lynton Slates.

LOWER DEVONIAN.

Meadfoot Beds.

These beds have been so named by Mr. Pengelly from their exposure at Meadfoot, east of Torquay. They consist of grey and brownish grits and slaty beds, which well exhibit the phenomena of cleavage, bedding, and jointing. They pass up into the Lincombe and Warberry Grits, and are the oldest strata exposed near Torquay. They probably represent the Lynton Slates. They contain in abundance *Pleurodictyum problematicum* (*P. problematicum* beds), etc.

Mr. Pengelly obtained a scale of *Phyllolepis concentricus* at the base of the cliff between Meadfoot beach and the Thatcher Rock, Torbay.

Lincombe and Warberry Grits.

These beds were named by Mr. Champernowne from their occurrence at Lincombe and Warberry, near Torquay. They consist of red and grey quartzose and sometimes flaggy grits, interstratified with sandy shales. They have been opened up south of Kent's Hole, in the Lincombe new drive, also near Ellacombe, near Upton

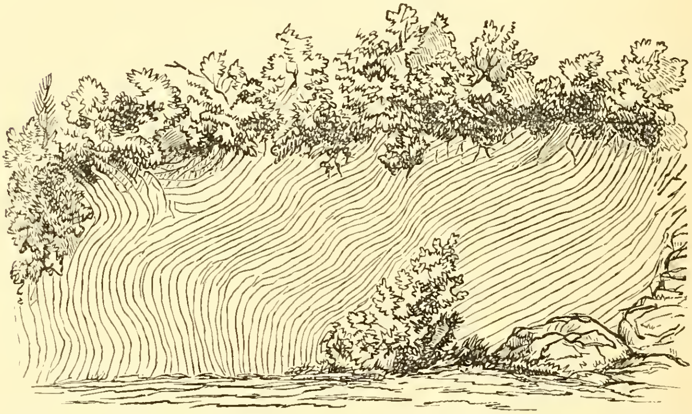
[1] Proc. Geol. Assoc. viii. 442, 458.

Church, and at Hope Farm, and Smuggler's Cove, west of Hope's Nose. Among the fossils are *Homalonotus elongatus*, *H. crassicauda*, *H. Champernownei* (*Homalonotus* beds), *Holopella ? Chonetes sordida*, *Spirifera cultrijugata*, *Leptæna laticosta*, and some obscure Lamellibranchs. Mr. Champernowne has observed that "some Lower Devonian beds are so like some Ludlow Rocks (only red-stained), and with flakes of greenish clay within the gritty layers, as we see in the Usk district with *Holopellæ* and *Chonetes*, as sorely to try the faith of the most orthodox."[1]

The Lincombe and Warberry Grits probably represent the Hangman Grits of North Devon.

FIG. 18.—DEVONIAN SLATE BETWEEN HOUGHTON AND HIGH WEEK, NEWTON ABBOT.

(W. A. E. Ussher.)



The chief curves in the slates are due to contortion by faulting and upheaval. The small surface-curves are due to the intrusion of roots from above. On the right-hand side of the section, there is a boss of eruptive rock.[2] (See remarks on 'Terminal curvature,' p. 13, and sequel.)

MIDDLE DEVONIAN.

Lower Slates and Great Devon Limestone.

Although these Slates as a mass chiefly underlie the Limestones, yet they are intimately connected with them, and evidently replace them laterally here and there, as near Abbots Kerswell and other places. The Slates may be clearly traced beneath the Limestone south-east of Daccombe, at Barton, Anstey's Cove, Wickaborough, and other localities near Newton Abbot and Torquay. They consist of bluish, purplish, and greenish slates, soft in the upper part, and

[1] Geol. Mag. 1881, pp. 487, 489; Dr. H. Woodward, *ibid.* 489, 528; E. B. Tawney, Rep. Devon Assoc. 1870, p. 291; Holl, Q. J. xxiv. 428.

[2] W. A. E. Ussher, Q. J. xxxiv. 54.

containing many eruptive rocks, especially towards their lower part. In a well-boring in Fleet Street, Torquay, the thickness of the limestone was proved to be 130 feet, and that of the underlying slates 185 feet. The Lower Slates occupy the country between the Ashburton and Bickington ranges of Limestone, and between those of Dartington and Ogwell; but their total thickness cannot be estimated.

At the base of the Limestone, the passage-beds (red shaly limestones) contain the zone of *Calceola sandalina* at Daddy Hole, Torquay, at Mudstone Bay, at Brooking, near Dartington, and at Chircombe Bridge, near Newton Abbot. Below comes the zone of *Cyrtoceras bdellalites* at Mudstone, east of Brixham, and Meadfoot near Torquay. A specimen of *Scaphaspis cornubicus* was found by Lieut. Wyatt-Edgell at Mudstone Bay.

The beds of Lammerton, north of Tavistock, were placed by Mr. Etheridge about this horizon.

The total thickness of the Limestone at Dartington is estimated at 450 feet by Mr. Champernowne; but the thickness is subject to much variation.

In the Devonian Limestone, we find many points of resemblance to the Carboniferous Limestone. Some beds are of a dense blue colour, with few veins of calcite; others again are very freely veined with a fine network of spar, or contain broad bands of crystalline matter. Beds of nearly white limestone occur near Ideford, others again are oolitic in structure. The beds often occur in great wedge-shaped masses, suggesting irregular accumulation. It may be remarked, also, that many of the beds of Devonian Limestone, when fractured, emit the same sulphureous smell as does the Carboniferous Limestone; while the slaty beds beneath sometimes exhibit similar alternate bands and nodular beds of limestone. The limestone is sometimes dolomitic.

Sedgwick and Murchison noticed the occurrence of "thin laminæ of bright coal" in the limestone near Plymouth.[1] Mr. Godwin-Austen too observed that "the limestone of the Ashburton band is exceedingly carbonaceous, containing even seams of anthracite," and he detected the same feature at Totnes. About six feet of black carbonaceous shale has been noticed by Mr. Champernowne at Skinner's Bridge, near Dartington. The formation of the carbonaceous matter may have been due to marine rather than to terrestrial vegetation.[2]

The weathering of the Devonian Limestone is naturally similar to that of the Carboniferous Limestone. Some of the honeycombed surfaces that may be seen on joints and exposed edges of the rock in a quarry at Wolfsgrove Farm, near Kingsteignton, showed that when fossils occurred, they stood out in relief in the cavities, proving that here at least the phenomena resulted from the action of atmospheric agents, and not that of snails. (See sequel.)

The Limestones of Chudleigh, Ashburton, Ogwell, Ipplepen, Berry Pomeroy, Dartington, Totnes, Brixham, Torquay, Petit Tor, Babbacombe, St. Mary Church, and Newton Abbot[3] (the Great Devon Limestones) are as well known for their purely economic value for marble, building- and paving-stone, as some bands of the rock are for the richness of their palæontological contents.

[1] Trans. Geol. Soc., 2nd series, vol. v. p. 651.
[2] Godwin-Austen, Idem, vol. vi. pp. 461, 469.
[3] The name of the village of Newton Bushel, well known as a locality for Devonian fossils, is now merged in that of Newton Abbot.

The numerous remains of Corals render the rock, when polished, very beautiful : it is termed Madrepore Marble. These Corals belong to the species *Heliolites porosa*, *Favosites polymorpha*, var. *cervicornis* (Buck's Horn Marble, or Feather Stone), *Cyathophyllum cæspitosum*, *Acervularia* (*Astræa*) *pentagona*, *Alveolites suborbicularis*, *Smithia* (*Arachnophyllum*) *Hennahi* (Barton Star), *Zaphrentis*, etc. The Feather Stone is found at Bradley Woods, Newton Abbot. Corals are so rich in places as to give to the Devonshire marbles much the appearance of Coral-reefs.[1]

Among the Mollusca, *Orthoceras undulatum*, *Cyrtoceras nodosum*, *Clymenia lævigata*, *Goniatites excavatus*, *Loxonema*, *Euomphalus*, *Murchisonia spinosa*, *Megalodon cucullatus*, *Rhynchonella cuboides*, *R. pleurodon*, *Spirifera disjuncta*, *Stringocephalus Burtini*, *Streptorhynchus umbraculum*, *Uncites gryphus*, etc., are found. The Hydrocorallines include *Stromatopora concentrica*, *S. polymorpha*, and *Amphipora ramosa*; a Sponge, *Receptaculites*, is also met with. The Crinoids, *Actinocrinus*, *Cyathocrinus*, *Platycrinus*, and *Cupressocrinus crassus*, likewise occur. The Great Devon Limestone is sometimes termed the Stringocephalus Limestone, from the occurrence of *S. Burtini*; good specimens of this Brachiopod are not readily to be obtained, although crushed specimens are to be seen in great profusion at Westhill, south of Chircombe Bridge.

Trilobites are met with in the limestones, and in the underlying slates, as *Phacops latifrons*, *P.* (*Trimerocephalus*) *lævis*, *Bronteus flabellifer*, etc. These fossils are not common in the limestone, but *P. lævis* has been met with in some abundance in the volcanic ash at Knowle's Hill, Newton Abbot. The Starfish *Helianthaster filiciformis* was discovered by Mr. Champernowne in a gritty bed in the slates at Harbertonford, near Totnes. While Corals and Encrinites help to form a large portion of the Devonian Limestone, no Foraminifera have been recorded from it.[2]

The age of the Petherwin (*Clymenia*) limestone, south-west of Launceston in Cornwall, has been matter of much dispute. *Clymenia* has been obtained at the Landlake Quarry, also *Goniatites*, *Spirifera Verneuili*, *S. disjuncta*, *Orthis striatula*, *Producta subaculeata*, *Euomphalus serpens*, and the Trilobite *Portlockia*. Attention was first directed to the fossils of this limestone by Mr. S. R. Pattison.

Dr. Ferdinand Roemer regards the limestone as belonging to the *Clymenia* stage of the Upper Devonian;[3] but according to the grouping now adopted, it must be placed with the Middle Devonian.

In a limestone quarry at Lower Dunscombe, near Chudleigh, *Goniatites intumescens* and *G. multilobatus* were discovered by Mr. J. E. Lee in the upper beds, which consist of thin red limestones. The former species sometimes attained a diameter of nine inches. *Cardiola retrostriata*, *Orthoceras*, *Phacops cryptophthalmus* and *Coccosteus*

[1] G. Mag. 1864, p. 42; W. Pengelly, Trans. Plymouth Inst. 1863, p. 17.
[2] See Dr. H. C. Sorby, Address to Geol. Soc. 1879.
[3] G. Mag. 1880, p. 147. See S. R. Pattison, Rep. R. G. S. Cornwall, 1850, p. 132, and Proc. Geol. Assoc. ii. 279; Phillips, Palæozoic Fossils of Cornwall, etc., p. 195; and Sharpe, Q. J. iii. 77.

also occur in the beds, which here are overlaid in apparent conformity by the Culm-measures.[1] In the red clay-slate of Saltern Cove, south of Paignton, Mr. Lee has obtained *Goniatites* (six species), *Cardiola retrostriata*, *Pleurotomaria turbinea*, *Orthoceras Schlotheimi*, etc.[2] The beds at Lower Dunscombe and Saltern Cove are grouped by Dr. Roemer as representing the *Goniatites intumescens* stage, beneath the Clymenia stage.

If we regard the Great Devon Limestone as remnants of a Coral-reef, it might be expected, as Mr. Ussher suggests, to present abrupt natural terminations.[3] Near Newton Abbot, however, the frequently abrupt terminations of the limestone are due to well-marked faults. This is also conspicuously the case with the Chudleigh Limestone, which, although regarded by Mr. Austen as belonging to "the slate and calcareous system" of South Devon, was, owing to its apparent intercalation in the Culm-measures, placed with that group on the Geological Survey Map. De la Beche indeed admitted the difficulties in the way of such a grouping; and Mr. Clement Reid has since traced the fault.

Berry Park and Dartmouth Slates, and Ashprington Series.

Ashprington Series.—This series, so named by Mr. Champernowne from the village of Ashprington, south-east of Totnes, comprises porphyritic and amygdaloidal diabase and tuffs interstratified with slates; and has a thickness of about 1100 feet, at Greenway Hill, on the Dart. The great development of tuffs is probably local. On the whole, this diabase series is largely made up of slaty volcanic rocks, much resembling the Nassau Schalstein (shale stone). The soil, which is usually red, supports some of the best arable- and grass-land of the South Hams.

Ramsleigh Limestone.—This division occurs above the main mass of limestone at East Ogwell, near Newton Abbot, being separated from it by ash-beds and slate. Mr. Champernowne states that the Ramsleigh rock is the only striking instance of a "Frasnian"[4] reef in Devonshire; the parallel being maintained even to the large infiltration-veins of calcite simulating organisms ("*Stromatactis*" of M. Dupont). This limestone contains *Rhynchonella cuboides*, *Acervularia pentagona*, *Chonophyllum*, etc. Calcareous bands occur on a similar horizon in other parts of the district, near Dartington and Littlehempston.

Dartmouth Slates.—These beds, taking their name from their development at Dartmouth, consist of greenish slates, having much the same characters as the Morte Slates, with which they were originally classed by Sedgwick, who used the term Dartmouth

[1] See C. Reid, and A. Champernowne, G. Mag. 1880, pp. 286, 381; and Dr. H. B. Holl, Q. J. xxiv. 413.
[2] G. Mag. 1877, p. 101.
[3] Proc. Geol. Assoc. viii. 444.
[4] A division made by the Belgian geologists, from Frasne.

group.[1] They occur over a large part of the area around Kingsbridge. They may represent the entire series between the Great Devon Limestone and the Cockington Beds, but their vertical range is uncertain.

Berry Park Slates.—These slates are so termed by Mr. Champernowne from Berry Pomeroy, east of Totnes. They comprise bluish and dark olive-coloured slaty shales, with *Streptorhynchus umbraculum.* In some places the Berry Park Slates rest on the Ashprington Series, but in other places the slates appear to represent that series. At Dartington Hall, north of Totnes, the Berry Park Slates are represented by the Upper Dartington Beds, which include volcanic tuffs; in fact the tuffs pass insensibly into slates. The beds attain a thickness of about 1500 feet.

UPPER DEVONIAN.

Cockington Beds.

These beds, originally described by De la Beche as Old Red Sandstone, consist of reddish-brown micaceous sandstone, purple and grey grits and shales. The name Cockington Beds has been applied by Mr. Champernowne, as the beds are well exposed near the village of Cockington, south-west of Torquay. The beds are exposed in quarries about a quarter of a mile north-east of Livermead. Here they are faulted against the Lower Slates and Limestone according to Mr. Champernowne, a structure not suspected by the writer, who formerly regarded the Cockington Beds as below these rocks.[2] Mr. Champernowne, however, states that the Berry Park Beds pass up into the Cockington Beds, which form the highest ground between the Dart and Torbay, at Westerland Beacon and Windmill Hill south-west of Collaton Kirkham; and he estimates their thickness in Windmill Hill at about 1300 feet. Sedgwick, too, was of opinion that the South Devon limestones were overlaid by red sandstones.[3] Mr. Champernowne regards the purple sandstones and slates of Cockington, Ockham, etc., as of Upper Devonian age, and the equivalents of the Pickwell Down Sandstones. Hence they may be said to represent the Upper Old Red Sandstone.

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3. PLYMOUTH.

In the Plymouth district we owe much of our knowledge to the early labours of the Rev. Richard Hennah,[4] as well as to Phillips and De la Beche. In recent years Mr. R. N. Worth has done much geological work, and the beds have also been studied by Mr.

[1] Q. J. viii. 3.
[2] H. B. W., G. Mag. 1877, p. 449. See also De la Beche, Proc. G. S. i. 32; and D. Sharpe, Q. J. ix. 26.
[3] Q. J. viii. 3.
[4] T. G. S. v. 619.

Champernowne and Mr. Ussher. The Devonian beds in this neighbourhood have been divided as follows by Mr. Ussher:—

	Plymouth.	*Torquay* (See p. 131.)
Upper Devonian	Picklecombe and Staddon Grits	Cockington Beds.
Middle Devonian.	Green Slates of Rame Head. Lilac and Grey Slates.	Berry Park and Dartmouth Slates, and Ashprington Series.
	Plymouth Limestone	Great Devon Limestone.
	Red and Greenish Slates.	Lower Slates.
Lower Devonian.	Looe Grits and Schists.	Lincombe and Warberry Grits, etc.

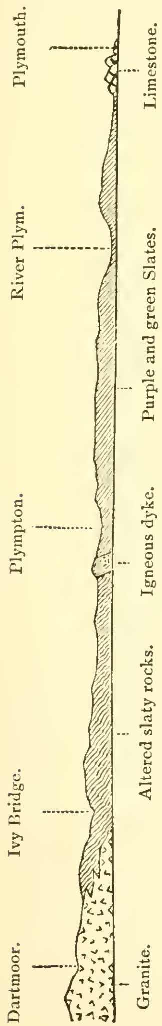

Fig. 19.—Generalized Section from Dartmoor to Plymouth.[2]
(After Sedgwick and Murchison.)

Looe Grits and Schists.—The oldest beds comprise green, red and grey slaty grits, and schistose beds, that are exposed at Looe and Looe Island, west of Plymouth. They contain some badly-preserved fossils. The beds of Yealmpton Creek have also been placed on this horizon.

Red and greenish Slates. — Beneath the Plymouth limestone, grey, red, and greenish slates, with intercalated grits, are exposed in the railway-cuttings between Plymouth and St. German's. North of Plymouth, the lowest beds near Dartmoor consist of grey and drab slates, with lodes and elvans (Buckland and Bickleigh Beds); above these come slates with interbedded volcanic materials in great variety (Weston and Compton Beds); and higher still, purple and green slates nearest to Plymouth (Mutley Beds).[1] These names are taken from localities north-east of Plymouth. (See Fig. 19.)

Plymouth Limestone.—The Plymouth Limestone (Plymouth Rag) is very similar in character to that of Torquay, previously described. (See p. 133.) The Plymouth streets are paved with this "marble." The main mass of the Plymouth Limestone terminates in the north part of Mount Edgecumbe Park. It dips southwards under shales, partly calcareous, and associated with ash-beds, and it appears to pass in places into calcareous shales, in the neighbourhood of St. John's, west of Devonport, as noted by Mr. Ussher.

Lilac and Grey Slates.—Above the Plymouth Limestone come lilac, greenish, and grey slates, with occasional gritty beds.

[1] Proc. Geol. Assoc. viii. 461.
[2] H. B. W., Science Gossip, Aug. 1877, p. 169.

Green Slates of Rame Head.—The beds, before mentioned, are surmounted at Rame Head, west of Plymouth Sound, by green or grey slates, with beds of fine grey quartz-veined grit. South of the Cawsand trap-rock, pale green quartz-veined slates are exposed on the coast forming Penlee Point.

Picklecombe and Staddon Grits.—Towards Picklecombe Fort, west of Plymouth Sound, shales intercalated with grey and red grits are exposed in reefs. At Staddon Pier, east of the Sound, these grits again occur; and in both cases they are very much disturbed and contorted.[1] These are termed the Staddon and Bovisand Grits by Mr. R. N. Worth,[2] as they occur also in Bovisand (Bovey Sand) Bay, close to Staddon. Grey micaceous slates, very much altered, are met with at Salcombe and Bolt Head. These beds are now sometimes grouped as Archæan. (See p. 46.)

The following Table shows the local grouping of the Devonian Rocks of West Somerset and North and South Devon:—

Plymouth.	Torquay.	North Devon and West Somerset.
(Not known.)	(Not known.)	Pilton, Baggy and Marwood Beds.
Picklecombe and Staddon Grits.	Cockington Beds.	Pickwell Down Sandstones.
Green Slates of Rame Head. Lilac and Grey Slates. Plymouth Limestone. Red and Greenish Slates.	Berry Park and Dartmouth Slates, and Ashprington Series. Great Devon Limestone. Lower Slates.	Morte Slates and Ilfracombe Beds.
Looe Grits and Schists.	Lincombe and Warberry Grits. Meadfoot Beds.	Hangman Grits. Lynton Beds.

Mr. Champernowne has come to the conclusion that the physical conditions which prevailed in South Devon during Middle and Upper Devonian times, had a far closer analogy to those of the Nassau and Belgian areas, than to those of North Devon and West Somerset, so much nearer geographically.

[1] W. A. E. Ussher, P. Geol. Assoc. viii. 445; Trans. Roy. Cornwall G. S. 1881.
[2] Trans. Devon Assoc. 1883, xv. 396; G. Mag. 1883, p. 423.

4. CORNWALL.

The stratigraphical relations of the slaty rocks of Cornwall have yet to be determined with precision.

Fossil shells were as early as 1817 noted by the Rev. J. J. Conybeare[1] in the slates of Tintagel. These include *Spirifera gigantea*, often distorted by the cleavage.[2] Sedgwick, Murchison, De la Beche, and more recently Mr. J. H. Collins, have described the rocks. The greater part of the area is made up of slaty rocks, with the exception of the tracts where granitic and igneous rocks are exposed. These slaty rocks, known under the general name of Killas or Clay-slate, are usually grey or bluish-grey in colour, sometimes green, brown, or violet. Quartz-veins occur here and there. At Penzance and St. Ives hornblendic slates are developed.[3] (See p. 46.)

Mr. Champernowne thinks that the Liskeard group of Sedgwick and Murchison may represent the Middle Devonian beds of Plymouth and Torquay—the limestone itself being absent or feebly represented, and this appears to have been the view taken by Sedgwick.[4] The Liskeard group, however, in part included the Fowey Beds now considered by Mr. Collins to be Silurian.

The separation of the Cornish rocks has been retarded, as Mr. Collins has pointed out, by the assumption that all the rocks called "Killas" by the miner, are of one age. He has made the following divisions:—

Ladock Beds. Fowey Beds.	Devonian and Silurian?
Gorran Haven Beds. Ponsanooth Beds.	Cambrian (see pp. 66, 75).

Fowey Beds.—This great series of strata, named from Fowey, south-east of St. Austell, is described by Mr. J. H. Collins as comprising dull greyish-brown slates. In some parts, as in several quarries in the parish of St. Veep, these pass into a yellowish or reddish sandstone, containing fossils. Westwards the Fowey beds are cut off by the Hensbarrow granite, but they appear to rest on the older rocks of Mevagissey. They occupy the country round Lostwithiel, Bodmin Road Station, St. Veep and Polruan; and attain a thickness estimated at 10,000 feet.

Large numbers of fish-remains were found by Mr. C. W. Peach in 1841, and subsequently by Mr. Pengelly and others in these beds at Lantivet Bay, Polperro and Looe; they include *Pteraspis*, *Cephalaspis?* *Phyllolepis concentricus*, *Holoptychius*, *Onchus*, etc., also Brachiopods, Encrinites, Trilobites, Echinoderms, and

[1] Trans. G. S. iv. 424.
[2] See also J. Phillips, Rep. Brit. Assoc. for 1856, pp. 388, 391.
[3] See J. A. Phillips, Q. J. xxxi. 321; T. G. Bonney, Q. J. xxxix. 20.
[4] G. Mag. 1881, p. 414; Q. J. viii. 3.

Corals, mostly in a bad state of preservation, but presenting a Silurian facies.[1] (See p. 106.)

Ladock Beds.—These beds are the most recent of the rocks of Central and West Cornwall, and are so named from the parish of Ladock, north-east of Truro. They extend to St. Agnes Head, and over the country around St. Columb, Padstow, etc. They consist of dark-grey or blue and sometimes yellowish slates, or schists, together with beds of sandstone, conglomerate and quartzite. The sandstone has become much silicified in places, and there it forms an excellent road-metal. The Halebote rock in the parish of Creed is composed of this sandstone. The conglomerate forms a remarkable bed, stretching from Nare Point towards Trelowarren: some of its included masses of hornblende-slate, and quartzite, weigh several tons. The thickness of the Ladock Beds is estimated by Mr. Collins at from 1000 to 1500 feet. They do not include any limestones, and no fossils are recorded from them in the area he has described.[2]

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5. LONDON AREA.

In some deep well-borings in and near London, rocks of Old Red Sandstone and Devonian age have been identified. (See account of Well Sections.)

Purple shales, with fossils of Devonian type, were met with in the boring at Turnford, near Cheshunt. And at Meux's Brewery, Tottenham Court Road, London, mottled red, purple, and light green micaceous shales, with thin seams of red and grey quartzite, were proved. From these beds Mr. Etheridge identified *Spirifera disjuncta*, *Rhynchonella cuboides*, *Edmondia*, *Orthis*, and *Chonetes*.

Red sands, sandstones, and clays were proved in a deep boring at Kentish Town. These beds, formerly grouped as Lower Greensand, are now regarded as probably Upper Old Red Sandstone by Prof. Prestwich.

At Crossness, near Erith, beds of hard quartzose sandstone and red and grey shale were reached. These are grouped as Old Red Sandstone or Devonian by Prof. Prestwich.[3]

At Richmond variegated sandstones and marls were reached, and these are grouped (doubtfully) as Poikilitic by Prof. Judd, but are regarded as more probably Old Red Sandstone by Prof. Prestwich.[4] A specimen in the Museum at Jermyn Street appears to more closely resemble the latter rock.

Mr. Whitaker is of opinion that the red rocks at Kentish Town and Crossness may belong to the New Red Sandstone (Poikilitic)

[1] 12th Report Cornwall Polyt. Soc. p. 66; G. Mag. 1868, p. 568, see also p. 247; Sedgwick, Q. J. viii. 2; W. Pengelly, Report R.G.S. Cornwall, 1850, p. 116, and Trans. Devon Assoc. 1868.

[2] Journ. Roy. Inst. Cornwall, vii. (1881).

[3] Q. J. xxxiv. 913; see also E. Hull, G. Mag. 1881, p. 508.

[4] Q. J. xl. 749, 762.

series, and no doubt it is difficult to distinguish with certainty the red sandstones that belong to the Old Red and New Red series. Specimens at Jermyn Street, from the Kentish Town Well, closely resemble rocks of the New Red Series. At the same time the argument that because Devonian rocks are present at Cheshunt and at Meux's Brewery, therefore rocks of Old Red Sandstone type are not likely to occur at Kentish Town, is open to question, because we know that near Torquay rocks of the two types occur near together; and if the Middle Devonian division is intermediate between the Upper and Lower Old Red Sandstone, the argument loses weight.[1]

Economic products, etc., of the Devonian Rocks.[2]

The Killas, shillet, or clay-slate of Cornwall and Devon varies very much both in colour and in character in different places. It is the matrix of much of the mineral wealth of the district, including ores of tin, copper, silver, lead, and iron. (See sequel.)

Of Cornish slates, the grey slates of De la Bole west of Camelford, and Tintagel, are most highly valued. The De la Bole Quarries produce roofing-slates, flagstones used for paving-purposes, tombstones, etc.

Slate has been quarried near Launceston, Tavistock, Plymouth (Cann slate-quarry to north-east), Newton Ferrers, Kingsbridge, Ivybridge, Buckfastleigh (Penrecca slate-quarry), Ashburton, Brixham, and other places in South Devon, and near Wiveliscombe in Somerset. Devonian slate called Kingstone Stone has been quarried near Taunton, on the Quantock Hills. At Hestercombe the slate by contact with a syenitic dyke has become metamorphosed and forms in places a hone-stone. Hone-slate has also been procured from the neighbourhood of Truro. At Tavistock, in Devonshire, oilstones have been obtained.

The Limestones of Plymouth, Torquay, etc., are largely quarried for building-stone and road-metal, and to be burnt for lime.

Emery, which is a greyish-black and amorphous variety of Corundum (Alumina), occurs at Madron in Cornwall. The Emery generally used in this country, however, comes from abroad. A remarkable vein of chalcedony, nearly three feet wide, occurs in the cliffs of Perranzabuloe. Axinite is abundant at Lostwithiel and other places.

Rock Crystal (Cornish diamond) occurs in many parts of Cornwall, at Tintagel, De la Bole Slate Quarries, Carnbrea, etc. Small crystals of quartz have been noticed by Mr. Champernowne in a Devonian dolomite at Ash (or Aish), east of Totnes.

Beekite (named after the late Dr. Beeke, of Bristol) is abundant in the New Red beds of Torbay, especially at Livermead Head and Paignton. It is found also at Teignmouth and North Tawton. It consists of masses of orbicular silex or annulated chalcedony, and these may originally have been Devonian corals or other fossils more or less completely replaced by silica, for they are sometimes hollow, and in other instances contain a nucleus of fossil coral, shell, or limestone.[3] Heavy Spar (Sulphate of Barytes) or "cawk" is obtained from some of the Cornish mines, and manufactured into the paint known as "permanent white."

[1] Whitaker, Guide to the Geology of London, edit. 4, p. 23; H. B. W., Geol. Mag. 1886, p. 43.

[2] See also R. Hunt, Bath and W. of Eng. Agric. Journ. xvi; and J. H. Collins, Mineralogy of Cornwall and Devon, 1871.

[3] S. P. Woodward, G. Mag. 1864, p. 42; Pengelly, Trans. Plymouth Inst. 1863, p. 18; A. H. Church, Journ. Chem. Soc., and Phil. Mag. Feb. 1862; T. R. Jones, P. Geol. Assoc. iv. 454.

UPPER OLD RED SANDSTONE.

The Upper Old Red Sandstone consists of red, variegated, and yellowish-grey sandstones, quartzose conglomerates, and red marls, attaining a thickness estimated at 4000 feet.

In the West of England and in South Wales the conglomerates occur chiefly at the base; they are overlaid by red marly beds, and these are succeeded by red and yellowish-grey sandstones, which pass upwards, as in Dean Forest and on the Mendip Hills, into the Lower Limestone Shales.

The organic remains comprise some plant-remains, such as *Sphenopteris*, *Sagenaria* or *Lepidodendron* (*Knorria*), etc., including the earliest known British fern, and the earliest traces of Equisetaceæ and Gymnosperms (Conifers). The more conspicuous fossils are the fishes *Holoptychius* and *Pterichthys*. The Pteropod *Conularia* has also been met with.

The most westerly beds of Old Red Sandstone occur in Pembrokeshire, where they comprise alternations of conglomerate, with sandstone and marl.[1] Specimens of *Serpula* were found by Mr. Salter in the upper beds of Caldy Island.[2] Slaty cleavage in nearly vertical lines traverses the beds around Milford Haven.

The Brecknockshire Beacons, which rise to a height of 2862 feet, and the Vans of Brecon and Caermarthen, forming a range sometimes called the Black Mountains,[3] are composed of Old Red Sandstone. The rocks on the summit of the Brecknockshire Beacons consist of the Brownstone series, which is overlaid by beds of conglomerate. There is a white marly quartzose conglomerate on the Brecknockshire Vans similar to that on the Scyrrid, and to beds which cap the Caermarthenshire Beacons: this is the basement bed of the quartzose conglomerates.[4]

Conglomerate is exposed on the Blorenge above Abergavenny, in the banks of the Wye from Ross to Monmouth, and west of Mitcheldean. Quartz-conglomerates occur on the hills near Monmouth, where enormous blocks of this rock and small isolated tors occur, as on Kymin Hill and the "Brick-stone" not far off.[5]

The Brownstone Series, described by the Rev. W. S. Symonds, consists of red marls and shales, chocolate-coloured sandstones and flagstones, and thin cornstones. It contains fragments of *Cephalaspis* and *Pteraspis*. The beds are quarried above Bitterly Court, west of Titterstone Clee, and at Abdon and Ditton below the Brown Clee; and the beds may be seen near Tenbury.[6] (See pp. 118, 119.) The precise relations of these beds have yet to be determined.

[1] De la Beche, Mem. Geol. Surv. i. 62, 110.
[2] Q. J. xviii. 476.
[3] These are distinct from the Black Mountain between Abergavenny and Hay.
[4] Records of the Rocks, p. 246.
[5] Buckland and Conybeare, T.G.S. (2), i. 280.
[6] Records of the Rocks, pp. 212, 241.

An excellent section of the transition beds from the Upper Old Red Sandstone to the Carboniferous Limestone has been exposed near the Hawthorns, in the "Deep Cutting" of the road from Ross to Drybrook in the Forest of Dean.[1]

At Farlow, between Brown Clee Hill and Cleobury Mortimer, in Shropshire, the yellow sandstones quarried for building-purposes have yielded palatal teeth of fishes and other interesting fossils. A Pterichthys-bed with *P. macrocephalus* was noticed by Prof. J. Morris and Mr. G. E. Roberts.[2] Remains of *Holoptychius* and *Conularia* have also been found at this locality. The Farlow sandstones and pebble-beds appear to belong to the passage-beds between the Old Red Sandstone and Carboniferous rocks; and they are famous as having yielded the remains of fishes which characterize the celebrated beds of Dura Den in Fife, Scotland.[3]

The Old Red Sandstone of Portishead, near Bristol, consists of red sandstone, marl, and conglomerate, with a Fish-bed yielding *Holoptychius* and *Coccosteus*. This bed was discovered by the Rev. B. Blenkiron.[4]

The denudation of the Mendip Hills has exposed the Old Red Sandstone in several tracts, the most easterly exposure is about a mile north of Frome: westwards it is most prominent at Black Down, and may be seen also near Winscombe. (See Fig. 24.)

Beds of red conglomerate and sandstone belonging to the Upper Old Red Sandstone occur in the Lake District: they rest unconformably upon the Cambrian and Silurian rocks, and indeed contain pebbles with Cambrian and Silurian fossils. The beds are overlaid conformably by the Carboniferous Limestone Series, and according to Sedgwick, beds of red sandstone, of similar type to that of the Old Red Sandstone, alternate in thick masses with the limestone. The Old Red Sandstone, or rather conglomerate, is very variable in thickness; it is stated by Mr. J. G. Goodchild to attain a thickness of from 1000 to 1200 feet in the Ulleswater area, from 900 to 1000 feet near Melmerby, beneath the Pennine Chain, and 1000 feet or more near Sedbergh. Professor Harkness considers its thickness near Shap to be 270 feet, while near Lowther it is not more than 40 or 50 feet, and under Ingleborough it is almost entirely unrepresented. These beds, sometimes grouped as Basement (Carboniferous) conglomerate, may be seen at Great Mell Fell, south of Troutbeck railway-station.

In the Cheviot District the Upper Old Red Sandstone rests unconformably on the Cheviot Volcanic Series. (See Fig. 16, p. 114.) The series consists of the following divisions:—

3. White and red sandstones.
2. Red earthy beds.
1. Conglomerates (local).

[1] John Jones and W. C. Lucy, Proc. Cotteswold Club, 1857, p. 175.
[2] Q. J. xviii. 95.
[3] Symonds, Records of the Rocks, p. 250.
[4] Proc. Bristol Nat. Soc. ii. 79. See also Dr. S. Martyn, ser. 2, vol. i. p. 141.

These beds are quarried in places. Scales of fishes occur and also plant-remains: *Holoptychius* has been met with near Jedburgh. The conglomerate rests indifferently on the Cheviot Volcanic Series and on the Silurian rocks; according to Prof. James Geikie, it may be in part of glacial formation.[1] Hungry Law, Carter Fell, and Peel Fell (1964 feet high) are formed of the Calciferous Sandstones.

Upper Old Red Sandstone, consisting of conglomerate, red and grey sandstone, and cornstone, 600 feet, has been observed in Anglesey, resting unconformably upon the older rocks, and overlapped by the Carboniferous Limestone.[2]

In Denbighshire about 80 feet of red conglomerates and sandstones, with beds of impure limestone (cornstone), rest unconformably on the Wenlock Shale. The occurrence of pebbles with Upper Ludlow fossils in these conglomerates has been noticed by Messrs. A. Strahan and A. O. Walker.[3] These beds are now usually grouped as the Basement Beds of the Carboniferous System.

In the Isle of Man there are certain beds which have been assigned to Old Red Sandstone: they occur in the cliffs north of Peel, and fringe the Carboniferous Limestone north of Castletown. They consist of brecciated conglomerates, and of fine breccia interstratified with red sandstones: they occasionally contain beds of cornstone. Their thickness has been estimated by the Rev. J. G. Cumming[4] to be 300 feet. The sandstone is extensively quarried at Peel for building-stone, flags, and tombstones. At Castletown Bay, conglomerate occurs, containing pebbles and boulders of sandstone and quartzite. It is overlaid conformably by, and indeed passes up into, limestone of Carboniferous age; and it rests unconformably on the Skiddaw Slate, as may be seen on the western side of Langness. Conglomerate is also interstratified with the red sandstone in the cliffs north of Peel. These beds have been classed with the Calciferous Sandstone series of Scotland by Mr. J. Horne,[5] and they are spoken of as the 'Basement Conglomerate' of the Carboniferous series, by the Rev. J. C. Ward.[6]

In West Somerset, North and South Devon, beds of the same mineral character as the Old Red Sandstone occur in places. In North Devon the Pickwell Down Sandstones are now regarded as the equivalents of the Upper Old Red Sandstone, and near Torquay the Cockington Beds are placed on the same horizon. (See p. 122.)

[1] See articles in Good Words, 1876.

[2] A. C. Ramsay, Mem. Geol. Survey, vol. iii. (edit. 2), p. 255.

[3] Q. J. xxxv. 268. See also A. Strahan, Geology of Rhyl, etc. (Geol. Survey), p. 3.

[4] Q. J. ii. 321; The Isle of Man, 1848. See also G. H. Morton, G. Mag. 1879, p. 213; J. C. Ward, *Ibid.* 1880, p. 1; J. Horne, Trans. Edin. Geol. Soc. ii. 1874.

[5] Trans. Edin. Geol. Soc. ii.

[6] G. Mag. 1880, p. 4.

Beds of the age of the Upper Old Red Sandstone may also have been reached in some of the deep borings in and near London. (See p. 140.)

The Upper Old Red Sandstone is used for building-purposes, and for road-metal, whilst under the name of "firestone" it has been employed for making hearths.[1] A greyish-brown sandstone, quarried near Chepstow, was used in the construction of Tintern Abbey : the stone has also been worked near Monmouth, and near Crickhowel. The conglomerates have been used as cyder-millstones. When disintegrated, as at Beacon Hill, on Mendip, these beds have been worked for gravel.

The outline of the country formed by the Upper Old Red Sandstone is generally hilly and undulating. The soil, pale red and stony, is generally unproductive, and is frequently found as moorland, wet and boggy in places. This is the case on the Mendip Hills, where the sterile character is exaggerated by elevation and exposure.[2]

[1] The term Firestone is generally applied to rocks that cannot be 'burnt,' and are therefore capable of withstanding great heat.

[2] Buckland and Conybeare, T.G.S. (2), i. 221.

CARBONIFEROUS.

The term Carboniferous was applied by Conybeare in 1822 to that system of formations, intimately linked together, which in our country include the great coal-producing rocks. It is, however, chiefly in the upper portion or in the Coal-measures proper that coal is worked.

For reasons previously given the Upper Old Red Sandstone may now be grouped with the Carboniferous system. Hence this division comprises the following formations :—

Upper Carboniferous.	Coal Measures.	
	Millstone Grit.	
Lower Carboniferous.	Upper Limestone Shales and Yoredale Rocks.	Bernician and Calciferous Sandstone Series.
	Carboniferous or Mountain Limestone.	
	Lower Limestone Shales and Tuedian Beds.	
	Upper Old Red Sandstone and Basement Conglomerate. (See p. 142.)	

When traced across England from Devonshire to Somersetshire and South Wales, and thence through Derbyshire to Northumberland, very marked lithological changes take place in the strata. We have much yet to learn about the Carboniferous rocks of Devonshire, where they consist of grits and shales, and but little limestone. The Lower Limestone Shales do not form so distinct a group in the north (where they are only locally represented), as they do on the Mendip Hills and in South Wales. And in the northern areas it is not easy to draw any separating line between the representatives of the Upper Old Red Sandstone or Basement beds of the Carboniferous system, and the overlying Carboniferous rocks. The Carboniferous Limestone of South Wales and Somersetshire loses its marked calcareous character when traced beyond Derbyshire, and becomes a series of limestones, shales, and sandstones, with seams of coal in the far north ; the Millstone Grit exhibits many modifications in different localities ; the Yoredale Rocks, scarcely noticeable in the South of England and in North Wales, attain great importance in the North of England ; while the Coal-measures, perhaps the most persistent type of the series, is at least a very unprofitable member in Devonshire.[1]

[1] See papers by Prof. E. Hull, Q. J. xviii. 137 ; xxiv. 319 ; xxxiii. 640.

Evidences of volcanic activity have been met with in the Lower Carboniferous rocks, but no contemporaneous eruptive rocks are known in this country, higher up in the series.

The following Table exhibits the chief divisions of the Carboniferous System in this country:—

	Devonshire.	*South Wales and Somersetshire.*	*Derbyshire and Yorkshire.*	*N.W. Cumberland and Northumberland.*	
	Culm-measures.	Coal-measures.			
		Millstone Grit.			
		Upper Limestone Shales.	Yoredale Rocks.	Bernician and Calciferous Sandstone Series (Tuedian Beds).	Carboniferous Limestone Series.
		Carboniferous Limestone.			
Upper Devonian.	Pilton, Baggy, and Marwood Beds.	Lower Limestone Shales.			
	Pickwell Down Sandstones, etc.	Upper Old Red Sandstone and Conglomerate.			

Although connected with the Upper Old Red Sandstone by gradations that forbid any sharp line of demarcation being drawn, yet the organic remains of the succeeding Carboniferous rocks are distinct from those of the Old Red Sandstone, and the beds were evidently deposited under different physical conditions. The area in which they were accumulated was, on the whole, a subsiding one, during a long period of time. Thus in South Wales, in proceeding westwards from Llandeilo, it has been pointed out by De la Beche, that the (Upper) Old Red Sandstone begins to overlap the Silurian rocks, and to rest directly upon older strata. Still further west the Old Red Sandstone is overlapped by the Carboniferous Limestone, which again near Haverfordwest is overlapped by the Coal-measures, the latter thus resting in that neighbourhood on the Cambrian rocks.[1]

The arenaceous deposits of the Upper Old Red Sandstone were perhaps laid down in large lakes or inland seas. Deeper and more open sea conditions attended the deposition of the muddy sediments that now form the Lower Limestone Shales of the West of England ; while still deeper and clearer marine conditions prevailed locally during the accumulation of the Carboniferous Limestone, with its rich beds of Crinoids and Corals and Brachiopods. The Corals formed part of old

[1] Mem. Geol. Survey, i. 24.

fringing or barrier reefs. The nearest land, excepting islands, was probably situated in the north and north-west, for the intercalation of shales and sandstones as well as seams of coal in the Lower Carboniferous (Bernician) rocks of Northumberland, suggests that land was not far off, and no doubt, as Dr. A. Geikie has remarked, the Highlands of Scotland rose up above the waters at this epoch. Shallower water conditions, still for the most part marine, prevailed during the deposition of the Yoredale Rocks and the Millstone Grit, and these rocks are intimately connected by similar forms of life; but in the Coal-measures the conditions became estuarine and terrestrial, or terrestrial interrupted by inundations leaving bands of sandstone and clay, and occasional layers of limestone with marine organisms.

While on the whole the area appears to have been slowly subsiding, yet the Yoredale Rocks did not extend much over the West of England; indeed, in North Wales the Millstone Grit overlaps them, and rests in places directly on the Carboniferous Limestone. Again, the Coal-measures overlap the Lower Carboniferous Rocks in parts of the West of England and Wales.[1]

The Carboniferous rocks therefore were mostly formed in the sea and not far from land, and as the remains of terrestrial vegetation occur in them at all horizons, the epoch has sometimes been termed the Phytozoic Period, or Age of Plants. In the Carboniferous rocks we find the earliest traces of Fungi yet known, for their mycelium has been preserved in woody stems of Carboniferous age.[2]

The Ferns, Equisetaceæ, and Lycopodiaceæ form the most noteworthy plant-remains of this epoch, and they will be noted more in detail further on. The Corals include the genera *Lithostrotion* and *Lithodendron*. The Crinoids include *Platycrinus* and *Actinocrinus*. Many Polyzoa are met with. Brachiopoda are very abundant, including *Spirifera*, *Orthis* and *Productus*. Lamellibranchiata and Gasteropoda are not uncommon, and we find the latest representatives of the Trilobites. Among the Fishes, *Megalichthys* is a characteristic Carboniferous genus, and the period has been termed the Megalichthyan by Prof. Phillips. Insects and Amphibia (so far as at present known) appear for the first time in this country in the Coal-measures.[3]

[1] See also A. H. Green, Geol. Yorkshire Coal-field (Geol. Survey), pp. 22-26.

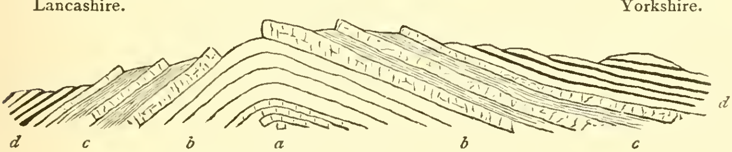
[2] W. C. Williamson, Geol. Address, Brit. Assoc. 1883.

[3] There has been no confirmation of the supposed remains of Mammalia noticed by Mr. T. P. Barkas, in his Illustrated Guide to the Fish, Amphibia, etc., of the Northumberland Carboniferous Strata, 1873.

The Lake District and parts of North Wales suffered much disturbance and denudation after the Silurian period, for the Upper Old Red conglomerates, or Basement beds of the Carboniferous series, rest with marked unconformity on the older rocks.

After the deposition of the Coal-measures great disturbances took place before any newer strata were laid down in the English area. The upheavals were attended by many undulations of the strata, and accompanied or followed by great denudation; and the Coal-measures are preserved for the most part in the synclinal folds, which form the Coal-basins.[1] While as De la Beche remarked in 1846, "From the movement of the older rocks many a mass of Coal-measures may be buried beneath the Oolites and Cretaceous rocks on the east, the remains of a great sheet of these accumulations, connecting the districts we have noticed, with those of Central England and of Belgium, rolled about and partially denuded prior to the deposit of the New Red Sandstone."[2]

FIG. 20.—DIAGRAMMATIC SECTION ACROSS THE PENNINE ANTICLINAL.[3] (J. W. Davis.)



d. Coal-measures. *c.* Millstone Grit. *b.* Yoredale Rocks. *a.* Carboniferous Limestone.

The Pennine Chain was upheaved, perhaps mainly after the Permian period, although its elevation must have been commenced soon after the close of Carboniferous times.[4] Broadly speaking, it constitutes a faulted anticlinal of Lower Carboniferous rocks, supporting on the east the Coal-fields of Northumberland, Yorkshire and Derbyshire, and on the west the Lancashire and Cheshire Coal-fields. (See Fig. 20 and Fig. 3, p. 25.)

The Carboniferous rocks were mapped for the Geological Survey in South Wales mostly by Sir William E. Logan; in Gloucestershire and Somersetshire by William Sanders and D. H. Williams, with revisions in the Mendip Hills by H. W. Bristow, W. A. E. Ussher, J. H. Blake, and the writer. In the Midland

[1] See Sedgwick, T. G. S. (2), iv. 57.
[2] Mem. Geol. Survey, vol. i. p. 214; Godwin-Austen, Q. J. xii. 38.
[3] G. Mag. 1878, p. 504.
[4] E. Wilson, Geol. Mag. 1879, p. 500; Midland Naturalist, iii. 1, iv. 97, etc.; see also E. Hull, G. Mag. 1879, p. 573, and Q. J. xxiv. 323.

counties the Carboniferous rocks were surveyed chiefly by W. W. Smyth, J. B. Jukes, E. Hull, and A. H. Green; in North Wales by W. W. Smyth, with revisions by C. E. De Rance and A. Strahan; and in Yorkshire and Northumberland the work has been done chiefly by H. H. Howell, A. H. Green, W. Topley, J. R. Dakyns, R. H. Tiddeman, C. Fox Strangways, R. Russell, G. A. Lebour, J. G. Goodchild, W. Gunn, T. V. Holmes, A. C. G. Cameron, Hugh Miller, and C. T. Clough.

LOWER CARBONIFEROUS.

CARBONIFEROUS LIMESTONE SERIES.

(Bernician and Calciferous Sandstone Series.)

Tuedian Beds.

The lowest beds of the Carboniferous Series in Northumberland and the Tweed valley were classed in 1855 as the Tuedian Beds by Mr. G. Tate.[1] They consist of grey, green and lilac shales and calcareous sandstones, with thin beds of argillaceous limestone, sometimes dolomitic, and with cement-stones and occasionally chert. The thickness is from 800 to 2000 feet or more. The beds contain remains of Plants, Mollusca, Entomostraca, and Fishes. Mr. R. Etheridge, jun., has described a specimen of *Eurypterus* from this series in Berwickshire.[2]

The fossils include a considerable variety of species, similar in character to those of the Lower Carboniferous rocks, generally.

In the eastern part of the Eden Basin, resting on the Upper Old Red Sandstone, there is a series of shales, impure limestones, calcareous conglomerates, obliquely-laminated sandstones (locally stained red, sometimes containing pebbles of quartz and assuming a conglomeratic character), which passes horizontally into the principal mass of the Carboniferous Limestone. This series, described by Mr. J. G. Goodchild under the name of the Roman Fell Series, includes the conglomerates of Cross Fell (formerly regarded as Old Red Sandstone), the beds of Ash Fell, Roman Fell, etc., and is now regarded as being on the horizon of the Calciferous Sandstone Series (or Cement-stone Group) of Scotland.[3] The thickness of the series in the district mentioned is from 800 to 1600 feet, and its character is changeable. The beds may be regarded as representing in part not only the Carboniferous Limestone, but also the Lower Limestone Shales.[4] (See p. 143.) Some Gasteropoda from

[1] Trans. Nat. Hist. Soc. Northumberland and Durham, ii. 6.
[2] Q. J. xxxiii. 223.
[3] Named by C. Maclaren, Geology of Fife, 1839, p. 70.
[4] Q. J. xxx. 394. See also J. C. Ward, G. Mag. 1875, p. 57.

Penton, north-east of Carlisle, have been described by Miss Donald, of Stanwix. They include *Aclisina costatula*, *Orthonema quinquecarinata*, etc.[1]

In Northumberland sandstones form a considerable part of the series; the limestones are for the most part inconstant, and like cement-stones in character. In this district fossils are rare, but obscure specimens of *Nautilus* and *Athyris*, together with Plant-remains (*Ulodendron*), have been noticed. Carter Fell, in the Cheviot Hills, is in part made up of Tuedian Beds. (See p. 144.)

Referring to the boundary between the Tuedian and Bernician beds in Northumberland, Prof. Lebour observes that in places the Harbottle grits, in the Upper Coquet, and the Great Dour grits, form a lower line very distinct from the Tuedian purple shales and cream-coloured beds upon which they rest. In other places there is no distinct line of demarcation. *Anodonta Jukesii* has been met with in these passage-beds. On the flanks of the porphyritic mass of the Cheviots, the Tuedian beds assume the red hue and coarse structure which are characteristic of the Scottish Calciferous Series. Prof. Lebour concludes that the divisional line between the Tuedian and Bernician beds is one which in Northumberland separates conditions of deposition rather than rigid horizons, and hence it is a variable line.[2]

Bernician Series.

This term, derived from Bernicia, a Saxon kingdom occupying what is now Berwickshire and much of the adjoining country, was used by S. P. Woodward in 1856[3] for the Lower Carboniferous beds; and the same name was independently suggested by Prof. G. A. Lebour in 1875, for the representatives of the Carboniferous Limestone and Yoredale rocks in those parts of the North of England where no separating line can be drawn between them.[4] As before mentioned, it is highly probable that the Tuedian Beds (Calciferous Sandstone Series) represent a part of the Carboniferous Limestone. Professor Phillips remarked, that in passing through Northumberland these rocks become continually more and more subdivided by interpolations of sandstone, shale, and coal, till on the sea-coast, north of Belford, a part of this series contains a number of bands of limestone, separated by many times their thickness of sandstone and shale, and under the whole lie workable seams of coal. The character of the surface of the western and north-western part of Northumberland corresponds to this change of the component strata. Instead of the beautiful green pastures

[1] Trans. Cumberland Assoc. 1885, p. 127.

[2] Proc. N. of England Inst. Mining Engineers, vol. xxv.; Geology of Northumberland, p. 45. See also W. Gunn, G. Mag. 1885, p. 93; and Prof. J. Geikie, Trans. Inst. Engineers, Scotland, 1871.

[3] Manual of Mollusca, p. 409.

[4] G. Mag. 1875, p. 543; 1877, p. 19.

which delight our eyes amidst the calcareous dales of Derbyshire and Yorkshire, wide, heathy, and boggy moorlands overspread the surface of sandstones and shales, and we seem to wander in a region of barren Coal-measures, rather than on a tract of the thickest Carboniferous Limestones.[1]

On the Northumberland coast the Bernician rocks are well exposed near Beadnell and North Sunderland point. The uppermost beds, no doubt, are equivalent to the Yoredale rocks, but, as Prof. Lebour has pointed out, there is nothing in this part of England to enable one to draw a line separating the Yoredale from the rest of the Carboniferous Limestone series—hence the utility of the term Bernician.

The beds include a series of limestones, shales, grits, and sandstones, of very variable character. The upper beds consist chiefly of sandstones and shales; and the lower beds of limestones, thin coals, and fire-clays. The thickest limestone seldom exceeds 30 feet, and the total thickness of the series is from 500 to 8000 feet.

In the Alston Moor district the thickness of the series, according to measurements by Westgarth Forster, is about 2500 feet; and near Alnwick it is about the same; but, as Prof. Lebour points out, between these two regions, in the tract lying between the Tyne and the Coquet, the maximum thickness is at least 8000 feet.[2]

The Coal-seams occur with and without underclays, and are in every way comparable, except as to commercial importance, with those of the Coal-measures. The Bernician coal-seams, however, exhibit a much greater tendency to split up, thicken and thin out in short distances, than do the seams in the Coal-measures. The coal-seams are known by different terms, and include the Redesdale, Plashetts, Shilbottle, and Beadnell Coals. The Beadnell Coal is about three feet in thickness.

Among the limestones, the Great Limestone is most persistent; it is extensively quarried, and frequently forms a distinct feature in the country. It averages from twenty-five to thirty feet in thickness. Other limestones are the Fell Top Limestone, Ebb's Nook Limestone, the Eight-yard or Four-fathom Limestone, the Six-yard Limestone forming the Blythe Rocks at Benthall, the Scremerston Limestone south of Berwick, the Lamberton or Dun Limestone north of Berwick, and the Beadnell or North Sunderland Limestone. (See p. 164.) The last-named limestone is capped by layers largely made up of *Productus longispinus* and *Spirifera trigonalis*.[3]

In the Four-fathom Limestone a Foraminifer, named *Saccamina Carteri* by Dr. H. B. Brady, was discovered by Sir W. C. Trevelyan at the Elf Hills quarry, near Scot's Gap. This minute fossil, which gives the rock an oolitic appearance, has since been found at other horizons.

[1] Manual of Geology, 1855, p. 167.
[2] Geology of Northumberland, p. 33.
[3] G. A. Lebour, Trans. N. of England Inst. Mining Engineers, xxxiii. 69. See also vol. xxv.

The upper beds of limestone (equivalent to the Yoredale Series) have yielded many fossils at Lowick and other places. They include *Spirifera lineata*, *S. symmetrica*, *Productus giganteus*, *Pinna flexicostata*, *Edmondia sulcata*, *Sanguinolites iridinoides*, *Solenomya primæva*, *Dentalium dentaloideum*, etc.

The Budle Shales (or Budle Schists of G. Tate, 1853), which consist of red shales, are exposed at Budle Bay on the coast of Northumberland, between Holy Island and Bamburgh. They belong probably to the upper part of the Bernician Series, and contain, besides Plant-remains, *Lingula mytiloides*, *Spirifera bisulcata*, *Orthis Michelini*, *Posidonomya Becheri*, and *Euomphalus pentangulatus*.[1]

The Ridsdale ironstone-beds, which correspond to the Scar Limestone Series, yield *Lithostrotion irregulare*, *Rhynchonella pugnus*, *Strophomena analoga*, *Chonetes Hardrensis*, *Conularia quadrisulcata*, *Goniatites obtusus*, etc.[2]

Among grits, there are the Inghoe, Simonside and Harbottle Grits—the last-named belonging perhaps to the Tuedian Series. The Annstead Rocks are formed of brown false-bedded sandstone. The Rothbury Grits, so named by Mr. W. Topley, comprise thick beds of sandstone in the Bernician Series.

CARBONIFEROUS LIMESTONE SERIES.

Lower Limestone Shales.

This term is applied in South Wales, Gloucestershire, Somersetshire, and, locally, in the north-west of England, to the beds between the Carboniferous Limestone and the Upper Old Red Sandstone. They are sometimes known as the Lower Carboniferous Shales. They consist of clays and shales, sometimes mottled, sandy and micaceous, of various tints, blue, greenish-grey, and brown; with occasional beds of tough bluish limestone, like Carboniferous Limestone, in the upper part, and alternating with beds of sandstone in the lower. In fact, they form a passage between the Upper Old Red Sandstone and the Carboniferous Limestone, and Sedgwick observed that they might be probably here and there replaced by the conglomerates at the top of the Old Red Sandstone.[3] Sometimes the shale is very feebly represented, occurring in thin beds rapidly alternating with limestone.

In the gorge of the Avon the aggregate thickness of the beds is stated to be 500 feet; in the Forest of Dean 250 feet; at Caldy Island 400; and on the Mendip Hills 500 feet. In the north-west of England the beds vary from a few feet to nearly 300 feet.

[1] G. A. Lebour, G. Mag. 1885, p. 73.
[2] G. A. Lebour, Geology of Northumberland, pp. 60, 66; Trans. N. of England Inst. Mining Engineers, xxii.
[3] Proc. G. S. iv. 223.

In South Brecknockshire they appear to be but thinly represented, and also in North Wales at Moel Hiraddug, on the borders of Flintshire and Denbighshire.

The beds may be well studied in East and West Angle Bays, and east of Stackpole Quay in Pembrokeshire.[1] They were termed the Caldy Series by John Phillips. Some of the shales here are cleaved and become like the Carboniferous Slate of Ireland.

Amongst the fossils are *Rhynchonella pleurodon*, *Athyris Royssii*, *Orthis resupinata*, *Spirifera duplicostata*, *S. striata*, *Discina nitida*, *Chonetes perlata*, *Camarophoria globulina*, *Conularia quadrisulcata*, *Sanguinolites complanatus*, *Modiola Macadami*; *Poteriocrinites*, *Platycrinus*, and other Crinoidal remains, as well as Trilobites of the genus *Phillipsia*.[2] Many remains of Fishes also occur, and some Plant-remains (*Sphenopteris ?*) have been noticed in North Wales.

At or near the base of the Lower Limestone Shales of Clifton near Bristol and the Mendip Hills, is found the fish-bed or palate-bed, a dark red conglomeratic bone-bed, four to six inches thick, so named on account of the number of coprolites, palatal teeth and spines of Fishes met with in it. The Fish-remains are those of *Psammodus*, *Cladodus*, *Ctenacanthus*, *Cochliodus*, etc. Brachiopoda also occur, as well as the Polyzoa *Fenestella* and *Ceriopora*.

Trilobites are met with near the junction with the Old Red Sandstone at Burrington, on the Mendip Hills, and near the top of the Shales at Clifton near Bristol. Many fossils have been obtained by Mr. E. Wethered at Drybrook, in the Forest of Dean.[3] (See also p. 143.)

The lower part of the Culm-measures of North Devon, as well as the Pilton, Baggy, and Marwood Beds, are probably of Lower Carboniferous age. (See p. 122.)

In the South-west of England and in South Wales, the Lower Limestone Shales form a band of generally depressed land surrounding the Old Red Sandstone, bounded again by an escarpment of the Carboniferous Limestone. Swallow-holes frequently mark their junction with the newer rock.

From their appearance, on the Mendip Hills, they have sometimes led to fruitless searches for coal. Such soft black shales often contain a good deal of carbonaceous matter, but they also contain (as colouring matter) sulphide of iron.

CARBONIFEROUS LIMESTONE.

The Carboniferous Limestone, so named by Conybeare in 1822, is generally a tough bluish-grey crystalline limestone, which emits a fetid odour when fractured. This odour is probably due to sulphuretted hydrogen. The rock occurs in beds of variable

[1] Murchison, Silurian System, p. 383. See also J. W. Salter, Q. J. xix. 477.

[2] For a detailed account of the fossils see W. W. Stoddart, Proc. Bristol Nat. Soc. ser. 2, vol. i. p. 318.

[3] Q. J. xxxix. 211.

thickness, but often massive, some of which are oolitic in structure. It is frequently traversed by veins of calc-spar, and by strings or nodules and bands of chert. Layers of chert are sometimes met with which merge gradually into the masses of limestone, and the rock is locally much stained by infiltrations of iron-ore. It has long been popularly termed the Mountain Limestone, and it was spoken of by Sedgwick as the Great Scar Limestone.[1]

The beds are fossiliferous, and chiefly of organic origin, being often largely made up of fragments of Brachiopoda, Corals, Polyzoa, Crinoids, and Foraminifera;[2] but sometimes few traces of organic remains are discernible, without the aid of a microscope.

In thickness the Carboniferous Limestone is estimated to attain 3000 feet. In many localities it is much less, and this variation is caused to some extent by the unequal surface of the older rocks on which the Limestone sometimes rests.[3]

The Corals include *Lithostrotion* (*striatum*) *basaltiforme*, *Lithodendron irregulare*, *Syringopora reticulata*, *Lonsdaleia floriformis*, *Zaphrentis cylindrica*, *Chætetes radians*, *Clissiophyllum*, and *Cyathophyllum regium*.[4]

The Polyzoa include *Fenestella*, *Ceriopora*, and *Polypora;* the Crinoids include *Cyathocrinus planus*, *Actinocrinus polydactylus*, *Platycrinus coronatus*, etc. The rock is often an Encrinitic or Crinoidal limestone. The name of St. Cuthbert's Beads has been applied to the loose joints of Encrinites.

The Brachiopoda include *Productus semireticulatus*, *P. punctatus*, *P. giganteus*, *Spirifera cuspidata*, *S. lineata*, *Strophomena analoga*, *Orthis resupinata*, *O. Michelini*, *Retzia radialis*, *Chonetes Hardrensis*, *C. sordida*, *Streptorhynchus crenistria*, *Athyris Royssii*, *Rhynchonella pugnus*, *R. pleurodon*, etc.

The other forms of Mollusca include *Posidonomya Becheri*, *Aviculopecten papyraceus*, *A. granosus*, *Conocardium giganteum*, *Conularia quadrisulcata*, *Pleurotomaria biserrata*, *Loxonema*, *Euomphalus nodosus*, *Bellerophon apertus*, *Orthoceras cinctum*, *Goniatites Listeri*, etc.; and the Trilobites include *Phillipsia*, *Griffithides*, and *Brachymetopus*.[5]

Among the Fishes are *Ctenacanthus*, *Psammodus*, *Cochliodus*, *Lophodus*, *Cladodus*, *Petalodus*, and *Polyrhizodus*.[6]

Fossils are best obtained from old weathered surfaces and joints of the limestone, where Nature has left them standing out in relief from the more easily dissolved matrix.

The name Scar Limestone, which was applied by Sedgwick to

[1] T. G. S. (2), iv. 70.

[2] H. C. Sorby, Address to Geol. Soc. 1879; E. Wilson, Midland Naturalist, iii. 220.

[3] Dr. C. Ricketts, G. Mag. 1883, p. 350.

[4] See H. A. Nicholson, On the Structure and Affinities of the Tabulate Corals of the Palæozoic Period, 1879.

[5] Dr. H. Woodward, G. Mag. 1883, p. 534; 1884, p. 484.

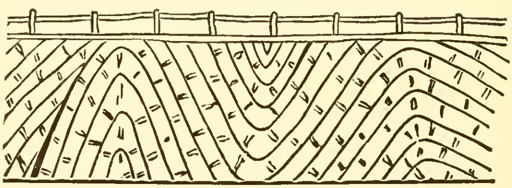
[6] See J. W. Davis, Trans. R. Dublin Soc. ser. 2, vol. i. p. 327, 1883; R. H. Traquair, Carb. Fishes (Palæontogr. Soc.).

the Carboniferous Limestone of the Lake District and Yorkshire, derives its name from the characteristic features or 'scars' produced by the rock. These bare precipices or mural escarpments occur near the base of Ingleborough, Penyghent (Pennegent) and Whernside, also above Giggleswick and Malham, in Gordale, etc.

Under Ingleborough there is at the base a nearly undivided mass of calcareous rocks from 500 to 650 feet thick; with only three or four limestones in the Yoredale Series above. Amongst the rocks of this district are the Great Whernside Limestone (1000 feet), the Melmerby Scar Limestone, the Dufton Scar Limestone, etc.

At Skipton there are several quarries, known as the Skipton Rock and Hambleton Rock quarries, and Draughton quarry. At the last-named spot, situated behind the Matchless Inn, the Limestone exhibits two sharp synclinal and anticlinal folds.[1] (See Fig. 21.)

Fig. 21.—Draughton Quarry, near Skipton.
(Dr. C. Ricketts.)



Carboniferous Limestone.

In the valley of the Ribble, north of Settle, the Carboniferous Limestone rests on the Silurian rocks; and at Combe quarries, near Clapham, there is a fine section showing the Limestone lying unconformably on the upturned and folded edges of the Silurian slates and grits.

A large collection of fossils from the Carboniferous Limestone of Yorkshire (now placed in the British Museum at South Kensington) was made by William Gilbertson of Clitheroe.[2] At Bolland or Bowland, near Clitheroe, and at Settle in Yorkshire, many fossils have been found, including the Trilobites *Phillipsia truncatula*, *P. laticaudata*, *Griffithides globiceps*, *G. acanthiceps* and other species.[3]

The Carboniferous Limestone series (from 600 to 2000 feet in thickness) forms a narrow band on the eastern side of the Vale of Eden; and bordering the western side of the vale, it forms a belt around the old slaty region of the Lake District between Kirkby

[1] See Dr. C. Ricketts, Proc. Liverpool G. S. iv. 133; and S. A. Adamson, Trans. Leeds Geol. Assoc. 1886.

[2] Many of the specimens were figured by John Phillips, Geology of Yorkshire, part ii. 1836; see also R. Etheridge, jun., G. Mag. 1879, p. 161.

[3] Dr. H. Woodward, G. Mag. 1883, pp. 445, 481. See also West Yorkshire, by J. W. Davis and F. A. Lees, edit. 2, p. 64.

Stephen and Egremont. It may be seen near Ulverston, Cartmel, Kendal, Kirkby Lonsdale, Sedbergh, Orton, Lowther, Caldbeck, Cleator, etc. Everywhere it forms bold hills; often presenting rough precipices toward the Lake Mountains, which are known by the name of "Scars."[1] Its rests unconformably on the older rocks.

The Limestone is much quarried in the neighbourhood of Hesket Newmarket.

In the Isle of Man the Carboniferous Limestone series consists of the Poolvash black marble and limestone group, overlaid by the '*Posidonia* schists,' with *Posidonomya Becheri*, and underlaid by the (lower) Castletown limestone, and the Old Red Conglomerate.[2] (See p. 144.)

In the Isle of Anglesey the Carboniferous Limestone is represented by the grey and black Pentraeth Limestone, with occasional beds of sandstone. The thickness of the limestone series here is estimated at from 200 to 500 feet. The beds are exposed on the shore of Lligwy Bay, and the passage from the Old Red Sandstone and conglomerate, through yellow sandstone, thin shales, and limestone with quartz pebbles, is on the whole gradual.[3] The Limestone is also exposed on the Caernarvonshire side of the Menai Straits.

In Denbighshire and Flintshire the Carboniferous Limestone has been divided as follows by Mr. G. H. Morton:[4]—

North Flintshire.		*South Flintshire.*		*Llangollen.*	
Upper Black Limestone	200	Arenaceous Limestone	400	Upper Grey Limestone	300
Upper Grey Limestone	150	Upper Grey Limestone	200	Upper White Limestone	300
Middle White Limestone	600	Middle White Limestone	600	Lower White Limestone	120
Lower Brown Limestone	200	Lower Brown Limestone	100	Lower Brown Limestone	480
	1150 feet.		1300 feet.		1200 feet.

In North Flintshire the Black Limestone (known as the Aberdo Limestone) is quarried at Afon Goch, and near Holywell. Here the beds yield *Posidonomya Becheri*, *Aviculopecten papyraceus*, *Goniatites bilinguis*, etc.[5] South of Halkin Mountain, the upper part of the Carboniferous Limestone contains alternations of sandstone and limestone, and this feature continues to Llandegla, in the neighbourhood of Mold.

[1] Article by J. Phillips, in Black's Guide to the Lake District, p. 253.

[2] Rev. J. G. Cumming, Isle of Man, 1848; Q. J. ii. 317. See also G. H. Morton, G. Mag. 1879, p. 212.

[3] A. C. Ramsay, Geol. North Wales (Geol. Survey), edit. 2, p. 256.

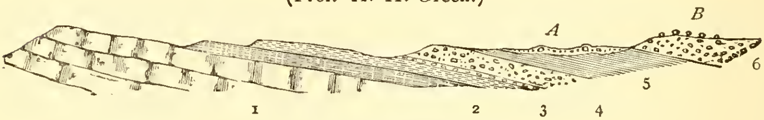
[4] Proc. Liverpool Geol. Soc. iii. 166, iv. 390. See also the Carboniferous Limestone and Cefn-y-Fedw Sandstone, etc., by G. H. Morton, 1879 (reprint of former paper).

[5] A. Strahan, Geology of Rhyl, etc. (Geol. Survey), p. 8.

Mr. G. H. Morton has remarked that one of the grandest and most accessible exposures of the Lower Carboniferous series occurs near Llangollen. The precipitous and lofty ridge known as Creigian Eglwysegle, or more commonly as the Eglwyseg rocks, near Tan-y-Castell, presents the whole of the beds in an unbroken series, from the Old Red Sandstone to the Millstone Grit. No particular band of shales intervenes between the Carboniferous Limestone and Old Red Sandstone, but shales occur interbedded with the Limestones.[1]

FIG. 22.—SECTION ACROSS THE EGLWYSEGLE ROCKS, NEAR TAN-Y-CASTELL, DENBIGHSHIRE.

(Prof. A. H. Green.)



A. Sandy Drift. *B*. Boulders of Igneous rocks.

Millstone Grit and Yoredale Rocks ?
- 6. Soft fine-grained sandstone, with white quartz pebbles.
- 5. Shales.
- 4. Hard close-grained sandstone, with small quartz pebbles.

Carboniferous Limestone.
- 3. Flaggy and sandy limestone, with small quartz pebbles; band of encrinital limestone at the top.
- 2. Thin-bedded earthy limestone. Corals and shells abundant.
- 1. Grey Limestone.

Among the fossils are *Productus comoides*, *P. giganteus*, *P. Llangollensis*, *Athyris Royssii*, *Spirifera lineata*, *S. bisulcata*, *Euomphalus Dionysii*, *Syringopora geniculata*, etc. A Radiolarian (*Calcisphæra*) and *Saccamina Carteri* have also been met with.[2] The Limestone may be studied at the Trevor quarries, near Castell Dinas Bran, at the Garth limestone quarries, and at Dolcoch, near Oswestry.

South of Congleton in Cheshire the Carboniferous Limestone is exposed at the Astbury limeworks. In Coalbrook Dale the limestone is exposed at Lilleshall and Steeraways. In this district it is much attenuated, being from 40 to 100 feet in thickness.

The Carboniferous Limestone presents its characteristic features and maintains great uniformity in Leicestershire, Derbyshire, South Wales, Monmouthshire, Gloucestershire, and Somersetshire. Its thickness, however, varies much. It is a great calcareous mass, with few marked clay beds or other divisions.

Much of the Carboniferous Limestone of Leicestershire is dolomitic; it has been quarried at Grace Dieu, Breedon Hill (Breedon Stone), Ticknall, and other places. At Grace Dieu there are traces of Upper Limestone Shales. (See Fig. 23.)[3]

In Derbyshire, the Carboniferous (or Derbyshire) Limestone is well known in the numerous dales whose picturesque scenery is so attractive, while the associated and contemporaneous masses of

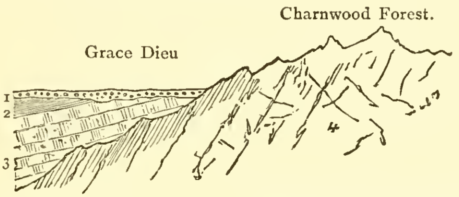
[1] See also A. H. Green, G. Mag. 1867, p. 12; and Proc. Geol. Assoc. iv. 568.
[2] G. W. Shrubsole, Proc. Chester Soc. Nat. Sc. 1884, p. 106.
[3] Q. J. xviii. 137.

toadstone, of which two or three beds occur, impart additional interest to it. It attains a thickness estimated by Prof. Green at about 1600 feet.[1] It is occasionally dolomitic.

Chee Tor in Miller's Dale is a fine cliff of the rock. Excepting Dovedale, the most interesting scenery lies in the valley of the Wye, between Bakewell and Buxton, including Monsal and Miller's Dales. A marble quarry in Tideswell Dale shows a remarkable bed of red columnar clay, resting on highly crystalline limestone, and capped by basalt (toadstone). (See sequel on the Igneous Rocks.)

FIG. 23.—SECTION OF THE CARBONIFEROUS AND TRIASSIC STRATA LYING ON THE EDGE OF THE OLDER ROCKS OF CHARNWOOD FOREST.

(Prof. E. Hull.)



1. Triassic Breccia.
2. Upper Limestone Shales.
3. Carboniferous Limestone.
4. Slaty rocks, etc. (See p. 45.)

In South Wales, the Carboniferous Limestone contributes much to the scenery between Bridgend and Cardiff. Many fossils have been collected in the vicinity of Swansea.[2] On the northern escarpment of the Limestone the Castell Coch Rock and the Trefil Limestone are well known to the south-west and south-east of Brecknock. On the Pembrokeshire coast Stacpole Cliffs are remarkable for many natural arches and caverns. (See Fig. 29.)

Near Haverfordwest the Carboniferous Limestone has become much attenuated.[3] The stone is quarried in many localities near Pembroke. At Caldy Island, however, the Limestone is about 2000 feet in thickness; while near Llangadock, on the north side of the coal-basin, it becomes reduced to 510 feet. In the Forest of Dean it is under 400 feet; and in the northern part of Glamorganshire, 500 to 600 feet. In Monmouthshire it is 1000 feet, and in the Mendip Hills about 3000 feet in thickness.

The main mass of the Mendip Hills in Somersetshire is formed of the Carboniferous Limestone, which is exposed in the picturesque vales of Vallis, Whatley, and Nunney near Frome, in Burrington Combe, in the Ebber Rocks, and in the grand cliffs of Cheddar. The rugged hill of Dulcot near Wells, and Crook Peak near Axbridge, are formed of the Limestone, which stretches out to the

[1] See Geology of N. Derbyshire (Geol. Survey), by A. H. Green, C. Le Neve Foster, and J. R. Dakyns; also Geol. Derbyshire, by J. M. Mello, p. 28.

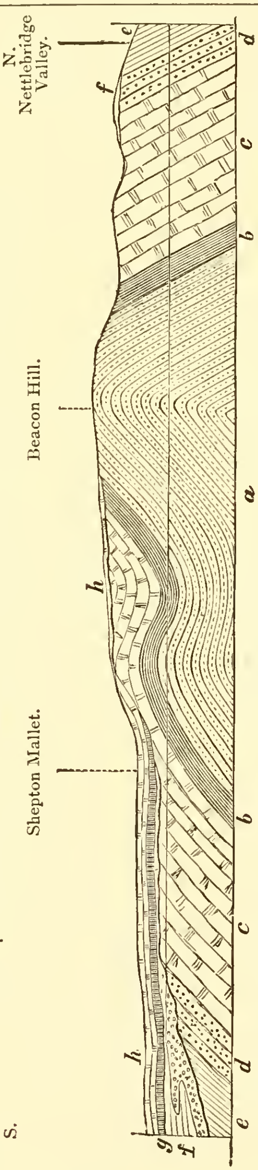
[2] See G. H. Morton, Science Gossip, Nov. 1880; Proc. Liverpool G. S. 1881.

[3] De la Beche, T. G. S. (2), ii. 1.

sea in the ridge of Brean Down, south of Weston-super-Mare, and is exposed again at Worle Hill by that town.

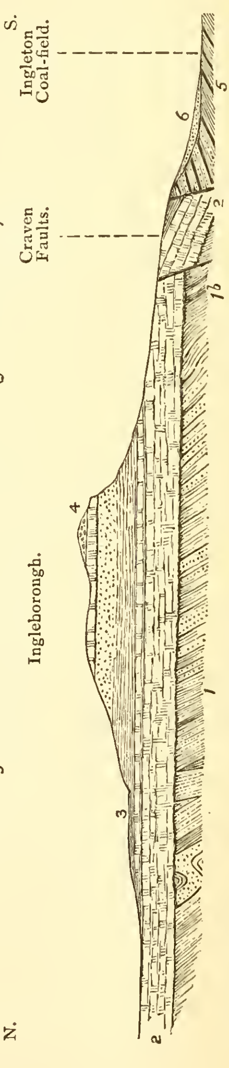
North of the Mendips between Wrington and Bristol, Brockley

FIG. 24.—SECTION ACROSS THE MENDIP HILLS. Horizontal Scale an inch to one mile.



h. Lower Lias.
g. Rhætic or Penarth Beds.
f. Red Marl and Dolomitic Conglomerate (Keuper).
e. Coal-measures.
d. Millstone Grit.
c. Upper Limestone Shales and Carboniferous Limestone.
b. Lower Limestone Shales.
a. Upper Old Red Sandstone.

FIG. 25.—SECTION ACROSS INGLEBOROUGH. (J. G. Goodchild.)



6. New Red Breccias.
5. Coal-measures.
4. Millstone Grit.
3. Yoredale Rocks.
2. Carboniferous Limestone.
1*b*. Upper Cambrian or Ordovician rocks containing Bala fossils.
1. Older Cambrian rocks.

and Cleve Combs afford opportunities for studying the Carboniferous Limestone, amid very pleasant surroundings. (See Fig. 2, p. 14, p. 30, and Fig. 24.)

The islets known as the Steep and Flat Holmes in the Bristol Channel are formed of Carboniferous Limestone. Both islets exhibit an anticlinal structure in the Limestone, and in the Steep Holme the anticlinal appears to be inverted. West of Dolberry Camp the Limestone exhibits a 'fan-shaped' structure, which may be simply the result of a synclinal, but possibly it may be connected with this apparently inverted anticlinal in the Steep Holmes.

Several isolated masses of Carboniferous Limestone in the neighbourhood of Luckington and Vobster, near Mells, on the northern side of the Mendip Hills, have attracted attention. They appear to rest on the Coal-measures, which have at one or two points been proved beneath the Limestone. Mr. J. McMurtrie considers these masses of Limestone to have been folded over from the Downhead anticlinal of the Mendip range. The physical structure is, however, opposed to this inversion, and the occurrence of the Limestone masses is better explained by a local faulted anticlinal structure.[1] A section opened at the west end of the Limestone at Vobster, to which I was conducted in 1885 by the Rev. George Horner, showed a series of dark shales (Upper Limestone Shales), and Millstone Grit, above the Carboniferous Limestone; these beds were faulted against the Limestone on the north. This evidence is opposed to the view that the Carboniferous Limestone is here inverted.[2]

In so disturbed a tract of ground as this portion of the Somersetshire Coal-field, one must interpret the grand earth-movements in a large way, for the numberless contortions and twistings in the Coal-measures themselves are but the exaggerated representatives of great folds in the older and more stony strata. The Lower Coal-measures, for the most part easily squeezed up and crumpled, cannot in themselves explain these phenomena, and therefore a study of the folds that are readily to be traced out in the Carboniferous Limestone and in the Old Red Sandstone is very necessary before we attempt to picture the amount of disturbance in the district. Moreover, the structure of the Mendip Hills is not that of one simple anticlinal fold dipping to the north-east and south-west, and trending north-west and south-east; but the structure comprises a number of folds, which trend in an easterly and westerly direction, and which are products of that line of upheaval, which, only when looked at in a large way, can be termed the "Mendip Anticlinal." And it is the prolongation of these known disturbances into the Coal-measures that must help to account for the great dislocations and contortions that affect them.

The existence of such Limestone masses in the midst of an

[1] See Memoir on the Geology of East Somerset and the Bristol Coal Fields, p. 196; G. Mag. 1871, p. 149; 1876, p. 455; Proc. Bath Nat. Hist. Club, v. 24.
[2] See H. H. Winwood, G. Mag. 1882, p. 238, also p. 286.

area of Coal-measures is not without its parallel elsewhere in England. There are patches of Limestone situated in the Coal-tract of Clapton-in-Gordano, near Bristol; and near Chudleigh, in Devonshire, in the midst of the Culm-measures, there are some very puzzling masses of Devonian Limestone. (See p. 131.) Were a geologist, indeed, whose mind was filled with Glacial theories, to come directly from Norfolk or Lincolnshire, having been impressed with the really wonderful transported masses of Chalk met with in the Drift of the one county, or of Inferior Oolite and Marlstone that are occasionally met with in the other, he might be led to suggest a similar explanation to account for the isolated masses of Limestone that occur on the Coal-measures of Somersetshire. But, after all, the question is not which agent is most capable of producing the phenomena, but which agent capable of the work is most in accordance with facts.

A very detailed section of the Carboniferous Limestone at Clifton, near Bristol, and indeed of the whole of the beds between the Millstone Grit and Old Red Sandstone, was made many years ago by Mr. D. H. Williams. The Carboniferous Limestone is dark grey and reddish in colour; partially divided by shales; in places compact or oolitic, shelly and crinoidal. It is about 1500 feet in thickness. The lower beds, comprising Encrinite- and Fish-beds, are worked in the Black Rock Quarry. Above come other beds characterized by various fossils, *Lithostrotion aranea*, *Productus longispinus*, *Euomphalus nodosus*, *Bellerophon apertus*, *Cyclophyllum fungites*, *Chætetes radians*, etc.[1] (See Fig. 26.) Fossils may also be obtained at Portishead, Henbury, Clevedon, Weston-super-Mare, etc.

At Cannington Park, near Bridgewater, there is a mass of limestone, much disturbed, which has by different geologists been classed as Devonian or Carboniferous: it resembles both in lithological character, but is no doubt of Carboniferous age, on account of the fossils collected by Mr. W. Baker, Mr. J. D. Pring, Mr. E. B. Tawney, and others. These fossils include *Lithostrotion irregulare*, *Clissiophyllum turbinatum*, etc.[2]

At the base of the Culm-measures in Devonshire are impersistent beds of black limestone, which probably represent portions of the Carboniferous Limestone. As these beds are intimately connected with the Culm-measures above, it will be most convenient to describe them together. (See sequel.)

Economic products, etc.

The Carboniferous Limestone is extensively burnt for lime. It is also largely used for road-mending, for which purpose it is conveyed to great distances. The stone quarried in the Mendip Hills is advertised as "Mendip Granite"! From its hardness it is not serviceable as a freestone, but it is locally used for building

[1] De la Beche, Mem. Geol. Survey, i. 113; W. W. Stoddart, Proc. Bristol Nat. Soc. (2), i. 322; and Proc. Cotteswold Club, vii. 144 (plate).

[2] See S. G. Perceval, G. Mag. 1872, p. 94; Tawney, Proc. Bristol Nat. Soc. ser. 2, vol. i. p. 380; Champernowne and Ussher, Q. J. xxxv. 547.

walls, etc. Some of the beds are polished and used as marble for ornamental purposes. The Derbyshire marble is found very serviceable for chimney-pieces and other ornaments, and from its varied characters is known as Black, Rosewood, Shelly or Mussel, Bird's-eye, Dog's-tooth, Coralloid, Entrochal, or Encrinital Limestone. Formerly there were Marble Mills at Mells, in Somerset.

In the southern part of the Lake District may be mentioned the Kendal grey marble; while, near Egremont, the Cleator Limestone is of local repute. Carbonaceous and bituminous matter appear to be the colouring principle of the darker beds, and its irregular diffusion constitutes the beauty of some marbles in the North of England. The Beetham Fell Marble, near Milnthorpe, Westmoreland, is a remarkable instance, it is of a cloudy character.[1] In some places the upper beds partake so greatly of the nature of chert as to be unfit for the purposes of the lime-burner.[2] In Flintshire, and other places, where these beds crop out on the surface, masses are ploughed up from beneath the soil, exhibiting the casts of the inside of Crinoids in chert; these are commonly called *screw-stones*. Blocks of these were heretofore used in the forming of millstones, which were employed instead of the French buhr-stone.

Elaterite, or mineral caoutchouc (popularly known as "mineral india-rubber"), an elastic variety of bitumen, which emits an unpleasant odour, is met with at Windy Knoll, near Castleton.

The Carboniferous Limestone has yielded ores of zinc and lead in the Mendip Hills, Derbyshire, Cumberland, Westmoreland, the north-west of Yorkshire, Flintshire, Denbighshire, etc. There are "Old lead works" between Llangan and Penlline, about four miles south-east of Bridgend.

The Hæmatite of Ulverston, Whitehaven, and Cleator Moor, and the Ironstone beds of Ridsdale or Redesdale in Northumberland, occur in the Carboniferous Limestone series; while in some places Iron-ores occur in pockets of the Limestone beneath superincumbent New Red rocks, as south of Llantrissant, in Glamorganshire. Fossils are met with in the Hæmatite of Cumberland and other places.[3]

In the Forest of Dean, iron-ore was worked during the Roman occupation; the ore occurs in pockets at the top of the Limestone.

Barytes (Sulphate of Baryta) or Heavy Spar occurs in Derbyshire, and has been raised there for use as a pigment, and for the adulteration of white lead. Fluor spar (Fluoride of Calcium) is found in Cumberland and Derbyshire; in the latter county a blue or purple nodular variety, generally known as 'Blue John,' is obtained at the Blue John mine at the foot of Mam Tor, near Castleton, where it lines veins in the Carboniferous Limestone. It is manufactured into ornaments. Portions of veins of calc-spar coloured with iron-oxide are sold at Bristol as "Bacon Stone." Beekite has been met with in Flintshire and Yorkshire. (See p. 141.)

The soil on the Carboniferous Limestone is very often thin, but when present it is usually a ferruginous loam; and where covered by short, sweet turf, it forms good ground for sheep-farms.

The rock, however, frequently juts out to the surface, and gives a rugged and picturesque aspect to the scenery. Many of the cliffs, combes, dales, and caverns, of Somersetshire, Derbyshire, and Yorkshire, are formed in this rock.

The Carboniferous Limestone yields many springs of water, which find their way through joints and fissures. (See sequel.) Analyses by Mr. George Shrubsole of the Carboniferous Limestone near Llangollen, show from 95 to 97 per cent. of carbonate of lime, a small quantity of carbonate of magnesia, together with silica, iron oxide, alumina, and traces of phosphoric acid.[4]

[1] Sedgwick, T. G. S. (2), iv. 72.

[2] Conybeare and Phillips, Outlines of the Geology of England and Wales, p. 399.

[3] J. G. Goodchild, Trans. Cumberland Assoc. part vii. p. 116; see also p. 108 (lead-ore); J. D. Kendall, Trans. N. of Eng. Inst. Mining Eng. xxviii. 107.

[4] G. W. Shrubsole, Proc. Chester Soc. Nat. Sc. 1884, pp. 107, 110.

YOREDALE ROCKS AND UPPER LIMESTONE SHALES.

The Yoredale Rocks were named by Professor Phillips from their development in Yoredale (or Wensleydale) in Yorkshire, where they consist of alternations of flagstones, gritstones, shales, seams of coal, and limestones, altogether from 500 to 1500 feet in thickness.

The general characters of the Yoredale rocks may be thus stated. In the upper part they consist of alternations of limestones, sometimes siliceous, with sandstones, shales, and coal-seams; from 80 to 450 feet in thickness. In the lower part they consist of alternations of flagstones, grits, shales, coal-seams, and three or four beds of limestone; from 250 to over 1500 feet in thickness.

The limestones in the Yoredale rocks are remarkably persistent, and the following lists, furnished by Mr. J. G. Goodchild, contain the chief beds (in descending order) in the areas of Yoredale and Alston Moor:[1]—

	Yoredale or Wensleydale.	Alston Area.
3.	Crow Limestone.	Fell Top Limestone.
	Red Beds Limestone.	Crag Limestone. Little Limestone.
	Main Limestone.	Great or Twelve Fathom Limestone.
2.	Undersett Limestone.	Four Fathom Limestone.
	Third Sett Limestone.	Three Yard Limestone.
	Fourth Sett Limestone.	Five Yard Limestone.
1.	Middle or Fifth Sett Limestone.	Scar Limestone.
	Simonstone (Simonside) or Sixth Sett Limestone.	Cockle Shell Limestone. Post Limestone.
	Hardra (Hardrow) or Seventh Sett Limestone.	Tyne Bottom Limestone (22 feet). Jew Limestone.

In Wensleydale the beds, together with associated grits, flags, and shales, were grouped by Prof. Phillips into three divisions as noted above:—3. Cam or Upper Scar Limestone; 2. Hawes Flagstone; and 1. Black Limestone.[2]

Prof. A. H. Green observes that in the Yorkshire coal-field, towards the top of the Carboniferous Limestone, the limestone beds become thinner and more earthy, and the shale partings grow more numerous, and a passage takes place upwards into the Yoredale Rocks. This group consists of dark shale, with beds of limestone and sandstone. The limestones are usually thinly bedded and more or less earthy, and frequently pass into calcareous shales. In some cases a sharp line of division may be seen between the groups: but the line drawn in various places is not likely to

[1] See also Sheet 102 N.E. of the Geological Survey Map, by C. T. Clough, and others.

[2] See West Yorkshire, by J. W. Davis and F. A. Lees, edit. 2, p. 78; T. Sopwith, An Account of the Mining Districts of Alston Moor, etc., 1833.

correspond to the same point of time, while the formation of limestone may have gone on longer at some spots than at others.[1]

The Yoredale rocks present no very special palæontological features as distinguished from the Carboniferous Limestone; they comprise beds of marine, and, possibly, estuarine origin, and some that are suggestive of fluviatile and terrestrial conditions.

The fossils are for the most part marine, but fewer in number than in the Carboniferous Limestone.

Among the fossils of the Yoredale series, occurring chiefly in the limestones, are *Orthoceras Steinhauerii*, *Nautilus cyclostomus*, *Goniatites sphæricus*, *G. Listeri*, and other species, *Posidonomya Gibsoni*, *Aviculopecten papyraceus*, *Spirifera glaber*, *Productus semi-reticulatus*, *Phillipsia gemmulifera*, etc. Fossil plants, such as *Stigmaria*, *Calamites*, etc., are likewise met with.

Fish-remains, belonging to the genera *Petalodus*, *Lophodus*, *Psammodus*, and *Pleurodus*, have been found in some of the upper limestones of Yoredale.[2] Mr. Horne, of Leyburn, has discovered relics of a large Labyrinthodont in the upper part of the Yoredale rocks, above the main Limestone, in a railway-cutting near Leyburn, in Yoredale (Wensleydale).[3]

The Yoredale Rocks extend from the coast of Northumberland round the western borders of Durham to Ingleborough, forming the principal part of the moorlands that lie to the east of the Pennine fault.[4] (See p. 151.)

Near Halifax the Yoredale strata (including the shales of Hebden Bridge) attain a thickness of 600 feet. They form a somewhat different type of the series, formerly known as the Upper Limestone Shales, and extend south of the Craven fault as far as Derbyshire. Over a great part of North Yorkshire all sandstones, coarse and fine, are known as grits.[5]

At Harrogate beds formerly classed with the Millstone Grit were subsequently placed in the Yoredale series by Prof. Phillips; these include the Spofforth Haggs roadstone (10 feet), the Follifoot coal-grit (30 feet), the Almes Cliff grit (50 feet), the Harrogate Tunnel sandstones (20 feet), and the Harrogate roadstone (50 feet); interstratified with these beds are shales, sometimes containing *Stigmaria*. The beds are grouped as follows:—

Upper Shale.
Calciferous Encrinital Grit (Harrogate roadstone).
Lower Shale.
Lower Grits.

In Edenside, finely-laminated siliceous beds are associated with the limestones of the Yoredale rocks, and they occasionally pass into beds of nearly pure chert, notwithstanding their obviously

[1] Geology of the Yorkshire Coal-field, pp. 12, 13.

[2] J. W. Davis, Q. J. xl. 614. See also West Yorkshire, by J. W. Davis and F. A. Lees, edit. 2, p. 99.

[3] L. C. Miall, Q. J. xxx. 775.

[4] Sedgwick, T. G S. (2), iv. plate 5, fig. 3.

[5] On the formation of grit, see Dr. H. C. Sorby, Proc. Geol. and Polyt. Soc. W. Riding, iii. 232, 372, 669.

sedimentary and fossiliferous character. Mr. J. G. Goodchild, whose observations we quote, is disposed to regard these beds as representing deposits of siliceous mud, derived from Diatoms, Radiolarians, and Sponges inhabiting the deep sea at that period.[1] The beds, although of different origin, are of similar character to those occurring in the Millstone Grit of North Wales. (See p. 170.) Deposits of the same nature are also met with in the upper Yoredale rocks in north-west Yorkshire.[2]

At Hesket Newmarket there are grits, limestones, and shales, with thin bands of coal; and at Dent there are beds of black limestone or marble, known as the Dent Limestone, which is on the same horizon as the Hardra Limestone. Below Great Whernside the Parkhead Limestone (30 feet) is conspicuous.

In the Ribble Valley and at Bowland Forest, the Millstone Grit and Yoredale rocks admit of the following divisions:—

Millstone Grit.	4. Upper Yoredale Grit, consisting of grits and beds of sandy shale, also conglomerate, 1000 to 1200 feet.
	3. Bowland Shales, black and grey bituminous shales, with beds of sandstone and limestone, 600 to 700 feet. These beds were named by Prof. Phillips from the Forest of Bowland.
	2. Lower Yoredale Grit, consisting of grits, sandstones, shales, and ironstones, having a thickness of about 600 feet.
Yoredale Rocks.	1. Shales with Limestones, with, near the top, the Pendleside Limestone (so termed by Mr. R. H. Tiddeman), which shows a thickness, with interbedded shales, of about 350 feet, at Pendle Hill. The total thickness of this division is upwards of 3000 feet.[3]

The Yoredale Grits at Longridge Fell have been termed the Lower and Upper Longridge Grits.[4] These beds are now grouped (under the name of the Shale Grit) with the Millstone Grit by Prof. Green. (See p. 170.) In Flintshire the Millstone Grit rests directly on the Carboniferous Limestone, having apparently overlapped the Yoredale Series.

Near Oswestry the Yoredale Series has been divided by Mr. D. C. Davies as follows:[5]—

2. Calcareous sandstones passing into limestones, burnt for lime at Mold, and quarried at Wern.
1. Red and yellow sandstones with *Schizodus*.

The lower portions of the Cefn-y-Fedw sandstone have been grouped by Mr. G. H. Morton with the Yoredale Series. (See p. 171.)

The Yoredale sandstones form the long anticlinal dome of Gun Hill, north of Leek, also Badger's Clough. These beds consist of hard close-grained sandstone, with shales.

[1] Trans. Cumberland Assoc. part vii. p. 125.
[2] Phillips, Geol. Yorkshire, part 2.
[3] Geology of Burnley Coal-field, p. 17. Notes by R. H. Tiddeman and W. Gunn.
[4] C. E. De Rance, G. Mag. 1883, p. 501.
[5] P. Geol. Assoc. iv. 564.

In Derbyshire, Mam Tor, or the 'Shivering Mountain,' is composed of rocks belonging to the Yoredale Series, which is there sometimes called the Limestone Shale. The series forms a wet soil, causing landslips of great extent, beneath the Millstone Grit summits; and the scarp of Mam Tor has been caused by a gigantic landslip which has carried away one side of the hill. In this district the Yoredale Rocks comprise the following divisions:—

Yoredale Sandstones, about 2000 feet.
Shales, with thin earthy limestones.

Fine sections of the Yoredale rocks may be seen by walking from Back Tor to Edale (Grindsbrook), a magnificent gorge in the grits on the flank of Kinder Scout.[1]

In Leicestershire and Monmouthshire the upper beds of the Carboniferous Limestone consist of limestones alternating with dark shales.

In Glamorganshire, immediately above the Carboniferous Limestone of Gower, at Penrice, and between Llanrhidian and Oystermouth, there is a considerable development (1600 feet) of black shales with sandstones, to which the name Gower Series has been applied. These beds appear to represent the Upper Limestone Shales, and perhaps also the Millstone Grit. At Tenby they are but a few feet thick, but there they contain beds of dark limestone, and yield *Goniatites*, reminding one of the Black Limestones of North Devon that occur at the base of the Culm-measures. (See sequel and Fig. 29.)

In the Forest of Dean the Upper Limestone Shales are estimated by Mr. E. Wethered to have a thickness of 116 feet.

At Clifton, between the Carboniferous Limestone and Millstone Grit, there is an alternation of red and grey limestones, shales, and sandstones, 300 or 400 feet in thickness, sometimes classed as the Upper Limestone Shales. These beds are shown in the Avon cliffs on either side of the Observatory Hill. To the north of this hill the beds are faulted against the Carboniferous Limestone—the downthrow being estimated at about 1150 feet.[2] No less than 52 species of fossils, principally Corals, Crinoids, and Brachiopods, have been recorded from these beds. At Vobster, near Mells, to the north of the Mendip Hills, black shales intervene between the Carboniferous Limestone and Millstone Grit. (See p. 161.)

Economic products, etc.

The lead-mines of Alston Moor, Weardale, Arkendale, Wensleydale, and Swaledale are situated in the Yoredale rocks.

Rotten-stone, due to the removal of the calcareous portion from siliceous limestone, is met with near Ashford and Bakewell in Derbyshire, and elsewhere.

The fine-grained micaceous grit-stones of the lower series are much used for

[1] P. Geol. Assoc. v. 189.

[2] C. Lloyd Morgan, Q. J. xli. 146. See also W. W. Stoddart, Proc. Bristol Nat. Soc. (2), i. 330.

building- and paving-purposes, as at Bakewell Edge, etc. Gritstone has also been worked at Rawthay Gill, between Ravenstone Dale and Sedbergh ; at Longridge ; and at Gatherly Moor near Richmond in Yorkshire.

The thin coals, as Prof. Phillips observes, are not worth the expense of the fruitless trials in search of them, although, locally, some seams attain a thickness of four or five feet. Coal has however been worked near Haltwhistle and Hexham ; also at Barbon and Casterton, near Hawes, Kirkby Stephen, and Garsdale Head.

The Bishopley Limestone, quarried near Frosterley, Durham, the Prudham stone, near Hexham, and the Gilling stone, quarried near Gilling, Yorkshire, are beds of economic value in the Yoredale Series.

Encrinital Limestone has been obtained from the Twelve-fathom Limestone at Snays-wold, between Dent and Garsdale, also from the Four-fathom Limestone. Some of the beds have been polished for ornamental purposes.

Bitumen occurs at Clithero. Beautiful specimens of 'Flos ferri,' coralloidal Aragonite, have been met with in the Dufton Mines in Westmoreland.

UPPER CARBONIFEROUS.

MILLSTONE GRIT.

This formation consists of coarse sandstones, grits, shales, and conglomerate, with occasional thin beds of limestone and seams of coal. It generally crops out along the margin of our coal-fields, and indeed forms the immediate foundation upon which they rest; and from the circumstance of its being below the Coal-measures, and containing, in the South-west of England and South Wales, no valuable coal-seams, it has in those districts been termed the 'Farewell Rock.' The name Millstone Grit was no doubt given because the formation has yielded stone serviceable for millstones. The maximum thickness of the Millstone Grit is estimated at 5000 feet.

The fossils of the Millstone Grit are few; Mollusca are confined to a few limited horizons, but Plant-remains are common throughout the series. These include *Stigmaria*, *Calamites*, *Lepidodendron*, etc.

The Mollusca include *Productus semireticulatus*, *Streptorhynchus crenistria*, *Athyris ambigua*, *Spirifera striata*, *Bellerophon costatus*, *Aviculopecten papyraceus*, as well as species of *Modiola*, *Posidonomya*, *Orthoceras*, and *Goniatites*.

Trilobites, such as *Phillipsia*, have been found high up in these beds near Kirkby Stephen by Mr. J. G. Goodchild. Fish-remains belonging to the genera *Acrolepis* and *Acanthodes* have also been noticed.[1] Rain-prints, sun-cracks, and worm-tracks have been noticed in the Haslingden Flags.

At Alston Moor the Millstone Grit consists of alternations of sandstones, shales with ironstone and coal, attaining a thickness

[1] See West Yorkshire, by J. W. Davis and F. A. Lees, edit. 2, p. 123 ; also The Millstone Grit, by Fort Major T. Austin, 1865. The new species described in the latter work have, however, not been generally accepted.

of at least 400 feet. In Swaledale the series embraces coarse gritstones, shales, sandstones, and coal, having a thickness of 500 feet. At Wensleydale the series is very similar in character, but is less in thickness. At Penyghent the remnant of the series left on the summit is less than 200 feet thick. Other outliers occur at Whernside and Penyghent. (See Fig. 25, p. 160.)

In Northumberland, as Prof. Lebour observes, the place where the Millstone Grit should be undoubtedly exists, but the grits themselves are sadly deficient, both in character and in thickness. Shales, shaly sandstones, and sandy shales, with a few beds of sandstone, seldom coarser in grain than many beds in the Coal-measures, and not nearly so coarse nor so thick as some of the grits of the limestone series below—these, in considerable spreads between the Derwent and the Tyne, and in a narrow band from the latter river to the sea near Warkworth, are the component parts of the Northumbrian Millstone Grit.[1] The beds are also to be seen in the Wansbeck valley, at Mitford, near Morpeth.

In West Yorkshire the Millstone Grit occupies much of the country around Pateley Bridge, Ilkley, and Keighley, to the west of Harrogate, Bingley, and Halifax. Thence it stretches southwards to the Peak in Derbyshire, and the country west of Sheffield.

The following divisions of the Millstone Grit in parts of Mid- and South-Yorkshire and Derbyshire have been determined by the Geological Survey :[2]—

		Feet.
Upper Grits.	Rough Rock (First or Topmost Grit), coarse felspathic grit	50 to 200
	Shales (impersistent)	
Middle Grits.	Flags [Haslingden Flags (Second Grit)], fine-grained sandstones and shales	60 to 100
	Shales and Coal [Brooksbottom Series]	75 to 150
	Grits and Shales (Third or Roaches Grit), massive gritstone, forming bold mural escarpments in places .	100 to 300
	Shales and sandstones [Sabden Valley shales (1500 to 2000 feet)]	300 to 500
Lower Grits.	Kinder Scout Grit (Fourth Grit), coarse and often conglomeratic grit and flagstone	500 to 1000
	Shales. . . . . . } Shale Grit or Yoredale Grit } . .	(See p. 166.)

The several divisions are, however, not always represented, and they are subject to great changes in thickness.

The name Kinder Scout Grit was proposed by Professors E. Hull and A. H. Green ; the rock forms the high table-land of Kinder Scout, in the Peak country, where the disintegration of the quartzose conglomerate yields numbers of white quartz pebbles.

The Kinder Scout Grit forms the Rowtor and Cratcliff rocks near Bakewell, the

[1] G. A. Lebour, Proc. N. of Eng. Inst. of Mining Engineers, vol. xxv. ; Geology of Northumberland, p. 30.

[2] Geology of the Yorkshire Coal-field (Geol. Surv.), by A. H. Green and others ; E. Hull and A. H. Green, Q. J. xx. 249 ; also Geology of Stockport, etc. (Geol. Survey), p. 12.

ridges of Harrop Edge, Millstone Edge, Diggle Edge, Charnel Rocks, Warlow Pike, Harridge Pike, Tintwistle Knar, Roe Cross, etc., in Staffordshire, etc., also Derwent Edge. It occupies the moorlands between the Wigan and Burnley coal-fields, in Lancashire. The Shale Grit, so named by J. Farey, and subsequently known as the Yoredale Grit, is now placed with the Millstone Grit by Prof. A. H. Green.[1] The First Grit or Rough Rock is well seen in the Stannedge quarries, near Chesterfield; also at Houghton Towers, between Preston and Blackburn. The Sabden shales near Preston contain thin beds of limestone with encrinites. The Henclouds and Leek Roaches are rocks near Leek, which are formed of the Third Grit. The Chatsworth and Rivelin Grit is placed in the lower part of the Middle Grits (Third Grit). The Pendle Hill Grit occurs locally at the base of the Millstone Grit, in Lancashire, and is equivalent to the Yoredale Grit, the beds in this position having formerly been grouped with the Yoredale Rocks. (See p. 166.)

In Lancashire the Millstone Grit contains thin coals (Brooksbottom coals) in the shales above the Third Grit. It is estimated to have a thickness of from 3500 to 5000 feet.

Near Oswestry the beds consist of white and buff sandstones, with coarse pebbly beds.[2]

The Plumpton (Plompton) or Knaresborough Grits, and certain red beds near Spofforth and Cayton Gill, at one time grouped with the Permian, have proved to belong to the Millstone Grit, being stained by infiltration from New Red rocks.[3] The Plumpton grits, however, owe their colour in part to fragments of red felspar contained in them.

The Cayton Gill Beds, according to Mr. W. H. Hudleston, constitute a fossiliferous horizon at the base of the Plumpton Grits on both sides of the Harrogate anticlinal. They yield *Productus semireticulatus*, *Streptorhynchus crenistria*, *Fenestella*, joints of Encrinites, etc.[4]

The Brimham Rocks near Pateley Bridge, and Birk Crag near Harrogate, are formed of Millstone Grit, and well illustrate the action of atmospheric disintegration on rocks of unequal hardness.

The Ilkley Crags near Bradford, and Ryeloaf Hill near Settle, are also formed of Millstone Grit.

In North Flintshire the Millstone Grit rests directly on the Carboniferous Limestone. It consists of chert beds, having a thickness of 350 feet or more. This chert, as remarked by Mr. A. Strahan, is probably a siliceous sediment of extreme fineness, and it passes in the neighbourhood of Holywell and further south into a fine-grained quartzose sandstone with bands of chert, and then into a grit with quartz pebbles.[5] (See also p. 165.)

[1] Geol. N. Derbyshire (Geol. Survey), edit. 2.

[2] D. C. Davies, P. Geol. Assoc. iv. 564.

[3] J. C. Ward, Q. J. xxv. 294. Mr. E. W. Binney and the Rev. J. S. Tute have expressed similar views concerning the Carboniferous age of these red rocks.

[4] P. Geol. Assoc. vii. 426; see also C. F. Strangways, Geol. Harrogate (Geol. Survey).

[5] Geology of Rhyl, etc. (Geol. Survey), p. 18.

The variations of the Millstone Grit will be seen from the following divisions noted by Mr. G. H. Morton:[1]—

	North Flintshire.		*South Flintshire.*	
Cefn-y-Fedw Sandstone.	Gwespyr Sandstone	120	Aqueduct Grit	50
	Cherty Sandstone	250	Upper Sandstone and Shale	100
			Cherty Shale	250
			Lower Sandstone and Conglomerate	50
		370 feet		450 feet

In the country around Llangollen the beds have been divided as follows by Mr. Morton:[2]—

		Feet.	
Cefn-y-Fedw Sandstone.	Aqueduct Grit, or Upper Sandstone and Conglomerate	70	Millstone Grit.
	Upper Shale	30	
	Dee Bridge Sandstone	30	
	Lower Shale, with Fireclay and Bands of Limestone	18	Yoredale Series.
	Middle Sandstone	200	
	Cherty Shale	50	
	Lower Sandstone and Conglomerate	250	
	Sandy Limestone	75	
Carboniferous Limestone.			

Many fossils have been found in the Cefn Sandstones, including the Trilobite *Phillipsia*.

In Anglesey the thickness of the Millstone Grit has been estimated at 400 feet. It consists of yellow sandstone and conglomerate, and contains a bed of coal about a yard thick, which has been worked at Glantraeth.

In Leicestershire the thickness is about 200 feet. The beds consist in the lower part of quartzose conglomerate, seen above the Carboniferous Limestone at Ticknall, and other places; in the middle, of grits worked at Stanton, Melbourne and Repton Rocks, for millstones, troughs, and building-purposes; and in the upper part of grits and shales, which pass by almost insensible gradations into the Coal-measures above. Sections of this passage have been observed near Castle Donnington and Thringstone.

In Monmouthshire the beds consist of hard sandstone and conglomerate, with shale partings, and have a thickness of 330 feet. They form the Blorenge Mountain, south-west of Abergavenny. In the Forest of Dean the thickness is 470 feet. Mr. E. Wethered states that the rock there in places contains 98 per cent. of silica.

In South Wales, on the northern margin of the Coal-basin, the Millstone Grit forms a continuous band and generally a marked feature, from near Haverfordwest to Pontypool, having at Merthyr Tydfil a

[1] Proc. Liverpool Geol. Soc. vol. iv.
[2] Proc. Liverpool Geol. Soc. iii. 174.

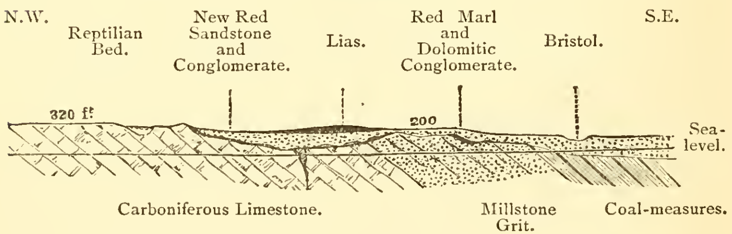
thickness of 330 feet. At Mynydd Garreg the lower portions consist of sandstone and conglomerate, the upper of arenaceous shales and flaggy sandstone; these indeed are its prevalent characters, the conglomerate being composed of quartz pebbles, the sandstone sometimes passing into quartzite. Large blocks of these rocks are generally scattered about on the line of outcrop. The shales and occasional coal-seams render the boundary-line with the Coal-measures above very vague. The Millstone Grit forms a thin and inconspicuous band north of Cardiff; but farther west, at Cefn Hirgoed and Cefn Crubwr, the beds stand out in bold ridges, and here the broad outcrop is probably duplicated by a fault.

As before mentioned, the Millstone Grit is not definitely identified in the Gower peninsula, and it remains to be proved whether the Gower shales should be correlated with it, or whether it be represented by certain sandstones above them and now included with the Coal-measures.[1] (See p. 167.) At Cwm Afon, near Aberafon, a seam of coal two feet in thickness, called the Crow's-foot vein, is worked in the Millstone Grit.

On the Pembrokeshire coast the Millstone Grit is represented by hard white sandstone and grit.

At Bristol the Millstone Grit rises up in Brandon and Clifton Hills. Its thickness in this neighbourhood has been estimated at about 1000 feet. (See Fig. 26.)[2]

Fig. 26.—Section from Durdham Down to the City of Bristol.
(R. Etheridge.)



In the Mendip country sections are rarely seen; the beds are generally represented by close-grained quartzite with iron-stained spots. The beds have been exposed at Leigh Down, near Winford, between Mells and Ashwick, and at Vobster. To the south of the Mendips, traces of the rock occur between Easton and Priddy, and near Dinder east of Wells.

In Devonshire the Millstone Grit has not been distinguished, although no doubt represented in the lower part of the Culm-measures,—perhaps by the Coddon Hill Grits. (See sequel.)

[1] Science Gossip, Aug. 1880; see also E. Hull, Q. J. xxxiii. 632; De la Beche, Mem. Geol. Surv. i. 143.
[2] R. Etheridge, Q. J. xxvi. 188.

Economic products, etc.

Excellent paving- and building-stones are furnished by the Millstone Grit in Yorkshire, Lancashire, and Derbyshire. At Horsforth, near Leeds, flags are worked, and the upper beds (80 to 180 feet in thickness) yield the famous 'Yorkshire stone' used for building and other purposes.

The massive Kinder Scout Grits furnish blocks for engine-beds, foundations, and reservoir work. The beds are quarried at Eyam Moor, Derwent Edge, etc. The variable beds of the Middle Grits yield flagstone, also good building-stone at Beeley and Darley Moors, and Addingham Edge, while the Calliard furnishes excellent road-metal. Flags at the base of the Rough Rock furnish good flagstones at Haslingden, Entwistle, Edgworth, etc. The Rough Rock is quarried for building-stone: the Bramley Fall quarries near Leeds being noted.

Near Accrington the Rough Rock yields sand which is dug in places.

The Cefn Sandstone of Flintshire contains beds largely used for road-mending, and one bed (the Aqueduct Grit) furnishes good building-stone. Caernarvon Castle was built of this rock. Scythe-stones have been made at the Talacre quarry in Flintshire.

In the Vale of Neath, the celebrated Dinas fire-bricks are manufactured from sandy beds belonging to the Millstone Grit. The material, known as "Dinas clay," contains 98 per cent. of silica, with traces of alumina, protoxide of iron, lime, potash and soda.[1] These bricks are used for lining copper-furnaces, etc. The chert beds in the Millstone Grit of Flintshire are quarried at Pentre, near Gronant, for use in the Staffordshire Potteries.

In the Escarpment of the Rough Rock near Bury, north of Rochdale, is the Feather Edge Coal, which has been extensively mined. Coal has also been worked near Ovingham, in Northumberland. Zinc-ore is worked at the Talacre mine, in Flintshire.

The Millstone Grit is generally very unproductive and barren, so far as the soil is concerned, and much of the country occupied by it is moorland.

COAL MEASURES.

The term Coal-measures was used by William Smith in 1817, and previously by the Rev. John Michell. No doubt the term had long been in common use.

The Coal-measures consist of a series of clays and shales, grits, sandstones, and ironstones, characterized by the abundance of coal-seams and the general absence of limestones. Of these beds the seams of coal are the most persistent, while the sandstones are often very irregular and inconstant.

The strata usually occur in what are termed 'Basins'; that is, in synclinal areas or troughs: these basins, however, are

[1] Percy, Metallurgy, 1875, p. 146.

not necessarily the areas of deposition, but are caused by disturbances and by denudation of the Coal-measures, which in many tracts were no doubt formerly connected. It is seldom, perhaps never, that we obtain the full thickness of the Coal-measures, because great denudation has in nearly all cases affected the strata: thus, although the Lancashire coal-field is 6600 feet in thickness, the strata have never been seen to graduate upwards into the New Red Sandstone, and, consequently, their upper boundary is unascertained.[1] In some instances, where the New Red rocks have been supposed to rest conformably upon the Coal-measures, the red rocks have proved to be Coal-measure sandstones stained red by infiltrations of iron-oxide.

In South Wales the total thickness of the Coal-measures has been reckoned at from 7000 to 8000 feet, or more. Estimating the increase of sediment at two feet a century, and admitting with Mr. C. Maclaren that it might take 1000 years to form a bed of coal one yard in thickness, Prof. Hull has calculated that the deposits forming the South Wales Coal-field (including the Millstone Grit) might have been accumulated in 640,000 years.[2] This estimate is, of course, very vague.

COAL.—This 'fossil fuel' is not, strictly speaking, a mineral, being of organic origin; but it is nevertheless frequently classed as such amongst the Hydrocarbons. Chemically, in addition to carbon (about 75 to 94 per cent.) and hydrogen, coal contains nitrogen and oxygen in variable proportions. Sulphur is almost always present in the form of iron-pyrites, etc., and silicate of alumina occurs in small quantities, constituting the ashes after coal is burnt. Coal is composed of vegetable matter, which through chemical change and pressure, as well as from original decomposition, has lost most of its structure. Numerous spores and spore-cases of Lycopodiaceous plants, however, and sometimes woody structure, may be here and there detected. Amongst the conspicuous kinds of plants which helped to form it are Ferns, Horse-tails (*Equisetaceæ*), Giant Club Mosses (*Lycopodiaceæ*), and Conifers.

Sir William Logan first pointed out in 1840, that every coal-seam in the Great South Wales Coal-field rested upon a bed of clay, called 'underclay,' which was penetrated by the roots known as *Stigmaria*, and evidently formed the old terrestrial soil upon which the plants originally grew.[3] This

[1] E. W. Binney, Q. J. ii. 26.
[2] Coal-fields of Great Britain, edit. 4, p. 71.
[3] Proc. G. S. iii. 275; T. G. S. (2), vi. 491.

fact has been found to be generally applicable in our coal-fields. *Stigmaria ficoides* has been shown by Prof. W. C. Williamson to be the root alike of *Lepidodendron* and *Sigillaria*.[1] In many places conspicuous traces of stumps with roots have been observed, affording relics of the old Coal-measure forests.

The physical and palæontological evidence prove that the Coal-measures were formed in an area undergoing slow and gradual subsidence, during which pauses occurred which are marked by the different beds of coal. These seams of coal can in some cases be correlated over large areas, while in other cases it is scarcely possible to indicate the extent of any one particular seam.

That the beds were mostly deposited in a freshwater and fluvio-marine area is proved by the organic remains ; at the same time in some localities, especially in the Lower Coal-measures, there are indications of purely marine accumulations. The conditions presented were probably those of an inland sea, bordered by swamps, into which several rivers brought and deposited sand and mud. The luxuriant growth of vegetation is suggestive of a warm and equable climate, while the atmosphere no doubt was moist. The coal-beds were formed when either an increase of sediment or a slight elevation produced a land area, or an extensive swampy plain. Many remains of plants were, however, drifted, although not very far. The Cypress Swamps of the Mississippi and the Great Dismal Swamp of Virginia (described by Lyell) appear to furnish the nearest analogues to the conditions prevailing in Coal-measure times.

Although an immense amount of carbonic acid gas is now locked up in our Carboniferous rocks,[2] Mr. Carruthers thinks it not at all likely that the atmosphere was charged with more of that gas than it is at the present day.[3]

It has been remarked by Prof. A. H. Green that wherever we approach one of the old margins of the swamps in which the coal was formed, it becomes impure from earthy admixture, and is more and more split up by partings of shale and sandstone until the coal is entirely replaced.[4] Jukes too observed that in the South Staffordshire Coal-field there is every gradation from a mere carbonaceous shale to a perfectly pure bright coal with very little earthy matter.[5] In other cases, where the coal is sharply cut out

[1] Geol. Mag. 1881, p. 520.
[2] Dr. T. Sterry Hunt, Chemical and Geol. Essays, 1879.
[3] Geol. Mag. 1869, p. 300 ; 1871, p. 497 ; see also J. D. Hooker, Mem. Geol. Survey, ii. part 2, 387.
[4] Geology of Yorkshire Coal-field, pp. 20–22.
[5] Geology of the South Staffordshire Coal-field, edit. 2, p. 17.

by sandstone (features known by the name of "rock faults" among the colliers), the rock undoubtedly occupies the old beds of a stream and its tributaries, which became gradually silted up.

The constancy of coals is, however, a very remarkable fact. In the case of the 'Arley Mine' in Lancashire, which is the same as the Silkstone coal of Yorkshire, we have a seam that seldom exceeds five feet in thickness, which originally must have spread over an area of 10,000 square miles.[1]

There is still some difficulty in accounting for the purity of coal, and its general freedom from foreign materials. If, however, we picture a vast alluvial plain covered with a Cryptogamic forest of giant Lepidodendra and Sigillariæ growing on a stiff tenacious clay-soil, capable of retaining the rain-fall, then we have the conditions suited for the rapid production of peat; and that is the purest form we know of any great accumulation of vegetable matter *unmixed* with foreign material, freedom from which is the peculiar feature of the Coal-seams.[2] The general purity of peat is sometimes produced by the cleansing of muddy water in passing through a reedy marsh.

While most coals were certainly land-growths, Prof. Green observes that Cannel Coal, and some of the small lenticular patches of coal occasionally met with in shales and sandstones, were formed under water. Cannel Coal occurs in lenticular patches, associated sometimes with ordinary coal, but it very frequently contains Fish-remains, and is often found to pass gradually into carbonaceous shales. Probably the plants of which it is composed were drifted into shallow ponds or lakes, and reduced by soaking to a vegetable pulp.

There are many different kinds of coal, and these are due partly to the pressure and chemical changes they have undergone, and partly no doubt to their original composition. The principal varieties of coal are as follows:—

Anthracite or *Stone-coal*, which is the most highly mineralized form of coal, has a shining conchoidal fracture, and does not soil the fingers. It does not ignite so readily as other kinds of coal, but is almost pure carbon, containing from 87 to 94 per cent. of it, and on burning leaves but little ash. It is sometimes described as non-bituminous, and has probably been altered by pressure, if not by the proximity of igneous rocks; it exhibits no traces of organic structure. *Culm* is a variety of Anthracite.

Bituminous coal (ordinary house coal) is rich in hydrocarbon gases, although it contains no bitumen, but it is termed bituminous because it has a 'more flaming character in burning than anthracite.' The varieties generally recognized are mostly named after their application or chief properties: Free burning, steam or

[1] Hull, Coal-fields of Great Britain, edit. 4, p. 255.

[2] Dr. H. Woodward, Geol. Mag. 1871, p. 500; P. Geol. Assoc. ii. 241. See also Carruthers, Geol. Mag. 1869 p. 282; and E. W. Binney, Mem. Lit. Soc. Manchester (2), viii. 148.

smokeless coal, and non-caking coal. These, in different grades, approach towards the anthracites, and are chiefly valued for engine and smelting purposes. They contain from 70 to 85 per cent. of carbon. They often exhibit, in parts of the seams at least, a peculiar fibrous structure, passing into a singular toothed arrangement of the particles, called *cone-in-cone* or *crystallized coal.*[1] Steam coal is spoken of as semi-bituminous: it is compact and hard, and is adapted for raising the largest quantity of steam. Caking coals are 'bituminous' coals, which are generally used for household purposes, having a tendency to cake, emitting jets of gas and giving off much flame and smoke: they contain from 77 to 83 per cent. of carbon, while non-caking coals have from 70 to 80 per cent. The 'Smalls' have the property of fusing together in large masses when duly heated, whence they are turned into coke for iron-smelting and for burning in locomotives.

Cannel (*candle*) *coal* is a hard, dull, and clean coal, containing much volatile matter; it readily ignites with a yellow flame, and is much used for gas-making. It has a much larger proportion of hydrogen and oxygen than anthracite, and leaves but little ash, having from 80 to 84 per cent. of carbon. Cannel coal presents no direct traces of its vegetable origin. *Parrot*, *Splent* or *Splint coal* is a variety with a slaty structure.

There is also a variety called '*Peacock coal*,' which exhibits iridescent colours. The term '*Mother Coal*' is applied to the soft 'mineral carbon' or 'charcoal' occurring between brighter laminæ of coal. It is composed of the broken-up tissues of plants converted into anthracite, but still retaining their external forms.

Prof. Morris originally pointed out that the seam known as the "Better-bed-coal" at Bradford, in Yorkshire (see sequel), owed its peculiar chemical composition, which gave it its great value for smelting purposes, to the fact that it was composed almost entirely of a mass of spore-cases, which belong to a Lepidodendroid genus known as *Flemingites*, and to *Sigillaria*, etc. Prof. Huxley subsequently observed, from specimens prepared by Mr. E. T. Newton, that these spore-cases were buried in the shed spores themselves, and both together make up the substance of this most remarkable deposit of Coal.[2] Under the microscope, coal itself appears to be formed of three kinds of layers, termed by Mr. Newton the bright, dull, and intermediate layers. The dull layers contain dotted tissue, the intermediate layers contain macrospores and microspores, and the bright layers ("mother-coal") are usually structureless, but are sometimes composed of spores. Spores are abundant because they resist decomposition more effectually than woody tissue.[3]

Different seams of coal are suited for different purposes—for smiths, steam, gas, or the household. They vary in thickness from an inch to thirty feet.

[1] See John Young, G. Mag. 1885, p. 283; and Prof. J. S. Newberry, *Ibid.* p. 559.
[2] Dr. H. Woodward, G. Mag. 1871, p. 497.
[3] See E. Wethered, Q. J. (Proc.), xl. 59.

Coal was worked in England as early as A.D. 852 in the Northumberland Coal-field, but not to any extent until the thirteenth century. In 1210 we have the first record of a Coal-mine in England; in 1239 Henry III. granted a charter to the freemen of Newcastle-on-Tyne for liberty to dig coals; and shortly afterwards coal was sent to London by ship, and known as 'Sea-borne coal.' It was not, however, until about the 17th century that coal was generally used in London. Coal, however, had been known many years before the Christian era; it was known to Theophrastus about 238 B.C. It was likewise known to the Ancient Britons in Lancashire, and probably in Northumberland, and to the Romans in A.D. 60.

In early times the coal was quarried at the surface, but as the supply that could be worked in this way was in time exhausted, it was necessary to have recourse to mining.

There are two systems of working the coal underground, termed respectively the 'Pillar and Stall,' and the 'Long Wall' systems. In the former case the coal is worked out in square galleries called stalls, while pillars or posts of coal are left to support the roof: in the latter case long galleries are driven to the full extent of the mine, and the coal is then worked out as far as possible in the intermediate spaces. The latter plan is usually adopted in working thin coals.

Many faults and disturbances affect the Coal-measures in various places: some of these will be alluded to in the sequel. These faults frequently do not affect the overlying Secondary strata.

One of the deepest mines in England is at Rose Bridge, near Wigan, 815 yards; but the deepest mine is that at Ashton Moss Colliery, also in Lancashire, 897 yards. At the depth of 860 yards the temperature was 78° Fahr.

Much danger arises in the mines from the escape during the working of the imprisoned gas called 'fire-damp' (carburetted hydrogen), which is highly explosive when mixed with air, and when ignited produces the much dreaded 'choke-damp,' 'after-damp,' or 'black-damp' (carbonic acid gas); so that a good system of ventilation and the use of the Davy lamp are very necessary. In some few districts, as near Radstock in the Somersetshire Coal-field, 'fire-damp' is unknown, and the miners work with naked candles. It has, however, been shown by Mr. W. Galloway that a mixture of fire-damp and air becomes inflammable at ordinary pressure and temperature when charged with fine coal-dust; and to this cause many explosions may be attributed.[1] Danger of another kind sometimes arises from what are called "creeps," when the pressure of the strata on the sides of the passages or upon the pillars causes the floor to swell up.[2]

[1] See also Report of Commission on Accidents in Mines, noticed in Nature, April 15, 1886.

[2] For further details on the subject of Coal, its history, uses, and the method of working it, see W. W. Smyth, Treatise on Coal and Coal Mining, edit. 2, 1872; E. Hull, Coal-Fields of Great Britain, edit. 4; R. Meade, The Coal and Iron Industries of the United Kingdom, 1882; Coal, its History and Uses, by Professors A. H. Green, L. C. Miall, and others, 1878; and the Rev. T. Wiltshire, History of Coal, 1878.

Concerning the strata among which the seams of coal occur, it may be remarked that the shales known to the miners as 'binds' or 'plate,' are more persistent than the sandstones, and they yield some of the finest specimens of Coal-plants.

The sandstones are very variable in character. Where they are protected from the weather, they are usually blue or grey, and they then contain iron as ferrous carbonate. Where exposed to the atmosphere, they are frequently red or brown in colour. The materials of which the sandstones are composed have in many cases been furnished by the wear and tear of crystalline rocks, such as granite.

The Underclay is known as 'Spavin' in Yorkshire; as 'Thill' in Durham; as 'Warrant' or 'Seat-earth' in Lancashire; and as 'Bottomstone' or 'Pouncin' in South Wales. The rocks grouped under this head vary much in composition. Very frequently they consist mainly of clay, but many of them (as in the Yorkshire coal-field) are hard clayey sandstones. The most siliceous form, known as Ganister or Calliard, is a hard, close-grained siliceous stone. The underclays are unstratified, and usually form the floor of a seam of coal, but sometimes no coal occurs, when a seam of carbonaceous black shale is usually met with.

The hard seat-earth, known as Ganister, though it is found in the Millstone Grit, and is not altogether absent from the Middle Coal-measures, occurs oftener in the Lower Coal-measures than elsewhere among the Carboniferous rocks. One seam of coal, distinguished as the Ganister Coal, has almost invariably a Ganister floor. Hence the name Ganister (or Gannister) Beds has been given to the Lower Coal-measures.[1]

Amongst the fossils of the Coal-Measures may be mentioned the following:—Plants, *Sternbergia* and *Noeggerathia*, belonging to the group *Coniferæ; Sigillaria*, *Lepidodendron*, *Lepidostrobus* (fruit-cones), *Ulodendron* and *Asterophyllites* belonging to the group *Lycopodiaceæ; Calamites* belonging to the group *Equisetaceæ*; and the Ferns *Alethopteris*, *Pecopteris*, *Neuropteris*, *Sphenopteris* and *Caulopteris*.[2]

In the Lower Coal-measures certain marine Mollusca have been found, including *Aviculopecten papyraceus*, *Spirifera pinguis*, *Productus semireticulatus*, *Nautilus armatus*, *Goniatites Listeri*, *Lingula squamosa*, *Posidonomya Gibsoni*, *P. Becheri*, *Conularia quadrisulcata*, etc. In the Middle and Upper Coal-measures the Mollusca include *Anthracosia* and *Anthracomya*, forms usually regarded as belonging to fresh-water; *Anthracosia*, however, may have been an estuarine shell like *Scrobicularia*.

Among other fossils are the Annelide, *Spirorbis pusillus* (*carbonarius*); Crustacea, *Beyrichia*, *Estheria*, *Anthrapalæmon*, *Eurypterus*, *Prestwichia*, *Belinurus*, *Dithyrocaris*; Insects, including remains of

[1] A. H. Green, Geology of Yorkshire Coal-field, pp. 19, 25.

[2] See J. Lindley and W. Hutton, The Fossil Flora of Great Britain, 1831–37; and more recent memoirs by Sir J. D. Hooker, W. Carruthers, W. C. Williamson, E. W. Binney (Palæontograph Soc.), and R. Kidston, (Catalogue of Palæozoic Plants, British Museum).

Coleoptera (*Curculioides*) and *Palæodictyoptera* (*Brodia*, *Archæoptilus*, and *Etoblattina*, a kind of Cockroach);[1] Myriapods such as *Xylobius*, and Arachnida, *Eoscorpius* (Scorpion), *Eophrynus*; Fishes, *Megalichthys*, *Ctenodus*, *Acanthodes*, *Pleuracanthus*, *Lepracanthus* (Ichthyodorulites), *Rhizodus* (16 to 18 feet in length) and *Cœlacanthus*; and upwards of 30 Labyrinthodont Amphibia, including *Pholiderpeton*, *Archegosaurus*, *Parabatrachus*, *Anthrakerpeton*, etc. Mr. R. Etheridge, jun., has pointed out that the Tubicolar Annelide *Spirorbis pusillus* was not necessarily marine; but may have been able to live in freshwater.[2] The undoubtedly marine fossils found in the Coal-measures are limited to a few horizons, and these, as before mentioned, belong chiefly to the Lower division.[3]

The Coal-measures are frequently divided (as are most other formations) into the Upper, Middle, and Lower Series; the Upper and Middle divisions being regarded as essentially freshwater (lacustrine) and estuarine. These divisions, while noted in different Coal-fields, cannot be regarded as corresponding with any minute accuracy in different areas.

The term Coal-field is applied to the several geographical tracts over which the Coal-measures are exposed, including the area they occupy beneath newer strata, where they are so connected as to form one field; but many of the different coal-fields may be connected at great depths beneath newer strata. The total area of the coal-fields in England and Wales is estimated at about 3000 square miles.

1. NORTHUMBERLAND AND DURHAM COAL-FIELD.

This coal-field extends from the River Coquet, near Warkworth, to Morpeth,[4] Newbiggin, Newcastle, North and South Shields, Jarrow, and Durham, across the valleys of the Tyne, Wear, and Tees, to Bishop Auckland. The strata are thus divided:—

Upper Series, with thin coals and a band of ironstone, 900 feet.
Middle Series, with thick coals, from the High Main Coal to the Brockwell Coal, 2000 feet.
Lower Series, with two beds of coal, between 2 and 3 feet thick, 150 feet.

The High Main and Low Main are the most important coal-seams: they are from 3 to 6 feet in thickness. The Hutton seam, from 2 to 4 feet 6 inches in thickness, is noteworthy as yielding good household, gas, and steam coal.

[1] S. H. Scudder, Geol. Mag. 1881, p. 293; and 1885, p. 265.
[2] G. Mag. 1880, pp. 113, 219.
[3] E. Hull, Q.J.G.S. xxxiii. 615.
[4] One of the earliest descriptions of this district was by N. J. Winch, T.G.S. iv. i. The Coal-field has also been illustrated by John Buddle, Nicholas Wood, Westgarth Forster (1821), and others. See G. A. Lebour, Geology of Northumberland; J. B. Simpson, Sections of the Northumberland and Durham Coal-field, 1877; J. W. Kirkby and J. Duff, Nat. Hist. Trans. Northumberland, etc. iv. 150.

The best household coal was for many years procured from the High Main coal of the Tyne, at a colliery at Wallsend. The superior 'Wallsends' of the Tyne being worked out, the term 'Wallsend' is now-a-days indifferently applied to coal from various localities, which, however, furnish that best adapted for household purposes. The term 'was originally descriptive of the coal drawn from the spot where the old Roman wall ends on the northern side of the Tyne.' The original Wallsend pit was sunk in 1770, and abandoned in 1853. In one year a clear return of £60,000 is said to have been realized.

The Newcastle Coal-field, as this district is sometimes called, does not contain any anthracite, and only in one locality a thin bed of cannel coal. Among the well-known collieries are those of Hartley and Seaton, north of Tynemouth, Lambton, Hetton, Monkwearmouth, etc. The south-eastern portion of the coal-field is concealed by Permian rocks.

Two extensive "slip dykes," or faults, cross the entire coal-field from east to west. One is the great ninety-fathom dyke, which extends from the sea near Cullercoats, on the east, to Tynedale Fell on the west. The beds are thrown down on the north, and the dyke produces an extraordinary prolongation of the coal-field westwards along its course, forming the small detached coal-fields at Stublick, Coan Wood, Midgeholme or Hartley Burn, etc., south of Hexham and Haltwhistle. The other dyke is called the Butter-knowle forty-fathom dyke, the strata being depressed along the south side of it to that extent. There are several basaltic dykes crossing the coal-field, generally in an east and west direction. One of them, the "Cockfield Dyke," extends through the New Red Sandstone, Liassic and Oolitic strata of North Yorkshire.[1]

Here and there in the Middle and Upper Coal-measures, layers known as "Mussel Bands" are met with. These consist almost entirely of the shells of *Anthracosia*. Mr. Lebour notes also the occurrence of *Lingula mytiloides* in one of these shell-beds at Ryhope, in Durham. From the Low Main Coal-shales Mr. T. P. Barkas has obtained numerous fish-remains, as well as other fossils.[2]

Among the stones of economic importance, the Shawbank stone, of Stainton quarries, Barnard Castle, in Durham, belongs to the Lower Coal-measures; and freestones have been worked at Heddon-on-the-Wall, west of Newcastle, and at Kenton, north of the city. Newcastle grindstones are made from fine-grained sandstones obtained at Byker Hill, Whickham Banks, and Gateshead Fell. There are iron-works in the Wear valley, west of Bishop Auckland.

2. WHITEHAVEN OR CUMBERLAND COAL-FIELD.

This Coal-field extends along the coast of Cumberland by Whitehaven, Harrington, Workington, and Maryport; and as the

[1] For many of the above particulars I am indebted to a Report on Coal, Coke, and Coal Mining, published by N. of Eng. Inst. of Mining Engineers, 1863.

[2] G. Mag. 1868, pp. 486, 495; 1873, p. 315; 1874, p. 163.

strata dip seawards, much of the Coal-field is beneath the waters of the Irish Sea. Inland the Coal-measures extend to Aspatria.

The following divisions are made in the rocks of this tract:—

Upper Series.—Purplish-grey sandstones of Whitehaven, 100 to 150 feet.
Middle Series.—Developed at Cleator Moor, containing 7 workable coal-seams.
Lower Series.—Containing 4 or 5 thin and inferior coal-seams.

The seams vary from 2 to 7 feet in thickness. It has been a matter of some dispute whether the Whitehaven sandstone should be classed as Permian or as Coal-measures. Sedgwick regarded it as Lower New Red Sandstone.[1] But it is now generally grouped with the Coal-measures, although, as seen in the cliff south of Whitehaven, it rests unconformably on the Coal-measures beneath. According to Mr. T. V. Holmes, it occupies the same position in Cumberland that is held by the Red Rock of Rotherham in Yorkshire.[2]

At Workington the coal is obtained beneath the sea, the mines extending two or three miles under water. The Coal-measures in places rest on the Lower Carboniferous rocks.

A small coal-field, consisting of true Coal-measures, and overlying 1000 feet or more of Millstone Grit, was discovered by Mr. J. G. Goodchild at Argill, near Brough in Westmoreland;[3] and this may give encouragement to those who hope to find workable coal beneath the New Red rocks of the Vale of Eden.

3. NORTH LANCASHIRE OR INGLETON AND BURTON COAL-FIELD.

The tract of Coal-Measures near Ingleton is much obscured by Permian and Drift Beds. It contains some beds of coal, 1 to 9 feet in thickness, which have been worked along its southern border from Black Burton on the Greeta, eastwards, to the Craven fault, south of Ingleton.[4]

4. SOUTH LANCASHIRE OR WIGAN COAL-FIELD.

This important tract is broken up by faults and denudation into several coal-fields. Thus it includes, in addition to the main coal-field, those of Chorley (Coppul district), Burnley, and Manchester; a small tract in Cheshire near Stockport, sometimes called the Cheshire Coal-field; and the Goldsitch Coal-field, north of Leek. The main district embraces St. Helens, Wigan (see Fig. 27),[5]

[1] T. G. S. (2), iv. pl. xxv. See also Sedgwick and W. Peile, Proc. G. S. ii. 420.
[2] P. Geol. Assoc. vii. 409.
[3] Trans. Cumberland Assoc. part vii. p. 163. See also T. V. Holmes, part ix. p. 109.
[4] Geology of Kirkby Lonsdale and Kendal (Geol. Survey), by W. T. Aveline, T. McK. Hughes, and R. H. Tiddeman, p. 27.
[5] E. Hull, Q. J. xxiv. 328.

Fig. 27.—Ideal Section across the South-Western extremity of the Pendle Range, Lancashire. (Prof. E. Hull.)

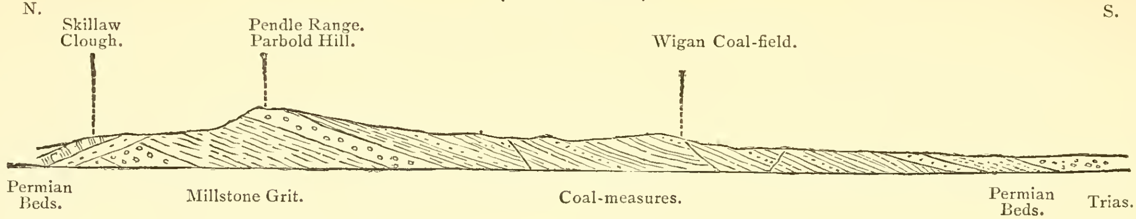
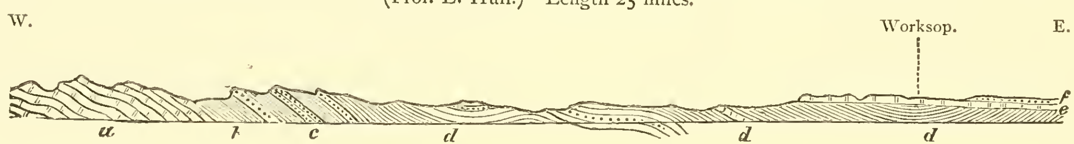


Fig. 28.—General Section across the Derbyshire and Yorkshire Coal-Field. (Prof. E. Hull.) Length 25 miles.



f. Trias.
e. Permian Beds.
d. Coal-measures.
c. Millstone Grit
b. Yoredale Rocks.
a. Carboniferous Limestone.

Bolton, Rochdale, Oldham, Ashton-under-Lyne, and Staleybridge. The Coal-measures admit of the following divisions:[1]—

Upper (Ardwick) Series.—Shales, sandstones, and limestone with *Spirorbis*, Fish-remains, etc. Thin coal-seams. 1680 to 2000 feet.

A bed of black-band ironstone with *Anthracosia* also occurs in this series. The limestone, known as the Ardwick Limestone, from Ardwick near Manchester, is an important horizon in the higher part of this series. It contains *Spirorbis*, *Anthracomya*, etc.

Middle Series.—Sandstones, shales, clays, and thick coal-seams, from the Worsley Four-foot Coal to the flags below the Arley Mine, 3000 to 4000 feet. This division includes the celebrated Cannel Coal of Wigan, which there attains its greatest development (three feet). Many Fish-remains have been found in it. *Anthracosia* and *Anthracomya* have also been found in the series.

Lower or Ganister Series.—Flags, shales, and thin coals, with Ganister floors and roofs of shales, 1400 to 2000 feet. Near Billinge and Upholland these beds have yielded *Goniatites Listeri*, *Aviculopecten papyraceus* and *Spirorbis*.

The terms Arley Mine, Mountain Mine, Balcarres Mines, etc., are applied to seams of coal. The seams worked vary from two to nine feet in thickness. The Wigan Cannel Coal takes a fine polish, and has been manufactured into various useful and ornamental objects. Peacock Coal has been met with at Rochdale. The term "Bullion" is used for nodules of argillaceous limestone.

The Blenfire Rock, a massive red sandstone exposed in Oldham Edge, and the Chamber Rock, a flaggy sandstone quarried at Rocher, belong to the Middle Coal-measures. The Riddle Scout Rock (flagstone), the Upholland flags, the Old Lawrence Rock (flagstone) of Huyton, the tilestones of Dineley Knowl, and the Woodhead Hill Rock (hard flaggy sandstone), are locally known in the Lower Coal-measures. Some of the beds have been used for the manufacture of grindstones and scythe-stones.

Among other rocks of economic importance are the Burnley and Rochdale flagstones, and rocks quarried at Orrel and Billinge Hill, near Wigan, Rainhill, Bolton, and St. Helens.

The Burnley Coal-field is a detached basin on the north:[2] the Cheshire Coal-field is an off-shoot to the south. The Cheshire Coal-field comprises a small area lying to the south of the Mersey, above Stockport, and extending to the east of that town by Poynton to Macclesfield; and also a narrow strip of Coal-measures exposed along the eastern shore of the estuary of the Dee, known as the Park Gate Coal-field. Near Macclesfield the Kerridge Rock comprises a thick mass of sandstones in the Lower Coal-measures.

5. SOUTH YORKSHIRE, DERBYSHIRE, AND NOTTINGHAMSHIRE COAL-FIELD.

This is the largest Coal-field in England, and extends from Leeds and Bradford, by Halifax, Wakefield, Dewsbury, and

[1] See works on the Geology of Prescot, Oldham, Wigan, and Bolton-le-Moors (Geol. Survey), by E. Hull; and on the Geology of Stockport, etc., by E. Hull and A. H. Green; also papers by E. W. Binney, Trans. Manchester Geol. Soc. vol. i. etc.; and C. E. De Rance, P. Geol. Assoc. v. 389.

[2] See Geology of the Burnley Coal-field (Geol. Survey), by E. Hull, J. R. Dakyns, R. H. Tiddeman, J. C. Ward, W. Gunn, and C. E. De Rance; Geology of Stockport, etc., by E. Hull and A. H. Green; and E. Hull, Q. J. xxxiii. 627; Coal-fields of Great Britain, ed. 4, p. 232.

Huddersfield, Barnsley, Sheffield, Chesterfield, and Staveley, to the country between Derby and Nottingham.[1] (See Fig. 28.)

The strata are thus divided:—

Upper Series.—Red beds with coal-plants of Conisborough pottery, near Rotherham, etc. 54 feet.

Middle Series.—Sandstones, shales, and clays, with ironstones and coal-seams (Cannel Coal, etc.), *Anthracosia*, Fish-remains, etc. 2000 to 3000 feet.

Lower or Ganister Series.—Flagstones and shales, with thin coal and Ganister floors. Marine fossils in places. 900 to 1600 feet.

Mr. J. W. Davis has obtained many Fish-remains from the Cannel Coal and other beds in the Coal-measures. In most instances they are found on the surface of the coal, rarely in the shales above, and never in the sandstone. Near Bradford the Fish-remains form quite a Bone-bed above the Better-bed Coal in the Lower Coal-measures.[2]

The seams of coal vary from two to nine feet in thickness. In Derbyshire the principal coals are the "Top hard" and "Lower hard" seams, producing the valuable splint-coal, also the "Upper soft" and "Lower soft" coals; and in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is identical with the "Arley Mine" of Lancashire, and has the highest reputation as a house coal. Silkstone is a village west of Barnsley. Clay Cross near Chesterfield, and Shireoaks near Worksop, are well-known localities in this Coal-field. The Adwalton stone coal is also an important bed.

The Better-bed coal (from 6 in. to 2ft. 6in.), worked at Low Moor, Bowling, and Farnley, near Bradford and Leeds, is a 'bituminous' coal, well adapted for smelting purposes on account of its freedom from sulphur and other impurities. (See p. 177.)

The Black-bed ironstone of Low Moor, etc., yields about 30 per cent. of metallic iron, and occurs in layers and nodules in carbonaceous shale, altogether about 1ft. 10in. thick. The Tankersley or Mussel-bed ironstone in the Middle Coal-measures near Sheffield is often full of specimens of *Anthracosia*. The Honeycroft ironstone is a local bed in the Derbyshire Coal-measures.

Fireclay, which occurs beneath the Better-bed coal, is worked at Wortley near Leeds. In composition it contains 56 per cent. of silica, and 31 of alumina. The term Ganister or Calliard is used to designate a peculiarly hard and fine-grained siliceous sandstone, which sometimes forms the floors of the seams of coal in the Lower Coal-measures. It is often penetrated by the roots known as *Stigmaria ficoides*. Economically, it is used for road-metal, and when ground down and mixed with fireclay, it makes excellent fire-bricks, or forms a good fire-resisting lining for the inside of furnaces. Near Bradford the Ganister is ground to a fine sand, and used in the casting of iron and brass.

[1] See Geology of Yorkshire Coal-field, by A. H. Green and others.

[2] Q. J. xxxii. 332, xxxvi. 56; P. Geol. Assoc. vi. 359.

The term Rotherham Red Rock has been applied to beds of iron-stained Coal-measure sandstone, which occur at different horizons. These beds are generally included by Prof. A. H. Green with the Middle Coal-measures. In this series he places the Red Rocks of Rotherham and Harthill, which are quarried for building-purposes and for scythe-stones and grindstones. In the same series the sandstones designated by the following names (chiefly from localities where they are quarried) are of economic importance for building-purposes, etc. :—Wickersley (grindstones much used by cutlers), Houghton Common and Pontefract, Dalton, Brierly, Cadeby, Ackworth, Upper and Lower Chevet rocks, Houghton, Treeton, Ackton and Oaks, Woolley Edge, Abdy, Kent's Thin and Thick rocks, Barnsley, Emly, High Hazles, High Hoyland, Handsworth, Woodhouse, Horbury rock (between Bretton and Ossett), Kexborough, Manor, Birdwell, Thornhill, Park Gate and Birstal, Silkstone, Sheffield, and Falhouse rocks.

In the Lower Coal-measures there are also many sandstones serviceable for building and for paving, as the Penistone flags, Grenoside and Farnley rocks, Oakenshaw and Clifton rocks, Bradford and Elland flagstone, Idle, Wharncliffe, and Middle rocks, Brincliffe Edge and Greenmoor rocks, Loxley Edge rock, and Crawshaw sandstone. Some flags of a size twelve feet square have been obtained. Thin beds are locally used for roofing. The flags are largely used for paving the streets of London, etc. At Almondbury, near Huddersfield, stone has been hardened for road-metal by being burnt.[1]

In the Lower Coal-measures the Potternewton stone, is largely dug for building- and paving-purposes near Leeds. The stone, consisting of fine grit and sandstone, is very variable, the hard massive beds seen in one place deteriorating rapidly, and passing into shaly beds in another. Quarries are filled up and deserted, as soon as all the good stone has been worked out.

The *Sheffield grindstone* is a hard and coarse stone used for common purposes ; it is found at Ardsley, fourteen miles north of Sheffield. The *Sheffield blue stone* is a fine-grained stone, used for finishing fine goods. The act of grinding on a blue stone is termed '*whittening*'—the Sheffield whittle from the earliest periods being in all probability ground on this stone.[2] Scythe-stones have been manufactured in Derbyshire. Near Rotherham a variety of Reddle, or Raddle, is obtained, which is much used for polishing lenses, etc.

6. ASHBY-DE-LA-ZOUCH OR LEICESTERSHIRE COAL-FIELD.

There are four separate divisions of the Leicestershire Coal-field, three of which only are productive. Of these three, two are on the east and one on the west side of Ashby respectively ; that on the north-east being spoken of as the Coleorton, and that on the south-east as the Ibstock and Bagworth Coal-field. The district to the west is the Moira, Gresley, and Swadlincote Coal-field. The intermediate district near Ashby contains the lower beds of the series, which are unproductive. The following divisions are made in the Coal-measures :[3]—

Upper Series.—Coarse grits of Moira and Newall, resting unconformably on lower beds. 20 to 50 feet.

Middle Series.—Sandstones, shales, and clays, with about twenty coal-seams, of which ten are workable, 1500 feet.

Lower Series.—Shales and sandstones, with a few seams of coal beneath the Heath-end coal, 1000 feet.

[1] C. Tomlinson, P. Geol. Assoc. i. 50.

[2] Descriptive Guide to the Museum of Practical Geology, by R. Hunt and F. W. Rudler, edit. 4, 1877.

[3] See E. Mammatt, Geological Facts, etc., of the Ashby Coal-field, 1834 ; E. Hull, Geology of Leicestershire Coal-field (Geol. Survey) ; and W. J. Harrison, Geology of Leicestershire and Rutland, 1877.

Boulders of quartzite have been found in the "Lount Nether" coal, at the Coleorton colliery.[1] The seams of coal vary from three to nine feet in thickness. The main coal of Moira is from twelve to fourteen feet thick.

Prof. Hull mentions that at Whitwick a sheet of dolerite intervenes between the Coal-measures and New Red Sandstone. At Whitwick colliery it is sixty feet thick, and has turned to cinders a seam of coal with which it comes in contact.

The saline waters for which this district is noted will be mentioned further on.

7. WARWICKSHIRE OR TAMWORTH COAL-FIELD.

This tract of Coal-measures extends between Tamworth and Nuneaton, and has been divided as follows:[2]—

Upper Series.—Sandstones and shales, at the base of which is a band (two to three feet thick) of limestone, with *Spirorbis pusillus* (*carbonarius*), 50 feet.

Middle Series.—Sandstones and shales, with five workable coals (1 seven-foot seam) lying near the centre of the series, 1400 feet.

Lower Series.—Shales, etc., unproductive of coal, and traversed by dykes of basalt, 1500 feet.

The five workable coals, which at the northern end of the coal-field near Tamworth are separated by about 120 feet of shales and sandstones, combine at Bedworth and Wyken near Coventry to form one bed 26 feet in thickness. Fire-bricks are manufactured at Tamworth.

8. NORTH STAFFORDSHIRE COAL-FIELD.

This Coal-field lies mostly to the north-east and west of Stoke-upon-Trent, Newcastle-under-Lyne, Hanley and Burslem (the Potteries), and includes the Coal-fields of Cheadle and Wetley. The beds have been divided as follows:—

Upper Series.—Brown sandstones, greenish conglomerate with thick beds of red and purple mottled clays; thin coals and ironstone, and a bed of limestone ('Spirorbis limestone') at Fenton. 1000 to 1500 feet.

Middle Series.—Sandstones, shales with ironstone, with about 40 coal-seams, including the ten-foot coal of Hanley. Fish-remains. 3500 to 4000 feet.

Lower Series.—Black shales and flags, with Wetley Moor thin coals, and the red ironstone of the Churnet Valley. Marine fossils. 1000 feet.

The coal-seams are from three to ten feet in thickness.

Many organic remains have been obtained from the Coal-measures.[3] The coarser kinds of earthenware, tiles, bricks, and drain-pipes are made in large quantities from the clays of the

[1] W. S. Gresley, G. Mag. 1885, 553.

[2] See The Warwickshire Coal-field (Geol. Survey), by H. H. Howell.

[3] See W. Molyneux, Rep. Brit. Assoc. for 1864, p. 342; and 1865, p. 42; Thomas Wardle, Geology of Leek, 1863; and C. J. Homer, Trans. N. Staff. Inst. i. 102, ii. 11.

Upper Coal-measures. But "The Potteries" are especially noted for china-ware, which is the product of china-clay from Devonshire and Cornwall, of gypsum from Chellaston, chalk-flints from the South of England, and chert from Derbyshire.[1] Peacock Coal has been found at Hanley.

9. SOUTH STAFFORDSHIRE OR DUDLEY COAL-FIELD.

Although mainly situated in South Staffordshire, yet this Coal-field extends into the adjoining counties of Warwick, Worcester, and Salop. It extends from Cannock Chase on the north to Halesowen, including the country east of Wolverhampton, and around Bilston, Wednesbury, Tipton, etc.[2] The beds comprise :—

Upper Series.—Consisting of red, green, and mottled clays, red and grey sandstone, etc., 800 to 1300 feet.
Middle and Lower Series.—Shales, sandstones, etc., with thick coals, ironstone, etc., 400 to 510 feet.

Marine mollusca occur in the ironstones, including *Discina*, *Producta*, and *Conularia*. Fish-remains occur, such as *Holoptychius*, *Megalichthys*, and *Cochliodus;* and also Arachnida.

At Parkfield Colliery, near Wolverhampton, many stumps of trees have been laid bare in an open work of the Coal-measures; no less than seventy-three fossil trees have been counted in the space of a quarter of an acre. Hence this "Fossil Forest" has attracted a good deal of attention.[3]

The occurrence of a boulder of quartzite in one of the coal-seams has been noted by Prof. T. G. Bonney.[4]

The most remarkable seam in the Dudley district, or indeed in the British Islands, is the 'Ten yard' or 'Thick coal,' which has a general thickness of 30 feet. This, however, is due, as Mr. Jukes has pointed out, to the fact that over a considerable area a number of coals come together, resting one upon another, with little or no interstratified shale or partings. The number of beds composing this thick seam is reckoned at from 10 to 14 in different places. The thick coal is maintained more or less completely over all the district around Dudley as far as Bilston, Wednesbury, Halesowen, and Kingswinford. At Fox-yards, two miles north of Dudley, this coal-seam was obtained formerly by "open work" in a large quarry. Eventually it splits up into ten seams with a total thickness of 500 feet of strata.

Cannock Chase and Walsall are localities of importance in this Coal-field; and the Rowley Rag basalt is well known in connection with the district; according to Jukes, it forms part of the Coal-measure Series, having been poured out as a sheet of lava during this

[1] Hull, Coal-fields, edit. 4, p. 193.
[2] The South Staffordshire Coal-field, by J. B. Jukes, edit. 2, 1859 (Geol. Survey).
[3] See H. Beckett, Q. J. i. 41; and Proc. Dudley Geol. Soc. iii. 128.
[4] G. Mag. 1873, p. 289.

period. The coal beneath the basalt has been altered and has lost its inflammability.

A group of sandstones, known as the Halesowen Sandstones, 200 to 300 feet thick, occurs in the Upper Coal-measures, above the red and mottled clays in the southern portion of the Coal-field.

The Coal-measures rest on an irregular surface of the Silurian rocks, which rise to the surface at Dudley, Sedgley and Hay Head. The lowest beds of the Coal-measures consist of sandstones, containing pebbles of quartz and fragments of Silurian shale and limestone. The junction was well shown in the railway-cutting at Trindle Gate, east of Dudley.[1]

The Ironstone measures, which supply material for the iron-foundries of Dudley and the factories of Birmingham, range beneath the Thick coal from Wednesbury and Bilston, Walsall and Wolverhampton, to Cannock Chase. To the south they occupy the district between Stourbridge and Halesowen, and yield the well-known "fire-clays."[2] The term Blackband ores is applied to layers of ironstone and clay, alternating with coaly matter.

At Bilston, in Staffordshire, certain fine sandstones are quarried for the *Bilston grindstones*, which are of great excellence. A burning coal-seam has been noticed at Bradley, near Bilston.[3]

10. SEVERN VALLEY COAL-FIELDS.

The Severn Valley Coal-fields include several straggling and isolated tracts of Coal-measures in Shropshire and Worcestershire. Among these are the Shrewsbury Coal-field, the Coalbrookdale Coal-field, and the Forest of Wyre Coal-field.

The Shrewsbury Coal-field includes a tract extending southwestwards of that town, and a detached tract extending to Le Botwood to the south. In the upper series of Coal-measures, here and in the Forest of Wyre, there are two beds of limestone, from three to seven feet in thickness, containing *Spirorbis pusillus*, and known as the 'Spirorbis Limestone.'[4]

In the Coalbrookdale Coal-field, which extends from near Lilleshall, southwards between Wellington and Shiffnal, and includes the district around Broseley, Madeley, and Iron-Bridge, the Coal-measures are divided as follows:[5]—

Upper Series.—Mottled clays and greenish grits; calcareous breccia with band of Spirorbis Limestone. 300 feet.

Middle Series.—Yellow sandstones, shales and clays, with ironstones, and coal-seams. Fish-remains, *Anthracosia*.

Lower Series (*Ganister* or *Pennystone Series*).—Sandstones, shales with coal and ironstone (Pennystone and Crawstone bands). Marine fossils.

[1] South Staffordshire Coal-field (Geol. Survey), edit. 2.
[2] Murchison, Proc. G. S. ii. 408.
[3] G. Mag. 1867, p. 47.
[4] Daniel Jones, Trans. Manchester G. S. x. 37.
[5] See E. Hull, Q. J. xxxiii. 629; also J. Prestwich, T. G. S. (2), v. 428.

The thickness of the Lower and Middle Coal-measures is estimated at about 1000 feet. The coal-seams vary from one to six feet in thickness. Cannel Coal is rare.

There appears to have been some denudation of the lower portion of the Coal-measures before the uppermost strata were deposited.[1] And the Great Symon "Fault," according to Mr. Marcus W. T. Scott, indicates the existence of an old valley or estuary of denudation of the Coal- and Ironstone-measures, in which, subsequently, other strata of the Coal-measures were deposited.[2]

The Pennystone Ironstone nodules found in the Lower Coal-measures often yield, when split open, impressions of Ferns, fruits of *Lepidodendron*, Insects, and Crustacea. The Crustacea belong to the order *Xiphosura*, and the genus *Prestwichia*, named by Dr. H. Woodward, is allied to the recent King-crabs.

The Chance Pennystone is the highest bed of ironstone in the series. In former years Coalbrookdale produced the best iron in England.

The Forest of Wyre (or Bewdley Forest) Coal-field is connected with that of Bridgenorth by a band of Coal-measures stretching through Billingsley; and southwards the Coal-measures extend to Bewdley and Abberley. The Coal-measures rest on the Old Red Sandstone and are overlaid by Permian rocks.[3] The coal-seams of the Forest of Wyre are thin and of inferior quality, being charged with much pyrites. The coal is, however, useful for lime-burning, etc.[4]

Outlying tracts of Coal-measures occur on the Titterstone and Brown Clee Hills in Shropshire, and at Cleobury Mortimer. In the former two cases the beds are capped by basalt, locally known as Jewstone. In the Cornbrook Coal-field (Titterstone) the Coal-measures are to a large extent covered with this igneous rock, which has served to protect them from denudation. It varies in thickness from 60 to 150 feet. In the Brown Clee Hills the Coal-measures rest on the Millstone Grit and Lower Old Red Sandstone, while at Harcott there is a trace of Coal-measures resting directly on the Old Red Sandstone.[5]

Further south, between Malvern and May Hill, several exposures of Coal-measures occur between the New and Old Red Sandstone. In this tract, sometimes termed the "Newent Coal-basin," four seams of coal were at one time worked at Bowlsden, near Newent.[6]

[1] D. Jones, G. Mag. 1871, p. 200.
[2] Q. J. xvii. 463.
[3] Q. J. xxiii. 32.
[4] G. E. Roberts, The Rocks of Worcestershire, p. 130.
[5] See Murchison, Silurian System, p. 113; D. Jones, G. Mag. 1871, p. 363, 1873, p. 350.
[6] Murchison, Proc. G. S. ii. 121; J. Phillips, Mem. Geol. Survey, vol. ii. part i. pp. 104, 158.

11. FOREST OF DEAN COAL-FIELD.

This Coal-field extends from near Mitcheldean by Coleford to near Lydney, in Gloucestershire.

The Coal-measures attain a thickness of 2765 feet, and contain fifteen seams, of which eight are of a thickness of two feet and upwards. The thickest seam is about five feet.

As remarked by Prof. Hull, this Coal field forms a more perfect "basin" than any other in England. The uppermost strata comprise about 830 feet of sandstones and shales with thin coals, beneath which are the principal seams worked, and these belong to the Lower Coal-measures.

There is a remarkable instance of what is called a 'horse' in this Coal-field, which appears to have been a channel cut amongst a mass of vegetable matter, and afterwards filled with mud, during the Coal-measure period. The Dean Forest stone is used for building-purposes and grind-stones.

Along the south-west side of this Coal-field, near Lydney, the Millstone Grit and Carboniferous Limestone are overlapped unconformably by the Coal-measures.[1]

12. BRISTOL AND SOMERSET COAL-FIELDS.

The principal portion of these Coal-fields extends from Cromhall Heath near Tortworth in Gloucestershire, by Iron Acton, Brislington, and Mangotsfield, between Bristol and Bath, to Radstock, and other places north of the Mendip Hills. The Coal-measures are divided as follows:[2]—

Upper Series.—	*a.* Radstock, etc. *b.* Farrington Gournay and Coal-pit Heath.	Sandstones, shales and coal. 2000 feet.
Middle Series.—	Chiefly sandstone.	2000 feet (Pennant Grit, 970 feet).
Lower Series.—	*a.* Kingswood, etc. *b.* Bristol, Vobster, etc.	Sandstones, shales, and coal. 2500 feet.

Three Coal-basins are exposed at the surface, that of Bristol and Radstock (which is, however, much concealed by Secondary strata), the little faulted tract of Clapton-in-Gordano, and that of Nailsea. One other has been proved by Mr. C. Richardson, in the bed of the Severn, and this may possibly be connected with the Clapton Coal-field. The Severn Tunnel was excavated partly in Millstone Grit, Coal-measures, and Triassic Rocks.[3] While to the south of

[1] See Mushet, T.G.S. (2), i. 288; H. Maclauchlan, *Ibid.* v. 195; J. Buddle, *Ibid.* vi. 215; De la Beche, Mem. Geol. Survey, vol. i. p. 203.

[2] Geology of East Somerset and the Bristol Coal-fields (Geol. Survey), 1876 (this contains a list of works by J. M'Murtrie and others); J. Anstie, The Coal-fields of Gloucestershire and Somersetshire, 1873; E. Wethered, Midland Naturalist, iv. 25, 59; H. E. Hippisley, G. Mag. 1878, p. 345; H. Cossham, E. Wethered and W. Saise, The Northern End of the Bristol Coalfield, *Colliery Guardian*, Sept. 17, 1875. See also Buckland and Conybeare, T.G.S. (2), i. 210.

[3] Evan D. Jones, P. Geol. Assoc. vii. 339.

the Mendips beneath the flats of Sedgemoor there is very little doubt that another Coal-tract exists. (See Fig. 24, p. 160.) The eastern limits of the Coal-basin to the north of the Mendips may be pretty well defined, but those of the probable basin to the south are not known.

The productive Coal-measures are divided into an upper and lower series, separated by a middle unproductive series, which includes the Pennant Grit. The middle series is largely composed of grit-beds, which are much used for building-purposes. Grits are exposed at Yate Common, Iron Acton, Mangotsfield, Hanham, Brislington, Nailsea, Temple Cloud, etc. The Pennant Grit and the Francomb Stone belong to this division, which is sometimes termed the Pennant Grit Series. In the Bristol district the Holmes Rock, formerly classed as Millstone Grit, and the Doxall Stone, are included in the lower series of Coal-measures.

Although the Radstock coal-district is much concealed by Secondary strata, yet owing to their attenuation pits are sunk through the Lias, and at Clan Down, even through Inferior Oolite. The heaps of refuse, or "tips," thrown out from the mines form very marked features in the country near High Littleton, Paulton, and Radstock. The depths of the Coal-pits vary from 500 to 2000 feet. Few Coal-pits are so free from fire-damp. At Radstock the colliers work with naked candles, but in some parts, as in the Nettlebridge Valley, there is a liability to fire-damp. The seams of coal worked are often very thin, being near Radstock from one to three feet in thickness.

The Radstock district is noted for the variety and preservation of the fossil plants.[1]

Among the remarkable features of this Coal-field are the masses of Carboniferous Limestone at Luckington and Vobster (see p. 161); the Radstock slide fault, in which the downthrow is as much as 180 feet in places, and the 'overthrust' 1050 feet; while in the Nettlebridge Valley the beds are greatly disturbed, in some places the coal seams are vertical, and in others so twisted and faulted that the same seam of coal has been penetrated three times in one shaft. These disturbances are somewhat similar to those met with in the Belgian Coal-fields.

13. NORTH WALES COAL-FIELDS.

The Coal-measures of North Wales are separated by an extensive fault into two tracts, respectively called the Flintshire and Denbighshire Coal-fields. Probably they are connected underground with the North Staffordshire Coal-field. (See Fig. 3, p. 25.)

In Flintshire the beds extend along the borders of the Dee, by Mostyn and Flint, and further south from Mold to Hawarden. In Denbighshire the beds extend from Minera, west of Wrexham, by Ruabon, and Chirk to Oswestry in Shropshire.

[1] See also E. Wethered, Proc. Cotteswold Club, vii. 73.

The general thickness in the Denbighshire Coal-field is as follows:—

Upper Series.—Red and grey sandstones, red clays, shales, and thin coals, with Spirorbis Limestone. 1000 feet.
Middle Series.—Sandstones and shales, with coals and ironstone. Fish remains, *Anthracosia*. 800 feet.
Lower Series.—Grits, flags, and shales, with thin coals. *Goniatites*. 1000 feet.

In North Flintshire the Millstone Grit is overlaid by the Gwespyr Sandstone (upwards of 100 feet thick), and by the Holywell Shales, which occur near Holywell.[1] The Shales contain bands of limestone which have yielded *Posidonomya Gibsoni*, *Aviculopecten papyraceus*, etc.

Near Leeswood, south-east of Mold, there is evidence of contemporaneous erosion in the Coal-measures, as Mr. A. Strahan informs me that a channel filled with debris of Cannel Coal, etc., occurs in the Coal-measures. This is a feature like the 'horse' in the Forest of Dean.

In the Denbighshire Coal-field the Coed-yr-allt rock, 30 to 60 feet in thickness, a greenish-white and grey sandstone, belonging to the Upper Coal-measures, has been quarried. The Newbridge shales belong to the Upper Coal-measures in this district. These rocks have been described by Mr. D. C. Davies, who has drawn attention to the occurrence of coal-seams in beds which he regarded to be of Permian age near Ifton, between Wrexham and Oswestry in Shropshire.[2] There is little doubt, however, that these beds are iron-stained Coal-measures. At Oswestry there is but one bed of good coal.

A small patch of red unproductive Coal-measures rests on the Carboniferous Limestone opposite Caernarvon. A band of unproductive Coal-measures forms a narrow strip of coast-line between Caernarvon and Llanfair-is-gaer, and is succeeded by a belt of Carboniferous Limestone thence to Gored-girth on the coast near Bangor.

In Anglesey a little tract of Coal-measures is preserved at Malldraeth Marsh, owing to a great fault, which has a downthrow of upwards of 2000 feet. The Coal-measures attain a thickness of over 1300 feet, and contain seams from one to nine feet in thickness, which have been worked.[3]

14. SOUTH WALES COAL-FIELD.

This is the largest Coal-field in England and Wales. It occupies parts of the counties of Monmouth, Glamorgan, Caermarthen, and Pembroke, including an area of about 900 square miles. The Coal-measures are developed to the south of Haverfordwest, and again at Swansea, Neath, Llantrissant, Caerphilly, in the Taff and Rhondda Vales, at Pontypool, Tredegar, and Merthyr Tydfil.

[1] A. Strahan, Geology of Rhyl, etc. (Geol. Survey), p. 20.
[2] Proc. G. Assoc. iii. 138; Q. J. xxxiii. 10, xli. 107 (Proc.).
[3] A. C. Ramsay, Geology of North Wales (Geol. Survey), edit. 2, pp. 10, 11, 261.

FIG. 29.—SECTION OF THE SOUTHERN SIDE OF THE SOUTH WALES COAL-FIELD, NEAR SWANSEA.[1]
(Sir W. E. Logan.) Scale an inch to 2 miles.

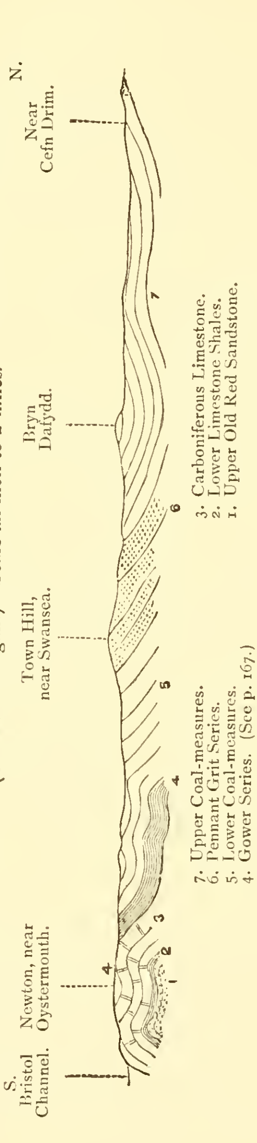
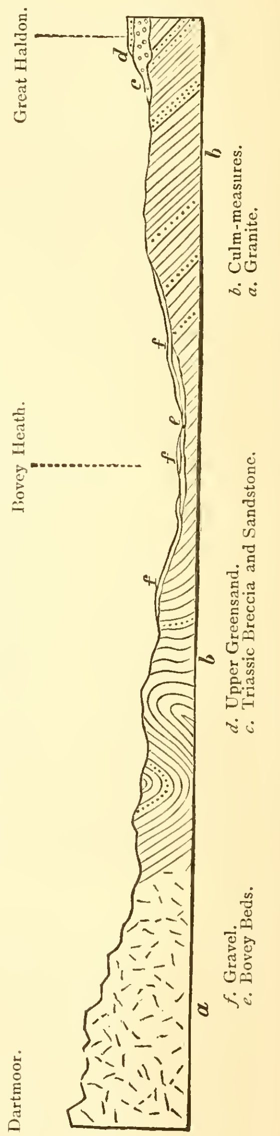


FIG. 30.—GENERALIZED SECTION FROM DARTMOOR TO GREAT HALDON.
Scale half-an-inch to a mile.



[1] See Horizontal Sections, Sheet 9 (Geol. Survey).

The following general succession of the Coal-series has been given by De la Beche:[1]—

Upper (*Penllergare*) *Series.*—Sandstones, shales, and 26 coal-seams, more than 3400 feet in thickness.
Middle Series (Pennant Grit).—Hard and thick-bedded sandstones, with 15 coal-seams, 3246 feet in thickness. Cockshoot rock at base.
Lower (*or White Ash*) *Series.*—Principally shales, rich in ironstone, 34 coal-seams, 450 feet thick near Pontypool, to 850 feet near Merthyr Tydfil. (Ironstone Series.)
Millstone Grit and Gower Series. (See p. 167.)

The Lower Coal-measures form the iron-bearing strata at Merthyr Tydfil and the Taff Vale. The clay-ironstone is an impure carbonate of iron, which yields from 50 to 80 per cent. of ore. Fortunately the strata are rolled into two or more anticlinal axes, one of which, running through the neighbourhood of Maesteg, brings the Lower Coal-measures near the surface over a much larger area than would otherwise have been the case.

The total thickness of all the coal-seams taken together has been estimated at 120 feet: they vary in thickness from two to nine feet. Peacock Coal has been met with in the Mynydd Ystwyn Vein, in Monmouthshire.

The junction of the Lower Coal-measures and Pennant Grit is marked near Maesteg, east of Neath, by two or three beds of quartz-rock, known as the "Cockshoot Rock."

A remarkable feature in connection with the coal is, that while bituminous in the neighbourhood of Swansea, and to the east of Neath, it becomes anthracitic westward and northward. The changes, which appear to be gradual, are chiefly due to a loss of oxygen and hydrogen, and it is considered clear that similar changes must be going on where carbonic acid gas and carburetted-hydrogen are given off.

That the change from bituminous coal to anthracite might be connected with igneous eruption has been suggested from the fact that in Pembrokeshire eruptive rocks occur in proximity to the Coal-measures; but Prof. L. C. Miall has pointed out that coal altered by contact with igneous rocks does not form anthracite, but "cinder coal," or "soot coal." According to his experiments, coal loses its volatile constituents at ordinary temperatures, and this is facilitated by disturbance of the strata.[2] Mr. E. Wethered attributes the change in the coals to the changes in the sedimentary strata accompanying them, which must have had a considerable effect on the vegetable mass.[3] In any case, by the changes undergone, fuel of great variety, and suitable for numerous purposes, has been furnished. In Pembrokeshire the beds are much dislocated and contorted. Culm is exposed at Landshipping.[4]

[1] Mem. Geol. Survey, vol. i. p. 197.
[2] Proc. Geol. and Polytech. Soc. W. Riding (2), i. 22. See also Murchison, Proc. G. S. ii. 227; and E. T. Hardman, Journ. R. G. S. Ireland (2), iv. 200.
[3] G. Mag. 1881, p. 470.
[4] See Murchison, Silurian System, p. 371; Siluria, edit. 5, p. 290.

The Pennant Grit is essentially a sandy series. De la Beche described a section at the Town Hill, Swansea, of 3246 feet of strata belonging to the series, of which 2125 feet were sandstone. It comprises some seams of workable coal (Hughes's vein, five feet), underclay, and shale. Mr. E. Daniel divides the Pennant Grit into three groups.

One of the most remarkable beds in the South Wales coal-field is that discovered by Logan in the Pennant sandstones, on either side of the Tawe Valley, Swansea. It consists of a conglomerate containing pebbles of coal, sometimes four inches in diameter, pebbles of ironstone, and boulders of granite and mica-slate; these latter very rarely.[1] The presence of this bed indicates that the Lower Coal-measures must have been (at any rate locally) consolidated and upheaved prior to the accumulation of the Pennant Grit; and this disturbance might perhaps have had something to do with the production of the anthracite. Pebbles of anthracite have been noticed in the Pennant Grit and Upper Coal-measures of the Bristol Coal-field.[2]

The Pennant Grit forms a marked escarpment above the Lower Coal-measures, from the Garth Hill (1650 feet high) near Cardiff, by Llantrissant and Margam to Aberafon, Neath, and Swansea. North of the coal-basin the Pennant Grit is conspicuous near Aberdare and Merthyr Tydfil.

The South Wales Coal-field thus forms a basin which is one of the most uniform and well-marked in the country, although its continuity is broken by the bays of Swansea, Caermarthen, and St. Bride; and the Coal-measures themselves stand up in bold hills, for the most part above the southern edge of the basin.

One advantage of the deep valleys is the beautiful scenery they afford to ramblers in search of the picturesque;[3] another advantage lies in the fact that the coal crops out along their sides, and can often be worked by adits and galleries driven into the hills, instead of by shafts sunk from their summits.

In the Upper Coal-measures are the beds of Penllergare north of Swansea, and of Llanelly; and they occur at Mynydd Drumau and Mynydd March Howel.

Remains of *Anthrakerpeton*, an air-breathing Reptile, have been found in the Coal-measures of Llantrissant, by Mr. J. E. Lee.

15. DEVONSHIRE CULM-MEASURES.

The Coal-measure rocks of Devonshire can only for the sake of convenience be grouped with those of other parts, for they certainly form a very unproductive series so far as coal is concerned. They were grouped with the Carboniferous System in 1836 by Sedgwick and Murchison.

[1] T. G. S. (2), vi. 491.
[2] Geol. Mag. 1865, p. 134; see also H. K. Jordan, Q. J. xxxiii. 932.
[3] See papers by Dr. G. P. Bevan, Geologist, i. 49, 124; iii. 90; and G. Mag. 1865, p. 158.

The term Culm-measures was applied to the 'Carbonaceous' rocks of Devonshire on account of the workings for Culm near Bideford and other places. The term 'Floriferous Slates' was used by the Rev. D. Williams, because plants are very generally distributed, while culm is confined to a small area.

Looked at in a large way, they consist of a series of black shales, sometimes cleaved, greenish-grey sandstones and grits, occasional beds of quartzose conglomerate, chert-beds, with bands of limestone here and there. The shales are locally known as "Shillet," and the sandstones as "Dunstone."

The series occupies a trough between the Devonian rocks of North Devon and West Somerset and those of South Devon and Cornwall. The beds may therefore be said to occupy a basin or synclinal, but they exhibit in almost every section faults and great undulations and contortions, so that any estimate of their thickness must be very vague.

Some authorities have placed them, generally, on the horizon of the Millstone Grit, but there seems to be good reason to include with them representatives of at least a portion of the true Coal-measures, and also of the Carboniferous Limestone, and Lower Limestone Shales. (See p. 147.)

The following general divisions may be made in the Series:—

Culm-measure Series.	Lower Coal-measures?	Thick even-bedded grey grits, with slates and shales. Sandstones, grits and shales, with beds of culm.
	Millstone Grit?	Coddon Hill Beds (local).
	Lower Carboniferous?	Shales, with thin grits, impersistent limestones and occasional beds of culm.

The Culm-measures, above the Coddon Hill Beds, have been described as containing ironstone and coal-measure plants, and resembling the coal-deposits of Pembrokeshire.

Some of the culm-beds of Devon have been considered to be subordinate to the Millstone Grit, although most of it overlies the presumed equivalent of that formation, and is probably on the same horizon as the culm of Pembrokeshire.

Until the divisions of the Culm-measures are mapped out in detail, we must refrain from committing ourselves to any definite correlation, for Mr. W. A. E. Ussher, who is intimately acquainted with the area, tells me it is quite possible that the Coddon beds may underlie the limestones, or their representatives, near Venn, Morebath, and Ashbrittle.[1] However, this uncertainty may arise from flexures in the strata, which disturb their natural sequence.

Among the fossils of the Culm-measures, the plant-remains include *Calamites Roemeri*, *Sigillaria*, *Lepidodendron*, *Dadoxylon*, *Pecopteris*, *Asterophyllites*, etc.[2] *Anthracosia* and *Cœlacanthus* have

[1] Proc. Somerset Arch. and Nat. Hist. Soc. vol. xxv. 1881.

[2] See T. M. Hall, Trans. Devon Assoc. vii. 367, and Geology of Devonshire (in White's History), 1878; also R. Kidston, G. Mag. 1884, p. 534 (footnote).

also been met with. The upper beds of the Culm-measures, according to Mr. Ussher, include the fine-grained even-bedded grits of Eggesford (Eggesford grits) south of Chumleigh. They contain subordinate beds of shales and slates, and occur over the area between Hatherleigh and Torrington, at Iddesleigh, etc. The middle beds of Culm-measures consist of sandstones, grits, and shales, with beds of culm, and outcrop to the north and south of the Eggesford grits, which overlie them. They comprise rather coarse grits and shales, with culm near the base, and are developed at Hartland Point, at Bideford, Morchard Bishop south-east of Chumleigh, and Umberleigh between Chumleigh and Barnstaple.

The Coddon Hill Beds, of Coddon Hill, south-east of Barnstaple (described by Phillips), consist of pale grey, or black chert, in thin striped beds like some of the bedded chert of Leyburn, in Wensleydale. Black grits, with jasper rock and lydian stone, and shales of variable thickness, go to make up this series, the total thickness of which was estimated at from 1500 to 2000 feet by the Rev. D. Williams.[1] *Orthoceras*, *Goniatites*, and *Posidonomya* occur in the shales.

The lowest beds comprise a series of black shales with thin grits and impersistent bands of dark or black limestone (Culm-limestone), containing similar fossils, and known as the *Posidonomya* (*Posidonia*) limestone. This limestone extends from Bampton to Fremington, near Barnstaple, and has been worked at Instow, Swimbridge, and Venn near Barnstaple, and near South Molton, frequently exhibiting remarkable folds and contortions.

The limestones are also exhibited at Westleigh and Canonleigh, near Holcombe Rogus, and Hockworthy, between Wellington and Tiverton, where the beds also are much disturbed. From the last-named localities the Rev. W. Downes has obtained *Chonetes Laguessiana* (*C. Hardrensis ?*), *Orthis Michelini*, and *Spirifera*, also *Posidonomya Becheri* and *Goniatites*.[2]

No limestones appear in the centre of the Culm-measure district, but they reappear in South Devon at Trescott, near Launceston, Lifton, Lew Trenchard, Bridestow, Oakhampton, South Tawton, and Drewsteignton. Remains of *Cœlacanthus* have been met with at Instow.

Certain black shales at or near the base of the Culm-measures in South Devon have hitherto been regarded as yielding few fossils; but in 1884 Mr. J. E. Lee obtained a number of interesting specimens, including Trilobites, from shales that overlie the Devonian Limestones at Waddon Barton, near Chudleigh. These include four species of *Phillipsia* (described by Dr. Henry Woodward), together with *Goniatites sphæricus*, *Orthoceras striolatum*, *Posidonomya Becheri*, *Avicula lepida*, *Chonetes deflexa*, *Spirifera Urii*, etc.[3] These

[1] Proc. G. S. iii. 116 ; De la Beche, Report on the Geology of Cornwall, etc. p. 101 and P. G. S. ii. 106 ; Phillips, Palæozoic Fossils of Cornwall, etc. pp. 189–195 ; Sedgwick and Murchison, T. G. S. (2), v. 670 ; H. B. Holl, Q. J. xxiv. 400.

[2] Trans. Devon Assoc. 1878 and 1879.

[3] G. Mag. 1884, p. 538.

species are Lower Carboniferous types, although *Phillipsia* is known in the Millstone Grit. (See p. 168.)

The lower beds of the Culm-measures occasionally contain seams of culm. Good sections of the beds are exposed at St. David's, Exeter; they extend to Holsworthy, and on the north side of the Culm-trough they outcrop at Appledore and north of Bideford.

Mr. T. M. Hall observes that the transition from the Upper Devonian slates to the Lower Carboniferous shales is almost imperceptible, although the boundary is much concealed in North Devon by detritus and superficial deposits. Thus immediately north of Barnstaple the slates contain numerous Upper Devonian (Pilton) fossils; south of the town the slates, to all appearance precisely similar, contain well-known Carboniferous species. (See p. 129.)

The Culm-measures are exposed along the coast between Boscastle in Cornwall and Bideford in Devonshire, where in general there is a splendid series of cliffs, those near Clovelly and Hartland being especially remarkable, not only for their height, but also for the manner in which the beds have been dislocated, crumpled up, overturned, and contorted.[1] North of Boscastle the beds are traversed by large quartz-veins.

It is generally considered that the Culm-measures were consolidated prior to the intrusion of the Dartmoor granite. In the higher part of the Teign valley, near Lustleigh, and other places bordering the granite of Dartmoor, the rocks are much disturbed and metamorphosed, and there beds of indurated black slate and grits with chert-beds occur.[2] Some beds pass into lydian stone: this is a very siliceous rock, containing carbon, which gives it a grey or black colour, hence it is sometimes known as Black Chert. Jasper also occurs in the so-called Carboniferous rocks near Brent Tor: this is an impure and opaque form of silica, coloured red, yellow or brown by oxides of iron.

The Culm-measures in this area are not only broken by dykes of "greenstone," but also by veins of quartz-porphyry (elvan).

The boundary of the Culm-measures and Devonian rocks in South Devon has not, however, been very definitely fixed in the neighbourhood of Dartmoor, and Mr. F. Rutley informs me that it is questionable whether the granite comes in contact with the Culm-measures on the western side of this range. Near Tavistock the beds are rich in metalliferous deposits.

The Culm-measures, particularly between Barnstaple and South Molton, are noted for the occurrence of Wavellite (hydrous phosphate of alumina). It was discovered in a band of indurated shale at the latter locality about 1785. It exhibits its radiating crystals on the broken transverse joints of the slaty rocks: hence the term 'Wavellite schists.' The same mineral has also been met with in the Gower Series of Glamorganshire.

[1] T. M. Hall, Geology of Devonshire (in White's History), 1878. See also J. J. Conybeare, T. G. S. ii. plates 33 and 34.

[2] Dr. H. B. Holl, Q. J. xxiv. 411; G. W. Ormerod, Q. J. xv. 191, and Trans. Devon Assoc. 1867.

Mines of Lead, Iron, and Manganese have been opened in different places in the Culm-measures.

The beds of Culm stretch across the country from Barnstaple Bay and Bideford towards Chittlehampton west of South Molton, and they have been worked at different periods, although never with any great profit. They vary from 6 inches to 14 feet in thickness, occurring in lenticular masses, and at different horizons. They may be seen at Greenacliff on the coast near Bideford, Hiscott, and Umberleigh. The softer varieties of culm, when ground to a powder, are sold as a pigment, under the name of 'Bideford Black.' As a fuel it is useful for lime-kilns, etc. Murchison has suggested that possibly some of the culm-strata of Devon, devoid as they are of any workable coal, may yield bituminous products by the application of heat.

The beds of grit are sometimes sufficiently developed to be useful for building-purposes and road-metal, as near Chudleigh, while flagstone-beds are worked near Launceston and at Ashwater, Beaworthy, and other places west of Oakhampton. The Grinshill freestone has been worked near Bideford. Beds suitable for roofing-slate have been obtained at Boscastle.

According to Sedgwick and Murchison, some of the shales are calcareous, and contain masses of a variety of Rottenstone like that in Derbyshire. (See p. 167.)

The Culm-limestones are lenticular and impersistent, often passing into calcareous shale. In the large quarries seldom more than a third or fourth part can be burnt for lime; the alternating bands of dark indurated shale are used for flagstones or coping-stones.

The soil is usually poor, and the area is largely made up of rough pasture, woodland and moorland; but, as Mr. Ussher has remarked, the rocks afford some very charming river-scenery, and locally exhibit very pleasing contours.[1]

POSSIBILITY OF COAL-MEASURES IN THE EAST AND SOUTH-EAST OF ENGLAND.

It has been a fertile topic for speculation whether other Coal-basins may be met with beneath the Secondary and newer rocks, of the east and south-east of England. Although, as before mentioned (see p. 149), the idea had occurred to De la Beche, the subject was first discussed in a very elaborate memoir by Mr. R. A. C. Godwin-Austen.

Judging from facts brought to light in working the Coal-measures of Belgium and the North of France, "and reasoning also on theoretical considerations connected with the extension of the old coal-growth in the west of Europe, Mr. Godwin-Austen concluded that Coal-measures might possibly extend beneath the south-eastern part of England." Illustrating his remarks by a map, "he showed that the Coal-measures which thin out under the Chalk near Thérouanne probably set in again at or near Calais, and are prolonged (beneath the Tertiary strata and the Chalk) in the line of the Thames Valley parallel with the North Downs, and continue thence under the valley of the Kennet, into the Bath and Bristol coal area. He showed, upon well-considered theoretical grounds, that the Coal-measures of a large portion of England, France, and Belgium were once continuous, and that the present coal-fields were merely fragments of a great original deposit, which he inferred had been broken up in two directions previously to the

[1] Physical Features of Devonshire, Trans. Devon Assoc. 1880.

deposition of the Secondary rocks. He showed that the main line of disturbance had a general east and west direction, that part of it formed the great anticlinal of the Ardennes, by which the Belgian coal-field had been tilted up, and brought to the surface, and that the Mendips with the Somerset coal-field were on the same line of strike."[1] (See p. 161.) This is but a brief outline of the general conclusions arrived at in the paper, which really deals with the physical geography of the European area at many past epochs.

The possible occurrence of productive Coal-measures beneath the Cretaceous and Oolitic rocks of Norfolk has been pointed out on many occasions by Mr. J. Gunn; as yet, however, the matter remains a purely speculative one, and, inasmuch as the rocks exposed at the surface furnish no clue to the character or arrangement of the Palæozoic rocks beneath, the question can only be settled by boring.[2]

Several borings have been made which have reached Palæozoic rocks in the area under consideration; at present, however, the rocks thus met with are all older than the Coal-measures; and these older rocks are frequently so much disturbed, and sometimes even inverted, that no accurate calculations can be made on the probable position of the Coal-measures here or there, from the facts at present made known by our deep borings.

Thus at Harwich a dark bluish-grey slaty rock of Carboniferous age, probably of an age immediately antecedent to the Coal-measures, was met with at a depth of 1029 feet beneath the Eocene beds and Chalk. Under London, rocks classed as Devonian have been reached at a depth of 1066 feet; at Richmond and Kentish Town red rocks have been proved at depths of 1240 and 1114 feet (see p. 140); while at Ware in Hertfordshire, Silurian rocks (Wenlock Shale) were touched at a depth of only 800 feet beneath the surface. Moreover, in Belgium and the North of France, Coal-measures are found sometimes at depths of only 300 to 400 feet beneath the Chalk and Tertiary strata; and here they are accompanied, seemingly in perfect conformity, by Devonian rocks, like those found under London. (See also account of Well Sections.) Prof. Prestwich was disposed to think that the slaty (Carboniferous) rock at Harwich lay on the north side of a coal-basin, in which case the Lower Carboniferous and Devonian beds would rise beyond it and pass under Suffolk.

The accompanying diagram shows in a general way the evidence made known, and the depth at which the older rocks would be likely to occur.[3] (See Fig. 31.)

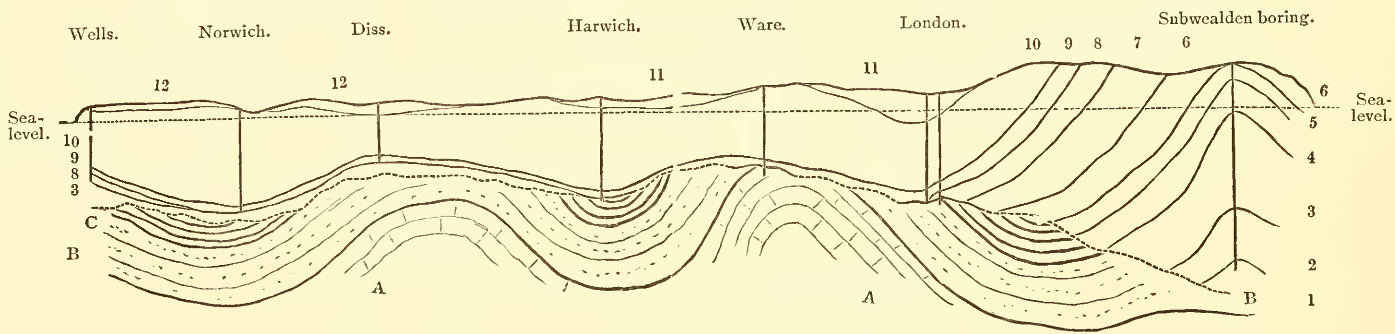
The evidence furnished by the Richmond boring is opposed to the prospect of finding coal at workable depths under the southern part of the London Basin. But Prof. Judd has noted the occurrence in the junction-beds above and below the Great Oolite at Richmond, of fragments of anthracite mingled with pebbles of Coal-measure sandstone; indicating that Coal-measures formed a part of the Palæozoic land at the time when the Jurassic strata were laid

[1] Q. J. xxii. 38. See Prestwich, Report Royal Coal Commission, vol. i. 1871, p. 146.

[2] See Geology of Country around Norwich, p. 168.

[3] Proc. Norwich Geol. Soc. i. 102; see also Whitaker, Guide to Geol. of London, edit. 4, and Topley, Geol. of Weald, p. 242.

FIG. 31.—DIAGRAM TO SHOW THE POSSIBLE OCCURRENCE OF COAL-MEASURES IN THE EASTERN COUNTIES.



Longitudinal Scale—25 miles to 1 inch.

Vertical Scale—2000 feet to 1 inch.

12. Glacial and Pliocene.
11. Eocene.
10. Chalk.
9. Upper Greensand and Gault.
8. Lower Greensand.
7. Weald Clay.

6. Hastings Beds.
5. Purbeck Beds.
4. Portland Beds.
3. Kimeridge Clay.
2. Corallian Beds ?
1. Oxford Clay.

C. Carboniferous rocks (shown in basins with thick lines).
B. Devonian and Old Red Sandstone.
A. Silurian.

N.B.—The vertical lines indicate borings and wells.

down in this area. Hence he truly observes that "Coal under London" has really been found, though as yet, unfortunately, not *in situ*.[1]

Economic products, etc., of Coal-measures.

Supply and Duration of Coal.—The subject of our supply of coal has been exhaustively treated in the Reports of the Royal Coal Commission.[2] It appears that there is a quantity of Coal in England and Wales in the visible Coal-fields, available at a depth not exceeding 4000 feet, equal to upwards of 80,000,000,000 of tons; whilst the amount of coal similarly available beneath the Permian and newer strata, is estimated at about 56,000,000,000 of tons. The probable duration of our supply is variously estimated, but it is considered good, at depths readily accessible, for about 250 years. Mr. R. Meade has estimated the entire amount of coal available from 1880 in the known Coal-fields of England and Wales at 69,192,056,317 tons; while reckoning the coal of Scotland and Ireland, and of the concealed Coal-fields as well, he thinks that supplies are insured for 920 years hence.[3]

In illustration of the economic uses of coal, it may be mentioned that the products of the distillation of 100 tons of Cannel Coal (according to Sir H. E. Roscoe) would be as follows:—

Gas	10,000 cubic feet, or 22 tons.
Coke about	60 tons.
Ammonia liquor	9½ ,,
Tar	8½ ,,

The ammonia liquor is sold for purposes of manufacturing ammoniacal salts and alum. The coal tar yields carbolic acid, naphthaline, paraffin, and benzole; and from benzole are produced the beautiful aniline colours (mauve, magenta, etc.).

Paraffin was formerly distilled from the Cannel Coal of Leeswood, south-east of Mold.

The flags and sandstones are extensively quarried for building- and paving-purposes, for firestone and for grindstones; while some of the beds (in Yorkshire) are used for polishing marble and the copper-plates for engravers.

The clays of the Coal-measures are used in the manufacture of bricks and tiles, earthenware and pottery. The Fire-clays have been extensively manufactured into fire-bricks at Stourbridge, and also at Newcastle, Bradford, and in South Wales. These clays, known as 'Refractory Clays,' are so termed because they resist exposure to high temperatures, without melting or becoming soft or pasty. They contain but little iron, and are nearly free from lime and alkalies. The Stourbridge clay consists of 79 per cent. of silica, and 13 per cent. of alumina, and contains but little water of combination, on which the plasticity of clay depends.[4]

In Shropshire a red marl from the Coal-measures has been employed in the manufacture of encaustic tiles.

Hæmatite occurs in nodules and bands in the Coal-measures of Cumberland, also near Leek, and at the fire-clay workings at Swadlincote, near Burton-on-Trent.

The Clay-ironstones (Sphærosiderite) of the Coal-measures yield much of the iron in this country, and they occur sometimes in thin seams, but usually in nodules. They are composed mainly of carbonate of iron, with also carbonates of

[1] Q. J. xl. 760.

[2] See also W. S. Jevons, The Coal Question, 1865.

[3] The Coal and Iron Industries of the United Kingdom, 1882, p. 313.

[4] J. Percy, Metallurgy, 1875. See also Catalogue of Specimens in the Museum of Practical Geology of British Pottery, etc., 3rd edit., by T. Reeks and F. W. Rudler. Appendix on clays, by G. Maw.

lime and magnesia, as well as argillaceous matter. They are worked principally in Staffordshire, Shropshire, Yorkshire, Derbyshire, and in North and South Wales. In the lower beds of the Coal-measures near Bradford, iron-pyrites has been worked for the manufacture of sulphuric acid and sulphate of iron.

Veins of Galena have been met with and worked in the Lower Coal-measures at Whaley in Cheshire, and near Chapel-en-le-Frith.

In the South Wales Coal-field, near Merthyr Tydfil, Hatchettine, or mineral tallow, a hydro-carbon, is found in crevices of the clay-ironstone. Petroleum springs have been met with in the Coal-measures near Broseley; one called the 'Burning Well' existed about a century ago.

The Coal-measures form generally an unproductive soil; but there are many exceptions. The fine deep soil in which the people of Pomfret (Pontefract) grow the liquorice-root to manufacture the "Pomfret Cakes," for which, among other things, their town is famous, seems to be largely composed of the débris of the Pontefract rock.[1]

[1] J. W. Kirkby, Q. J. xvii. 296.

Part ii.

SECONDARY OR MESOZOIC.

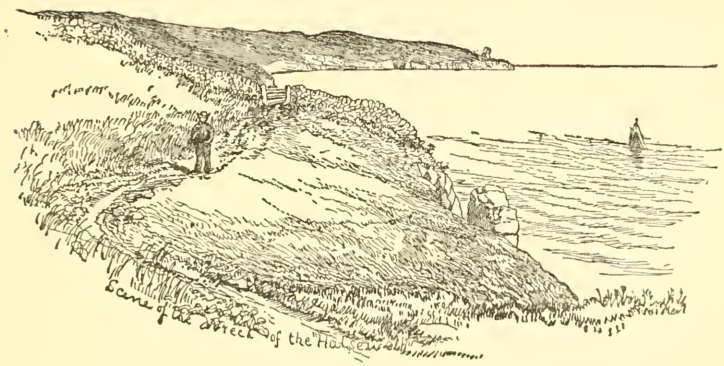


FIG. 32.—VIEW OF THE DORSET COAST, FROM NEAR HALSEWELL QUARRY LOOKING TOWARDS ANVIL POINT, NEAR DURLSTON HEAD. (Portland Rocks.)

COMPARED with the older rocks, the Secondary strata in England and Wales form a distinct group. The beds, although well consolidated, are yet, on the whole, free from the striking signs of alteration or metamorphism which are present in some of the older rocks. The lines of stratification are marked and easily recognizable, and the beds have suffered but little from the effects of great disturbance which are often so conspicuous in the deposits of earlier times. The rocks consist chiefly of alternations of sands, clays, and limestones, with every intermediate variety of these rocks. The term Mesozoic (signifying middle life) was proposed by John Phillips.[1] (See p. 31.)

[1] The name Floetz Class was applied by Werner to the Secondary strata, in the early days of Geology. It is a German term expressive of the fact that the beds most usually occur in flat horizontal layers. The term Supermedial Order was used by Conybeare in 1822. The term Neozoic was employed by Edward Forbes, to include the Secondary and Tertiary groups.

Although on the whole the Secondary strata lie unconformably upon the denuded Palæozoic rocks, yet, as Lyell remarked, "nowhere have geologists found more difficulty in drawing a line of separation than between the Secondary and Primary series," for there is no great palæontological break between them. Thus some geologists include the Permian rocks in the Palæozoic era, while others associate them with the Triassic rocks on account of the similarity in their characters and method of formation. This latter grouping is here adopted.

The formations from the New Red Sandstone to the Purbeck and Wealden Series are generally speaking conformable. In places these strata were upheaved and much denuded before the overlying Cretaceous rocks were laid down: for the Chalk and Upper Greensand overstep the outcropping edges of the older Secondary strata, and transgress from the Purbeck and Wealden Beds of Dorset to the New Red Marls and Sandstones of Devonshire. In Yorkshire, also, there is a similar overstep of the Upper Cretaceous rocks.

The following are the Secondary systems:—

Cretaceous.	Upper. Lower.	
Jurassic.	Oolitic Series. Liassic Series.	Mercian.[1]
New Red Sandstone or Poikilitic.		

The Secondary rocks are characterized by Marsupial Mammalia; by numerous remains of Reptilia, such as the *Ichthyosaurus* and *Plesiosaurus*, the *Ceteosaurus* and the *Megalosaurus*; by Mollusca, of the genera *Ammonites*, *Belemnites*, *Pleurotomaria*, *Pholadomya*, *Lima*, and *Trigonia*; by the Brachiopoda *Rhynchonella* and *Terebratula*; by Corals of the genera *Montlivaltia*, *Thecosmilia*, *Isastræa*, and *Thamnastræa*; and by Cycadeiform plants.

[1] Term suggested by Prof. T. McK. Hughes, Proc. Cambridge Phil. Soc. iii. 247.

NEW RED SANDSTONE OR POIKILITIC.

The term New Red Sandstone was originally applied to the red rocks that occur between the Coal-measures and the Lias, and it was used by Conybeare to distinguish these strata from the Old Red Sandstone, which underlies the Carboniferous rocks. Subsequently the New Red Sandstone was divided as follows :—

Trias.
Permian.

The name 'Poikilitic' (or Pœcilitic, from *poikilos*, meaning *variegated*) was likewise suggested by Conybeare as an equivalent term for New Red Sandstone. In their general lithological characters there is a marked similarity throughout the Permian and Triassic series, consisting as the rocks do of red, yellow, and variegated sandstones, conglomerates, and marls, with occasional beds of limestone.

The group forms a conspicuous band, stretching across England from the mouth of the Tees near Redcar and Hartlepool, to the mouth of the Exe, with a branch running to the mouth of the Mersey ; thus marking off the Palæozoic ground of the North of England, of Wales, and of the S.W. of England, from the Secondary and Tertiary tracts, which lie to the east and south-east. Another tract of the Red rocks occupies the Vale of Eden to the north and east of the Lake District.

The Permian and Triassic rocks, from their prevailing red colour, are equally prominent in the landscape, and the 'red ground' and 'red rocks' have given names to hamlets, villages, and towns, such as Retford, Radford, Radcliffe, Radstock, etc. : there is also the village of Redmarley Dabitot, in Worcestershire, between Newent and Upton-on-Severn. The red cliffs between Seaton and Torquay are striking features in our coast scenery ; while the red soils, and the deep red lanes mark the country in many places inland.

As before mentioned, the Permian and Triassic beds have been differently classed by geologists. On physical grounds Sedgwick grouped the Permian rocks with the Trias, while John Phillips first suggested that the Magnesian Limestone should on palæontological grounds be classed as Palæozoic ; but he subsequently united the Permian and Triassic rocks under the general heading

Poikilitic.[1] Thus, whilst the organic remains of the Permian rocks are considered to bind them more closely to the Palæozoic rocks than to the Trias, in their lithological characters and in the evidences of their method of formation, the two series are inseparably connected, and with them the Rhætic Beds may conveniently be classed. Of course different groupings of strata might be made on palæontological grounds, by considering the evidence of the land fauna and flora instead of the marine organisms;[2] but in this country, as a rule, organic remains are scarce, except in the Magnesian Limestone, which belongs to the Permian series, and in the Rhætic Beds, which occur at the top of the Trias.

The evidence of the Permian flora is not satisfactory, from the fact that much of the "Lower Red Sandstone," originally grouped as Permian, has proved to be iron-stained Coal-measures;[3] hence some of the plants recorded as Permian have in reality come from older rocks. (See p. 170.) The unconformity between the Red rocks and the Palæozoic rocks is generally very marked. This is the case throughout the south-west of England; and in Lancashire and Yorkshire the unconformity is equally striking, for the Carboniferous rocks had evidently undergone great disturbance and a large amount of denudation before the Permian epoch, so that the newer strata rest indifferently on various members of the older system.[4] (See Fig. 27, p. 183.) The symptoms of conformity between Permian and Coal-measures, noted in a few localities in the North of England, may in some cases be due to accidental concordance in the lie of the strata, and in other cases to the confusion which has arisen between the stained Coal-measures and the Permian rocks. Thus Mr. D. C. Davies was of opinion that at Ifton, in Shropshire, there is a passage upwards from the Coal-measures into Permian rocks, and that the latter contain seams of coal.[5] This view, however, has not been supported.

Some difficulties respecting our New Red rocks have arisen from attempts to correlate their divisions with those recognized on the Continent; but in a great mass of false-bedded sediments, it is not to be expected that beds of particular lithological character will be maintained for great distances. Moreover, even in this country it is not always easy to distinguish Permian from Triassic rocks; and in the case of the Bunter 'pebble-beds,' we have sometimes to apply the term to rocks that have few, if any, pebbles in them. In Devonshire, where there is exposed a clear succession of red rocks, it is questionable whether Permian is represented as well as Trias, and it is not possible to say for certain where

[1] Geol. Oxford, etc., p. 94.

[2] See Huxley, Address to Geol. Soc. 1870; P. M. Duncan, Address, 1877; also W. T. Blanford, Q. J. May, 1886.

[3] R. Howse, Ann. Nat. Hist. (2), xix. 37; see also J. W. Kirkby, Nat. Hist. Trans. Northumberland, iii.

[4] E. W. Binney, G. Mag. 1866, p. 49.

[5] Q. J. xxxiii. 10; and xli. 107 (Proc.).

the representative of the Bunter division commences or terminates in the series.

The presence in Central Europe of the Muschelkalk, comprising compact red and grey limestones with dolomite, about 1000 feet in thickness, and the absence of this calcareous division from Britain, has led to our series being regarded as incomplete; but there is no reason for doubting that other kinds of sediment may in this country represent it.[1]

Near Nottingham there is evidence of the overlap of Permian rocks by the Trias, which crosses some of its upper divisions, and finally rests on the Coal-measures.[2] Even here there is no positive evidence of denudation between the Permian and Bunter formations, inasmuch as the overlap by the Bunter Sandstone may have coincided with a depression of the area that took place after the Upper Permian Beds were deposited. Similar instances of overlap are met with in other parts of the North of England; and, as Mr. E. Wilson has pointed out, the fluctuations in character and thickness of the New Red rocks depend on the physical inequalities and limitations of the areas of deposition, and on the contemporaneous inequalities of subsidence. Evidences of local and contemporaneous erosion occur at all horizons in the New Red series.

From the occurrence of brine-springs and beds of rock-salt in the higher portions of the New Red rocks, the term Saliferous System has been employed for the entire series of these rocks.

In treating of the physical history of the Permian and Triassic rocks of Great Britain, Sir Andrew Ramsay has pointed out that the beds were deposited in great inland lakes for the most part salt. One objection might be taken to this theory, inasmuch as the organic remains of the Magnesian Limestone are truly marine types. But these are very much restricted when compared with those of Carboniferous times, and in the poverty and dwarfing of the forms, the fossils of this rock may be compared with the still less numerous fauna of the Caspian; so that they might have lived similarly in a large inland salt lake which had previously been connected with the open ocean.[3] There were perhaps

[1] G. Mag. 1874, p. 385. On the subject of Permian and Trias, see Murchison, Siluria, edit. 5, p. 327; W. T. Aveline, Geol. Nottinghamshire, etc., edit. 2 (Geol. Survey Map, 82 N.E.), p. 26; Rev. A. Irving, P. Geol. Assoc. iv. 52, 79; G. Mag. 1874, p. 315; 1882, pp. 158, 272, 316; and 1884, p. 324; E. Hull, G. Mag. 1882, p. 491; Q. J. xiv. 224; W. T. Aveline, G. Mag. 1877, p. 155; E. Wilson, G. Mag. 1880, p. 93.

[2] G. Mag. 1877, pp. 155, 239, 309.

[3] Q. J. xxvii. 189, 241. See also Prof. A. H. Green, G. Mag. 1872, p. 99; J. G. Goodchild, Trans. Cumberland Assoc. No. ix. 1885; and E. Wilson, Midland Naturalist, iv. 202.

times when the sea had access to the area, but on the whole the New Red Sandstone was deposited when the physical conditions were somewhat similar to those of the Old Red Sandstone.

The red colour of the rocks is in many cases due to the component materials being coated with films of peroxide of iron during the formation of the beds. The deposition of iron-ore in this form is not known to take place in modern marine accumulations, but instances occur in some of the Swedish lakes. Hence the red colouration, taken in conjunction with the occurrence of gypsum and rock-salt, helps to confirm the view that the New Red rocks were formed in lacustrine areas.

Evidences of Glacial action during Permian times have been brought forward by Sir A. C. Ramsay, but they have been questioned. (See sequel.)[1]

The New Red Sandstone series in the northern and midland counties of England was traced out on the Geological Survey Maps, chiefly by Mr. H. H. Howell, Prof. E. Hull, Mr. J. G. Goodchild, Mr. T. V. Holmes, Mr. C. E. De Rance, and Mr. A. Strahan; in the south-west of England the rocks originally surveyed by De la Beche and others, have been re-mapped in detail chiefly by Mr. W. A. E. Ussher.

PERMIAN OR DYAS.

The name Permian was proposed by Murchison in 1841, from the ancient kingdom of Permia, in Russia.

In England the Permian rocks consist of red sandstones, conglomerates, marls, and magnesian limestones, of which the following series is generally established:—

	Durham.		*Yorkshire.*
Upper Permian or Magnesian Limestone Series (Zechstein).	Red Sandstone and Marl. 50 feet. Magnesian Limestone. 500 to 600 feet. Marl Slate (Kupfer Schiefer). 10 to 60 feet.	or	Upper Red Marl and Sandstone. 50 feet. Upper Magnesian Limestone. 120 feet. Middle Red Marl, Sandstone and Limestone. 200 feet. Lower Magnesian Limestone. 120 feet.
Lower Permian (Roth-liegende?).	White or yellow false-bedded sand (Quicksand), with occasional seams of breccia. 20 feet or less.		

The total thickness of the Permian rocks is from 500 to 700 feet.

Zechstein is a German term signifying 'Mine stone,' as it yields copper-ore; Kupfer Schiefer signifies copper-slate; and Roth-liegende (or Roth-todt-liegende), used by Werner, is a German term signifying 'Red layers,' or 'Red dead layers,' as the copper ceases or "dies off" before this bed is reached.

[1] See also J. Gunn, G. Mag. 1884, p. 73.

From this two-fold arrangement of the rocks in Germany, the term Dyas was proposed in 1859 by Jules Marcou; and many authorities at the present day prefer this term to that of Permian.

Fossils are abundant in the Magnesian Limestone and Marl Slate: they include the Brachiopoda and Mollusca *Camarophoria crumena*, *C. globulina*, *Terebratula elongata*, *Lingula Credneri*, *Strophalosia Goldfussi*, *S. lamellosa*, *Streptorhynchus pelargonatus*, *Athyris pectinifera*, *Productus horridus*, *Spirifera alata*, *S. Urei*, *Spiriferina multiplicata*, *Monotis* (*Avicula*) *speluncularia*, *Schizodus* (*Axinus*) *obscurus*, *Bakewellia antiqua*, *Pleurophorus costatus*, *Turbo Mancuniensis*, and *Chiton*. Few Cephalopods occur. The Polyzoa include *Acanthocladia* (*Glauconome*) *anceps*, *Synocladia virgulacea*, and *Fenestella retiformis*; and the Fishes *Platysomus striatus*, *Pygopterus mandibularis*, *Dorypterus*, *Cœlacanthus*, *Palæoniscus elegans*, *P. comptus*, and other species — hence the term Palæoniscian applied to the series by Phillips; there also occur *Proterosaurus*, the oldest known Lacertilian Reptile, and *Lepidotosaurus*, one of the Labyrinthodonts. The plants *Voltzia* and *Caulerpites* are recorded from the Lower Permian Sandstone. The flora, which may include *Sigillaria*, *Alethopteris*, and *Neuropteris*, is perhaps allied to that of the Coal-measures; but Mr. Carruthers has observed that the Permian vegetation also possesses Mesozoic affinities, and in fact that the commencement of the Mesozoic flora is to be sought in the Permian. As before mentioned, the evidence of the Plant-remains must be received with caution.

The genera *Productus*, *Strophalosia*, *Spirifera*, *Camarophoria*, *Streptorhynchus*, *Athyris*, and *Fenestella*, although not exclusively Palæozoic, are yet links that strongly bind the Permian fauna with that of the Carboniferous period which preceded it.[1]

Mr. J. W. Kirkby has stated that in the Magnesian Limestone at Hampole (or Hampall), near Doncaster, "in but a quarter of an ounce of limestone I have picked out 298 separate organisms, the majority being specimens of *Turbo helicinus*. Another experiment of a like kind, the quantity of limestone being the same, yielded even more astonishing results. From it I extracted 461 specimens of *T. helicinus*, 18 of *Turritella Altenburgensis*, 7 of *Rissoa Leighi*, 2 of *Terebratula elongata*, 1 of *Bairdia plebeia*, 24 of *Miliola pusilla*, and 8 fragments of *Stenopora Mackrothi*; in all 513 organisms."[2]

Some beds in the Lower Magnesian Limestone of South Yorkshire, at Brodsworth, Cadeby, etc., are almost wholly composed of fragments of Polyzoa.

The Magnesian Limestone, which is the most important member of the Permian series, may be compared with the Muschelkalk; for although occupying a different horizon, both beds belong to the same system, and both are locally developed; the former being present only in Nottinghamshire and the northern counties of England, and the latter being absent from this country. The Magnesian Limestone comprises several beds differing much in

[1] J. W. Kirkby, Q. J. xvi. 415. See also Prof. W. King, Permian Fossils (Palæontograph Soc.); R. Howse, Catalogue of Permian Fossils, 1848.
[2] Q. J. xvii. 292, 313.

character, and it owes its origin to chemical and organic agencies.[1] (See p. 218.)

We owe our first and best descriptions of the Permian rocks to Prof. Sedgwick.[2]

The New Red rocks of the Lake District occupy the Vale of Eden or Cumberland Plain, resting unconformably upon the Carboniferous rocks. They also border the sea-shore from St. Bees Head to the estuary of the Duddon, and still further south at Walney Island and the adjoining portion of Lancashire. The following is a general summary of the beds :[3]—

Keuper and Bunter.		Red and greenish-grey marls, with thin beds of marly limestone (Stanwix Marls). 30 to 50 feet.	
		Soft red and white false-bedded sandstones (Kirklinton Sandstone). 170 feet.	
		Upper Gypseous Shales, proved in boreholes at Abbey Town and Bowness, but nowhere exposed to view. 700 feet.	
		Red, brown, and white fine-grained sandstone, not usually false-bedded (St. Bees Sandstone). 500 to 2000 feet.	
Permian.	Upper.	Red shales, etc. 250 feet.	Lower Gypseous Shales. 400 to 500 feet.
		Magnesian Limestone of Barrowmouth and Hilton Beck. 10 to 25 feet.	
		Thin-bedded sandstones and shales, with bands of impure coal and magnesian limestone (Hilton Plant-beds). 40 feet.	
	Lower.	Breccia (Upper Brockram). 150 feet.	
		Bright-red false-bedded sandstone (Penrith Sandstone). 300 to 1000 feet.	
		Breccia (Lower Brockram). 100 feet.	

The thickness of the Permian series has been estimated to be about 1400 feet in the neighbourhood of Appleby, and about 3500 feet near Penrith.[4] Mr. Holmes observes that while in places the Kirklinton Sandstone rests unconformably on the New Red beds beneath, and is itself overlaid unconformably by the Stanwix Marls, yet the entire series belongs to one system. These unconformities are based on the local absence of some of the members of the series, and not on any distinct evidences of erosion. Moreover, the age is questionable, both of the Upper Gypseous Shales and of the St. Bees Sandstone, which Mr. Holmes regards as Permian. (See sequel.)

The Penrith Sandstone is quarried at Penrith and Lazonby (Lazonby stone). The term 'Brockram' (signifying broken rock) is locally applied to the breccias, which are formed to a large extent of fragments of Carboniferous Limestone embedded in a red sandy matrix. They are well developed near Appleby and Kirkby

[1] H. C. Sorby, Address to Geol. Soc. 1879; see also E. Wilson, Midland Naturalist, iv. 202, and plate viii.

[2] T. G. S. (2), iii. 37.

[3] T. V. Holmes, Q. J. xxxvii. 286, P. Geol. Assoc. vii. 404. See also Murchison and Harkness, Q. J. xx. 149; E. W. Binney, Mem. Lit. Soc. Manchester, xii. xiv.; James Eccles, Trans. Manchester G. S. x. 30; Dr. H. A. Nicholson, Geol. Cumberland, etc., p. 81.

[4] J. G. Goodchild, P. Geol. Assoc. vii. 411; G. Mag. 1882, p. 223.

Stephen, and are largely quarried in places for lime and building-stone. Some of the beds were used by the Romans in the construction of Hadrian's Wall. Sedgwick remarked on their similarity to the Dolomitic Conglomerate of the Mendip Hills.[1] The Brockram is also dolomitic in places, and although much older than the Dolomitic Conglomerate, it was evidently one of the shore-deposits of the lake in which the New Red rocks were accumulated, and represents different horizons of the Penrith Sandstone. Mr. Goodchild has suggested that shore-ice may have aided in its formation.[2]

Footprints of animals (Ichnites—Reptilian ?) have been met with in both the Penrith and the St. Bees Sandstones.[3]

The Hilton Shales or Plant-beds were first described by Mr. E. W. Binney from Hilton Beck, a stream that descends from Roman Fell to the Eden, near Appleby. They have yielded specimens of *Ullmania*, *Alethopteris*, *Cardiocarpum*, *Odontopteris*, *Sphenopteris*, etc., and may represent the Marl Slate of Durham.

The St. Bees Sandstone is quarried near Curthwaite and Aspatria. It forms much of the beautiful rock-scenery along the banks of the Eden, south of Corby Castle, and for this reason the name Corby Sandstone was assigned to it by Murchison. Certain shaly beds included with the St. Bees Sandstone at Cummersdale, south of Carlisle, are locally known as the Cummersdale Beds.

While Sedgwick and other authorities have considered the St. Bees Sandstone to be Bunter, Murchison regarded it as Permian, a view adopted by Mr. Holmes, because the Sandstone appears to be more closely connected with the New Red strata on which it rests, than with those overlying it.[4] At the same time, when we compare the succession of beds with that exhibited in other areas, there appears little doubt that the St. Bees Sandstone should be grouped as Bunter. The following is the section at St. Bees Head (Barrowmouth):—

		Feet.
Bunter.—St. Bees Sandstone		
Permian.	Red and green marls or shales with gypsum	30
	Yellow magnesian limestone with casts of fossils	11
	Breccia with fragments of Whitehaven Sandstone	3
Coal-measures.—Whitehaven Sandstone.		

The sandstone of St. Bees Head was used in the construction of Furness Abbey.

The Limestone breccia at Park, in Furness, is termed the "Crab rock." The Hæmatite ores are said to be sealed up by this rock. They occur in cracks and cavities of the Carboniferous Limestone of Ulverston, and at Cleator, south-east of Whitehaven, over an area at one time covered by Permian rocks.

[1] T. G. S. (2), iv. 383.
[2] Trans. Cumberland Assoc. No. ix. 1885, p. 31. See also T. McK. Hughes, Q. J. xxxiii. 422.
[3] G. Varty Smith, Q. J. xl. 479.
[4] Sedgwick, T. G. S. (2), iv. 388; Murchison and Harkness, Q. J. xx. 151, 157, xviii. 205, 216; Rev. A. Irving, G. Mag. 1882, p. 162.

The Permian rocks are largely developed in the north-eastern and midland counties.

In Northumberland and Durham the beds consist chiefly of Magnesian Limestone underlaid by Yellow Sand and Sandstone. (See p. 210.) The beds occur as far north as Cullercoats near Tynemouth, and they are exposed in the cliffs from North and South Shields, by Marsden Bay, Sunderland, Ryhope, and Seaham, to East and West Hartlepool.[1]

A thickness of 50 feet has been assigned to Upper Permian Marls, above the Magnesian Limestone in Durham, but in the opinion of Mr. E. Wilson, it is doubtful if these beds are represented.[2] The Magnesian Limestone in this area is divided as follows:[3]—

Magnesian Limestone.	Upper Limestone	Yellow, oolitic, botryoidal, concretionary, and crystalline limestone of Whitburn, Marsden, Fulwell, Roker, Hartlepool, etc. 250 feet.
	Middle Limestone.....	"Shell and Cellular limestone" ("Fossiliferous and Pseudo-brecciated limestone" of Prof. King) of Tunstall and Humbleton Hills, Ryhope, Galley's Gill, Down Hill, Clacksheugh, etc. 150 feet.
	Lower Limestone......	"Compact Limestone" of Pallion, Whitley, Pensher, Houghton-le-Spring, Ferry Hill south of Durham, Thickley, etc. 200 feet.
	Marl Slate	Marl Slate of Clacksheugh, Down Hill, Midderidge, Ferry Hill, East Thickley, near Bishop Auckland, etc. 10 to 30 feet.

The Marl Slate of Durham is noted for fine specimens of fossil fishes (*Palæoniscus*, *Platysomus*, etc.), Ferry Hill being a well-known locality, as well as Fulwell near Sunderland. The rock is a laminated shaly limestone or calcareous shale. It has also yielded a few Mollusca, and some Plant-remains (*Neuropteris*, etc.).

In Yorkshire the Permian rocks form a band extending through Bedale, Masham, Ripon, Knaresborough, Wetherby, Tadcaster, Pontefract, and west of Doncaster, to Tickhill and Worksop.

It is considered by some observers that the different members of the Permian formation are not strictly conformable to one another. A most decided instance of unconformity (due to contemporaneous erosion) is stated to occur in the railway-cutting at Tadcaster. The Middle Marl has there thinned away to a mere seam, so that the Upper Limestone rests almost directly on the Lower, and at the base of the former there is a thin bed of gravel formed of Lower Limestone pebbles.[4]

[1] Observations on the red sandstones of Tynemouth, the original drifting of the beds, and the direction of the old currents, have been made by Dr. H. C. Sorby. Geol. and Polyt. Soc. W. Riding, iii. 234.

[2] Midland Naturalist, iv. 188.

[3] Sedgwick, T. G. S. (2), iii. 37; J. W. Kirkby, Q. J. xx. 345; Kirkby and Binney, Geologist, vi. 196. See also R. Howse, Trans. Tyneside Nat. Club, iii. 239; Ann. Nat. Hist. 1857, xix. 1.

[4] Explan. of Quarter-Sheet 93 S.W. (Geol. Survey), by W. T. Aveline, A. H. Green, and others.

In South Yorkshire the Permian beds admit of the following divisions:[1]—

Upper Marls and Sandstones, with Gypsum.	West of Doncaster. 50 feet.
Upper Magnesian Limestone (Brotherton beds).	Brotherton Limestone (thin yellow or grey flaggy limestones) and Red Marl and Gypsum of Brotherton, Knottingley, Womersley, Hexthorpe, Wadworth, Tickhill, etc. 30 to 120 feet.
Middle Marls and Sandstones, with Gypsum.	(Local) North of the Wharfe. 30 to 50 feet.
Middle Magnesian Limestone.	"Small-grained Dolomite" (irregularly bedded) of Vale of Went, Lound Hill, Cusworth, Levit Hagg, Roche Abbey, Warmsworth near Doncaster; and in the picturesque crags of the Don, west of Doncaster. 200 feet.
Lower Magnesian Limestone.	Pontefract, Wentbridge, Hampole, Emsall, Brodsworth, Conisborough, Micklebring, Crakehall quarry near Bedale. 120 feet.
Marl Slates.	Kippax, Glass Houghton. 5 to 15 feet.
Quicksand.	Harthill, etc. 20 feet.

The Lower Magnesian Limestone (100 feet) is well exposed at Creswell Crags, in Derbyshire. The Quicksand, which consists of yellow incoherent sand and sand-rock, appears in places to be formed by decomposition of the sandy and gritty beds of the Magnesian Limestone that occur above it.[2] It occurs in Durham, and southwards to Harthill near Worksop. (See Fig. 28, p. 183.)

The greater part of the 'Lower New Red Sandstone,' which Conybeare first suggested to be the equivalent of the 'Rothliegende,' and which has been grouped as Permian, is now considered to be stained Carboniferous rocks. These rocks include the Plumpton (or Plompton) and Spofforth Grits, near Knaresborough, sometimes known as the Knaresborough Grits; and the Pontefract rock of William Smith.[3] Hence the "Pomfret (Pontefract) series," of old writers, embraces rocks belonging to two systems. (See p. 208.)

Prof. Hull has suggested that the Lower Permian series of the western and central parts of England may be arranged under two distinct types of strata, of which those at Enville in Shropshire, and the sandstone of Collyhurst, near Manchester, may be considered as representative beds. To the Salopian type he would refer the whole of the Permian rocks as they occur in Shropshire, Staffordshire, and Warwickshire; and to the Lancashire type, the rocks of this formation as they occur at Stockport in Cheshire, and

[1] J. W. Kirkby, Q. J. xvii. 287, 298. See also A. H. Green, G. Mag. 1872, p. 99; and E. Wilson, Midland Naturalist, iv. 122.

[2] C. F. Strangways, Geol. Harrogate (Geol. Surv.). The term Quicksand is applied to a loose and shifting or 'running' sand.

[3] J. C. Ward, Q.J. xxv. 291; Explan. Sheet 93 S.W. (Geol. Surv.); E. Wilson, Midland Naturalist, iv. 97.

near St. Helen's, Astley, and Manchester, in South Lancashire, and in the north-west of England.[1]

The beds of the Salopian type attain a thickness of about 1500 feet, and include:—

Red and purple sandstones and marls, breccia, calcareous conglomerate, and earthy limestones.

The separation of the iron-stained Coal-measures below, and of Triassic rocks above, from the Permian rocks in this area, has not yet been satisfactorily determined.[2]

The beds of the Lancashire type include:—

Red marls with numerous bands of fossiliferous limestone, worked for lime, 130 feet. (These beds are considered to be the representatives of the Magnesian Limestone of Yorkshire and Durham.)

Bright red and variegated sandstone (Collyhurst Sandstone), from 300 to 1500 feet.

The evidence furnished by these types led Prof. Hull to conclude that a ridge of Lower Carboniferous rocks crosses the plain of Cheshire beneath the Trias, and forms a boundary between the Permian rocks. Mr. A. Strahan has expressed the opinion that no Permian rocks are present under the Trias of South Lancashire, west of Warrington.[3] The Garstang sandstones, south of Lancaster, are probably Upper Permian.[4]

Permian beds are developed at Shrewsbury, near Shiffnal, Kenilworth, at Coventry, Wolverhampton, west of Birmingham, and around the Dudley Coal-field. The Alberbury breccia of Alberbury by the Severn, west of Shrewsbury, is of Permian age.

The occurrence of silicified stems of trees in the red sandstones at Allesley, north-west of Coventry, has been noted by Dr. Buckland. These fossil remains have also been met with in the Drift gravel of Warwickshire.[5]

Near Stafford the red sandstone has been worked for building-purposes. In South Staffordshire the thickness of the Permian beds is estimated at from 1000 to 3000 feet; and in North Staffordshire from 500 to 700 feet. Here the beds rest unconformably on the Coal-measures and older rocks; and they are exposed at Newcastle-under-Lyne.

In Cheshire the Permian beds attain a thickness of from 600 to 800 feet.[6] In the Vale of Clwyd traces of Permian beds have been indicated as resting on the Carboniferous Limestone, and being overlaid unconformably by Bunter beds. Here, however, Prof.

[1] Q. J. xxv. 171; Triassic and Permian Rocks of the Midland Counties (Geol. Survey), p. 11.

[2] See A. Strahan, Geology of Cheshire, Iron and Steel Inst. 1885.

[3] G. Mag. 1881, p. 436.

[4] G. Mag. 1882, p. 563.

[5] Murchison and Strickland, Proc. G. S. ii. 439; T. G. S. (2), v. 347; see also Howell, Geol. Warwickshire Coal-field, p. 32.

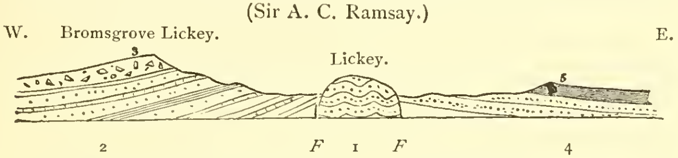
[6] E. W. Binney, Q. J. ii. 12.

Hughes has found it almost impossible to distinguish between Permian and Trias.[1]

In Anglesey the Permian beds rest unconformably upon the Coal-measures; they consist of red marls, sandstones, and conglomerates, and attain a thickness of about 400 feet.

Perhaps the most interesting Permian beds in the western counties are the conglomerates and breccias. In the Clent and Bromsgrove Lickey Hills are certain detrital beds, first described by Dr. Buckland, who identified among the pebbles quartzite similar to that of the Lower Lickey.[2] (See p. 91.) The breccias

FIG. 33.—SECTION ACROSS THE LICKEY HILLS, WORCESTERSHIRE.
(Sir A. C. Ramsay.)



3. Breccia } Permian.
2. Marls and sandstone. } Permian.
1. Quartzite.[3] (Cambrian and Silurian. See pp. 65, 91.)

F. Faults.
5. Red marl. Keuper.
4. White sandstone. Bunter.

of these localities (see Fig. 33), and also of Enville, the Abberley and Malvern Hills, are generally rough, coarse, and subangular; the stones and boulders being embedded in a red marly paste. In Sir Andrew Ramsay's opinion these are simply old boulder-clays, formed at a glacial period in Permian times. The boulders comprise mica-schist, quartz-rock, sandstone, grit, slate, and igneous rocks, some of which are polished and scratched. Jukes thought the fragments might be derived from adjacent rocks now concealed under the New Red beds of the neighbourhood.[4] The glacial origin of the scratches has been questioned by Prof. T. G. Bonney, and others, who attribute them to the friction between the stones themselves, caused by disturbances of the beds. (See p. 210.)

The following is the succession of the Permian rocks between Enville and the Forest of Wyre:[5]—

Permian. {
- Sandstone and red marls.
- Coarse breccia.
- Sandstone and red marls, containing two beds of calcareous conglomerate, with pebbles chiefly of Carboniferous Limestone.

At the Clent Hills, the Permian breccia is about 450 feet in thickness. On the eastern face of the Malvern Hills there is a

[1] Q. J. xxix. 406; see also Proc. Chester Soc. Nat. Science, 1885.
[2] E. Hull, Triassic and Permian Rocks (Geol. Survey), p. 17; see also H. E. Strickland, Proc. G. S. iii. 446.
[3] See W. J. Harrison, Midland Naturalist, viii. 102.
[4] Geol. S. Staffordshire Coal-field, edit. 2, p. 15.
[5] A. C. Ramsay, Q. J. xi. 185.

band of brecciated rocks, termed by Professor Phillips the Haffield Conglomerate, which is about 200 feet in thickness.[1]

Traces of Permian rocks (red and brown sandstones, with marly partings, 50 feet) occur south of Ashby-de-la-Zouch, in Leicestershire; but they form a doubtful fragmentary and unimportant deposit. The Magnesian Limestone is absent. Breccias occur in places, often in a gravelly and loose state, so that in one locality the deposit is known as the 'Poxon gravel.' The pebbles of the gravel and breccia forming the Permian deposits appear to have come from the west, no trace of Charnwood rocks having being discovered amongst them.[2] The Poxon (or 'Small-pox' gravel) owes its name to the occurrence of numerous nodules of red hæmatite, and these contain fossil Plants, Mollusca, etc., of the Coal-measures, from which rocks the nodules have evidently been derived.[3] (See p. 163.)

In Nottinghamshire the following divisions have been made:—

Upper Marls and Sandstone	5 to 90 feet
Upper Magnesian Limestone	20 to 40 ,,
Middle Marls and Sandstones	20 to 140 ,,
Lower Magnesian Limestone	25 to 60 ,,
Marl Slates with Breccia at base	10 to 200 ,,

The breccia or conglomerate may be the representative of the Quicksand. It is a brecciated calcareous conglomerate, containing pebbles of chert, quartz, and sandstone, and is known as "Plumcake." It was exposed in a cutting of the Erewash Valley railway at Grives Wood. Here about 15 feet of shales intervened between the Conglomerate and the Magnesian Limestone.

At South Scarle in Lincolnshire the Marl Slates are estimated to have a thickness of 200 feet, and the higher figures above given are based on the thicknesses of the Permian beds proved in the boring at that locality.[4]

It has been suggested that the lower New Red breccias in Devonshire may be of Permian age. (See sequel.) There are also beds of sandstone in Alderney, and of conglomerate in Jersey, which may be of Permian or of Triassic age.[5]

Economic products, etc., of the Permian Beds.

The Magnesian Limestone, geologically speaking, is one of the most changeable of beds. The stone itself is usually of a yellowish colour, and crystalline structure. In composition it contains nearly equal proportions of the carbonates of lime and magnesia, with two or three per cent. of silica: and it is sometimes termed Dolomite or Dolomitic Limestone, a name given after the geologist

[1] Mem. Geol. Survey, vol. ii. part 1, p. 111.

[2] See E. Hull, Geol. Leicestershire Coal-field, p. 57; Rev. W. H. Coleman, Geology of Leicester, 1846 (White's History); and W. J. Harrison, *Ibid.* 1877.

[3] W. S. Gresley, Midland Naturalist, ix. pp. 1, etc.

[4] E. Wilson, Midland Naturalist, iv. 122; W. T. Aveline, Geology of Nottingham, p. 11.

[5] Ansted and Latham, The Channel Islands, 1862; J. A. Birds, G. Mag. 1878, p. 79.

Dolomieu. Hence the Upper Permian rocks are sometimes termed the Dolomitic Series. An analysis of Bolsover stone showed the following composition :[1]—

Carbonate of lime	51·1
Carbonate of magnesia	40·2
Oxide of iron and alumina	1·8
Silica	3·6
Water and loss	3·3
	100·0

It is sometimes globular or botryoidal[2] in structure ; and this, as remarked by Sedgwick, is seen in its most imposing form on some parts of the coast of Durham, where the whole cliff resembles a great irregular pile of cannon balls.

The laminated limestone of Marsden, near Sunderland, yields a variety of flexible limestone, very fine specimens of which occur in a bed near the middle of the cliff near Marsden Rocks. Some beds in Yorkshire are fetid.

The Magnesian Limestone has been largely quarried at Bolsover Moor in Derbyshire, from which locality some of the stone used in the construction of the Houses of Parliament was procured. There is about twelve feet of workable stone, of a pale brownish-yellow colour, hence it is locally called Dunstone. As a building-stone for plain or ornamental work the Bolsover stone is, under ordinary circumstances, an exceedingly durable stone : the more perfectly crystalline varieties being esteemed the best, for some beds are liable to comparatively rapid decay. Intercalated among the beds of good stone are others of inferior quality, some of which weather into "Rustic work." Much of the stone used in the Houses of Parliament was brought from Huddlestone and the North Anston quarries ; the lower part only of the Palace of Westminster being built of the Bolsover and Mansfield Woodhouse Stone, which was that chosen by the Royal Commissioners.[3] In the quarries at Mansfield Woodhouse the stone is opened up to a depth of 60 or 70 feet. Mr. J. W. Kirkby has remarked that notwithstanding all the obloquy that has been thrown upon the Commission appointed to select the building-stone, for fixing upon a Magnesian Limestone, yet there can be no doubt they were right in their choice, the fault not being in the stone chosen, but apparently in the neglect of the architect in not seeing that it was taken from the right beds.[4]

Southwell Minster was also to some extent (the Norman portions) constructed from the Bolsover stone, and partly from that at Mansfield. Quarries have been largely worked at Conisborough, Roche (or Roach) Abbey, near Bawtry, in Yorkshire ; also in the neighbourhood of Doncaster, at Brodsworth, and Parknook, Steetley near Worksop, Shireoaks, Kiveton, etc.

The stone employed in the Museum of Practical Geology was obtained at Anston ; and that used in the construction of Westminster Hall was obtained at Huddlestone. Jackdaw Craig, near Tadcaster, and Smawse on Bramham Moor, are well-known localities for this building-stone. York Minster was partly constructed of stone from Jackdaw Craig, and Beverley Minster of stone from Smawse. The stone is quarried at Bulwell and Kimberley near Nottingham, furnishing building and paving-stone, road-metal, and being sometimes used for making troughs, etc. There are quarries also at Sutton-in-Ashfield.

Besides the yellow crystalline limestone of Mansfield Woodhouse there are in that neighbourhood red and white dolomitic sandstones, which are probably on the same horizon, and are only siliceous varieties of the Magnesian Limestone. They have been much quarried for building-purposes, and are known as the

[1] R. Hunt and F. W. Rudler, Descriptive Guide to the Museum of Practical Geology, edit. 4, p. 40 ; see also W. T. Aveline, Explan. of Sheets 71 N.E. and 82 N.E. and S.E. (Geol. Survey.)

[2] A term applied to an assemblage of concretions resembling a bunch of grapes.

[3] Explan. Sheet 82 N.E. (Geol. Surv.), by W. T. Aveline.

[4] Q, J. xvii. 292.

Mansfield White and Red Sandstones. The terrace at Trafalgar Square is paved with the white sandstone. The red sandstone is considered one of the best building-stones in the kingdom. Fine soft sands (Quicksand) at the base of the Magnesian Limestone occur at Glasshoughton and Pontefract, and they have been largely worked for moulding.

The Magnesian Limestone has been used for road-mending ; and it is largely burnt for manure, the limes of Kinnersley, Knottingley, Warmsworth cliff near Doncaster, Brancliff, Roche Abbey, Brotherton, Ferrybridge, Mansfield, etc., being celebrated for agricultural purposes. The calcareous conglomerates of Worcestershire, to the east of the Lickey and Clent Hills, have also been burnt for lime. Slabs of Magnesian Limestone have been polished at Knaresborough, Worksop, Sunderland, etc. The Lower Magnesian Limestone near Tadcaster contains beds of hard flinty rock, termed Calliard or Galliard, which is used for road-metal. In some of the chemical works on the Tyne the dolomites of the northern counties are used for the production of carbonate of magnesia ; while the magnesian limestones of Marsden are taken in considerable quantities to Sunderland, where, being treated with sulphuric acid, the magnesia is dissolved out, and from the liquor obtained, Epsom salt (sulphate of magnesia) readily crystallizes. A considerable amount of Epsom salts is thus obtained.[1]

Red sandstones have been quarried at Alveley, and Highley, south of Bridgenorth, for the manufacture of grindstones.

Staffordshire blue bricks are manufactured from dark red clays above the Coal-measures, which may be due in part to the degradation of basaltic rocks.[2] The deep blue colour is produced by sprinkling the bricks before firing with "iron swarf," that is, dust of stone and iron. The iron becomes oxidized and combines with the silica of the brick to form silicate of protoxide of iron. Glazing is effected by throwing common salt into the fire-holes of the kiln, as soon as the burning is completed.[3]

The middle Permian marls are used for brick-making, at Cinderhill, and near Bulwell, Hucknall Torkard, between Mansfield and Sutton-in-Ashfield. In the neighbourhood of Doncaster, Ferrybridge near Pontefract, and near Tadcaster, the lower Permian marls have yielded gypsum, formerly worked for Plaster of Paris. The red shales above the Magnesian Limestone have been worked for gypsum at Coat Hill, Eden Lacy, and Kirkby Thore near Carlisle. Rock-salt occurs in the marls at Middlesborough in Yorkshire, where a bed 100 feet in thickness has been penetrated ; gypsum also occurs here. The Permian age of these beds has, however, been questioned.[4]

Nodules of Hæmatite have been obtained in large quantities from Measham in Derbyshire, and also from the neighbourhood of Ashby-de-la-Zouch. They have been employed under the name of "bloodstones,"[5] as burnishers, and have been manufactured into "ironstone jewellery." (See p. 218.)

The Magnesian Limestone forms light, arable, and dry soil. It was termed the Redland Limestone by William Smith.

[1] R. Hunt and F. W. Rudler, Descriptive Guide to the Museum of Practical Geology, edit. 4, p. 40.

[2] C. Beale, Midland Naturalist, vii. 126.

[3] J. Percy, Metallurgy, 1875, p. 151.

[4] E. Wilson, Midland Naturalist, iv. 188.

[5] The true Bloodstone or Heliotrope is a jaspery variety of quartz of deep green colour, interspersed with red spots. Bristow, Glossary of Mineralogy, p. 46.

TRIAS.

The term Trias, introduced by H. G. Bronn, has been applied to this series of rocks, on account of the triple division which they exhibit in places on the Continent, where the three divisions are (in descending order) Keuper, Muschelkalk, and Bunter. The Muschelkalk, which (as its name implies) is a shelly limestone, has not been identified in this country (see p. 208); we may, however, include the Rhætic Beds, and thus arrange our Triassic series as follows :—

Trias.	Rhætic Beds.	Limestone, Shale, and Grey marl.
	Keuper Beds.	Red and variegated marl, and Dolomitic conglomerate. Sandstone and marl.
	Bunter Beds.	Upper Mottled sandstone. Pebble-beds. Lower Mottled sandstone.

In some localities there appear to be evidences of erosion or disturbance between the beds classed as Bunter and those known as Keuper, but there does not appear to be any satisfactory reason to conclude that such unconformity was produced at one time over the entire British area. Evidences of local erosion, as might be expected, are not uncommon at various horizons in the Trias; and the apparent discordance between the Bunter and Keuper is in some cases due to current-bedding. The beds indeed are subject to so much change that different divisions, based on lithological characters, may be made in different areas. The absence of the Muschelkalk from the British area must not therefore be taken as any evidence whatever of an unconformity, considering the very variable nature of the Triassic strata, and of the conditions under which the beds were deposited in different areas.[1] Calcareous beds, at one time thought to represent the Muschelkalk, were, however, noticed by Murchison at Broughton in Shropshire, and similar beds have been observed in other localities in the West of England.[2] (See sequel.)

The use of the terms Bunter and Keuper is, however, convenient, even if the beds in our country cannot be exactly correlated in time with the rocks distinguished by those names on the Continent.

The most remarkable fossils of the Trias are the Reptiles. Among these are genera of *Crocodilia*, *Dinosauria*, and *Lacertilia*. Of the Dinosauria, *Palæosaurus* is noteworthy, as the Triassic series has been named the Palæosaurian epoch by John Phillips.[3] Amphibia occur also, the footprints of the *Labyrinthodon* being not uncommon in some localities. Remains of Fishes, Entomostraca, and Plants have also been recorded.

[1] See De la Beche, Geol. Manual, p. 393; and Buckland, Proc. G. S. ii. 453.
[2] Silurian System, p. 37.
[3] T. H. Huxley, Q. J. xxvi. 42.

In the Rhætic Beds we have the earliest British Mammal, the *Microlestes*, and in these passage-beds we leave the comparatively barren New Red Rocks, and reach the commencement of the highly fossiliferous strata which characterize the Jurassic system.

The upper portions of the Triassic rocks (Keuper) are characterized by the occurrence in them of Rock-salt and Gypsum; and these rocks were evidently deposited in a large and irregular lake or lagoon, whose margin can in places be traced, although the greater part of it has been destroyed.

In certain localities the lower Triassic rocks contain pebbles of hard quartzites, etc., which suggest the action of more powerful waters than those of a lake. At the same time the red colour of these rocks, due to a pellicle of peroxide of iron coating the sand-grains, has been considered a proof that they were not laid down under the sea. It is possible that the pebbles may, in some instances, have been derived from old conglomerates, while from their local occurrence they may have been accumulated as delta deposits, the production of rivers draining the land-areas of the Triassic period.[1]

Regarding the Triassic rocks, however, as in the main of lacustrine origin, we may conclude that the sediment was in part brought down by rivers, and in part due to disintegration of bordering cliffs or islets, which would account for some of the huge blocks of porphyry and other rocks met with in the Trias of South Devon, and which Mr. Godwin-Austen attributed to the agency of moving ice. The same authority remarked on the glacial conditions under which the materials of the "Red Conglomerate" near Porlock were brought together.[2] (See sequel.) The rivers, too, which at first may have been rapid and torrential, would, by subsidence of the area, lose much of their transporting power and bring down only the finer sediment.

Bunter.

The red sandstones overlying the Magnesian Limestone series were identified in 1826 by Sedgwick with the Bunter (variegated) Sandstone of Germany, a formation so-named by Werner.

The general divisions of the Bunter beds are as follows:—

Upper Red and Mottled Sandstone. — Soft, bright-red, yellow, white, and variegated sand and sandstone.[3]

Pebble Beds or Conglomerate. — Harder reddish-brown sandstones, with quartzite pebbles, passing into conglomerate; with sometimes a base of calcareous breccia.

Lower Red and Mottled Sandstone.—Soft, bright-red, yellow, and striped or variegated sandstone, showing much false bedding; with subordinate breccias.

[1] T. G. Bonney, G. Mag. 1880, p. 407; A. Strahan, Geology of Cheshire, Iron and Steel Institute, 1885.

[2] Q. J. vi. 96, xxii. 2; see also W. Whitaker, Q. J. xxv. 157; and H. B. W. Q. J. xxxii. 235.

[3] For remarks on variegated Bunter beds, see G. Maw, Q. J. xxiv. 363.

The Lower Mottled Sandstone attains a thickness of about 650 feet at Bridgenorth; in Cheshire it is 400 or 500 feet; at St. Helen's Junction it is about 250 feet; in South Staffordshire 200 feet; while in Nottinghamshire it nowhere exceeds 80 feet in thickness.

The Pebble beds attain a thickness of from 60 to upwards of 1000 feet. They are composed chiefly of brown and liver-coloured quartzite and white quartz, the pebbles of which (according to Mr. Aveline) are found either loosely scattered amongst unconsolidated sand, or cemented into a hard conglomerate. In places the beds consist of sandstone with few pebbles, and so gradually do they pass into the sandstones below that there is no very definite line of separation. The thickness of the Pebble beds at Bootle near Liverpool has been estimated at 1200 feet; they form the most constant division of the Bunter.

The Upper Mottled Sandstone attains a thickness varying from 200 feet to 500 feet in South Staffordshire, and as much as 700 feet at Delamere Forest.

The total thickness of the Bunter beds is estimated at 1000 to 2000 feet.

The Bunter Beds rest sometimes on the Permian Series in the Midland counties, on the Carboniferous rocks in Derbyshire and Lancashire, and in Shropshire and Leicestershire on the Cambrian or older rocks. It is not always easy to separate them from the Permian strata. Indeed, in Cumberland, North Wales, and Nottinghamshire, there are signs of continuous deposition of the Permian and Lower Bunter rocks.[1]

Few, if any, organic remains are known to occur in the Bunter Beds of this country. It is true that some plant-remains have been recorded, as well as bones of Reptilia and foot-prints of Amphibia; but the evidence of the occurrence of many vertebrate remains is not satisfactory, as they were discovered in beds formerly classed as Bunter, but now recognized as Keuper.[2]

The Bunter Beds may be represented in Cumberland in part by the Kirklinton Sandstone, so named by Mr. T. V. Holmes, from a village north-east of Carlisle. (See p. 212.) This sandstone, is to be seen at Rockcliff and Netherby, but it is too soft to be of value as a building-stone, and is therefore rarely quarried. The age of the Kirklinton Sandstone is possibly Lower Keuper, and the St. Bees Sandstone may with more probability be regarded as Bunter. (See p. 213.)

The Bunter beds are not exposed on the Yorkshire coast, but they were proved to a depth of 600 feet at Middleton-one-Row on the Tees. They stretch from the neighbourhood of Yarm and Stockton-on-Tees, underneath the Red Marl and Drift of the Vale of York, to the neighbourhood of Nottingham. They are well developed in Staffordshire, Shropshire, Cheshire, and Lancashire.

[1] Rev. A. Irving, G. Mag. 1874, p. 315.
[2] Lyell, Student's Elements, 1871, p. 351; Phillips, Geol. Oxford, p. 97.

The Lower Mottled Sandstone is not always present where the Bunter beds are exposed. At Leek, the Potteries, Cheadle, Alton, Ashbourne and Derby the Pebble-beds rest directly on the Palæozoic rocks; but the sandstone appears near Nottingham. The greater part of Nottingham is built on a coarse white sandstone, containing scattered pebbles of quartzite, etc., belonging to the Pebble-bed division. The Castle stands on a cliff of the same rock, in which artificial caverns have been excavated. In this district the Lower Mottled Sandstone passes up into the Pebble-beds.

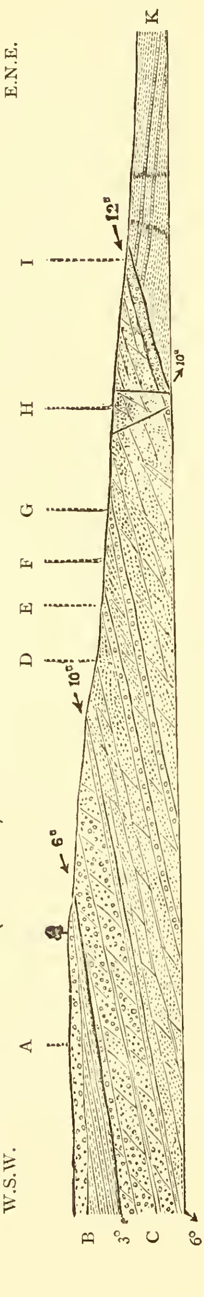


FIG. 34.—SECTION ON EAST SIDE OF TUNNEL, GREAT NORTHERN RAILWAY, AT MORLEY, NEAR DERBY. (E. Wilson.) Scale—Horizontal and Vertical—2 chains to an inch.

A. Boulder Clay.
B. Keuper Sandstone (Waterstones). 20 feet.
C. Pebble Beds (Middle Bunter). 25 to 38 ft.
D. Sandstone. 33 ft. } Lower Bunter.
E. Breccia. 4 ft. 6 in. }
F. Sandstone. 11 ft. 6 in. } Lower Bunter.
G. Breccia. 5 ft. }
H. Sandstone. 42 ft. }
I. Breccia. 7 ft. }
K. Lower Coal-measures (Ganister Series).

At Morley, near Derby, as pointed out by Mr. E. Wilson, Keuper Sandstone rests on the Pebble Beds, furnishing evidence of local unconformity between the Keuper and Bunter.[1] (See Fig. 34.) Here the attenuation of the Pebble-beds, the absence of the Upper Mottled Sandstone, and the overlap of the Keuper Basement Beds by the Waterstones, are significant facts.

In South Staffordshire the Lower Mottled Sandstone is met with at Stourbridge, but it is a very inconstant division. At Smethwick the Bunter conglomerates repose on Permian Sandstone.

The Upper Mottled Sandstone ranges from near Harborne, by Birmingham, to Sutton Coldfield. The town of Birmingham is built principally upon it, and it is exposed west of Wolverhampton and at Lichfield. The Pebble-beds form the high ground of Barr Beacon, Sutton Park, and Aldridge, north of Birmingham. Prof. Hull observes that in no part of

[1] G. Mag. 1880, p. 309. See also W. T. Aveline, Geol. Nottingham (Geol. Survey); and J. Shipman, Midland Naturalist, i. 18, 30.

the western counties is the Trias more clearly presented than in the neighbourhood of Shiffnal in Shropshire. Along the cuttings of the Wolverhampton railway all the subdivisions of the Trias, together with the Permian and Carboniferous rocks, are opened out in their order of succession.[1]

The Pebble-beds of Cannock Chase in Staffordshire consist chiefly of quartzites, grey and reddish, and occasionally liver-coloured, with also pebbles of white quartz and hard grit, felstone, etc. Prof. Bonney has observed that one variety of the quartzites is identical with rock that occurs in Ross-shire; a second variety is like the quartzite of Budleigh Salterton, the Lickey, and Hartshill. *Orthis redux*, var. *Budleighensis, Spirifera Verneuilii* and other species have been obtained from the Bunter Beds and from the Drift. These fossiliferous pebbles belong to rocks of the age of the Arenig, Bala, and May Hill series, as well as to Devonian rocks.[2] Pebbles and fossils from the Carboniferous Limestone occur also in the Conglomerates. The distant origin of the Bunter pebbles has been opposed on the ground that the pebbles become fewer, and ultimately disappear when traced northward; and Mr. W. J. Harrison has shown that they were most likely derived from land-surfaces of old rocks which existed in the Midland Counties in Pre-Triassic times, and some of which have been denuded and buried up beneath more recent accumulations.[3]

The Pebble-beds form a broad band of country in the neighbourhood of Sherwood Forest, east of Mansfield, and near Retford and Tickhill. As Mr. Aveline observes, it is owing to its poor sandy and gravelly soil that the Forest of Sherwood existed so long, the greater part being still retained as woodland or common. Market Drayton stands on the Pebble-beds, there represented by hard pebbly sandstone.

In the neighbourhood of Liverpool, Manchester, and Stockport, the Pebble-beds are represented by reddish-brown pebbly sandstone, largely quarried for building-purposes. Chester Cathedral was largely constructed of this stone from the neighbourhood of Chester. The Mersey Tunnel was to a large extent excavated through these Pebble-beds, which are here characterized by the rarity of pebbles.[4]

The Upper Red and Mottled Sandstone, both in structure and composition, appears to be the most uniform division of the Bunter. In the neighbourhood of Birkenhead, Liverpool, and Ormskirk, the lower portion of this subdivision is red, the upper yellow, and it is sometimes sufficiently hard for building-purposes. The apparent unconformity that has been noticed between the

[1] Triassic and Permian Rocks, p. 30.

[2] See Rev. P. B. Brodie, Q. J. xxiii. 210; S. G. Perceval, G. Mag. 1878, p. 333; J. H. Jennings, *Ibid.* 239; T. G. Bonney, *Ibid.* 428, 1880, p. 404, 1883, p. 199; W. Molyneux, Proc. Dudley Geol. Soc. iii. 139.

[3] Proc. Birmingham Philosoph. Inst. iii. 157; Midland Naturalist, viii. 194.

[4] C. E. De Rance, Proc. Geol. Assoc. vii. 324; T. M. Reade, Proc. Liverpool G. S. 1885.

Keuper and Bunter Beds at Ormskirk is, in the opinion of Mr. A. Strahan, due to false-bedding.[1]

The Lower Mottled Sandstone is well shown at Eastham in Cheshire. It is also developed in the country around Stourport, Bridgenorth, Bewdley, and Wribbenhall; and there the rock is remarkably false-bedded. At the base of the Pebble-beds in the Bridgenorth district there is a breccia of grits, quartz, slate, limestone, etc., which is 60 feet thick at Kidderminster, and forms the fine ridges of Apley Terrace, Pendlestone Rock, Abbot's Castle Hill, and Kinver Edge.

The following divisions in Worcestershire were made by G. E. Roberts:[2]—

Upper soft red sandstone (Bromesbarrow Beds)	200 feet.
Reddish conglomerate, of Kidderminster and Wolverley	400 ,,
Lower soft red sandstone, of Abberley and Stourport (Stourport Beds)	200 ,,

The Vale of Clwyd is formed partly in the Bunter Sandstone, belonging in all probability to the Lower Mottled Sandstone; but sections are rarely seen owing to the covering of drift. The beds are faulted on the east side of the Vale, against the Silurian rocks (Wenlock Shale), with a downthrow estimated by Mr. Strahan at not less than 1200 feet. (See Fig. 3, p. 25.)

The Bunter beds have not been identified with certainty south of Malvern, but there is a probability of their being represented in West Somerset and Devon (see sequel). Near Malvern they are represented by 400 feet of red and white sandstones and conglomerate.

The Bunter sandstone yields a good supply of water, being in fact one of the most prolific of the water-bearing strata. The Lower Mottled Sandstone yields an excellent moulding sand for iron-furnaces, in Nottinghamshire, etc. The Bunter Conglomerate of Cannock Chase has yielded lead and copper ores.[3]

Keuper.

The Keuper beds (or New Red Marl) which overlie the Bunter are locally divided into:—

Upper Keuper.—Red and variegated marls with beds of sandstone, 800 to 3000 feet; and sandstones and marls (Waterstones).

Lower Keuper or Basement Beds.—Sandstones, building-stones, and grits and breccias, having a thickness of 150 to 200 feet in Derbyshire and Staffordshire, and 250 feet in Lancashire and Cheshire.

The term Red Marl was used by William Smith in 1815. Keuper is a provincial German term.[4] The upper New Red Marls of

[1] G. Mag. 1881, p. 401; see also E. Hull, Triassic and Permian Rocks, p. 86.

[2] T. R. Jones, Mon. Fossil Estheriæ, pp. 62, 63; Rev. W. S. Symonds and A. Lambert, Q. J. xvii. 152.

[3] W. Molyneux, G. Mag. 1873, p. 16.

[4] Nom technique des mineurs de l'Allemagne occidentale, Alex. Brongniart, Tableau des Terrains, etc., 1829.

England were first identified by Sedgwick with the Keuper of Germany. The term Waterstones was originally used by Mr. G. W. Ormerod because the surfaces of some of the beds had a watery appearance, like watered silk. The term as generally understood expresses the water-bearing qualities of the strata. (See p. 228.)

Remains of Plants, Entomostraca, Fishes, Reptiles, and Amphibia have been obtained from the Keuper rocks.

Many foot-prints of Labyrinthodonts (*Cheirotherium*) have been discovered in the Keuper Sandstones, and particularly in Cheshire. Perhaps the quarries at Storeton (or Stourton) Hill, near Birkenhead, in the peninsula of Wirral, are the richest in these traces of ancient life. They have also been met with at Daresbury quarry, and in quarries at Lymm and Runcorn. These foot-prints are called the "lady's foot" by quarrymen. Ripple-marks and impressions of rain-drops have also been met with in the Storeton quarries. Another genus of Labyrinthodont (*Mastodonsaurus*) has been obtained from strata near Warwick.

Remains of the Dinosaurian reptile *Cladyodon*, and of the Lacertilians *Rhynchosaurus* and *Hyperodapedon* also occur, bones having been found near Warwick, Grinshill, and (of the last-named genus) near Sidmouth. Among Fishes, *Palæoniscus*, *Hybodus*, and *Acrodus* occur. The Ostracod *Estheria minuta*[1] is recorded from many localities. Annelide tubes have been obtained, also remains (casts) of plants identified as *Calamites*, *Echinostachys*, *Equisetum*, and *Voltzia*.

Lower Keuper (*Basement Beds*).[2]—This division consists of white and red sandstone, with sometimes coarse, irregularly-bedded sandstones, calcareous breccia, conglomerate, and lenticular bands of marl.

Upper Keuper.—The uppermost division of the Trias consists mainly of red and variegated marls, the red colour preponderating, and the beds being mottled with spots and streaks of a grey or green hue. The marl is soft and usually much broken up and fissured by cracks or joints and miniature faults; it thus presents a rubbly appearance, and is often separated into small masses of a cuboidal form. Interstratified with the marl there occur beds of hard red and sometimes grey or cream-coloured marl, marly limestone, and calcareous sandstone. And in the south-west of England, beds of Dolomitic Conglomerate are associated with the Marl. The presence of carbonate of lime in the Red Marl does not appear to be invariable, but the amount is sometimes so trifling as not to be detected by the application of hydrochloric acid.

The colouring matter of the red and green marls is due to different states of the oxides of iron contained in them. Mr. G. Maw believes that while variegation is partly due to infiltration and dissolution, it is mainly due to segregation.[3]

[1] This was originally termed *Posidonia* or *Posidonomya minuta*.

[2] E. Hull, Triassic and Permian Rocks of the Midland Counties, p. 66; and A. Strahan, Geol. of Chester.

[3] Q. J. xxiv. 369, 400. See also De la Beche, Mem. Geol. Survey, vol. i. p. 50, and Ramsay, Q. J. xxvii. 189.

The Waterstones comprise thick-bedded and flaggy sandstones, with beds of sandy marl. Ripple-marks are abundant, and sun-cracks, rain-prints, tracks of Annelides, etc., are sometimes met with. Remains of Fishes have been found in these beds in Nottinghamshire by Mr. E. Wilson.

In the Upper Keuper Sandstones near Taunton Mr. C. Moore has discovered remains of *Estheria minuta*, Fishes, *Labyrinthodon*, etc.[1] Prof. T. R. Jones and Mr. W. K. Parker have described a series of Foraminifera from the Red Marl series at Chellaston near Derby, including some species (*Nodosaria*, etc.) still existing;[2] I am, however, informed by Mr. Horace T. Brown that it is extremely doubtful whether these remains were really obtained from the Keuper Marls, as they may have been derived from superficial accumulations not recognized at the time.

The Keuper Marls and Sandstones form part of the plain of York, and stretch through Nottinghamshire, Leicestershire, Derbyshire, Cheshire, Staffordshire, Warwickshire, Worcestershire, Gloucestershire, and Somersetshire to the coast of Devonshire.

The Keuper Marls are exposed in the banks of the Eden, near Carlisle, and to them the name Stanwix Marls was applied in 1880 by Mr. J. G. Goodchild. (See p. 212.) They contain pseudomorphous crystals of rock-salt. In the Carlisle area there is much difficulty in separating the various divisions of the New Red rocks, owing to the mantle of Drifts. The Abbey Town Boring was carried through nearly 200 feet of Drift, and more than 700 feet of gypseous shales, down to the St. Bees Sandstone. These gypseous shales have been regarded as Keuper by Mr. Aveline, and therefore as on the same horizon as the Stanwix Marls.

Near Liverpool the Waterstones have been exposed at the Toxteth Cemetery, and have been termed the "Cemetery Shales" by Mr. G. H. Morton. They are seen also at Irby and Pensby.[3]

The Keuper series near Chester is thus divided by Mr. A. Strahan:[4]—

Red Marls [3000 feet?]	
Waterstones, about 200 feet.	Red and yellow sandstones, and red and greenish marls and shales.
Lower Keuper Sandstone or Basement Beds. 180 to 250 feet.	Soft, current-bedded, and bright red, white, and yellow sandstones (Frodsham Beds).
	Hard brown and white quartzose grits and breccias.

Previously the Waterstones were linked by the Geological Survey with the Lower Keuper Sandstone, but there is a sharp division between them; this is well shown in the railway-cutting at Runcorn station. At Frodsham, south of Runcorn, the upper part

[1] Q. J. xxiii. 468.

[2] Q. J. xvi. 452.

[3] C. E. De Rance, G. Mag. 1883, p. 505.

[4] Geol. Mag. 1881, pp. 396, 574; Geology of Chester (Geol. Surv.); see also E. Wilson, G. Mag. 1881, p. 523; and T. M. Reade, Q.J. xxxix. 123.

of the Lower Keuper Sandstone consists of a soft current-bedded mottled sandstone, where the current-bedding is on so large a scale as to have been sometimes mistaken for contortion. Mr. Strahan terms these the Frodsham Beds. Lines of erosion have been detected not only in the Keuper Sandstone, but at various horizons in the Bunter series.

The Keuper beds occur over Delamere Forest, east of Chester (450 feet), and in the Peckforton Hills south of Tarporley. The outcrop of the Basement Beds forms one of the most conspicuous and picturesque features in Cheshire, extending, as Mr. Strahan has observed, from Frodsham by Peckforton to near Shrewsbury, and thence by Hawkstone and Alderley Edge. The Marls are exposed at Eccleshall, Alton, north of Uttoxeter, Burton-on-Trent, Tutbury, Colwich, Rugeley, and other places in the northern part of Staffordshire.

In South Staffordshire the thickness of the Marls is 600 feet, and that of the underlying white and brown sandstone, with beds of red marl (Waterstones), 300 feet. At the base there is sometimes a bed of calcareous breccia and conglomerate. Sandstone occurs at Stowe, near Lichfield, and the marl and sandstone are developed at Oreton Hill, near Wolverhampton, and near Birmingham. Further south Moseley is on the Red Marl. In Nottinghamshire the Basement Beds of the Keuper consist of sandstone, marl, and conglomerate.[1] The Himlack (or Hemlock) Stone at Stapleford Hill, near Nottingham, which at one time was regarded as Lower Mottled Sandstone and Pebble-beds (Bunter), is considered by Mr. J. Shipman to be composed entirely of Keuper Beds. The cementing material in this and other Keuper Sandstones consists largely of barium sulphate, which is practically insoluble.[2]

Mr. James Plant has given the following general section of the Keuper Beds at Leicester:[3]—

5. Marls, containing beds of gypsum and several thin bands of green marly sandstone, on which were found numerous pseudomorphous crystals of rock-salt. 80 to 120 feet.
4. Thin sandy shales, with 'way-boards' of green marl. 25 to 30 feet.
3. Thick beds of soft white sandstone (Waterstones). 20 to 30 feet.
2. Thin sandy shales, similar to No. 4. 35 feet.
1. Red Clay.

The total thickness of the Keuper series near Leicester is from 700 to 1000 feet. The Waterstones have been worked for building-purposes at Castle Donnington and other places. Near the Mount Sorrel granite quarry, a side cutting showed Red Marls resting against the granite, and containing large fragments of the rock.[4]

The Red Marls form a plain around Market Bosworth and Hinckley, Atherstone and Nuneaton. Sandstone has been quarried

[1] E. Wilson and J. Shipman, G. Mag. 1877, p. 497, 1879, p. 532.
[2] Prof. F. Clowes, Brit. Assoc., 1885.
[3] Q. J. xii. 372.
[4] W. J. Harrison, P. Geol. Assoc. v. 148.

at Orton-on-the-Hill, north of Atherstone. The beds are also to be seen near Ashby-de-la-Zouch.

In Warwickshire the quarries in the Waterstones or "Lower Warwick Sandstone" at Cubbington, Coton-End, and Guy's Cliff, have yielded plant-remains, *Labyrinthodon* and *Cladyodon*, also the Lacertilian reptile *Hyperodapedon*. Warwick Castle was built of this stone. At Rowington Plant-remains, also *Palæoniscus superstes*, were obtained from the Upper Keuper Sandstone.[1] Leamington is situated on the Keuper marls and sandstones, which there appear to overlap the Bunter and rest on the Permian Beds.

The following divisions of the Keuper Beds have been made in Worcestershire by G. E. Roberts:[2]—

Upper Keuper Marls.	Grey and red marls, with pseudomorphous crystals of rock-salt. (Well seen at Crowle, east of Worcester.)	40 feet.
Upper Keuper Sandstone.	Sandstone with *Estheria*, Plants, and Fish-remains. (Well seen at Pendock.)	20 ,,
Lower Keuper Marls.	Variegated marls, with gypsum and pseudomorphous crystals of rock-salt. (Worcester Railway-station.) Saliferous red marls. (Droitwich)	1000 ,,
Lower Keuper Sandstones.	Reddish micaceous sandstone, with Plant-remains. (Ombersley, Bellbroughton.)	20 ,,
	Cupriferous and micaceous sandstone. (Ombersley, Hagley, Bellbroughton.)	200 ,,
	Thin-bedded red and white micaceous sandstone. (Drayton, Bellbroughton.)	30 ,,
	Thin grey calcareous bands. (Drayton.)	6 ,,
	Reddish breccia and conglomerate. (Hartlebury)	60 ,,

The beds may be studied at Bromsgrove (Bromsgrove Sandstone), Kidderminster, etc. Remains of *Dipteronotus* have been recorded from Bromsgrove. (See Fig. 33, p. 217.)

In Worcestershire, Warwickshire,[3] and Gloucestershire, the beds were described by Sir R. I. Murchison and Mr. H. E. Strickland, and they speak of a thin course of impure limestone, which may represent the Muschelkalk.[4] (See p. 221.) They refer to the Burge Hill quarries near Eldersfield, in Keuper Sandstone, and the Inkberrow quarries, north-east of Worcester, where stone of a very varied colour—white, red, and purple—has been obtained.

Leamington, Warwick, Henley-in-Arden, Stratford-on-Avon, Alcester, Newnham, and Worcester are situated on Red Marl, which contains occasional beds of Sandstone. In the neighbourhood of Tewkesbury there is a bed of white sandstone 20 to 30 feet in thickness in the Red Marl.

Malvern Chase is situated on the Red Marl. Pendock and Newent are on the Keuper Sandstone; at Pendock the stone is

[1] Rev. P. B. Brodie, Q. J. xiv. 165; Howell, Geol. Warwickshire, p. 40.
[2] T. R. Jones, Mon. Fossil Estheriæ, pp. 62, 63; see also Rev. W. S. Symonds and A. Lambert, Q. J. xvii. 152.
[3] See Rev. P. B. Brodie, Q. J. xii. 374.
[4] T. G. S. (2), v. 331, 346.

quarried, and here remains of Plants and Fishes have been obtained.[1]

Red sandstones and marls, possibly of New Red Sandstone age, have been met with in some of the deep borings near London. (See p. 140.)

TRIASSIC ROCKS OF SOUTH WALES AND THE SOUTH-WEST OF ENGLAND.

In Glamorganshire, Gloucestershire, and in the neighbourhood of the Mendip Hills in Somersetshire, the Red Rocks consist of Dolomitic Conglomerate, Dolomitic Limestone, Sandstone (generally very calcareous), and Marls.

The Dolomitic Conglomerate, locally called 'Millstone' or 'Millgrit rock,' is an old beach-deposit of Keuper age, derived chiefly from the Carboniferous Limestone. It occasionally contains pebbles of Millstone Grit and Coal-measure Sandstones; but rarely any pebbles of Old Red Sandstone, partly because they are not so extensively exposed along the old margins, and partly because most of the sandstones would be too friable long to resist the friction to which they were subjected. In thickness the Conglomerate is rarely more than 30 feet. The included fragments are sometimes well rounded, but often so slightly worn as to constitute a breccia rather than a conglomerate; they vary in size, from small stones to boulders two or three feet in diameter. These are often cemented together by the carbonates of lime and magnesia, whence the name Dolomitic or Magnesian Conglomerate; but frequently the cementing material is simply carbonate of lime, marl or ferruginous sand; the matrix is usually much coloured by peroxide of iron.[2]

The Dolomitic Conglomerate usually occurs at the base of the Red Marl, and yet at the same time it occurs at all horizons along the margin of that deposit, where the beds dovetail one into the other, proving, as De la Beche originally pointed out, that its formation continued throughout the entire series. (See Fig. 24, p. 160.)

Sir A. C. Ramsay regarded the Dolomitic Conglomerate not merely as of aqueous origin, but as in part formed of breccias which had covered the old land surface and had been worked up by the waters of the New Red period.[3] Mr. R. H. Valpy informed me that he had found striæ, which he considered might be of Glacial origin, on blocks of Carboniferous Limestone in the Dolomitic Conglomerate. Prof. W. J. Sollas also has noted striated pebbles in the Conglomerate at Portskewet in Monmouthshire;

[1] Rev. W. S. Symonds, Q. J. xi. 450.

[2] The term "Dolomitic Conglomerate" was applied by Buckland and Conybeare, T. G. S. (2), i. 292. The term "Magnesian" applied to the conglomerate has sometimes caused it to be considered of Permian age. It has also been ranked as a possible equivalent to the Muschelkalk, R. Etheridge, Q. J. xxvi. 189.

[3] Q. J. xxvi. 191.

this striation he believed to be due to local friction, subsequent to the deposition of the beds.[1] (See p. 217.)

At East Harptree beds of chert are associated with the marls and conglomerates.[2]

In the Dolomitic Conglomerate of Durdham Down, near Bristol, some Dinosaurian remains were found in 1836; these belong to the genera *Palæosaurus* and *Thecodontosaurus*, and were originally described by Dr. H. Riley and Mr. S. Stutchbury.[3] (See Fig. 26, p. 172.) Three-toed footprints of *Brontozoum* have more recently been discovered in similar rock at Newton Nottage, in Glamorganshire.[4]

The remarkably even manner in which the Carboniferous Limestone has been denuded is well shown at Wallcombe, near Wells, where the Keuper beds rest on the edges of that rock. This even line is also very conspicuous in the vales near Frome, beneath the Rhætic Beds, Lias, and Oolites. The Conglomerate sometimes makes fine bold scenery, presenting mural faces, as at Croscombe near Shepton Mallet, Wookey Hole, and Haydon Gully near East Harptree.

The road to Wookey Hall on one side of Wells, and that leading to Dulcot on the other, show in places in the Red Marl a bed termed the 'Wonder Stone,' described by Buckland and Conybeare as 'a beautiful breccia, consisting of yellow transparent crystals of carbonate of lime, disseminated through a dark red earthy dolomite.'

Beds of Dolomitic or Magnesian Limestone are conspicuous near Clevedon, and on the Glamorganshire coast, south of Penarth. At the former place the rock is fine-grained, and has been sculptured into architectural ornaments.

The Dolomitic Conglomerate is sometimes burnt for lime; it is also employed for building, and polished for ornamental purposes. The Draycot Stone, quarried near Axbridge, is well known in the district.

Red and brown oxides of iron are not uncommon in the Dolomitic Conglomerate, and they have been worked in many places, as at Llantrissant and Llanharry in Glamorganshire,[5] on the Mendip Hills, etc. Reddle (or raddle) has been largely dug at Winford near Chew Magna, for the manufacture of pigments. Ores of lead and zinc occur in the Mendip Hills.

At various localities large brown siliceous nodules are found in the Dolomitic Conglomerate; these are hollow and lined with crystals of quartz, of which the purest forms are known as Rock-crystal, and locally as 'Bristol diamonds.' The nodules or geodes are termed 'Potatoe Stones,' and they vary from an inch to a foot in diameter. They occur at Westbury near Bristol, Clevedon, Banwell, Sandford, Chilcompton, and other places. They sometimes contain crystals of Celestine, and Calc-spar. The formation of these geodes is a problem. The crystals of quartz which line the drusy cavities must have been deposited from solution, and probably by very slow evaporation, from the infiltration of water holding siliceous matter. According to Prof. T. Rupert Jones, their origin is pseudomorphic, silica having replaced the outer portions of limestone fragments.[6]

Calcareous Sandstones, worked for building-purposes, are met with at Claverham Court, near Yatton (Claverham or Clarham Stone), Brislington, Chew Magna, Sutton Mallet, near Chew Stoke, Litton, Pyle in Glamorganshire, etc. The upper

[1] G. Mag. 1881, p. 72; E. D. Jones, P. Geol. Assoc. vii. 346.
[2] Geology East Somerset, etc. (Geol. Survey), p. 60; G. Mag. 1871, p. 400.
[3] T. G. S. (2), v. 349; T. H. Huxley, Q. J. xxvi. 43.
[4] W. J. Sollas and J. Storrie, Q. J. xxxv. 515.
[5] Watson, Geologist, ii. 241.
[6] Proc. Geol. Assoc. iv. 454; see also Buckland, Trans. G. S. (2), iii. 421.

part of the Keuper series also contains beds of hard red and grey limestone, which are worked for building-stone and road-metal near Chew Stoke. An analysis of similar rock from Litton by Mr. Horace T. Brown (1884) showed the following composition:[1]—

Calcium carbonate	80·02
Magnesium carbonate	2·72
Iron, estimated as ferric oxide, but partly present as a ferrous salt...	1 99
Phosphoric acid (about)	·02
Matter insoluble in dilute hydrochloric acid, and soluble silica = clay and sand	15·66
	100·41

A microscopic examination of this stone led to the conclusion that the limestone was to a large extent mechanically derived from the Carboniferous Limestone.

To the north of the Mendips the thickness of the New Red series rarely exceeds 200 feet, and is generally less; here however the beds are nowhere far removed from the margin of the deposit. To the south of the Mendips the thickness increases rapidly as we recede from the older rocks; at Glastonbury it is estimated to be over 400 feet, while at Compton Dundon its base was not reached after 609 feet had been bored. The entire thickness of the New Red series in this part of Somersetshire is estimated at about 800 feet.

The New Red rocks of West Somersetshire and Devonshire comprise a series of Marls, Sandstones, Conglomerates, and Breccias, which rest unconformably on the Carboniferous and Devonian rocks. Looked at in a broad way, and as indicated in the coast-section between Axmouth and Teignmouth, the following order of succession is applicable to the country between Porlock, Taunton, and the shores of the English Channel, the beds increasing in thickness from West Somerset to the coast of South Devon:—

Trias.	Upper.	5. Upper Marls	1000 to 1350 feet.
		4. Upper Sandstones	200 to 530 ,,
		3. Conglomerates and Pebble-beds	70 to 100 ,,
	Middle.	2. Lower Marls, with Sandstone	120 to 850 ,,
	Lower.	1. Lower Sandstones and Breccias	500 to 1500 ,,
			1890 to 4330 ,,

The classification and thicknesses are taken from papers by Mr. W. A. E. Ussher, to whom we are indebted for the greater part of our knowledge of these strata. The coast-section is represented in Fig. 35.[2]

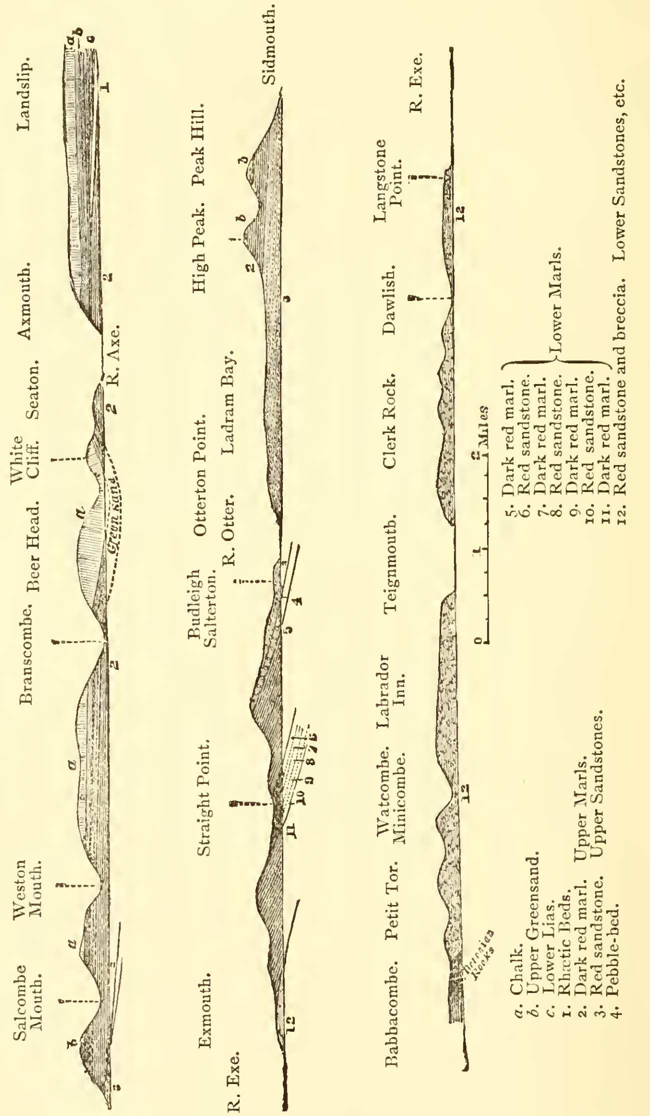
To the east of Axmouth, we meet with the Rhætic Beds, and thence trace their passage downwards into the variegated marls which appear along the cliff, at the base of the Greensand and Chalk. West of Seaton, we find low cliffs of Red marls, which appear again at Branscombe, dipping gently to the east. Continuing towards Sidmouth, the beds become less calcareous and finally quite loamy, until

[1] See also Geol. E. Somerset, etc. (Geol. Survey), p. 59.

[2] W. Whitaker, Q. J. xxv. 152; see also W. Pengelly, Trans. Plymouth Inst. 1861-65, Trans. Devon Assoc. 1863, 1866; Ussher, G. Mag. 1874, p. 163; Q. J. xxxii. 367, xxxiv. 459; Trans. Devon Assoc. 1877.

lower down in the series the Upper Sandstone crops out east of Sidmouth. Continuing westwards the sandstone, containing seams of calcareous concretions, is

FIG. 35.—SECTION ALONG THE SOUTH-DEVON CLIFFS FROM BABBACOMBE BAY TO THE DOWLANDS LANDSLIP WEST OF LYME REGIS. (W. Whitaker.)



overlaid by the Upper Marls, and further on it forms the low cliff at the mouth of the Otter. The sandstone continues through Budleigh Salterton; and beneath it in the high cliff to the west comes the famous Pebble-bed, and this again overlies variegated marl (Lower Marls). In the lower part of this division towards Exmouth there is an alternation of marl and sandstone, and in this direction the beds are much disturbed by small faults ; the strata rest upon breccia, at Exmouth. Crossing over the mouth of the Exe, we come to Langstone Point, and here we find a continuation of the breccia, which just appears at Exmouth. The cliffs between Langstone Point and Dawlish show sandstone and breccia interstratified, sometimes the one predominates, sometimes the other ; and they are much faulted on a small scale. Between Dawlish and Teignmouth the dip continues uniform, and the cliffs display a series of breccias with sandstone interstratified. Between Teignmouth and Babbacombe the beds undulate, but they are well seen in the cliffs of Watcombe, Minicombe (or Maidencombe), and Petit Tor, faulted in places against the Devonian Limestone. Here the lower beds, which might be termed conglomerate, are conspicuous from the fragments of limestone contained in them. (See p. 237.) The red rocks of Watcombe are underlaid by clayey beds (100 feet), which furnish material for the Terra Cotta works. At Livermead and Roundham Head, the beds appear similar to those on the Dawlish coast, and the sections show breccia and sandstone, with conglomerate at the base. The breccia and sandstone are shown also at Paignton, and at the Thurlestone Rock, a natural arch on the coast south-west of Kingsbridge.

There is thus a continuous series of rocks from the breccias and sandstones of Dawlish and Teignmouth up into the Rhætic Beds of Axmouth.

Fig. 36.—The Cliff West of Budleigh Salterton, Devonshire. (J. W. Salter.)

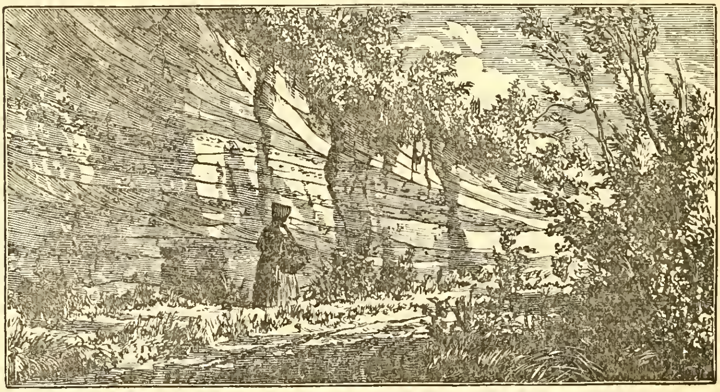
d. Gravel. *c*. Red sandstone. *b*. Pebble-bed. *a*. Red marl.

The Upper Marls appear on the southern edge or escarpment of the Polden Hills, and are visible in several outlying hills in the bordering moors. (See Fig. 39.) From Bridgewater the Marls extend north-west towards Watchet, and southwards towards the Vale of Taunton, where their boundary with the Upper Sandstone of Halse and Fitzhead is very ill defined. The Marls border the older rocks along the western side of the Quantock Hills, and thence at intervals to Porlock, but they do not exhibit conglomeratic conditions as is the case with the Dolomitic Conglomerate of the Mendip Hills ; hence it appears possible that portions of these older rocks were upheaved after the Triassic period. In an easterly direction the Marl is overlaid by the Greensand of Blackdown. At Keshill, near Broadhembury and Kentisbere, alternations of sandstone and mottled clay, which dovetail together, are seen in the lane cuttings.

Pseudomorphous crystals of Rock-salt have been noticed in the lower portions of these beds near Sidmouth, and there also Plant-remains (*Equisetites?*) have been found by Mr. P. O. Hutchinson.[1]

The underlying Upper Sandstones are generally composed of red rock, often false-bedded and in places mottled with greenish-grey streaks and patches, and they contain hard nodules and ferruginous concretions. Such beds are well shown near Williton, Halse, Milverton, Minehead, Wellington, Kentisbere, and Ottery St. Mary, as well as on the coast near Sidmouth. Near Williton the beds are very calcareous, and are burnt for lime. After a study of the red rocks near Minehead and Williton (1870-73), Mr. J. H. Blake came to the conclusion that the three divisions of the Trias were present, and he correlated the calcareous sandstones, well shown between Crowcombe Heathfield and Bishops Lydeard, with the Muschelkalk.[2] (See p. 221.)

FIG. 37.—SECTION OF TRIASSIC ROCKS NEAR DENBURY FARM, WIVELISCOMBE.



False-bedded red, brown, and yellow sandstone, with pebbly seams (Upper Sandstone).

In the sandstone series of Otterton Point Mr. Whitaker found the jaw of *Hyperodapedon*, a lacertilian reptile about six feet long; and more recently in the higher portion of the same series of beds, between Budleigh Salterton and Sidmouth, bones of Labyrinthodon have been discovered.[3]

Beneath the Upper Sandstones come beds of Conglomerate with large pebbles of grit and limestone, as at Tipnoller and other quarries east of Wiveliscombe, Vellow near Stogumber, Milverton, and Wellington; sandstone bands frequently occur between the beds of conglomerate. Between the sandstone and conglomerate there is often no hard line of demarcation; south of Milverton,

[1] Trans. Devon Assoc. 1879.

[2] Ussher, Q. J. xxxii. 380; see also P. Geol. Assoc. iv. 267.

[3] Q. J. xxv. 138, 156; H. J. Johnstone-Lavis, Q. J. xxxii. 274; and A. T. Metcalfe, Q. J. xl. 257.

and between Halse and the Preston Bower, there is a development of pebbly sandstone, and near Williton the Conglomerate is associated with beds of breccia and sandstone. (See Fig. 37.)

In some localities the limestone pebbles and boulders from the Conglomerate are burnt for lime; and the other pebbles of grit and sandstone are used for road-mending.

The Pebble-beds of Budleigh Salterton are made up largely of flattened quartzite pebbles, containing Palæozoic fossils: these beds extend inland to Straightway Head, west of Ottery St. Mary, and have been traced by Mr. Ussher to the quartzose pebble-beds of Burlescombe, and Whiteball Hill Tunnel.[1] The term 'Popple-rock' is sometimes applied to the conglomerates, and the Budleigh pebbles are locally known as 'Popples'; there is also the village Newton Poppleford.

The Lower Marls pass locally down into the beds beneath by intercalations of sand. They are used for brickmaking near Wiveliscombe and Cullompton, and occur over Kentisbere Moor, around Whimple, etc.

In Devonshire and West Somerset there are certain beds at the base of the New Red Series, which are termed Breccias. They are made up for the most part of slaty fragments embedded in a red sandy matrix, and are accompanied, sometimes abundantly, by pebbles of Devonian Limestone, by pebbles of Carboniferous and Devonian grits, and by boulders of Granite and various Igneous rocks.[2] The occurrence of Granite is important, for it is evidently derived from Dartmoor; and as the intrusion of this rock took place in late Carboniferous, or perhaps in early Permian times, the age of the red rocks of Devonshire must be later.

The Lower Sandstones and Breccias, containing clayey and marly beds, occur at Stogumber, Tiverton, Crediton, Heavitree east of Exeter, Topsham, Dawlish, Teignmouth, Kingskerswell, etc. They contain many limestone pebbles, some of which at Labrador Bay, south of Teignmouth, inclose *Goniatites*, *Clymenia* (*C. linearis*), and many Corals (Madrepores).[3] These pebbles are burnt for lime in places; and they are also polished for sale, for which purpose they are collected on the sea-shore, where they are derived chiefly from the Breccia, but some perhaps directly from the Devonian Limestone. Devonian fossils have also been found in the Trias near Tiverton and Silverton.[4] Beekite also occurs on the Devonshire coast (see p. 141), and it has been met with in Triassic conglomerate at Bouley Bay, Jersey.[5]

The brecciated beds near Exeter, known as the Exeter or red conglomerate, have been quarried at Heavitree,[6] Exminster, and

[1] Trans. Devon Assoc. 1877.

[2] J. J. Conybeare, Ann. of Phil. 1821; and W. D. Conybeare and Phillips, Outlines of Geol. England and Wales, p. 293.

[3] See A. Champernowne, G. Mag. 1880, p. 361.

[4] Rev. W. Downes, Trans. Devon Assoc. 1881.

[5] Ansted and Latham, Channel Islands, p. 274; J. A. Birds, G. Mag. 1879, p. 334.

[6] The Heavitree quarry was described by Dr. J. F. Berger, T.G.S. i. 99.

other places for building-purposes. The Wonford stone was used in the construction of the sea-wall at Torbay, and was formerly used for coarse millstones. Sandstone from the cliffs east of Exmouth was used in Exeter Cathedral. The beds are very irregularly impregnated with iron-ore, and this has influenced the weathering of the red cliffs, which, especially near Dawlish, assume grotesque forms. Sometimes the sand is very dark and almost black. Some of the brecciated clay-beds in the neighbourhood of Exeter and near Torre are worked for brick and tile-making. The red clay used in the Terra Cotta works at Watcombe (Watcombe and Petitor sands and clays) has been shown by Mr. Ussher to occur at the base of the Red rocks, although superficial loamy deposits have also been employed in the manufacture of this earthenware.[1]

The lower beds of Breccia between Teignmouth and Exeter have been long known to contain opalescent crystals of a variety of felspar known as Murchisonite, evidently derived as pebbles from the granitic or igneous rocks (quartz-porphyry, etc.) of the Dartmoor district, yet differing a little in colour and texture from the mineral when found *in situ*. Mr. Ormerod has endeavoured to trace out certain horizons in this series by the occurrence of Murchisonite, whence the name 'Murchisonite beds,' which he has applied to the strata.[2] Some Igneous rocks are associated with the beds near Tiverton, Crediton, and Exeter. (See sequel.)

As yet we have no positive proof, by any deep-boring, that the separate divisions that are visible in the coast-section between Teignmouth and Axmouth are continuous one beneath the other, so that at the latter locality all would be represented in vertical section were a boring carried through the series; and when the question of the method of accumulation of the strata comes to be solved some difficulties arise.[3]

It may be observed that nowhere are the conglomerates and breccias far removed from the margin of old rocks, but the pebble-beds of Budleigh Salterton are seemingly the most distant from their parent rocks. The former are all of local derivation, varying according to the characters of the Palæozoic rocks against which they rest. The derivation of some of the latter is not exactly known; the fossils collected by Mr. W. Vicary, Mr. W. Linford, and others, indicate species of Devonian and Cambrian age; and at one time the older pebbles were considered to have travelled from the French area, as Mr. J. W. Salter regarded the fossils as French, and not British species, and similar rocks occur in Normandy, Brittany, etc. It is now considered that they may have been derived from rocks at no very great distance from the spots where the pebbles are found; perhaps, as has been suggested, from Gorran Haven, Mevagissey, and Veryan, or more probably

[1] Trans. Devon Assoc. 1877; A. Tylor, Q. J. xxii. 466.
[2] Q. J. xxxi. 346; see also De la Beche, Report on Geol. Cornwall, etc. p. 208.
[3] See Godwin-Austen, T. G. S. (2), vi. 454.

from rocks destroyed in the formation of the English Channel.[1] (See p. 76.) Among the fossils there are Fucoids, Mollusca, and Trilobites. Most of the species are Devonian; and they include *Rhynchonella inaurita*, *Spirifera Verneuilii*, *Orthis Budleighensis*, *Lingula Hawkei*, *L. Lesueuri*, *Modiolopsis*, *Pterinea*, *Homalonotus*, *Phacops*, etc.; these are enclosed in the pebbles.

Mr. Godwin-Austen has shown that the western portion of the English Channel area was occupied during several distinct geological periods by a mass of crystalline and old Palæozoic rocks, and he thought shore-ice might have transported the pebbles. Considering their hard nature, it seems doubtful whether they were shaped in Triassic times. Such smooth pebbles of grit or quartzite are rarely found in the Red Conglomerates and breccias bordering the older rocks; hence the idea occurs that the Budleigh pebbles may have been derived from some old (Carboniferous?) conglomerate. The same remark, however, would apply to the Bunter Pebble-beds, which in some respects appear to be homotaxial. (See p. 222.) It is thus a significant fact, when looked at in a large way, that the coarser materials are nearer the old Palæozoic land-margin, as is the case with the Dolomitic Conglomerate of the Mendip Hills, Gloucestershire and Glamorganshire.

The former extent of the Triassic rocks in Devonshire is a difficult subject.[2] We find traces of Red rocks in Start Bay, Bigbury Bay, and even on the shores of Barnstaple Bay, and we find long spurs of Red rocks running into the heart of the county west of Tiverton and Crediton, and an outlier at Hatherleigh. Denudation has, however, been so complete that we have no positive evidences of overlap by the higher New Red beds in that region. The character of the Breccia itself is due to the nature of the bordering rocks which formed the old margin of the lacustrine area, and which consisted most largely of slates; and its thickness may be due to its having been banked up against the Devonian and Carboniferous rocks. Therefore no conclusions as to its age can be drawn from its lithological characters. Sir Roderick Murchison considered it to be Permian, agreeing with Conybeare and Buckland, who identified the Heavitree Breccia with the Roth-liegende of the Germans.[3] It may indeed be difficult to disprove this if we regard the Permian and Trias as one system; and therefore, as the red rocks of Devonshire form a connected series, the use of the term New Red or Poikilitic Series may be preferable to that of Trias. The lower beds have indeed been classed as Bunter, while the upper are

[1] Salter, G. Mag. 1864, p. 6; Vicary, Q. J. xx. 283, 286; T. Davidson, Q. J. xxvi. 70; Devonian Brachiopoda (Palæontograph. Soc.) vol. iv., Notes by H. J. Carter, p. 317; A. W. Edgell, Q. J. xxx. 45; W. Pengelly, G. Mag. 1878, p. 238; Hicks, Q. J. xxx. 49; Godwin-Austen, Q. J. xii. 45; xxx. 49.

[2] See W. Pengelly, Trans. Devon Assoc. 1866.

[3] Silurian System, p. 67; Siluria, edit. 5, p. 333; Sedgwick, T. G. S. (2), iv. 400, 403.

undoubtedly Keuper, passing gradually into the Rhætic Beds east of Axmouth. As Mr. Pengelly first pointed out, there is no unconformity in the series, and no doubt the Muschelkalk is represented here, as elsewhere in point of time, although it is hazardous to say by which beds in particular. (See pp. 221, 233.)

Economic products, etc., of the Keuper Beds.[1]

The Sandstones have been largely quarried for building-purposes at Ombersley and Hadley, near Droitwich. In the neighbourhood of Pattingham and Tattenhall the Basement beds have been burnt for lime. In the Hawkstone range in Shropshire, and at Grinshill north of Shrewsbury, the Lower Keuper sandstones have yielded good freestones, and thin flags sometimes used for roofing. They are quarried at Delamere, Peckforton, and other places in Cheshire; near Ashbourne, in Derbyshire; and at Alton and Hollington, in Staffordshire. The Basement beds yield the best building-stones of the Trias. Among the local stones may be mentioned the Bank Delf Stone of Bank Quarry, Melling, near Ormskirk; the Runcorn stone; the beds at Drayton Basset, south-west of Tamworth; and the Kingwood Stone in the neighbourhood of Codsall.

The Lower Keuper sandstones of Alderley Edge and Mottram St. Andrew have yielded much copper-ore, together with galena and cobalt-ore. Traces of copper-ore have also been met with at Grinshill, on the east side of the Peckforton Hills.[2]

In Cheshire and Worcestershire extensive beds of Rock-salt occur, interstratified with the lower beds of the Keuper Marl. Our culinary salt is largely manufactured from the brine-springs; hence the term 'Saliferous' is sometimes applied to the Upper Keuper strata.

Among the localities for rock-salt or brine-springs are Droitwich and Stoke, in Worcestershire; Northwich, Sandbach, Anderton, Middlewich, Wheelock, Winsford, Lawton, Dirtwich, Foulwich, and Nantwich in Cheshire; Adderley in Shropshire, and Shirleywich in Staffordshire. At Droitwich, and also at Nantwich, Middlewich, and Northwich, on the banks of the Weaver, the salt has been extracted from the brine for upwards of 1000 years. The rock-salt was accidentally found in 1670 in sinking a coal-pit at Marbury, near Northwich.[3]

The brine-springs yield about 25 per cent. of chloride of sodium, the water being pumped to the surface; they now furnish the chief supply, the total amount of rock-salt mined being about 150,000 tons annually, while that obtained from brine was 1,800,000 tons in 1880. The Rock-salt occurs sometimes in a massive or granular form, at others in large cubical crystals; Gypsum is often found with it. The former is usually of a dull red tint, and associated with red and pale green marls, and with greenish-grey splintery shale.

At Winsford, Northwich, and other places in Cheshire, where the salt is worked, the beds containing it are reached at a depth of from 50 to 160 yards below the surface. The number of saliferous beds in the district is five, they vary in thickness from a few inches to over 100 feet, and extend several hundred feet where proved. A considerable quantity of salt is also mixed with the marls associated with the purer beds. The descent to the mines is by a shaft, used for the general purposes of drainage, ventilation, etc. The roof, which is about twenty feet above the floor, is supported by pillars about fifteen feet in width. When

[1] In many instances, especially in parts relating to the south-west of England, the economic products have been previously mentioned.

[2] E. Hull, G. Mag. 1864, p. 65; Geology of Stockport, etc., p. 39.

[3] G. Ormerod, Hist. of Cheshire, i. p. xlvi. See also H. Holland, Agric. of Cheshire, 1808; and Trans. G. S. i. 38; L. Horner, T. G. S. ii. 94; C. Parkinson, Q. J. xl. 248; Hull, Geology of Altrincham, Cheshire; T. Ward, Mem. Lit. and Phil. Soc. Manchester, 1881-2; G. W. Ormerod, Q. J. ix. 187.

lighted up with numerous candles, the subterranean halls that have been excavated during the working of Rock-salt present an appearance which richly repays any trouble that may have been incurred in visiting them. The Witton mine, one of the largest, has been worked 330 feet below the surface, and from it, and adjacent mines, upwards of 60,000 tons of Rock-salt were annually obtained ; a part of this was exported, and the rest dissolved in water, and afterwards reduced to a crystalline state by evaporating the solution. The houses in which salt is manufactured are known as Wych-houses—*wich* or *wych* (of Saxon origin) meaning a salt-house or salt-works. In the reign of Henry VI. there were 216 salt-houses in Nantwich alone.[1]

The following section at Lawton is by Mr. G. W. Ormerod :[2]—

Soil and gypseous marls	126 feet
Salt	4 ,,
Indurated clay	30 ,,
Salt	12 ,,
Indurated clay	45 ,,
Salt sunk into	72 ,,
	289 feet.

In the Marston mine, near Northwich, there are two thick beds of Rock-salt ; the upper or Top-rock is 85 feet, the lower or Bottom-rock is 106 feet in thickness, and they are separated by 30 feet of indurated red clay containing strings of salt.

Pseudomorphous crystals of rock-salt occur abundantly in the Keuper sandstones and marls ; these pseudomorphs are sedimentary casts, often composed of silicate of protoxide of iron.[3]

Rock-salt occurs also at Middlesborough in Yorkshire, in the Keuper Marls, as well as in beds considered to be Permian. (See p. 220.)

Referring to the Cheshire district, Mr. Strahan has remarked that as a result of the removal of the vast amount of rock-salt, there have ensued the most disastrous surface-disturbances. "While the breaking-in of the old rock-pits has formed funnel-shaped abysses from 50 to 150 yards across, the continual abstraction of brine, and presumably of the upper part of the top-rock in solution, has led to the subsidence of broad tracts of land, and their consequent flooding by river water. The broad shallow lakes thus formed are known as 'flashes' ; one at Northwich occupies a space of about 100 acres." He adds that many Cheshire meres, for example, those of Delamere Forest, are shallow-basins in drift-sand, and owe their origin to other causes.[4] (See sequel.)

Alabaster, a semi-crystalline form of gypsum (hydrated sulphate of lime) occurs in abundance in some localities in the Red Marl or Gypseous marls of the Isle of Axholme, East Bridgeford, Newark and Orston, Nottinghamshire ; Chellaston and Aston, Derbyshire ; near Tutbury, and Fauld near Uttoxeter, in Staffordshire ; Aust, in Gloucestershire ; Droitwich, in Worcestershire ; Middlesborough, in Yorkshire ; near Whitehaven, Cumberland ; Syston, in Leicestershire ; at Watchet, and near Somerton, in Somersetshire. The Alabaster occurs in nodules, bands, and in veins which traverse the beds in all directions ; it is of local development. In colour it is sometimes milky-white, but is often clouded and streaked with red from the admixture of oxide of iron. The purer and variegated kinds are manufactured into ornamental articles, the common sort (but that most largely worked) is converted by burning into Plaster of Paris, which being largely used in forming moulds for the Staffordshire potters, the

[1] G. Mag. 1874, p. 260. See also D. T. Ansted, Geology, 1844, ii. 398; B. B. Woodward, Nat. Hist. Notes, ii. 180.

[2] Q. J. iv. 288.

[3] H. E. Strickland, Q. J. ix. 5 ; James Plant, G. Mag. 1869, p. 377.

[4] Geol. Cheshire, Iron and Steel Inst. 1885 ; see also G. A. Lebour, G. Mag. 1885, p. 514.

alabaster is known as Potter's Stone. The very coarse kinds are used as top-dressing for soils.[1]

Celestine, or 'Salt-stone' (Sulphate of Strontian), is found in some abundance in the Red Marl, and occasionally in the Dolomitic Conglomerate, of Gloucestershire and Somersetshire. Manganese-ores occur in some localities, in the red rocks of Devonshire.

The Red marl is not a water-bearing stratum. It is necessary to penetrate it before a suitable supply of water is reached; and this is generally met with in underlying sandstones. The town of Burton-on-Trent derives its commercial prosperity from the manufacture of ale, and the superior quality of this beverage is due to the character of the waters, which contain variable proportions of sulphate of lime, derived from the gypseous marls of the Keuper. Mr. Molyneux has calculated that (in various parts of the world) about 350,000 lbs. of gypsum are annually imbibed in potations of Burton beer.[2]

Fullers' earth has been raised from the marl beds at Raddle Pits near Braithweel, north-east of Rotherham, also at Renton in Yorkshire; and at Taschbrook, one mile from Warwick, a substance probably of the same nature, as it was intended as a substitute for soap, was raised in former years.[3]

Red marls belonging to the Keuper Beds are largely worked for brick-making near Nottingham, and at Everton near East Retford. The 'Red Clay of Tuxford' belongs to the series. Red marl is also worked for brick-making in Derbyshire and Leicestershire, at Stapenhill, near Burton-on-Trent, at Great Crosby between Southport and Liverpool, at Bristol, and other places.

The "Red ground" forms fine rich meadow- and pasture-land; and the Cheshire cheese may be said to be a product of the latter. The soil on the Marls is well suited for orchards, and also for teazels, which have been much cultivated for use in the cloth-mills. The Keuper Marl was formerly largely used for marling ground; hence the number of old marl pits. Marl has been used in agriculture since Saxon times.[4]

Rhætic or Penarth Beds.

The Rhætic Beds were so named by Dr. C. W. Gümbel, from the Rhætian Alps of Lombardy, the Grisons, and Tyrol, where the strata are well developed. Their determination in this country was due mainly to the researches of Mr. Charles Moore, Dr. T. Wright, and the Rev. P. B. Brodie. Considering it desirable that a distinctive name should be given to the English and Welsh representatives of the series, which were formerly grouped with the Lias, Mr. H. W. Bristow, in 1864, proposed the term Penarth Beds, because the strata are clearly and prominently exhibited in the cliffs of Penarth, south of Cardiff.[5]

[1] Keene's cement and Parian cement are made from plaster of Paris. R. Hunt and F. W. Rudler, Descriptive Guide to the Museum of Practical Geology, edit. 4, pp. 34, 43.

[2] Burton-on-Trent: its History, etc. p. 208.

[3] Conybeare and Phillips, Outlines of the Geol. England and Wales, p. 280.

[4] F. Seebohm, The English Village Community, 1883, p. 247.

[5] G. Mag. 1864, p. 238; and Rep. Brit. Assoc. for 1864, Sections, p. 50.

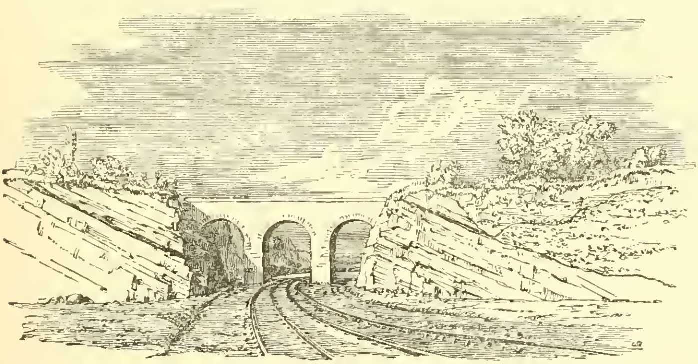
The Rhætic Beds, where fully developed, consist of the following divisions:—

3. White Lias,	from	1 to 25	feet.
2. Black Shales,	,,	8 to 30	,,
1. Grey Marls,	,,	10 to 50	,,

The total thickness of the series is sometimes as much as 150 feet.

White Lias.—The name White Lias is a quarryman's term, which was adopted by William Smith (1815), the stone being, as a rule, very distinct from the Blue (Lower) Lias above it. The White Lias comprises beds of white, pale-grey, and cream-coloured limestones and marls, which maintain much uniformity in tint and texture. The top-bed in the neighbourhood of Bath and Radstock is a hard, compact and smooth-grained stone, known as the Sun Bed; the term Jew Stone is sometimes applied to this bed (which may consist of two or more layers), near Wedmore and Street, and other parts of Somersetshire, south of the Mendip Hills.

FIG. 38.—SECTION WEST OF WESTON RAILWAY STATION, NEAR BATH.



Lower Lias. White Lias (Rhætic). Valley Gravel and Rubble. Lower Lias.

The Cotham or Landscape Marble, so well known from the dendritic markings which occur throughout it, is found at or near the base of the White Lias. It is a hard, compact limestone, like the Sun Bed, with generally an irregular mammillated or corrugated surface, and it is found in impersistent masses from two to eight inches thick. The name Cotham Marble is derived from Cotham House, north of Bristol.[1] This stone is generally present in the southern part of Gloucestershire and Somersetshire, extending even to the coast-section between Axmouth in Devonshire and Lyme Regis in Dorsetshire. Between Bath and the Mendip Hills, the Cotham Marble is frequently turned up in the ploughed fields,

[1] E. Owen, Observations on the Earths, etc., for some miles about Bristol, 1754.

but the quarries in the White Lias are rarely opened deep enough to expose it. Perhaps the best exposures of the stone are in the railway-cuttings at Weston, and Kelston near Bath. (See Fig. 38.) The irregular top of the Cotham Marble is not an eroded surface, for thin layers may often be split off, which correspond to the irregularities; the same kind of uneven concretionary surface, on a larger scale, may often be seen on the limestones of the Lower Lias, a structure perhaps induced during the consolidation of the beds. This concretionary and sometimes botryoidal surface is not uncommon in the lowermost Purbeck Beds. The dendritic or arborescent markings in the Cotham Marble were probably produced by infiltration of ores of manganese and iron in the soft calcareous mud from which the rock originated. A thin bed of limestone, showing imperfect dendritic markings, occurs also in the lower Purbeck Beds of Durlston Bay, Swanage and other localities.

Occasionally the upper surface of the Sun Bed or Jew Stone presents a striated appearance, being crossed in various directions by fine grooves. In some cases these appearances are produced by weathering along lines of minute joints, and in other cases they may be due to sun-cracks, modified subsequently by the erosive action of water.[1] Sun-cracks, ripple-marks, pseudomorphous crystals of rock-salt, sands, and conglomerates, occur at various horizons in the Rhætic Beds, telling of shallow water and of pauses in deposition. Perforations are occasionally met with in the upper beds of the White Lias, which have been referred to the action of boring Molluscs and Annelides. Specimens showing tubular perforations, extending from two to nearly six inches into the stone, were obtained by Mr. Bristow and Mr. Etheridge, from the White Lias at Curry Rivell, near Taunton; these perforations were probably the burrows of some marine animal in the soft calcareous mud of the period.[2]

The White Lias, which is well developed in Devonshire and Somersetshire, is poorly represented at Penarth, between Bristol and Gloucester, in the Midland Counties, and further to the north.

The fossils of the White Lias include *Modiola minima*, *Cardium Rhæticum*, *Ostrea Liassica*, *Plicatula intusstriata*, *Lima præcursor*, *Monotis decussata*, *Placunopsis alpina*, *Myophoria postera* (a form allied to *Trigonia*), *Pleuromya* (*Pteromya*) *Crocombeia*, *Schizodus* (*Axinus*) *cloacinus*, and other Mollusca.[3] An *Estheria*-bed with *Estheria minuta*, var. *Brodieana*, may sometimes be recognized in the lower part of the White Lias. *Cypris Liassica* also occurs; as well as Corals of the genera *Montlivaltia* and *Thecosmilia*. The fossils of the White Lias are, as a rule, poorly preserved; they are sometimes abundant in the marly layers between the harder beds of stone. Remains of Fishes and Insects are occasionally found in the Cotham Marble.

Black Shales.—These shales, which underlie the White Lias,

[1] See Rev. J. Sutcliffe, "A Short Introduction to the Study of Geology," 1817, p. 21.

[2] J. H. Blake and H. B. W., G. Mag. 1872, p. 196.

[3] For figures of Rhætic fossils, see Moore, Q. J. xvii. 516; and Etheridge, Trans. Cardiff Nat. Soc. iii. For lists of species, see also Geol. E. Somerset, etc. (Geol. Survey), p. 87, Wright, Q. J. xvi. 374, Brodie, "A History of the Fossil Insects," 1845.

form the most characteristic and persistent portion of the Rhætic Series. They consist of paper-shales and laminated clays, much impregnated with iron-pyrites, and containing also selenite and fibrous carbonate of lime ('Beef'). At or near the base of the shales, there may usually be found a layer, and sometimes two or more bands, of pyritic, micaceous, and calcareous sandstone, containing coprolites, and bones, scales, and teeth of Fishes. These bands constitute the well-known 'Bone-bed,' which was formerly termed the Bristol or Lias Bone-bed. The Fish-remains include *Gyrolepis Alberti*, *Ceratodus altus*, *Acrodus minimus*, *Hybodus reticulatus*, *Saurichthys apicalis*, and other species; bones of *Ichthyosaurus* and *Plesiosaurus* also occur. The Mollusca found in the Black Shales are generally much compressed. Most characteristic is the *Avicula* (*Cassianella*) *contorta*, originally described by Major-General J. E. Portlock;[1] and the Rhætic Beds, as a whole, are sometimes termed the Zone of *A. contorta*. *Cardium Rhæticum* is also abundant, and has sometimes, although unnecessarily, been taken to indicate a zone. *Pecten Valoniensis*, another characteristic form, is best preserved in thin layers of shelly limestone, which are met with here and there in the higher portions of the shales. Sandy beds occur in places, and are sometimes crowded with casts of *Pullastra arenicola*. Remains also of Insects, Echinoderms, and Plants, are occasionally met with in the Rhætic Beds. A Brittle-star, *Ophiolepis Damesii* has been obtained from the Shales at Garden Cliff. One Brachiopod, *Discina*, has also been recorded.

Grey Marls.—Below the Black Shales there is generally found a series of grey, tea-green, and cream-coloured marls, which pass down, often imperceptibly, into the red, green, and variegated Keuper Marls. The mere difference in colour between the deposits is likely to be subject to so much variation, that although the red disappears in the higher part of the series, yet a boundary-line drawn solely in reference to colour cannot be regarded as a definite horizon. On the Maps of the Geological Survey it has, however, been found most practicable to draw the boundary between the Rhætic and Keuper Beds at the base of the Grey Marls. In some localities the more marked boundary would be taken at the base of the Black Shales, as the Grey Marls appear more closely linked with the Red Marls;[2] but in other localities the Grey Marls present features markedly different from the Keuper Marls, and appear more closely connected with the Black Shales and White Lias. Near Axmouth and Watchet, bands of very dark, if not black, marl, alternate with pale grey and buff marls, above the Red Marls of the Keuper; so that we have a transition from the Red Marls into the Black Shales. The Grey Marls also contain bands of hard white and cream-coloured marl, which resemble the softer beds of White Lias.

Nevertheless, whether the Grey Marls be taken as the top of the Keuper, or the base of the Rhætic Beds, is a matter of little

[1] Rep. Geol. Londonderry, 1843, p. 126.
[2] E. Wilson, G. Mag. 1881, p. 464; Q. J. xxxviii. 451.

moment so long as the latter are regarded as Passage Beds; for such beds may naturally have a greater analogy with the overlying beds in one locality, and with the underlying beds in another.[1]

No doubt the Grey Marls, as a mass, mark some general change in the character of the sediments, which came on gradually and without any approach to uniformity. Were their colour due simply to superficial weathering or discolouration of Red Marls, we should expect the exposed surfaces of the Keuper Beds to be generally of a grey tint, which is not the case. The Grey Marls have yielded one fossil of the highest interest, namely a tooth of the oldest known British Mammal, *Microlestes* (*Hypsiprimnopsis*) *Rhæticus*, which was found by Prof. W. Boyd Dawkins at Watchet.[2] Fish-scales have also been recorded from marly limestones below the Black Shales at Penarth, and at Milton Lane, near Wells.[3]

The evidence afforded by the Fish-remains which occur in the Bone-bed would incline us to connect the Rhætic Beds with the Trias; for, as Sir Philip Egerton pointed out, some forms are allied to and some are identical with Muschelkalk species.[4] *Hybodus* and *Acrodus* are, however, common both to the Keuper strata and to the Lias. The Mollusca serve to link the Rhætic Beds with the Lower Lias, from which, nevertheless, they are distinguished in this country by the absence of Cephalopoda; no species of *Ammonites* or *Belemnites* being known from the beds.

In any case we may look upon the Rhætic Beds as forming the connecting link between the New Red Sandstone and the Jurassic strata, a fact of much interest considering the different physical conditions under which these two great systems of strata were deposited. Edward Forbes, many years ago, expressed the opinion that the fossils of the White Lias were curiously representative of the existing Caspian fauna. He then broached the notion that the Red Marls were formed in a great salt inland sea (a sort of Aralo-Caspian), during the last state of which, probably during influxes of the sea, the White Lias was formed: and that the area was subsequently depressed and turned into a part of the ocean, when the Liassic fauna came in.[5] In their method of formation the Rhætic Beds may thus, on the whole, be closely related to the Trias, and we may include them in that division as the uppermost member of the New Red Sandstone or Poikilitic System.

The Rhætic Beds have been found between the Red Marls and the Lower Lias, wherever sections have been exposed. They may therefore be said to extend across England from near Redcar on

[1] Prof. E. Renevier, Bull. Soc. Vaudoise des Sc. Nat. viii. 39; see also Prof. R. Tate, Geol. and Nat. Hist. Repertory, i. 364.
[2] Q. J. xx. 396; see also Q. J. xii. 252.
[3] Vertical Sections, Sheet 46 (Geol. Survey).
[4] Proc. G. S. iii. 409; see also J. W. Davis, Q. J. xxxvii. 414.
[5] Memoir of E. Forbes, by G. Wilson and A. Geikie, 1861, p. 418; Ramsay, Q. J. xxvii. 189.

the coast of Yorkshire, to near Lyme Regis and Axmouth on the coast of Devonshire.

The occurrence of Rhætic Beds in Cumberland has not been proved, but their presence may be inferred from an outlying mass of Lower Lias situated to the west of Carlisle, and from the occurrence of Rhætic Beds in the north-east of Ireland, for in this northern area the outcrop of the Rhætic Beds (if present) is entirely concealed by Drift. Nor have any definite traces of Rhætic Beds been found in the superficial deposits, perhaps because the Beds are represented by soft shales and marls, which would not readily be preserved in Boulder-drift.[1]

In Yorkshire the Rhætic Beds comprise about fifteen feet of shales with sandy beds, resting on about ten feet of blue or tea-green marls. The highest beds are nowhere well exposed. A band with *Pleuromya Crocombeia* (known as *Pleuromya*-limestone) has been taken as the base of the Lower Lias; although this species, first described by Mr. C. Moore from the White Lias of Beer Crocombe in Somerset, is also a Rhætic fossil. The beds are not exposed on the coast, but they occur at Lazenby, south-west of Redcar, and they may be seen at intervals, near Stokesley, also to the east of Northallerton, between York and New Malton, and at Londesborough, north of Market Weighton.[2]

In Lincolnshire, Nottinghamshire, and Leicestershire the White Lias is represented by fifteen or twenty feet of grey and yellow marls and shales with nodules of earthy limestone. The section at Gainsborough was first described by Mr. F. M. Burton,[3] and the beds have been traced northwards to Burton-upon-Stather by Mr. W. A. E. Ussher. At Newark-upon-Trent, a sharp line of demarcation, suggestive of local unconformity, has been noticed between the Black Shales and underlying Red Marls.[4] Sections of Rhætic Beds have been exposed in the railway-cuttings at Elton, near Nottingham,[5] and near Barrow-on-Soar.[6] The thickness of the Rhætic Beds at the Spinney Hills, near Leicester, has been estimated at twenty-six feet, whereas at Wigston the Black Shales are about forty feet in thickness, and these overlie about fifteen feet of tea-green marls.[7]

In Warwickshire the White Lias may be studied at Rugby, Southam, Loxley, and Eatington; while near Stratford-on-Avon, it is represented by the 'Guinea-bed' of Binton, Grafton, Wilmcote, and Bickmarsh, a limestone which is sometimes conglomeratic.

[1] T. V. Holmes, Q. J. xxxvii. 293.

[2] Phillips, Geol. Yorks, Part 1, edit. 3, p. 23; R. Tate and J. F. Blake, Yorkshire Lias, p. 30; C. F. Strangways, Geol. N.E. of York (Geol. Survey), p. 6.

[3] Q. J. xxiii. 315.

[4] See Geol. S. W. Lincolnshire, by A. J. Jukes-Browne, p. 19; G. Mag. 1874, p. 480.

[5] E. Wilson, Q. J. xxxviii. 451; see also Midland Naturalist, vi. 193; and Rev. A. Irving, G. Mag. 1874, p. 318, P. Geol. Assoc. iv. 82.

[6] W. J. Harrison, Q. J. xxxii. 212.

[7] E. Wilson and H. E. Quilter, G. Mag. 1884, p. 415.

The Rhætic Beds have been exposed near Long Itchington and Stretton-on-Dunsmore, but further north they are much obscured by Drift. Below the White Lias come black shales, sand and sandstone, and green marls.[1] Similar beds are exposed near Pershore in Worcestershire. Rhætic Beds have been observed in Needwood Forest, west of Burton-on-Trent, and south of Uttoxeter, in Staffordshire;[2] they have also been identified near Market Drayton in Shropshire, a district much obscured by Drift. South of Audlem Station in Cheshire, black shales and buff marl have been noted, the latter graduating into the Keuper Marls.[3]

The Rhætic beds, where they approach the Palæozoic land of the Bristol Coal Basin, the Mendip Hills or South Wales, frequently overlap the New Red rocks, whether Red Marl or Dolomitic Conglomerate, and repose directly upon the older rocks. They sometimes present conglomeratic characters, as at Nempnet near Chew Magna, near Frome, and Shepton Mallet.

To the south of Cardiff the Rhætic Beds are well displayed in the cliffs from Penarth Head to Lavernock Point. The section at Penarth, which has been measured in detail by Mr. Bristow and Mr. Etheridge, is as follows:[4]—

	Lower Lias.	Beds with *Ammonites planorbis*, *Ostrea Liassica*, etc.
Rhætic or Penarth Beds.	White Lias. Series. 18 feet.	Grey and pale-brown arenaceous shales, with occasional beds of hard limestone, but not very fossiliferous. *Modiola minima*, *Anatina*, *Lima*, etc.
	Black Shales. 24 feet.	Band with *Pecten Valoniensis*. Black shales with shelly limestones, *Avicula contorta*, *Cardium Rhæticum*, etc. Bone-bed with Fish-remains. Shales, etc.
	Tea-green marls. 28 feet.	Grey earthy limestone, with Fish-scales and lignite. Pale cream-coloured, greenish-grey, white and pale-red marls. Greenish-grey crumbling, jointed, and conchoidal marls.
	Keuper.	Red marls.

The Rhætic Beds have been traced in many parts of Glamorganshire, between Cardiff and Pyle, west of Bridgend. At Coed Mwstr, north-east of Bridgend, White Lias, greenish-clay and conglomerate occur; at Gelligaredig, north-west of that town, the beds comprise brown sands, resting on green and grey marls: and at Pyle, limestones, shales, and marls occur. At the Stormy Down Cement-works, between Pyle and Bridgend, the White Lias was recognized by Mr. Bristow beneath the Lower Lias limestone and conglomerate.

On the coast, at Sutton, Southerndown, and Dunraven, south of

[1] H. H. Howell, Geol. Warwickshire Coal-field, 1859; P. B. Brodie, Q. J. xxi. 160, xxx. 746; R. F. Tomes, Q. J. xl. 356.

[2] W. Molyneux, Burton-on-Trent: its History, etc., 1869, p. 170.

[3] G. Maw, G. Mag. 1870, p. 203.

[4] See Vertical Sections, Sheet 47 (Geol. Survey), and R. Etheridge, Trans. Cardiff Nat. Soc. vol. iii. (1872).

Bridgend, grey argillaceous limestones, shales, and hard cherty limestones and conglomerates occur. The mass of these beds, which rest on the upturned edges of the Carboniferous Limestone, belongs to the Lower Lias. At Sutton there is a series of fine-grained white limestones (Sutton Stone), with bands of chert, and conglomerate at the base, together about twenty feet thick, which Mr. E. B. Tawney in 1865 claimed as Rhætic.[1] Mr. Moore however, obtained from them *Ammonites angulatus* (about 20 feet above the base of the beds) and other species which indicate their Liassic age,[2] while on stratigraphical grounds Mr. Bristow maintained that the Sutton Series passed into the Southerndown Series, and that both were of Lower Lias age.[3] Mr. Tawney subsequently accepted these views. The Sutton Stone has yielded many Corals, at Brocastle and Ewenny, south-east of Bridgend, and at Cowbridge. These include *Montlivaltia*, *Thecosmilia* and *Astrocœnia*. Dr. Duncan remarked that they indicate a zone which in the Alpine Trias would be deemed St. Cassian. Mr. R. F. Tomes as early as 1863 expressed the opinion that the Rhætic Beds of Brocastle, Sutton, etc., might be represented by an interval during which no deposit of earthy matter took place, and that the fauna became mixed up with that of the true Lias, which was subsequently deposited.[4]

In Gloucestershire the section at Garden Cliff, near Westbury-on-Severn, and not far from Newnham, is one of the most famous exposures of the Rhætic Beds. The upper beds comprise cream-coloured limestones, marls, and clays, with *Modiola minima*, *Ostrea Liassica*, etc., eight or nine feet thick; beneath is a hard white marl (with *Estheria*-zone), a conspicuous feature in the cliff. Lower down come seven feet of grey marls with many fossils, and these rest on the Black Shales, about twenty feet thick, with *Avicula contorta* and *Cardium Rhæticum*. In the lower part of these shales are two or three Bone-beds, and also a layer with *Pullastra arenicola* (the *Pullastra*-bed); at the base is a thin Bone-bed containing teeth and scales of Fishes, and coprolites. These beds rest on the Grey Marls, which pass downwards into the red marls of the Keuper.[5]

Wainlode Cliff, on the Severn, between Gloucester and Tewkesbury; Coombe Hill, near Cheltenham;[6] and Aust Cliff, west of Thornbury in Gloucestershire, are well-known sections. Aust Cliff has long been noted for its conglomeratic Bone-bed, which contains teeth of *Ceratodus* and other Fishes, as well as coprolites,

[1] Q. J. xxii. 70; see also Dr. P. M. Duncan, Ibid. p. 89, xxxiii. 13, and xl. 375.

[2] Q. J. xxiii. 511; see also Prof. R. Tate, Ibid. p. 307.

[3] Q. J. xxiii. 199.

[4] Q. J. xxxiv. 180; xl. 356; see also W. C. Lucy, Proc. Cotteswold Club, 1885; and R. Etheridge, Trans. Cardiff Nat. Soc. 1872, vol. iii.

[5] Etheridge, Trans. Cardiff Nat. Soc. vol. iii. (1872), and Proc. Cottesw. Club, iii. 218; Wright, Q. J. xvi. 378; W. C. Lucy, P. Geol. Assoc. iv. 171; J. Jones and W. C. Lucy, Proc. Cottesw. Club, ii. 188.

[6] H. E. Strickland, Proc. G. S. iii. 585; Wright, Q. J. xvi. 379; Brodie, Fossil Insects, pp. 58, etc.

and bones of Saurians.[1] *Ceratodus* is a genus now living in the rivers of Australia. The Bone-bed is not persistent even in the cliff section at Aust; the uppermost bed of the Rhætic formation in this area is the Cotham Marble, the main mass of the White Lias being absent. Gold Cliff, on the Severn, opposite to Portishead, exhibits Lower Lias and Rhætic Beds.

In Somersetshire, the Rhætic Beds are well exposed at Blue Anchor to the west, and at St. Audrie's Slip to the east of Watchet, where the thickness is 150 feet. Among other well-known sections, are those in the railway-cuttings at Bitton (Willsbridge), Saltford, Kelston and Weston, near Bath (see Fig. 38); at Uphill, near Weston-super-Mare; Puriton, by Dunball Station, near Bridgewater; Midsomer Norton; Chilcompton; Shepton Mallet; Queen Camel, near Yeovil (150 feet); and Hatch Beauchamp, near Taunton.[2]

The Wedmore Stone is a tough shelly and sandy limestone, met with in the Black Shales at Wedmore, near Wells. The 'Flinty bed' is a compact limestone, with shelly bands, found at the base of the White Lias, at Beer Crocombe, near Taunton, from which bed many species of Mollusca were obtained by Mr. Moore. Sandy beds, with *Pullastra arenicola* and *Avicula contorta*, occur at Sand, near Wedmore, and at Harptree Hill and near Wigmore Farm, on the Mendips. A section of Rhætic Beds is exposed at Milton Lane, near Wells.[3]

Mr. Charles Moore has pointed out that many veins and fissures in the Carboniferous Limestone of the Mendip Hills have received infillings of Rhætic, Liassic, and Oolitic material. One vein has been

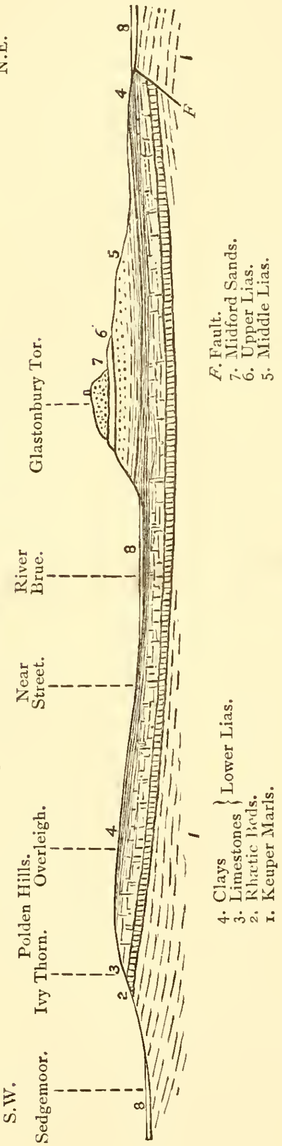


FIG. 39.—SECTION THROUGH GLASTONBURY TOR.

[1] Wright, Q. J. xvi. 380.
[2] Wright, Q. J. xvi. 382; Moore, Q. J. xxiii. 469, etc.; H. H. Winwood, Proc. Bath Nat. Hist. Club, ii. 1871; Vertical Sections, Sheets 46 and 47 (Geol. Survey); W. J. Sollas, P. Geol. Assoc. vi. 385; W. B. Dawkins, G. Mag. 1865, p. 481.
[3] Brodie, Q. J. xxii. 93.

proved to a depth of 270 feet at Charter House north-east of Cheddar, where a clayey deposit containing Liassic remains in abundance was met with. In the vales west of Frome at Vallis, Nunney, and Holwell, the Carboniferous Limestone is intersected by numerous dykes of mottled clay, white marl and irony sand, with fragments of limestone and other rocks. Thin beds of Rhætic clay, limestone, and conglomerate, may also be observed here and there on the upturned edges of the Carboniferous Limestone.

In the Limestone quarries at Holwell large bosses of rock have been left untouched by the workmen, and these are portions of dykes or fissures in the rock, filled with extraneous matter. The Limestone is not, however, so largely worked as formerly. On the south side of the road at Holwell, a fissure containing bones and teeth of Rhætic fishes may be observed. In 1864, Mr. Moore described three cartloads of clay and marl containing Rhætic fossils which he had obtained from one of the fissures at Holwell. From this material he had procured twenty-nine teeth of the Mammal *Microlestes Moorei*, together with relics of nine genera of Reptiles, and fifteen genera of Fishes; and he produced 70,000 teeth of *Acrodus* as the result of his labour, stating that the deposit had yielded him probably one million specimens.[1] Veins containg Rhætic and Liassic material occur also at Gurney Slade, near Binegar, north of Shepton Mallet. The period of the infilling of these veins cannot be fixed with certainty. Open fissures may, as Mr. Moore suggested, have received material during Rhætic and Liassic times. On the other hand, fractures in the Carboniferous Limestone may have been produced subsequently, and into the fissures to which they might give rise, material may have been introduced much later.[2]

In Devonshire the Rhætic beds may be studied between Axmouth and Lyme Regis, at Culverhole Point, Charton and Pinney Bays, as well as at Uplyme, where the White Lias is quarried.[3] The White Lias in this neighbourhood contains pebbles of compact limestone, of similar appearance to some layers in the White Lias, and on weathered surfaces these included fragments stand out in relief. The sections east of Axmouth show White Lias, 25 feet; Black Shales, 20 feet; Grey Marls, 35 feet. (See Fig. 40.)

The Sun Bed of Temple Cloud, near Clutton, has been recommended for purposes of lithography, on account of its closeness of texture and general purity. This bed is largely used for road-mending near Radstock. The White Lias beds are used for building-purposes, and are burnt for lime. The black shales are occasionally employed for brick-making. The grey marls have been used for marling land; they contain alabaster at Watchet and other places.

The Rhætic beds generally form a gentle escarpment overlooking the vales ot New Red Marl, and the junction with the beds below is frequently conspicuous in the ploughed fields, or in the faces of the more abrupt escarpments, as along the Polden Hills, in Somersetshire. (See Fig. 39.)

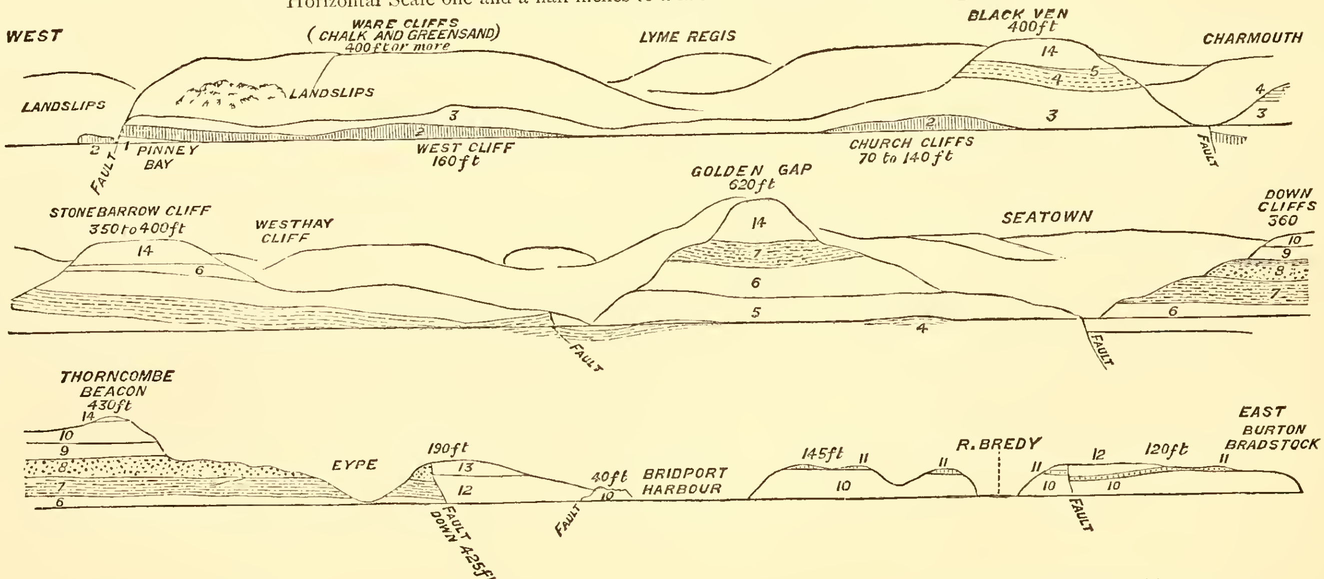
[1] G. Mag. 1864, p. 235, Q.J. xxxvii. 67.

[2] C. Moore, Q. J. xxiii. 481, etc.; J. McMurtrie, Proc. Bath Nat. Hist. Club, 1883; Geol. E. Somerset, etc. (Geol. Survey), p. 173; T. R. Jones, Fossil Estheriæ (Palæontograph. Soc.) 1862, p. 74.

[3] Wright, G. Mag. 1864, p. 290.

FIG. 40.—SECTIONS OF THE DORSETSHIRE CLIFFS, FROM LYME REGIS TO BURTON BRADSTOCK.

Horizontal Scale one and a half inches to a mile. Vertical Scale much exaggerated.



14. Chert gravel, Upper Greensand, and Gault.
13. Forest Marble.
12. Fuller's Earth.
11. Inferior Oolite.
10. Midford Sands.

9. Upper Lias.
8. Sand.
7. Laminated Beds. } Middle Lias.
6. { Starfish Bed. / Clay with *Ammonites margaritatus.* / Three Tiers (stone-beds). } Middle Lias.

5. Clay (Green Ammonite Beds). } Lower Lias.
4. Pale-grey Marl (Belemnite Beds). } Lower Lias.
3. Dark clays and shales. } Lower Lias.
2. Limestones (Blue Lias).
1. White Lias. Rhætic Beds.

[This section is reproduced from Report on Erosion of Sea-Coasts, by W. Topley, Brit. Assoc. 1885; see also Proc. Geol. Assoc. ix. 205, and E. C. H. Day, Q. J. xix. 278.]

JURASSIC.

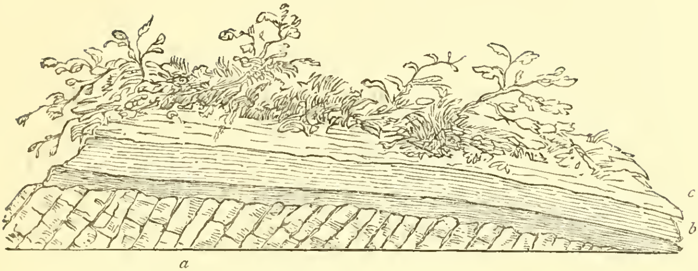


FIG. 41.—SECTION AT WHATLEY, NEAR FROME. (C. Moore.)

a. Carboniferous Limestone. *b*. Middle Lias. *c*. Rubble of Inferior Oolite.

The Jurassic system includes the several members of both Lias and Oolites, and derives its name from the development of these strata in the Jura mountains between France and Switzerland. The name Jurassic was given in 1829, by Alexandre Brongniart, but the term Jura limestone has been in use from time immemorial.[1]

The Liassic and Oolitic rocks have been divided into groups and stages, which are, as a rule, distinguished by marked lithological features, and by certain assemblages of organic remains. Although some of the chief divisions are remarkably persistent over large areas, yet the minor groups display a considerable variation in thickness when traced across the country, while some of them are quite locally developed. When we proceed to correlate the subdivisions of the rocks of the south-west of England with those in the midland and north-eastern counties, many difficulties present themselves. The variations in thickness, in lithology, and in the assemblages of organic remains, are striking. When, however, we look to the physical history of the period, and the method of deposition of the sediments, such changes appear but natural. It would be unreasonable to suppose that an argillaceous, a sandy, or a calcareous deposit should characterize any particular epoch of time, although any one of these deposits might be laid down over a considerable area. Such deposits were, no doubt, all being formed at the same time. The great variations in thickness and other modifications exhibited by the Liassic and Oolitic series suggest that

[1] Tableau des Terrains qui composent l'Ecorce du globe, p. 221; see also Buckland, Ann. Phil. xvii. (N.S. i.) 455; and Dr. A. Oppel, Die Juraformation Englands, Frankreichs und des Südwestlichen Deutschlands, 1856–58.

their subdivisions were not formed contemporaneously, but that a clayey condition, such as that which produced the Upper Lias, may have prevailed longer in one tract than in others, and the same may be said of the Midford Sands. The great thickness of Fullers' Earth in some places would likewise indicate a period of time which, in tracts where it has thinned away, was occupied by the deposition of rocks of a different lithological nature. Thus the conditions of sedimentary deposit may have changed at different times in different areas, and these changes would be marked, as a rule, by the modifications in the assemblage of organic remains which were suited to the then prevailing physical conditions. The clayey beds, it should be observed, are more persistent than the sandy or calcareous strata. Sir A. C. Ramsay considers that the Liassic and Oolitic formations were sediments laid down in warm seas surrounding an archipelago of which Dartmoor, Wales, and Cumberland formed some of the islands. The finer sediments were, no doubt, brought down by rivers, whose former presence is indicated by estuarine beds ; the calcareous sands and freestones have been formed in part from comminuted shell and coral : while evidences of coral-reefs occur at some horizons.[1]

On the whole, the Jurassic System stands out in marked contrast from the strata of the preceding New Red System, whose rocks furnish but little attraction to the collector of fossils, although the Rhætic beds may be said to usher in the earliest traces of Liassic life. The flora of the Jurassic period includes Conifers and Cycads ; and the fauna, many Corals, Echinoderms, Crustacea, Insects, Mollusca, Fishes, and Reptiles among which are the earliest Crocodilia found in this country.[2] Mammals likewise occur.

Among Mollusca, the Ammonites make their first appearance in this country, and they form a most important and striking set of fossils. It has been remarked that "The beds of closely-packed Ammonites, of every stage of growth, which occur in certain of the Jurassic rocks, would appear to be due to the effect of occasional rapid earthy deposits, which took place during that seasonal period, when the Molluscs, lying torpid and contracted within their shells, were at once entombed in that condition."[3] Belemnites are especially abundant in the Jurassic clays.[4]

[1] See H. C. Sorby, Addresses to Geol. Soc. 1879, 1880.

[2] A. Smith Woodward, G. Mag. 1885, p. 496.

[3] Morris and Lycett, Gt. Ool. Mollusca, p. 3.

[4] See Monographs of the Palæontographical Society, by Owen, Phillips, Wright, Davidson, and others ; also A. D. D'Orbigny, Paléontologie Francaise : Terrain Jurassique ; and L. Agassiz, Poissons Fossiles, 1833–43, Études critiques sur les Mollusques fossiles, 1840.

There is a marked succession in the forms of life that characterize the divisions of the Jurassic rocks, and this is notably the case with the Ammonites of the Lias and Inferior Oolite. Hence certain species have been taken to mark zones or epochs in the life-history of the strata, because as a rule their vertical range is more restricted than that of other equally abundant fossils; but while species of *Ammonites* have been generally selected as indices to zones, "their presence alone (as Prof. R. Tate has remarked) does not warrant us in assigning this limestone to the zone of *Ammonites angulatus*, or that clay to that of *Ammonites Turneri*, as the case may be; as they may range through several zones. For the Ammonite which gives its name to a zone is but one of many which mark a determinate stage in the life-history of the formation. Thus the zone is a zoological one, and signifies an assemblage of species, and not the range of an *Ammonite*."[1] Owing to the rarity of fossils in some localities, it may be impossible to determine the zones, while the particular species of *Ammonites* or other fossils taken to indicate the zone may be absent. Moreover, zones characterized by the same species, may not be precisely synchronous in different parts of the country: they are useful as marking the succession of life-forms, but they must not be regarded as definite stratigraphical divisions.

The Jurassic system is divided as follows:[2]—

Jurassic.	*Upper.*	Purbeck Beds.	*Upper.*	Oolites.
		Portland Beds.		
		Kimeridge Clay.		
		Corallian Beds.	*Middle.*	
		Oxford Clay, with Kellaways Rock.		
	Middle.	Great Oolite Series.	*Lower.*	
		Inferior Oolite Series.		
	Lower.	Lias.		

The mapping of the Jurassic rocks for the Geological Survey was done in the south-west of England, partly by Sir A. C. Ramsay and John Phillips, but chiefly by H. W. Bristow and E. Hull, with revisions in places by J. H. Blake, W. A. E. Ussher, and the writer; in the midland counties, the work was done by H. H. Howell, A. H. Green and J. W. Judd; and in the north-eastern counties (Lincolnshire and Yorkshire), by C. Fox Strangways, W. H. Penning, W. A. E. Ussher, W. H. Holloway, C. Reid, and G. Barrow.

[1] Q. J. xxiii. 300.

[2] Mr. Jukes-Browne (1884) has proposed the name *Glevonian* (from Gleva or Glevona, the old name of Gloucester) for the Middle Jurassic series; and *Clavinian* (from Clavinium, the old name of Weymouth) for the Upper Jurassic. G. Mag. 1884, p. 525.

LIAS.

The term 'Lias' is supposed to be the corruption of a word indicating *layers*; it was used by the Rev. John Michell in 1788, and was adopted by William Smith; but strictly speaking it was only the name of the Somersetshire quarrymen for the beds of argillaceous limestone in the lower part of the series to which the term Lias is now applied.[1] The Lias is characterized, on the whole, by marked regularity in the strata which compose it; and these comprise alternations of argillaceous limestone and clay or shale, together with thick beds of marl, clay, and also sand.

The Lias forms a conspicuous band stretching across England from Whitby and Redcar, on the coast of Yorkshire, to Lyme Regis on the coast of Dorset; it occupies extensive vales beneath the Oolitic escarpments, while the harder rocks in the Middle and Lower Lias also form escarpments which overlook vales excavated in the softer strata beneath.

The organic remains of the Lias are rich and varied; the numerous species of Ammonites and Belemnites, and many other marine Mollusca, are very characteristic, and indicate its essentially marine formation, although the presence of large Saurians and of Plant-remains, as well as the muddy nature of the deposits, suggest the proximity of land, and here and there give more definite evidence of estuarine conditions. Among the Mollusca, *Trigonia*, *Turritella*, *Littorina*, and *Nerita* appear, while *Cardinia* and *Hippopodium* are confined to the Lias. The remains of Reptiles, particularly of the genera *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus*, have led some to designate the period as the Age of Reptiles, or Saurozoic Epoch. Fish, Saurian, and Insect Beds may be recognized at various horizons in the Lias.[2]

The rapid alternation of limestone and clay in the Lower Lias is remarkable, but may perhaps be partly accounted for by segregation, the hard beds often having a nodular appearance, and frequently occurring in isolated nodular masses. The condition of an embayed sea near a large continent, such as is now seen on the eastern shores of Asia, where rivers, running over extensive flats, pour their waters into a sheltered portion of the ocean, is, in Prof. Ansted's opinion, likely to have characterized the deposition of the Liassic strata.

The Lias has always been a favourite collecting-ground for those in search of fossils. It is a formation easily recognized, and its fossils, when found, can often be extracted without much difficulty. At the same time the geologist who desires first-rate specimens, must rely largely upon the local collector and dealer. Whitby

[1] De la Beche, Report on the Geology of Cornwall, etc., p. 41.

[2] See The Yorkshire Lias, by R. Tate and J. F. Blake, 1876; Martin Simpson, Fossils of the Yorkshire Lias, edit. 2, 1884; J. Phillips, Geol. Oxford, etc., 1871, and Geol. Yorkshire, part 1, Coast, edit. 3, 1875 (edited by R. Etheridge); E. Witchell, Geology of Stroud, 1882; Wright, Lias Ammonites (Palæontogr. Soc.).

has long been famous for its snake-stones (*Ammonites*), but so great has been the demand for these, that supplies have been sent there from other localities such as Lyme Regis—a fact which collectors should bear in mind, as few fossils are of any scientific value unless their locality be definitely known.

Those who have studied and written about the Lias have unfortunately not adopted a uniform system in dividing the beds into zones. This arises in part from the fact that in different areas the organic remains are variously distributed, and subdivisions may be made in one tract that cannot be distinguished in another. Moreover the zone marked by a certain Ammonite in one tract may be marked by another (different or representative) species elsewhere.

The Lias was divided into Upper, Middle, and Lower divisions by John Phillips in 1829.[1]

The Table given on p. 258 will be useful in showing the groupings adopted by different geologists.

It is admitted that the line between the Middle and Lower Lias is geologically a vague and indefinite one, for being taken in a series of clays, there is seldom any physical feature either in the form of the ground or in the strata themselves to mark the boundary. Hence, whether the line be taken above or below the zone of *Ammonites capricornus* or that of *A. Henleyi*, it can only be determined by palæontological evidence. This evidence in itself suggests no break, and no reason for drawing a line ; thus opinions differ on the question where the Lower Lias ends and the Middle Lias begins. Were we to adopt divisions based on lithological characters, the Lower Lias limestones would form a lower group ; the Lower and Middle Lias clays, a middle group ; and the Middle Lias sands and Marlstone (Rock-bed) an upper group. The Middle Lias sands are however not developed in Lincolnshire as they are in Dorsetshire ; moreover *Ammonites margaritatus* is prevalent in the clays immediately underlying these sands in the south of England, and it occurs also in the rock-bed of that area together with *A. spinatus*. Hence neither palæontologically nor lithologically can satisfactory artificial divisions of the Lias be made. Whichever boundary-line is advocated will be open to some local objections ; but as the Geological Survey has adopted the line taken by Prof. Judd, and as it has been found a fairly good divisional-line in Yorkshire, Lincolnshire, and Northamptonshire, it is adopted in this work. The Table given on p. 259 shows the geographical distribution of the Ammonite-zones in this country.

Lower Lias.

The Lower Lias consists in its lower portion of blue and brown argillaceous limestones ('Blue Lias'), with partings of clay or shale, often bituminous ; in the higher portion the clay ('Blue

[1] Geol. Yorkshire, part 1.

TABLE SHOWING THE DIFFERENT GROUPINGS OF UPPER, MIDDLE, AND LOWER LIAS.

Grouping adopted in this work.	D'Orbigny.	Quenstedt. 1843.	Oppel. 1856.	Wright. 1860.	Judd. 1875.	Tate and Blake. 1876.
UPPER LIAS.	Toarcian in part (from Thouars or Touarsium).	ε	*Posidonomya Bronni.*	*A. bifrons.* *A. serpentinus.*	*A. communis.*	*A. communis.* *A. serpentinus.* *A. annulatus.*
MIDDLE LIAS.	Liasian.	δ	*A. spinatus.* *A. margaritatus.*	*A. spinatus.* *A. margaritatus.*	*A. spinatus.* *A. margaritatus.*	*A. spinatus.* *A. margaritatus.*
LOWER LIAS.		γ	*A. Davœi.* *A. ibex.* *A. Jamesoni.* *A. armatus.* (?)	*A. Henleyi.* *A. ibex.* *A. Jamesoni.*	*A. capricornus.* *A. ibex* (?). *A. Jamesoni.* *A. armatus.*	*A. capricornus.* *A. Jamesoni.* *A. armatus.*
		β	*A. raricostatus.* *A. oxynotus.* *A. obtusus.*	*A. raricostatus.* *A. oxynotus.* *A. obtusus.*	*A. oxynotus.* *A. obtusus.*	*A. oxynotus.*
	Sinemurian (from Semur or Sinemurium).	α	*Pentacrinus tuberculatus.* *A. Bucklandi.* *A. angulatus.* *A. planorbis.*	*A. Turneri.* *A. Bucklandi.* *A. planorbis.*	*A. semicostatus.* *A. Bucklandi.* *A. angulatus.* *A. planorbis.*	*A. Bucklandi.* *A. angulatus.* *A. planorbis.*

Except where otherwise stated, the zones are indicated by species of Ammonites. The horizontal lines show the divisions of the Lias, adopted by each author. See D'Orbigny, Prodrome de paléontologie, etc., 1850-1852; F. A. Quenstedt, Das Flözgebirge Württembergs, 1843, and Der Jura, 1858; Oppel, *op. cit.*; Wright, Q.J. xvi. 376, and Lias Ammonites (Palæontograph. Soc.); Judd, Geol. Rutland, etc., p. 89; Tate and Blake, Yorkshire Lias, p. 16.

Marl') preponderates, and there are only occasional bands of impure limestone or cement-stone, generally nodular.

The thickness of the Lower Lias is subject to much variation, and more particularly in the west of England and South Wales,

TABLE SHOWING THE GEOGRAPHICAL DISTRIBUTION OF THE AMMONITE-ZONES IN THE LIAS OF ENGLAND.

DORSETSHIRE.	SOMERSETSHIRE.	GLOUCESTERSHIRE.	MIDLAND COUNTIES.	LINCOLNSHIRE.	YORKSHIRE.
communis.	*communis.*	*communis.*	*communis.*	*communis.*	*communis.*
			serpentinus.	*serpentinus.*	*serpentinus.*
					annulatus.
spinatus	*spinatus.*	*spinatus.*	*spinatus.*	*spinatus.*	*spinatus.*
margaritatus.	*margaritatus.*	*margaritatus.*	*margaritatus.*	*margaritatus.*	*margaritatus.*
Henleyi.		*capricornus.*	*capricornus.*	*capricornus.*	*capricornus.*
			Henleyi.		
		ibex.	*ibex.*		
	Jamesoni.	*Jamesoni.*	*Jamesoni.*	*Jamesoni.*	*Jamesoni.*
	armatus.		*armatus.*	*armatus.*	*armatus.*
raricostatus.	*raricostatus.*	*raricostatus.*			
oxynotus.	*oxynotus.*	*oxynotus.*	*oxynotus.*	*oxynotus.*	*oxynotus.*
obtusus.	*obtusus.*	*obtusus.*			
			semicostatus.	*semicostatus.*	
Turneri.	*Turneri.*	*Turneri.*			
Bucklandi.	*Bucklandi.*	*Bucklandi.*	*Bucklandi.*	*Bucklandi.*	*Bucklandi.*
	angulatus.	*angulatus.*	*angulatus.*	*angulatus.*	*angulatus.*
planorbis.	*planorbis.*	*planorbis.*	*planorbis.*	*planorbis.*	*planorbis.*

where some conglomeratic modifications are met with. On the Dorset coast it is upwards of 450 feet, and in Yorkshire 750 feet.

The study of the Ammonites has led palæontologists to make certain subgenera, which may be useful to specialists, but which are not, as a rule, welcomed by the field-geologist:[1] hence the Zones of the Lower Lias may be noted as follows:—

Ammonites (*Ægoceras*) *capricornus*, and *A.* (*Ægoceras*) *Henleyi.*
,, (*Amaltheus*) *ibex*, and *A.* (*Ægoceras*) *Jamesoni.*
,, (*Ægoceras*) *armatus* and *A.* (*Arietites*) *raricostatus.*
,, (*Amaltheus*) *oxynotus.*
,, (*Arietites*) *obtusus.*
,, (*Arietites*) *Turneri*, and *A.* (*Arietites*) *semicostatus.*
,, (*Arietites*) *Bucklandi.*
,, (*Ægoceras*) *angulatus.*
,, (*Ægoceras*) *planorbis.*

The student must not be disappointed if in any one tract of country he fails to identify all the above zones. Many of them may be made out with time and patience in the cliffs of Lyme Regis and Charmouth, but even there he would be a bold man who stated precisely where one zone ended and another began. The general succession of forms is, however, an interesting fact, although here and there two or more of the zonal species may be commingled.

The zones in the Lower Lias of this country were first marked out by Dr. Oppel, and were subsequently examined in more detail by Dr. Wright.[2] Broadly speaking, the stone-beds comprise the zones up to that of *A. Bucklandi* and *A. semicostatus*; the clays comprise the zones above. Some of the more abundant fossils may now be mentioned.

In the zone of A. PLANORBIS (argillaceous limestones and shales)—*Unicardium cardioides*, *Ostrea Liassica*, *Pecten Pollux*, *Avicula cygnipes*, *Modiola minima*, *Lima punctata*, *L. gigantea* (small specimens), *Pleuromya Crocombeia*, *Ammonites Johnstoni* (*torus*), *Cidaris Edwardsii*, *Hemipedina Tomesii*, etc.

In the zone of A. ANGULATUS (limestones, etc.)—*Lima punctata*, *L. gigantea*, *Myoconcha psilonoti*, *Pinna Hartmanni*, *Cardinia ovalis*, *Unicardium cardioides*, *Nautilus striatus*, *Ammonites Conybeari*, *A. Charmassei.*

In the zone of A. BUCKLANDI (argillaceous limestones and clays)—*Rhynchonella variabilis*, *Gryphæa incurva* (or *arcuata*, known also as the Devil's Toe-nail), *Modiola Hillana*, *Cardinia Listeri*, *Lima gigantea* (large specimens), *Pholadomya glabra*, *Spirifera Walcottii*, *Nautilus striatus*, *Ammonites Conybeari*, *Pentacrinus tuberculatus* (Star-stones), etc.

In the zone of A. TURNERI (pale earthy and shelly limestone and clay)—*Rhynchonella variabilis*, *Cardinia ovalis*, *Gervillia lanceolata*, *Avicula inæquivalvis*, *Ammonites semicostatus*, etc.

In the zone of A. OBTUSUS (clay and marl with inconstant bands of limestone)—*Pleurotomaria Anglica*, *Ammonites multicostatus*, *A. Brooki*, *A. Birchii*, *A. stellaris*, *A. planicosta*, *Extracrinus Briareus*, etc.

[1] See R. Etheridge, Address to Geol. Soc. 1882.

[2] Q. J. xvi. 411. See also Stratigraphical and Physical Geology, by R. Etheridge, 1885.

In the zone of A. OXYNOTUS (blue clay with iron pyrites)—*Rhynchonella oxynoti*, *Pleurotomaria Anglica*, *Belemnites acutus*, *Ammonites densinodus*, etc.

In the zone of A. RARICOSTATUS and A. ARMATUS (dark shaly clays)—*Waldheimia numismalis*, *Hippopodium ponderosum*, *Cardinia Listeri*, *Pleurotomaria procera*, *Ammonites densinodus*, *A. subplanicosta* (*Carusensis*), *A. trivialis*, etc.

In the zone of A. JAMESONI (clays)—*Rhynchonella rimosa*, *Pecten liasinus*, *Pholadomya decorata*, *Pinna folium*, *Ammonites Taylori*, *A. Bronni*, *A. latæcosta*, *Belemnites elongatus*.

In the zone of A. IBEX (clays) — *Rhynchonella furcillata*, *Crenatula ventricosa*, *Arca elongata*, *Ammonites Maugenesti*, and var. *Valdani*, *A. striatus*, etc.

In the zone of A. CAPRICORNUS and A. HENLEYI (clays)—*Pholadomya ambigua*, *Inoceramus ventricosus*, *Arca elongata*, *Ammonites latæcosta*, *A. Bechei*, *A. Davæi*, *A. Loscombi*, *A. fimbriatus*, *Belemnites pencillatus*, *B. Milleri*.

Many of the species recorded from one zone range through other zones, hence it is impossible to give satisfactory lists of the fossils. In Yorkshire, for instance, *Hippopodium ponderosum* occurs in the zone of *A. Bucklandi*.

In addition to many species of Ammonites and Belemnites, the more abundant fossils of the Lower Lias are *Ostrea Liassica*, *Gryphæa incurva*, *Lima gigantea*, and *Cardinia* (several species).

The 'Saurian and Ostrea beds' are sometimes recognized as zones at the base of the Lower Lias, in the South of England. The 'Lima beds,' with *L. gigantea*, are generally equivalent to the zone of *Ammonites Bucklandi*. At the base of the Lower Lias in Gloucestershire there is a bed of limestone from a foot to three feet in thickness, termed the Fish and Insect limestone, in which the Rev. P. B. Brodie has obtained many Insect-remains. In Somersetshire other palæontological zones have been identified by Mr. Moore, as the Spirifer-bank, which at Camerton and Radstock yields fine specimens of *Spirifera Walcottii*, and the Foraminifera zone; both of which underlie the zone of *Ammonites raricostatus*.

The term Infra-lias, used by A. Stoppani, has sometimes been applied to the lower beds of the Lower Lias (Zones of *A. angulatus* and *A. planorbis*), including also the White Lias (Rhætic); but the term is a vague and unnecessary one. The name Hettangian, from Hettange, was proposed in 1864 as a substitute by E. Renevier.

Belemnites are not, as a rule, abundant in the limestones, but occur sometimes in great profusion in the clayey beds: they are popularly known as Fairies', Ladies', or Devil's Fingers, and Thunder Picks, and were first described in this country by Plot, in 1677.

Among other fossils are the Corals *Montlivaltia* and *Isastræa Murchisoni*. Crustacea of the genera *Eryon*, *Glyphea*, and *Scapheus* are sometimes met with, and also the elytra of Beetles.

Among the Fishes may be mentioned *Lepidotus*, *Acrodus* (the teeth are known as 'fossil leeches'), *Æchmodus*, *Pholidophorus*, etc. The Ichthyodorulites are the large bony fin-spines of fishes, such as *Hybodus*, allied to the *Cestracion* and *Chimæra*. The term Ichthyolite is applied to any portion of a fossil Fish.

The Reptiles include species of *Ichthyosaurus* and *Plesiosaurus*; of the former, specimens twenty-four feet in length have been obtained; and of the latter, with its long neck, specimens have measured from eighteen to twenty feet. The *Ichthyosaurus* was first found in 1811 at Lyme Regis, by Miss Mary Anning, and the same lady subsequently discovered the *Plesiosaurus*, and in 1828 the *Pterodactylus*. Lyme Regis has furnished many famous specimens, some of which, obtained many years ago by Mr. Thomas Hawkins, formed the subject of his great books on "Sea-Dragons."[1]

Remains of Plants, *Equisetites*, *Naiadites*, and *Otopteris*, have been recorded from the Lower Lias. In the upper clayey beds of the Lower Lias the fossils are often pyritic, being coated with or replaced by Iron-pyrites.

Among the many places of interest in England, few have, perhaps, attracted more geological visitors than Lyme Regis. The numerous remains of Fishes and giant Reptiles, not to mention the many and varied forms of invertebrate life, have enticed many an eager collector. It is true that the Lias has yielded an abundance of organic remains; and yet some who visit the cliffs of Lyme Regis in search of specimens return disappointed. The fact is, the fossils occur at particular horizons, and it is only by much time and labour that good specimens can be obtained. It is not that Lyme Regis was a specially favoured locality for the entombing of organic remains—the large exposures of Lias, and the number of collectors, have made it famous.

The thickness of the Lower Lias of Dorset may be estimated at about 450 feet. The coast-line between Axmouth and Bridport Harbour exhibits a complete section from the Rhætic Beds to the sands below the Inferior Oolite. The beds are disturbed here and there and sometimes repeated by faults, moreover there are many landslips, hence precise measurements are difficult; but with care the entire sequence of the beds may be traced.

One of the earliest accounts of the Lias of Dorsetshire was by De la Beche,[2] but the stratigraphical and palæontological details of the Lower Lias were first noted by Dr. Wright,[3] and those of the Middle and Upper Lias by Mr. E. C. H. Day.[4]

The various divisions are shown in the section (Fig. 40, p. 252). Starting from the west of Lyme Regis, we find at Pinney (Pinhay) Bay, a section of White Lias (Rhætic Beds), overlaid by the Lower Lias. In the zone of *Ammonites planorbis*, which rests on the White Lias there and at Uplyme, that fossil is not common, although it has been obtained: the cliff-sections however are not very accessible. To the east of Pinney Bay, we come gradually to the zone of *A. Bucklandi*, the intermediate zone of *A. angulatus* not being distinctly represented, although the species does occur. The limestones (altogether about 100 feet in thickness) which form the West Cliff, to the west of Lyme Cobb, belong mainly to the zone of

[1] Memoirs of Ichthyosauri, etc., 1834; The Book of the great Sea-Dragons, etc., 1840. The extinct marine Saurians are sometimes termed Enaliosauria.

[2] T. G. S. (2), ii. 21, and Report on Geol. Cornwall, etc.

[3] Q. J. xvi. 374; and Lias Ammonites (Palæontogr. Soc.), p. 38.

[4] Q. J. xix. 278.

A. Bucklandi, and large specimens of this fossil, and also of *A. Charmassei* (a form allied to *A. angulatus*), may be obtained. These beds contain many large forms of *Lima gigantea*, also *Rhynchonella variabilis*, *Gryphæa incurva*, etc. The stone is known as the 'Blue Lias' by the quarrymen, and is largely used for making cement, etc. The same series of limestones is repeated in the Church Cliffs to the east of Lyme Regis, and thence we reach higher and higher beds as we travel eastwards. A little distance above the main mass of the limestones, there is a conspicuous pale-grey band of hard marly limestone, known as the 'Table Ledge,' and which descends to the beach at the foot of Black Ven. This limestone contains *Rhynchonella variabilis*, etc., and is included by Dr. Wright in the zone of *Ammonites Turneri*. The dark clays and shales which form the lower portion of Black Ven include the zones of *Ammonites obtusus* and *A. oxynotus*, of which fine examples may be obtained. In the former zone *A. Brooki*, *A. Birchii*, *A. stellaris* and other species occur, generally at particular horizons well known to the local dealers and collectors. *A. planicosta* and small specimens of *A. obtusus* occur sometimes so abundantly in bands of limestone as to form a kind of Ammonite-marble, blocks of which may be picked up on the beach. Specimens of *A. Birchii* at times are found with the chambers lined with calc-spar, and are known as 'Tortoise-ammonites.' Fine specimens of *Extracrinus Briareus*, generally coated with or partly replaced by iron-pyrites, are met with in the zone of *A. obtusus*. A variety of *A. oxynotus*, termed *A. Lymensis*, occurs also at Black Ven. Specimens of *A. subplanicosta* (*A. Carusensis*), *A. trivialis*, etc., occur in the upper part of the dark clays at Black Ven, which represent in part the zone of *A. raricostatus*. Some of these small Ammonites are cut and mounted for brooches. The zones of *A. armatus*, *A. Jamesoni*, and *A. ibex*, although noted by Dr. Wright in the Dorsetshire Cliffs, are not distinctly defined, but they may be generally represented in the Belemnite Beds.[1] Saurian remains are met with at various horizons at Black Ven, and in the limestones of Church Cliffs, etc.; but good specimens of these of course can only be obtained by the workmen engaged in removing the stone, or by extensive excavations in the clays. Landslips occasionally reveal specimens, but some of our finest examples have been obtained piece by piece, by Mr. Samuel Clark, Mr. Robert Hunter, and others, who have carefully watched the cliffs, and then devoted much labour to developing the fossils from the limestone or cement-stone nodules in which they occur.

Many fossil Fishes have been obtained from the Lower Lias at Lyme Regis, and a number of genera have been founded, though Sir Philip Egerton has remarked that many are represented each by a single type-specimen.[2]

In 1829, Dr. Buckland drew attention to the discovery of Coprolites in the Lias at Lyme Regis. (See p. 104.) These had been called "Bezoar stones, from their external resemblance to the concretions in the gall-bladder of the Bezoar Goat, once so celebrated in medicine." They occur in the Lias shale and stone, and may be picked up on the beach. Occasionally they form the nuclei of small septaria. In size they vary from two to four inches in length, and from one to two inches in diameter. Dr. Buckland attributed them to Fishes and Saurians.[3] They frequently contain the beaks of Cuttle-fishes, besides Fish-scales, etc.

Above the dark clays of Black Ven, which rise to a height of about 180 feet, there is "a mass of marl, forming a cliff or wall, the dull-grey tint of which strikingly distinguishes it from the darker strata below." This marl, which is eighty or ninety feet thick, has been termed the Belemnite Beds by Mr. Day, who regarded the division as the commencement of the Middle Lias, although according to the grouping now adopted it must be included with the Lower Lias.[4] Thin bands of limestone yielding *A. raricostatus* separate the dark clays below from the Belemnite Beds above. Excepting Belemnites, these latter beds do not yield many fossils, but they are capped by a thin bed of pale-grey limestone, known as the Belemnite-stone, which yields *Ammonites Henleyi*, etc., as well as

[1] Lias Ammonites (Pal. Soc.), pp. 83, etc.
[2] G. Mag. 1876, p. 441.
[3] T. G. S. (2), iii. 223.
[4] Q. J. xix. 280.

many Belemnites. The platform of Belemnite-stone, which may well be seen at the base of Golden Cap, at low-tide, and the marls immediately beneath it, yield a profusion of Belemnites, including *B. longissimus*, *B. clavatus*, *B. pollex*, and *B. Bucklandi* (with sometimes the ink-bag preserved in the anterior of the phragmacone).[1] The Belemnite Beds extend from Black Ven through the cliffs east of Charmouth, to the base of Golden Cap, and are not exposed east of Seatown. Above them come the Green Ammonite-beds, bluish-grey clays with small nodules of limestone, about 100 feet in thickness. These beds are so termed by collectors from the green tint of the calc-spar which fills the chambers of the characteristic Ammonite, *A. latæcosta*. Fragments of this fossil are extremely abundant, and perfect specimens, as a rule, are only obtained from the small cement-stones. In Dr. Wright's opinion this species may be the middle age condition of *A. Henleyi*; but, as Dr. Oppel suggested, it appears to represent *A. capricornus*.[2] Other species found in these beds are *A. Henleyi*, *A. Bechei*, *A. Loscombi*, *A. fimbriatus*, and *A. Davæi*: the last-named species being taken by Dr. Oppel to indicate the zone.

The Three Tiers are prominent bands of fissile, micaceous, and calcareous sandstone, well seen in Golden Cap; they are, as a rule, unfossiliferous. They occupy a thickness of from 30 to 40 feet, and mark the base of the Middle Lias (zone of *Ammonites margaritatus*).

In Somersetshire the thickness of the Lower Lias varies from a few feet, in the neighbourhood of the Mendip Hills, to about 300 feet. Good sections of the lower beds of limestone are exposed on the coast at Watchet, and eastwards at intervals to Kilve. The beds are very much faulted. The zones of *Ammonites planorbis*, *A. Bucklandi*, and *A. Turneri* may be observed, but fossils are not numerous, except in particular layers. Near Watchet, specimens of *A. Johnstoni* (*torus*), a ribbed variety of *A. planorbis*, are not uncommon, and as the mother-of-pearl layer of the shell is well preserved, the fossils glisten with iridescent colours on the loose blocks of stone, or on the pavements of rock on the foreshore.

At Selworthy, near Porlock, the Lower Lias and Rhætic Beds are probably faulted against the Devonian rocks, as they dip at a high angle towards them.

The Lower Lias in the Vale of Ilchester consists of three members:—

3. Blue and brown clay (worked for brick-making).
2. Even-bedded blue limestones and shales; largely quarried at Keinton Mandefield, King Weston, Somerton, and Queen Camel.
1. Rubbly white earthy limestones and marls, with *Ostrea Liassica* and *Modiola minima*; resting on the White Lias (Rhætic).

The uppermost division (3) occurs over the flat country bordering the Middle Lias escarpment, north of Martock, at Marston Magna and East and West Lydford.

In the neighbourhood of Wedmore, at Street, and along the Polden Hills, the lower beds of the Lias consist of comparatively soft argillaceous limestones, sometimes graduating into a marl, together with coarse and compact blue limestones (termed 'clog').

[1] Phillips, Monograph on Belemnites (Palæontograph. Soc.); Day, Q. J. xix. 278; Bristow, Horizontal Sections, Sheet 21 (Geol. Survey). Drawings have been made from the 'Fossil Sepia' obtained from the Dorsetshire coast.

[2] Die Juraformation, pp. 155, 157.

The clay-bands are in great part represented by slaty marls. These beds belong to the zone of *Ammonites planorbis*. At Pylle, north of Pennard Hill, beds with *A. Bucklandi*, etc., are exposed.

The Lower Lias of Shepton Mallet presents many features of interest. The ordinary limestones and clays are well exposed in the cutting of the Great Western Railway, about a mile west of the station, and again in the cuttings of the Midland Railway south of the new station. Northwards a gradual change takes place in the beds, the clays die out, and we find the series to comprise sandy limestones and occasional conglomerates, formed of Carboniferous Limestone and chert pebbles, indicating that hereabouts was an old sea-margin. These beds, which are seen at Bowlish and Downside, are identical with the Lias conglomerates of South Wales, described by Sir H. T. De la Beche.[1] At Downside we find a brown and white granular limestone with irony specks, overlying the Carboniferous Limestone, to which it sometimes so closely approximates that it is difficult to distinguish between the two, while at this locality and also at Bowlish there is a soft thickly-bedded, white shelly-limestone, from which the shelly matter has frequently been removed, leaving cavities. (See Fig. 24, p. 160.)

A peculiar siliceous deposit occurs in the neighbourhood of Chewton Mendip, on Harptree and Egar Hills, at East End, Emborrow, and near Binegar. It reposes indifferently on the Dolomitic Conglomerate, the Carboniferous Limestone, and the Old Red Sandstone. The deposit is, in the upper part, a compact chert, containing shells; lower down come sandy beds, and here a cherty breccia occurs. The entire deposit must in places attain a thickness of at least thirty feet, and it is well shown in a pit east of the Harptree Road, about half-way between East Harptree and the inn known as the 'Castle of Comfort.' The pit is about sixty feet in diameter at the mouth, it is funnel-shaped, about twenty to thirty feet in depth, and is probably a natural "pot-" or "swallow-hole." The section consists almost entirely of massive-bedded chert, occurring in layers of from one to three feet in thickness, separated by thin ochreous clayey beds an inch or two in thickness, and standing out sharply, but sometimes weathering sandy at the exterior. Lower Lias fossils occur in the top beds, while very probably the lower beds represent the White Lias, but from these no fossils have been recorded. Among the fossils are *Ammonites planorbis*, *A. Johnstoni*, *Cardinia Suttonensis*, *Lima gigantea*, *Modiola minima*, *Ostrea Liassica*, *Myoconcha psilonoti*, and *Pecten pollux* (or *Suttonensis*).[2] Some of the Druidical Stones at Stanton Drew, near Chew Magna, are formed of cherty beds from the Lias and Keuper of this neighbourhood. (See p. 232.)

In the Radstock Coal-district, as Mr. C. Moore has pointed out,

[1] Mem. Geol. Survey, vol. i. p. 276. See also Moore, Q. J. xxiii. 508.

[2] Geol. East Somerset (Geol. Surv.), p. 108; G. Mag. 1871, p. 400. See also T. Weaver, T. G. S. (2), i. 364; Buckland and Conybeare, *Ibid.* 294.

the Lias exhibits a remarkable attenuation from paucity of sediment.[1] At Camerton, Timsbury, Paulton, and other localities near Radstock, fine specimens of *Spirifera Walcottii* have been obtained. They were originally discovered by John Walcott, and their position was defined by Mr. Moore as equivalent to the Spirifer-bank of Quenstedt;[2] they occur in the zone of *Ammonites Bucklandi*.

Quarries between Paulton and Radstock have, in a thickness of about ten feet, yielded evidence of the zones of *A. planorbis*, *A. Bucklandi*, *A. obtusus*, *A. raricostatus*, *A. armatus*, and *A. Jamesoni*.[3] The sections differ much in detail, within short distances, but the beds are usually very fossiliferous. At Keynsham, Pennyquick, near Twerton, Weston, and other places near Bath, the Lower Lias limestones have been extensively quarried. From one of the quarries the original specimen of *Ammonites Bucklandi* was obtained. This, like some other species, is occasionally found of great size, and without the inner whorls; and such was the case with the specimen originally obtained by Dr. Buckland, who, thrusting his head through it, rode home, dubbed by his friends the *Ammon Knight*.[4] There is a legend that St. Keyna, from whom Keynsham takes its name, resided there in a solitary wood full of venomous serpents, and her prayers converted them into stones, which still retain their shape.[5]

In Glamorganshire the Lower Lias or Lias Conglomerate frequently exhibits shore-conditions. The beds are well exhibited in the cliffs at Sutton, Southerndown, and Dunraven; and inland at Brocastle and Ewenny, near Bridgend, at Cowbridge and other places. The fossils include *Isastræa globosa*, *Montlivaltia*, *Gryphæa incurva*, *Pecten Pollux*, *Ostrea Liassica*, *Lima gigantea*, etc. Sometimes the beds approach in character the Carboniferous Limestone, so that it is difficult to distinguish between them. The Conglomerates are formed of Carboniferous Limestone pebbles. The clayey beds of the Lias are not represented. Mr. Bristow has stated that on the shore, where the sections are exposed to the influence of sea-water, they have become silicified, and so hard that it is exceedingly difficult to hammer the fossils out of the rock; while the calcareous shells of the fossils themselves, between high- and low-water mark, have sometimes been replaced by chalcedony. The Sutton-stone is a white tufaceous stone. (See p. 249.)

The Lower Lias is largely developed in Gloucestershire, Worcestershire and Warwickshire. The zones observed in Gloucestershire have been previously noted; that of *A. planorbis* has been

[1] Q. J. xxiii. 470.

[2] Walcott, Descriptions and Figures of Petrifactions found in the Quarries, etc., near Bath, 1779; Moore, Q. J. xxiii. 471.

[3] E. B. Tawney, Proc. Bristol Nat. Soc. (2), i. 167; Tate, Q. J. xxxi. 493.

[4] Sowerby, Mineral Conchology, ii. 69.

[5] See Nat. Hist. of Selborne, by the Rev. Gilbert White, edit. by T. Bell, vol. i. p. 480. See also Scott's Marmion, Canto 2, xiii.

exposed on the banks of the Severn at Elmore and Wainlode, and in the railway-cutting at Lassington; the zone of *A. angulatus* has been determined at Down Hatherly; the zone of *A. Bucklandi* may be studied at Fretherne and Purton-on-Severn; that of *A. Turneri* at Purton; and that of *A. obtusus* at Standish. The zone of *A. raricostatus* has been well exposed at the brick-pit at Marle Hill, near Cheltenham; it there contains the *Hippopodium*-bed, with *H. ponderosum* and *Cardinia Listeri*. The zones of *A. Jamesoni* and *A. ibex* have also been exposed in brickyards near Cheltenham.[1] The term Belemnite-beds has been used by Prof. R. Tate for the clayey beds of the Lower Lias above the zone of *Ammonites Bucklandi*; these he has also termed the zone of *Belemnites acutus*.

In Worcestershire the Lower Lias is developed at Pershore, Evesham, and other localities.[2]

Near Banbury the zones of *Ammonites Jamesoni*, *A. Henleyi* and *A. capricornus* have been observed by Mr. T. Beesley and Mr. E. A. Walford. From the zone of *A. Henleyi* many fossils, including a number of Foraminifera, have been obtained. The beds consist of dark-blue shaly marls, with occasional septaria, and with a thin bed of hard grey shelly limestone, known as Banbury Marble.[3] The zone of *A. Henleyi* is shown in brickyards east of Banbury, and it occurs below the zone of *A. capricornus*, which is exposed south of the town. The zone of *A. ibex* occurs rather as a sub-zone, between the beds with *A. Jamesoni* and *A. Henleyi*. The Banbury Sandstone, with *Belemnites pencillatus*, the Edgehill Sandstone, and the Downcliff sandy marl with *Ammonites armatus*, belong to the Lias of this district.

The zone of *Ammonites Jamesoni* is well developed at Fenny Compton, south-east of Warwick; and with it Mr. T. Beesley includes the zones of *A. ibex* and *A. Henleyi* at the top, and that of *A. armatus* at the bottom.[4] In Warwickshire the thickness of the Lower Lias is estimated at upwards of 600 feet. The zone of *A. angulatus* has been noted at Harbury, near Warwick. The beds may be seen also at Inkberrow, and outliers with underlying Rhætic beds occur at Copt Heath (Knowle), and Wootton Wawen.[5] The lower beds are well shown at Wilmcote and Binton, near Stratford-on-Avon, where they have been largely quarried.[6]

In Leicestershire the Lower Lias attains a thickness of 520 feet; the upper portion consisting chiefly of clays, and the lower 20 feet

[1] See E. Witchell, Geol. Stroud, pp. 8, 15; Murchison, Geol. Cheltenham, edited by J. Buckman and H. E. Strickland, 1845; and R. Tate, Q. J. xxiii. 307.

[2] See T. J. Slatter, on Lias of Broughton, near Pershore, in Wright's Lias Ammonites (Palæont. Soc.), p. 374.

[3] Beesley, G. Mag. 1872, p. 280; Proc. Warwick Nat. Club, 1872.

[4] Proc. Warwick Nat. Club, 1877, 1886.

[5] Rev. P. B. Brodie, G. Mag. 1864, p. 239; Q. J. xxi. 159.

[6] R. F. Tomes, Q. J. xxxiv. 182.

of limestones.[1] At Barrow-on-Soar the zone of *Ammonites angulatus* is represented by 12 feet of blue clays.

The cuttings on the Syston and Peterborough Railway, between Kirby and Whissendine, exhibit several divisions of the Lower Lias. The following divisions have been noted by Prof. Judd in that district:[2]—

Zones.		
A. capricornus	*m.*	Blue clays with much pyrites and many septaria. *Ammonites capricornus, Pentacrinus robustus.* Galley Hill, Neville-Holt, Little Bowden.
A. ibex?	*l.*	Clays with septaria, and thin sandy layers. *A. latæcosta, A. brevispina, A. Jamesoni,* etc. Stapleford Park, Little Dalby.
A. Jamesoni	*k.*	Clays with shelly limestones with *Cardinia attenuata, Hippopodium ponderosum.* Dalby, Staunton Wyville.
	h.	Blue laminated pyritous shales, with thin bands of limestone. *Ammonites bipunctatus, Spirifera Walcottii, Pentacrinus,* etc. Saxby, Thorpe Langton.
A. armatus	*g.*	Sandy clays with stone-beds. Loseby.
A. oxynotus	*f.*	Clay with much pyrites (producing selenite by its decomposition), and small septaria. *Belemnites clavatus, Plicatula spinosa.* Freeby.
A. semicostatus	*e.*	Ferruginous limestone, *Ammonites semicostatus, Cardinia Listeri, Gryphæa incurva.* Vale of Belvoir.
A. Bucklandi	*d.*	Blue clay with *Gryphæa incurva.* (Well at Stapleford Park.)
A. angulatus	*c.*	Clay with bands of pyrites, *Ammonites angulatus.* Barrow-on-Soar.
A. planorbis	*b.*	Coarse-grained and shelly limestones, *Ammonites planorbis, Nautilus striatus, Lima gigantea.* Sysonby.
	a.	'Fish and Insect Limestone,' finely laminated argillaceous limestone alternating with shale, and abounding with remains of fish, crustaceans, saurians, plants, and sometimes insects. Extensively worked at Granby, Barrow-on-Soar, etc., for the manufacture of hydraulic cement. Prof. Judd suggests that these beds be called the 'Strensham series,' from the village of that name east of Upton-on-Severn, in Worcestershire, where the beds were first studied by the Rev. P. B. Brodie.

With regard to the zone of *A. obtusus*, Prof. Judd observes that the beds at this horizon in the district are very obscure, and if they exist they are nowhere well exposed.

In Northamptonshire the Lower Lias has a thickness of about 650 feet; and in Lincolnshire the thickness is at least 400 feet.

In the north-west of Lincolnshire, at Frodingham and Appleby, there is a valuable bed of ironstone 27 feet thick, covering the wide plain on which is situated the village of Scunthorpe; this bed has been largely worked.[3] It occurs low down in the Lower Lias, in the zone of *Ammonites semicostatus*, and at Redmile and other places in the Vale of Belvoir this zone is represented by ferruginous stone. At Bracebridge and Waddington, near Lincoln, the clays with

[1] H. E. Quilter, G. Mag. 1886, p, 59.

[2] Geology of Rutland, etc. p. 58. In reference to the Insect Fauna, see Brodie, Fossil Insects (1845); H. Goss, P. Geol. Assoc. vi. 116.

[3] Rev. J. E. Cross, Q. J. xxxi. 119.

Ammonites capricornus are worked for brickmaking.[1] (See Fig. 42.) On the top of the Lower Lias in north-west Lincolnshire there is a Pecten-bed with *P. lævis*, which marks the junction with the Middle Lias.

The Lower Lias is exposed in places on the coast of Yorkshire, between Redcar and Staithes or Colburn Nab, and in Robin Hood Bay. The following divisions have been made:[2]—

Zones.	Feet
A. capricornus.—Shales, sandy and micaceous towards the upper part, with *A. fimbriatus*, *A. Henleyi*, *A. Bechei*, etc. Robin Hood's Bay, Rockcliff, Huntcliff, and Coatham Scars	150
A. Jamesoni (including zone of *A. armatus*).—Micaceous and sandy shales with 'doggers' of ferro-argillaceous limestone. *A. brevispina*, *A. Henleyi*, *A. Loscombi*, *A. fimbriatus*, etc. Robin Hood's Bay	220
A. oxynotus.—Shales and indurated marls. *A. obtusus*, *A. raricostatus*, *A. stellaris*, *A. semicostatus*, etc. Robin Hood's Bay	110
A. Bucklandi.—Shales with thin earthy and shelly limestones. *A. Turneri*, *A. Brooki*, *A. Birchii*, *A. semicostatus*, *A. multicostatus*, *Hippopodium ponderosum*. Redcar	180
A. angulatus.—Thin rubbly and earthy limestones, including *Cardinia*-shale with *C. ovalis*, *Hippopodium ponderosum*. Near Market Weighton and Redcar	50
A. planorbis.—Clays with thin limestones. North Cliff, near Market Weighton	50

Lower Lias has also been recognized at Prees in Shropshire, and at Audlem in Cheshire, over a tract of ground between the Hawkstone Hills, Whitchurch, and Market Drayton. The beds are much obscured by Drifts, but where exposed they have led to trials for coal. *Ammonites planorbis*, *A. Conybeari*, *A. Bucklandi*, and *Gryphæa incurva* have been recorded.[3] It has been suggested that traces of Lias may occur beneath the estuary of the Ribble, being preserved in a synclinal above the Keuper Marls, etc.[4]

In Cumberland, west of Carlisle, there is about 120 feet of dark shales and limestone (including, perhaps, the Rhætic Beds), in which the Rev. P. B. Brodie identified the Lima and Saurian Beds. The strata are much hidden by Drift, but they are exposed at Quarry-Gill, and one or two places between Aikton and Great Orton. They were first observed by Mr. R. B. Brockbank.[5]

Economic products, etc., of the Lower Lias.

Ironstone has been profitably worked in Lincolnshire, and it was formerly worked in the upper beds of the Lower Lias at Robinswood Hill, near Gloucester.

[1] W. D. Carr, G. Mag. 1883, p. 164. See also Geol. S. W. Lincolnshire (Geol. Survey), by A. J. Jukes-Browne and W. H. Dalton.

[2] Tate and Blake, Yorkshire Lias; Explan. Sheets 93 N.E. 95 N.W. and 96 N.E. (Geol. Survey), by C. F. Strangways, C. Reid, and G. Barrow; M. Simpson, Guide to the Geology of the Yorkshire Coast, edit. 4; J. F. Blake, Q.J. xxviii. 132.

[3] Murchison, Proc. G. S. ii. 115, and Silurian System, p. 23.

[4] C. E. De Rance, G. Mag. 1883, p. 505.

[5] E. W. Binney, Q. J. xv. 549; T. V. Holmes, Q. J. xxxvii. 293; and P. Geol. Assoc. vii. 418.

Ochre has been obtained from the cherty beds of Lias, near East Harptree. Iron-pyrites was formerly collected at Black Ven, Lyme Regis, and Charmouth, for the manufacture of sulphuric acid. Spontaneous combustion, due to the decomposition of iron-pyrites, or Marcasite, has sometimes taken place in the cliffs near Charmouth. Thus it is recorded that in August, 1751, after very hot weather followed by rain, the Lias cliffs at one spot began to smoke, and soon afterwards to burn with a visible flame.

The Lower Lias limestones are much quarried for building- and paving-purposes, and to be burnt for lime ; in many instances the separate beds have each a local name, known to the quarrymen. The quarries of Street and Keinton Mandefield, in Somersetshire, yield very large slabs, from six to twelve feet square. The Thurlbeer Lias and Knap Stone are locally known near Taunton.

The cement-stones at the base of the Lias at Barrow-on-Soar have been largely worked for the manufacture of hydraulic cement. The Limestone Beds at Lyme Regis and Aberthaw are similarly noted.

The 'Ammonite Marble' found at Marston near Yeovil is composed of *A. planicosta*, and *A. obtusus* (the young forms of which are sometimes known as *A. Smithi*). This stone was discovered in 1778 in the opening of a marl pit ;[1] and I am informed by Mr. A. Gillett that a large and apparently nodular mass of this stone was obtained at Marston when a well was sunk early in the present century, about the year 1815 ; and this mass, weighing a ton or more, has supplied most of the specimens known from this locality.

The Lower Lias Clays are often used for brick- and tile-making. Some of the beds are very bituminous, and near Chard and Axminster they have, early in the present century, led to fruitless trials for coal. Similar trials have been made in Lincolnshire, Leicestershire, Shropshire, in Needwood Forest, and Cumberland. Lignite occurs in the upper part of the Lower Lias on the Dorsetshire coast.

The soil is loamy and brashy, and often of a rich brown colour. Corn, oats, mangel-wurzel, turnips, cabbages, and, in places, beans and teazles are cultivated. In many places the soil is very heavy, where the higher beds come to the surface, as in the vale of Marshwood in Dorset, and the vale of Ilchester in Somerset.

The ground is generally flat or gently undulating, forming vales, with an escarpment at the junction with the Rhætic beds and Lias limestones, overlooking the vales of Red Marl.

The Lower Lias is not generally a water-bearing stratum, but holds up or throws out water when porous beds rest above it.

The pasture lands on the clays furnish material in the vales of Gloucester and Berkeley for the celebrated 'double Gloucester' cheese, and near Melton Mowbray and Leicester for the 'Stilton.' Cheddar cheese may be said to be the product of the pasturages on the Liassic Clays, Red Marl and Alluvium of Somersetshire.

Middle Lias.

The Middle Lias, or Marlstone as it was termed by William Smith, consists generally of two members. The upper 'Brown rock' or 'Rock bed' (=Marlstone proper) comprises tough iron-shot argillaceous limestones or marlstones; the lower member includes micaceous sands, marls, and clays, with occasional nodular limestones. The Middle Lias varies in thickness from one or two feet to over three hundred feet. It has been divided into two zones, as follows:—

2. Zone of *Ammonites* (*Amaltheus*) *spinatus*.
1. ,, ,, ,, ,, *margaritatus*.

[1] W. G. Maton, Observations on the Western Counties, vol. ii. p. 21 ; see also Sowerby, Mineral Conchology, vol. i. p. 167, and Tab. 73 and 406.

Ammonites spinatus characterizes the Rock-bed; and the other species the lower micaceous sands and clays. But the two forms occur together in the Rock-bed at Ilminster and near Yeovil.

By some authorities the lower zones of *A. capricornus*, *A. ibex*, and *A. Henleyi* have been included with the Middle Lias. (See p. 258.) Among the fossils are *A. Engelhardti*, *A. fimbriatus*, *Belemnites compressus*, *B. breviformis*, *Protocardium truncatum*, *Hinnites abjectus*, *Pecten æquivalvis*, *Myacites unionides*, *Pholadomya ambigua*, *Modiola scalprum*, *Gryphæa cymbium* (*Macculllochii* or *obliquata*), *Terebratula punctata*, *Waldheimia quadrifida*, var. *cornuta*, *Rhynchonella tetrahedra*, *R. acuta*, etc.

The Lower Lias passes upwards into the Middle Lias by insensible gradation, and as the boundary-line between the two formations is essentially a palæontological one, there is no marked division. It is indeed one of the most vague boundary-lines that is drawn upon geological maps.

The fossils are decidedly most numerous in the Marlstone. This bed at Ilminster has yielded many Plant-remains, Foraminifera, Echinodermata, Crustacea, Brachiopoda, Conchifera, Gasteropoda, Cephalopoda, bones of *Ichthyosaurus*, teeth of *Hybodus*, and scales of *Lepidotus*.[1]

On the Dorsetshire coast the Middle Lias is exposed in the cliffs between Charmouth and Bridport Harbour. (See Fig. 40, p. 252.) Curiously enough the upper part of the Middle Lias is united in one bed with the base of the Upper Lias, as observed by Mr. Etheridge in 1861. This is a pale cream-coloured and pink limestone in the upper part, and a brown nodular marlstone below. *Ammonites bifrons* and *A. serpentinus* occur in the upper part of the bed, and *A. communis* occurs in both. *A. spinatus* is found in the lower part, together with several species of *Pleurotomaria*. The following is the general succession of the beds:[2]—

	Upper Lias stone } Marlstone }	3 feet.
Middle Lias.	Clay	10 to 20 ,,
	Yellow micaceous sands, with indurated beds	60 ,,
	Bluish-grey marl (*Margaritatus*-bed of Mr. Day at base)	7 ,,
	Laminated sands and clays, with many layers of sandy nodules in the upper part, and beds of irregular and fissile sandstone in the lower	70 to 80 ,,
	Starfish-bed	5 ,,
	Grey micaceous clays and marls, with *A. margaritatus*, etc.	160 ,,
	The Three Tiers. (See p. 264.)	35 ,,
		370 ,,

Ammonites margaritatus has been met with in the Three Tiers, and it is found in some abundance in the grey marly clays above, although here, as a rule, only fragments are to be obtained. The Starfish-bed is a greenish-grey micaceous and slightly calcareous sandstone, upon the flat under-surfaces of which are found *Ophioderma Egertoni* and *O. tenuibrachiata*. This bed and the beds above are

[1] C. Moore, Proc. Somerset Arch. Soc. xiii.
[2] E. C. H. Day, Q. J. xix. 286.

best seen in the cliffs east of Seatown, under Down Cliff, and Thorncombe Beacon. Fossils are readily to be obtained from the fallen masses on the shore, but it is a matter of no great difficulty to trace them out *in situ*. The Starfish-bed will be easily recognized on the shore from its smooth surface, and the numerous oblong or square hollows which mark the places from which starfishes have been chiselled out by the fossil collectors. The junction-bed of the Middle and Upper Lias is very ferruginous, but its creamy and pink portion clearly distinguish it from a bed of fossiliferous brown sandy limestone (containing *Gryphæa cymbium* and *Pecten æquivalvis*), which occurs at a lower horizon, and is abundantly strewn on the shore.

Inland in Dorsetshire many charming lanes are excavated deeply in the rock-sands of the upper part of the Middle Lias; but from the examination of an isolated section it is very hard to distinguish the sands at the base of the Inferior Oolite, from the sands that occur in the Middle Lias series below the Marlstone or "Rock-bed."

In Somersetshire the Middle Lias is tolerably persistent in the escarpment below the Oolites. It is found at Ilminster, north-west of Yeovil, Glastonbury, Pennard Hill, and Brent Knoll; it is rarely exposed between Castle Cary and Bath. (See Fig. 39.) At Whatley, near Frome, thin beds of Middle Lias, yielding many fossils, have been found by Mr. Moore.[1] (See Fig. 41, p. 253.)

In the Cotteswold Hills the Middle Lias has a thickness of about 120 feet, the Rock-bed being 12 to 20 feet; at Bredon Hill the total thickness is 310 feet; at Wotton-under-Edge the Rock-bed is 12 feet, and the lower strata 186 feet. (See Fig. 44.) The Middle Lias may be studied also at Alderton and Dumbleton, between Tewkesbury and Evesham, at Gretton, Church Down, and Hewlett's Hill, Cheltenham, and also at Stroud.[2]

In Oxfordshire the lower beds, about 10 to 20 feet in thickness, consist of sands, clays, and sandstones; and the rock-bed, with much iron-ore, is from 6 to 12 feet in thickness. Mr. T. Beesley observed (1873) that for a long time past attempts have been made to introduce the Marlstone of this district as an available ore of iron; but it is only since the year 1870 that these attempts have met with success. Extensive excavations have been carried on at Adderbury and King's Sutton, south of Banbury; in the valley of the Evenlode, west of Charlbury, and at Fawler, west of Stonesfield. The ore, known as the Blenheim iron-ore, contains about 31 per cent. of iron. *Terebratula punctata* and *Rhynchonella tetrahedra* occur in the ironstone.[3] In the neighbourhood of Fawler the clays with *Ammonites margaritatus* repose on similar clay with *A. capricornus*.[4]

In Northamptonshire the Middle Lias is about 40 feet in thickness, and is exposed to the south-west of Northampton, between that

[1] Q. J. xxiii. 476.
[2] F. Smithe, Proc. Cotteswold Club, vi. 349; Witchell, Geology of Stroud, p. 17.
[3] T. Beesley, Proc. Warwick Nat. Club, 1872, p. 11; Hull, Geol. Woodstock (Geol. Survey), p. 9.
[4] F. A. Bather, Q. J. xlii. 144.

town and Banbury. Above the Marlstone Rock-bed there are thin beds of marly limestone and clay, characterized by *Ammonites acutus*, and containing *A. Holandrei*, but also many fossils of a Middle Lias character; and Mr. E. A. Walford, while noting it as a 'Transition-bed,' is inclined to group it with the Middle Lias, and as perhaps synchronous with the zone of *Ammonites annulatus* of Messrs. Tate and Blake, in Yorkshire. (See p. 258.) The Rock-bed, about 6 feet in thickness, is underlaid by marly clays and soft sandy limestone, about 12 feet thick, and these constitute the zone of *Ammonites spinatus*; below are marls and clays with sandy limestone, about 26 feet, which represent the zone of *A. margaritatus*. The beds, which are variable in character, may be seen at Bugbrook, Daventry, Byfield, Chipping Warden, Chalcomb, Milton, Staverton, Middleton Cheney, King's Sutton, etc. *Trigonia Lingonensis* has been obtained at Aston-le-Wall and Appletree. Mr. Beeby Thompson observes that the zone of *A. margaritatus* is characterized by Lamellibranchs, that of *A. spinatus* by Brachiopods, and the Transition-bed by Gasteropods.[1] In Warwickshire the Middle Lias (Marlstone) forms Edge Hill, south-west of Kineton.

In Rutlandshire and Leicestershire the Marlstone or Rock-bed varies much in thickness, attaining a maximum of about 30 feet; being about 18 feet at Tilton-on-the-Hill, and diminishing to 8 or 9 feet near Oakham. Belvoir Castle is situated on an outlier of Marlstone; Blackberry Hill to the west is capped by the same rock.

By the Railway Station at Market Harborough the Marlstone rock-bed (15in.) is underlaid by clays with nodules containing specular-iron. *Protocardium truncatum*, *Avicula cygnipes*, etc., occur. Slawston Hill is an outlier of Marlstone, capped by Upper Lias Clay and Northampton Sand. At Robin-a-Tiptoes Hill the Rock-bed is nearly twenty feet in thickness, and at Melton Mowbray it is thirty feet. The lower part of this bed, of a greenish-blue colour, is largely made up of specimens of *Terebratula punctata* and *Rhynchonella tetrahedra*. The blue ferruginous sandstone, by weathering passes into a friable brown sandstone, owing to its carbonate of iron being changed into peroxide of iron under the influence of air and water.[2]

In north-west Lincolnshire the Marlstone is but eight feet in thickness, the lower beds comprise about sixty feet of clay. Between Leadenham and Lincoln the Marlstone is not represented as a rock-bed, but it re-appears at South Carlton, north of Lincoln. Clays with *A. margaritatus* may be seen in brickyards south of Lincoln.[3] (See Fig. 42.) To the north of Lincoln Mr. Ussher has

[1] Walford, Proc. Warwick Nat. Hist. Club, 1878; and Thompson, Midland Naturalist, 1885–1886.

[2] W. J. Harrison, P. Geol. Assoc. v. 142; see also E. Wilson, The Lias Marlstone of Leicestershire as a source of Iron (reprinted from the Midland Naturalist, viii. 61, etc.); Beeby Thompson, Midland Naturalist, viii.; and P. B. Brodie, Proc. Cottesw. Club, i. 59.

[3] W. D. Carr, G. Mag. 1883, p. 164; P. Geol. Assoc. viii. 383.

observed that *A. capricornus* ranges upwards into the zone of *A. margaritatus*. In this area the Marlstone, which is a hard grey limestone, is so full of specimens of *Rhynchonella tetrahedra* as to constitute a Rhynchonella-bed. According to the Rev. J. E. Cross, *Ammonites spinatus* occurs in the lower part of it, and *A. serpentinus* and *A. communis* in the upper part. This case is somewhat similar to that on the Dorsetshire coast.[1] (See p. 271.)

In Yorkshire the Middle Lias comprises the following beds :—

2. Ironstone series. (Kettleness Beds.[2])
1. Sandy series. (Staithes Beds.[2])

As remarked by Messrs. Tate and Blake, the term Marlstone has been variously applied in Yorkshire, and is sometimes taken to include all the beds to the base of the zone of *Ammonites margaritatus*.[3] The beds are shown in the cliffs of Staithes Nab and Kettleness, between Redcar and Whitby, and again south of Whitby, between Saltwick Nab and Blue Wyke Point.

The Sandy Series (Marlstone of John Phillips), with *A. margaritatus*, is shown at Hummersea (100 feet), Huntcliff, etc., and is composed of beds of sandstone, shales, and clay-ironstone. Among the fossils it is noteworthy that very small specimens of *Ammonites capricornus* occur. *Protocardium truncatum* is an abundant form. The upper portion of the Middle Lias, which belongs mainly to the zone of *Ammonites spinatus*, consists of argillaceous shales with, locally, bands of ironstone, twenty to forty feet in thickness. Two prominent beds are the Cleveland main seam, and the Bottom seam, but other layers are known in places, as at Skelton Beck. This division includes the Grosmont series, near Whitby, and the Hawsker Beds of the cliffs of Hawsker Bottom, south of Whitby. In the main seam there occur *A. spinatus*, *Terebratula punctata*, *Rhynchonella tetrahedra*, etc. *Trigonia Lingonensis* also occurs in the ironstone, and this species has been met with in the Middle Lias of Northamptonshire.

Economic products, etc., of the Middle Lias.

The Cleveland Iron-ore is well known ; it is derived from the upper part of the Middle Lias of the Cleveland Hills east of Northallerton in Yorkshire, and was first worked in 1848. The ore occurs in several seams, but the main bed of ironstone is from 12 to nearly 20 feet in thickness. The beds worked extend inland from near Redcar to Eston Nab, near Middlesborough-on-Tees. There are mines at Upleatham, Hummersea, Rockcliff, Kettleness, etc. The ore is an impure carbonate, it is a bluish or greenish-grey oolitic ironstone, the colour being derived in part from silicate of iron, and it is highly fossiliferous. It yields about 30 per cent. of metallic iron. *Pecten æquivalvis* occurs in the main seam, which is called

[1] Q. J. xxxi. 120.
[2] Young and Bird, Geol. Survey of the Yorkshire Coast, 1822.
[3] Yorkshire Lias, p. 104 ; see also Phillips, Q. J. xiv. 96 ; Explan. Sheets, 93 N.E., 95 N.W., and 96 N.E. (Geol. Survey), by C. F. Strangways, C. Reid, and G. Barrow.

the Pecten-bed. Dr. H. C. Sorby has concluded that the Cleveland Ironstone was at first a kind of oolitic limestone, interstratified with ordinary clays containing a large amount of the oxides of iron mechanically derived, and also organic matter, which, by their mutual re-action, gave rise to a solution of bi-carbonate of iron—that this solution percolated through the limestone, and, removing a large part of the carbonate of lime by solution, left in its place carbonate of iron.[1]

In Lincolnshire and Leicestershire, at Eastwell and Long Clawson, north of Melton Mowbray, at Tilton, and Holwell, near Market Harborough; and in Lincolnshire at Denton, Woolsthorpe, and Caythorpe near Grantham, the Middle Lias Rock-bed is worked for iron-ore; about 750,000 tons of ore being obtained annually, which is sent to Stanton Bedale in Derbyshire to be smelted. Analysis of the ore at Caythorpe showed calcic carbonate 62 per cent. and ferric oxide 25. The stone in many places contains much bluish or greenish matter, attributed to phosphate, silicate, and sulphide of iron. The ironstone occurs in the upper part of the Marlstone, and is 8 or 10 feet thick.[2] (See also p. 273.)

In many places the Rock-bed is quarried for rough building-purposes and for road-metal. Near Banbury the Hornton Stone is of local repute; near Ilminster the Moolham Stone has been quarried for building walls, and for road metal, for which purposes the Marlstone is used in the neighbourhood of Yeovil. It is sometimes burnt for lime. Marlstone from Bagpath, near Dursley, has been polished. The lower beds are worked in places for brick-making, at Market Harborough, at Gonerby north-west of Grantham, also near Ilminster and Bridport.

The Middle Lias furnishes a rich soil, particularly favourable in the south-west of England to the growth of apple trees. The county of Rutland (red land) probably acquired its name from the prevalent colour of the soil; that on the Middle Lias being highly productive. At Northampton the beds yield a copious supply of water to the town.

Upper Lias.

The Upper Lias consists of blue or grey shale and clay, with nodules of blue limestone, and occasional beds of pale-grey earthy limestone. It is characterized by the presence of *Ammonites serpentinus*, *A. bifrons*, *A. annulatus*, *A. communis*, *A. Holandrei*, *A. heterophyllus*, *Nautilus intermedius*, *Belemnites Voltzii*, *B. vulgaris*, *Euomphalus minutus*, *Trochus duplicatus*, *Leda ovum*, *Nucula Hammeri*, *Discina reflexa*, etc. Among other fossils are *Trigonia literata* (Yorkshire); the Corals *Thecocyathus* and *Trochocyathus*; Fishes, *Lepidotus*, *Pachycormus*, *Leptolepis*, etc.; and the Reptiles, *Ichthyosaurus* and *Plesiosaurus*, including the huge *P. Cramptoni* from Whitby.

The Midford sands (zone of *Ammonites* (*Lytoceras*) *Jurensis*) that occur between the Inferior Oolite and Lias, were grouped with the Upper Lias by Dr. Wright; but these sands are more closely related to the Inferior Oolite.

The Upper Lias is sometimes termed the zone of *Ammonites* (*Stephanoceras*) *communis*; while other zones, those of *A.* (*Harpoceras*) *bifrons* and *A.* (*Harpoceras*) *serpentinus*, are in places identified.

[1] Geol. and Polytech. Soc. W. Riding, iii. 460; Address to Geol. Soc. 1879; see also J. Phillips, Q. J. xiv. 96; Tate and Blake, Yorkshire Lias, p. 165; G. Barrow, Proc. Cleveland Inst. Engineers, 1880, p. 180; Explan. Sheet 96 N.E. (Geol. Survey).

[2] See E. Wilson, *op. cit.* p. 152.

In some localities, however, the Ammonites are irregularly distributed in the Upper Lias. In thickness this formation varies from about 5 to 230 feet.

The Upper Lias in Dorsetshire is represented by a clay-deposit, about 70 feet in thickness, which rests on the remarkable junction-bed before noticed (see p. 271); the beds are well shown in the cliffs at Thorncombe Beacon. (See Fig. 40, p. 252.)

The Upper Lias in Somersetshire is sometimes not more than eight or ten feet thick, and it consists of thin beds of pale-grey marly clay, and rubbly and nodular limestones, which are sometimes septarian. The most remarkable bed is the Saurian and Fish-bed, consisting of nodular yellow limestone, which has yielded beautiful remains of *Ichthyosaurus*, *Teleosaurus*, numerous Fishes, Cephalopoda, Insects, and Crustacea. This bed has been observed in the neighbourhood of Ilminster. The Cephalopoda include the genera *Geoteuthis* and *Teuthopsis*. The softer parts of these cuttle-fishes have perished, leaving only the internal cuttle-bone, in the centre of which the ink-bag is usually found, still charged with its black pigment. Attention was drawn to this Saurian and Fish Bed by Mr. Charles Moore, who observed that the shape of the nodule conforms roughly to that of the enclosed organism. Beneath the Saurian and Fish zone come the Leptæna-beds, characterized by the presence of *Leptæna Moorei*, and *L.* (*Koninckella*) *Bouchardii*.[1] Similar Leptæna- and Fish-beds have been observed at Churchdown Hill, Gloucestershire, by Dr. F. Smithe.[2]

There are many quarries showing Upper Lias near Ilminster, South Petherton, and Yeovil. The beds occur at Pennard Hill, Glastonbury Tor and Brent Knoll, and they have been detected here and there in the Oolitic escarpments between Yeovil and Bath, and at Dundry Hill. (See Fig. 39, p. 250.)

In Gloucestershire the Upper Lias varies from about 10 feet at Wotton-under-Edge (see Fig. 44) to about 300 feet at Cleeve Cloud, and 380 feet at Bredon Hill, near Cheltenham. The thickness is at Stroud 30 feet, Nailsworth 105, and at Birdlip 200. In Oxfordshire the Upper Lias is sometimes very thin, being about 8 feet at Fawler and 10 feet at Charlbury; in places it is 40 feet, but it probably does not extend far to the south-east beneath the newer rocks in that area. In Leicestershire the thickness is about 300 feet; in Northamptonshire ('Blue Marl') it varies from 150 to 200 feet; and in Lincolnshire the thickness diminishes to 60 feet.

In Northamptonshire the Upper Lias may be seen at Milton, Eydon, Towcester, Middleton Cheney, Byfield, etc. It is exposed in the valley of the Nen and its tributaries at Bugbrook.[3] The lowest beds consist of finely-laminated shales (Paper-shales), with

[1] Moore, Proc. Somerset Arch. Soc. xiii. 119.

[2] Proc. Cottesw. Club. vi. 354.

[3] Brodie, Proc. Cottesw. Club, ii. 132; Beeby Thompson, The Upper Lias of Northamptonshire (Northampton Museum Report), Midland Nat. ix. 121.

a single band of limestone, known as the Fish and Insect Bed. Hence the beds are divided as follows:—

	ft. in.
Marl and limestone with *Ammonites communis*	6 0
Irregular whitish limestone and clay with *A. serpentinus*	2 to 6 feet
Fish and Insect Beds	1 6
Transition-bed with *A. acutus*. (See p. 273.)	
Rock-bed of Middle Lias	

In Rutlandshire, etc., the Upper Lias presents a thickness of about 200 feet, and is divided as follows by Prof. Judd:—

Leda ovum Beds.—Clays with septaria and many specimens of *L. ovum*, *A. bifrons*, *A. communis*, etc.
Dark blue clays with pyrites and jet (fossils rare).
Ammonites communis Beds.—Clays with *A. communis*, *A. annulatus*, etc.
Ammonites serpentinus Beds.—Clays with layers and nodules of limestone, *A. serpentinus*, *A. falcifer*, *A. concavus*, *A. radians*, etc.
Paper-shales with Fish and Insect Limestones.

Prof. Judd suggested the name Dumbleton Series for the Paper-shales, from the village of Dumbleton between Cheltenham and Evesham, at which locality the beds were first studied by the Rev. P. B. Brodie.[1] Remains of Dragon-flies, *Libellula*, have been obtained from this locality. The Upper Lias (20 feet) is shown in brickyards near the railway-station at Market Harborough.

In Lincolnshire the Upper Lias has been divided as follows by Mr. W. D. Carr:[2]—

Beds with *Ammonites bifrons*.	Paper-shales, with few fossils.
,, ,, *A. communis*.	Clay with septaria, many fossils (*Nucula Hammeri* Beds).
,, ,, *A. serpentinus*.	Clay with limestone and gritty bands. *Belemnites* very abundant. Pyritous clay with limestone bands.

The beds may be studied as Swan's brickyard on the north cliff, near Lincoln (see Fig. 42), at Bracebridge (Best's brickyard, upper pit), and at Navenby. *Trigonia pulchella* is a noteworthy fossil in the beds with *Nucula Hammeri*. The Upper Lias is about 70 feet in thickness.

The Upper Lias of Yorkshire varies in thickness from 200 feet on the coast, to 50 feet and less in some of the southern Cleveland Hills. It is exposed in the cliffs of Robin Hood Bay, near Whitby, and Rockcliff. Three lithological divisions have been recognized, and these broadly speaking are characterized by species of *Ammonites*:—

Zones of *A. communis* and *A. bifrons*.	Alum Shale. Shales with nodules (cement-stone beds), 110 feet.
,, ,, *A. serpentinus*.	Jet-rock series. Shale with jet and pyrites, 50 to 60 feet.
,, ,, *A. annulatus*.	Grey shale. Hard and compact grey micaceous sandy shale, 30 feet.

[1] Geol. of Rutland, etc. p. 79. See also Buckman, Proc. G. S. iv. 211.
[2] G. Mag. 1883, p. 164; P. Geol. Assoc. viii. 383.

The cliffs near Whitby, from three to four hundred feet in height, are partly composed of dark grey beds of shaly clay (Whitby shale), lying nearly horizontal, and stretching out at the base into an extensive flat pavement, on which the sea washes, and which is laid bare to a considerable distance at low water. In the lower "Grey Shale" *A. annulatus* is abundant in nodules of ferruginous and argillaceous limestone; *A. cornucopia* also occurs. Although the characteristic Ammonite is essentially an Upper Lias form, this division has been placed with the Middle Lias by Messrs. Tate and Blake, because *A. margaritatus* and other Middle Lias fossils occur also in it. The beds are exposed in Runswick Bay, south of Staithes, in West Arncliffe, etc. (See p. 273.) The Jet-rock series comprises hard shales with *A. serpentinus*, *A. heterophyllus*, and *Inoceramus dubius*, also lenticular masses of stone like huge cheeses ("cheese doggers"), and hard blue bituminous shale, 20 feet (the Jet-rock), containing jet in the interstices between the layers, in thin lenticular masses. "These shales are in places so highly impregnated with iron pyrites and bitumen that spontaneous ignition is not of infrequent occurrence; such natural fires have been burning for years at Staithes, Lofthouse, etc."[1] The Jet-rock may be well studied on the coast near Saltwick Nab, south of Whitby; also between Sandsend and Kettleness, hence the name Sandsend Beds of Young and Bird. Many fossils have been obtained on the shore at Runswick. Remains of Reptiles and Fishes are not uncommon, the "scale-fish," *Lepidotus semiserratus*, being most characteristic. Jet has

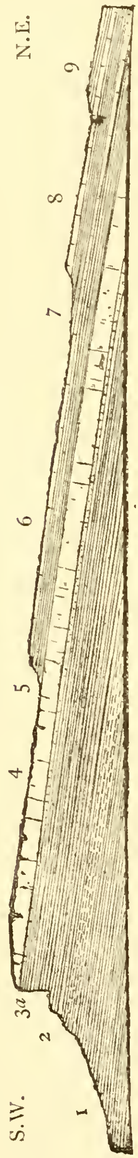


Fig. 42.—Section from Swan's Pit (Lincoln) to Sudbrook. (W. H. Dalton.)
Scale, an inch to a mile horizontal; an inch to 40 ft. vertical.

a. Messrs. Swan, Bros. Pit.
9. Oxford Clay.
8. Cornbrash.
7. Great Oolite Clay.
6. Great Oolite Limestone.
5. Upper Estuarine Series.
4. Lincolnshire Limestone.
3. Upper }
2. Middle } Lias.
1. Lower }

[1] Tate and Blake, Yorkshire Lias, pp. 173, etc.; Phillips, Geol. Yorkshire, part I. edit. 3; Louis Hunton, T.G.S. (2), v. 215; W. C. Williamson, *Ibid.* 223; M. Simpson, Fossils of the Yorkshire Lias, edit. 2, 1884; Explan. of Sheet 95 N.W. (Geol. Survey), by C. F. Strangways and G. Barrow.

been known since early British times, having at first been picked up on the sea-shore at Whitby and other places. It is now mined both in the cliff and inland. The largest seam of jet on record was obtained from the North Bats, near Whitby; it weighed 370 stone and was worth about £250.[1] Jet is one of the most valuable products of the Yorkshire coast, being extensively worked into ornaments. It is a resinous variety of lignite, and Prof. Phillips observes that it is simply coniferous wood, and in thin sections it clearly shows the characteristic structure. Impressions of Ammonites and other fossils sometimes appear on its surface.

The Alum Shale consists of hard blue shale with cement-stones. On exposure to the air the shale gradually becomes incrusted with sulphur, and occasionally with alum. The nodules are most abundant in the upper part, below comes the main mass of Alum Shale in which *Leda ovum* is abundant, the shales at the base are unproductive of alum. The remains of Reptiles, *Plesiosaurus*, *Ichthyosaurus*, and *Teleosaurus* are more abundant in the Alum Shale than in the lower divisions of the Lias. Belemnites and Ammonites are likewise abundant; among the species are *B. vulgaris*, *B. lævis*, *A. communis*, *A. bifrons*, *A. heterophyllus*, etc. *Trigonia literata* and *Discina reflexa* also occur. In composition the Alum Shale is as follows:—

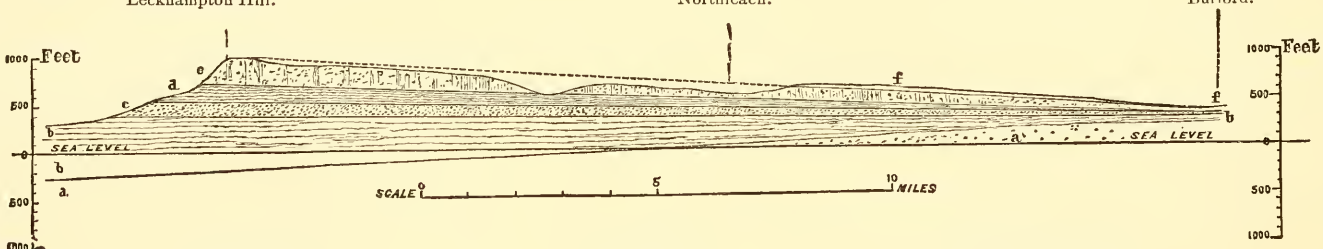
Iron sulphide	8·50
Silica	51·16
Iron protoxide	6·11
Alumina	18·30
Lime	2·15
Magnesia	·90
Sulphuric acid	2·50
Potash	trace
Soda	trace
Carbon	8·29
Water	2·00
	99·91

From this shale potash-alum was formerly made near Whitby and Redcar: the aluminium sulphate being extracted from the shale, and the potash-salt being added. The trade, which since the days of Queen Elizabeth has been largely carried on, has now almost passed away, as alum is now manufactured in other places from Coal-shale. Alum works formerly existed at the Peak, Robin Hood's Bay, Stow Brow, Sandsend, Kettleness, Lofthouse (Loftus), Osmotherly, etc.

At Whitby good hydraulic cement (Mulgrave cement) has been made from the nodules in the Alum-shale. The Upper Lias clay is frequently used for making bricks, tiles and drain pipes.

[1] Tate and Blake, Yorkshire Lias, pp. 178, 188.

FIG. 43.—DIAGRAM SECTION FROM LECKHAMPTON HILL TO BURFORD. (W. Topley.)

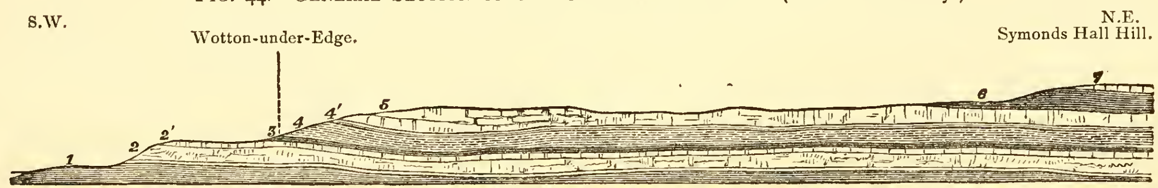


b. Lower Lias.
a. Keuper Marl, etc.

d. Upper Lias.
c. Middle Lias.

f. Great Oolite Series.
e. Inferior Oolite Series.

FIG. 44.—GENERAL SECTION OF THE COTTESWOLD HILLS. (Sir A. C. Ramsay.)



2'. Rock-bed
2. Sands and Clays } Middle Lias.
1. Lower Lias.

4'. Cephalopoda Bed
4. Sands. } Midford Sands.
3. Upper Lias.

7. Great Oolite.
6. Fuller's Earth.
5. Inferior Oolite.

OOLITIC.

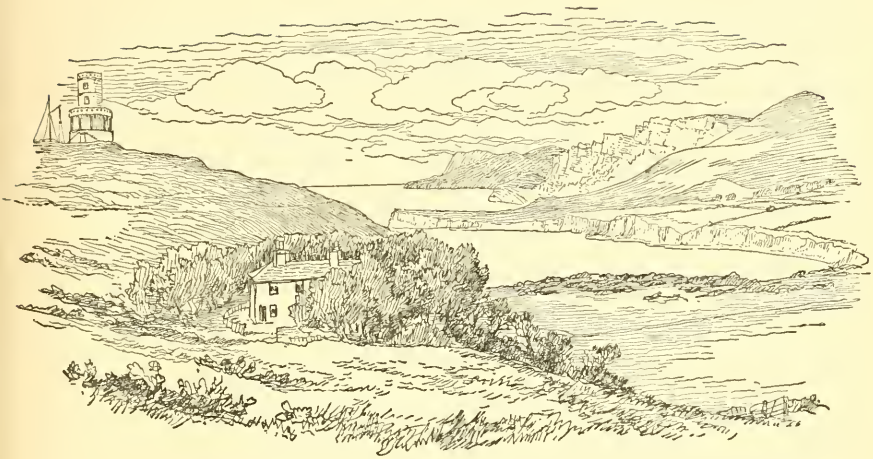


FIG. 45.—KIMERIDGE BAY, LOOKING WESTWARDS TOWARDS GAD CLIFF (PORTLAND ROCKS) AND LULWORTH.

The term Oolite, introduced by Wm. Smith, indicates the characteristic features of most of the limestones in the series, which have an oolitic structure; but it must be borne in mind that this structure is occasionally present in rocks of all ages. Oolite or roe-stone (derived from the Greek *oon*, an egg, and *lithos*, stone) is a name applied to limestones composed of small round particles of calcareous matter, which are cemented together and resemble the roe of a fish. When these particles approach the size of a pea or bean, the rock is termed Pisolite, Pisolitic limestone, or Pea-grit. Thus we have the Inferior Oolite, the Great or Bath Oolite, the Coralline or Oxford Oolite, and the Portland Oolite; also the Pea-grit, a local member of the Inferior Oolite.

The organic remains of the Oolitic period include the Reptiles *Megalosaurus* and *Ceteosaurus*, besides *Teleosaurus*, *Pterodactylus* and other forms known in the Lias. The period was termed the Megalosaurian by John Phillips. Among Mammalia, there were many genera of Marsupials; and these, together with Mollusca such as *Trigonia*, some species of *Terebratula*, and other forms of life, present many striking resemblances to the modern fauna and flora of Australia. The Mammals were mostly of diminutive size, and referring to them Sir R. Owen has remarked that the results of palæontology sometimes move one to exclaim, in regard to Tertiary

Mammals, "There were giants in those days!" but, descending to earlier periods, we find only dwarfs.[1]

Among the fossils of the Oolitic strata Mollusca, however, are the most abundant, and variously distributed, Cephalopods, Gasteropods, Lamellibranchs, and Brachiopods being in turn prevalent in different areas and at different horizons. Among the Lamellibranchs *Lima pectiniformis (proboscidea)*, *Ostrea gregaria*, and *Goniomya v-scripta* have a wide range. Among the Echinoderms are *Hemicidaris*, *Acrosalenia*, *Echinobrissus*, *Clypeus*, and *Pseudodiadema*. Corals are not uncommon in places, and many reef-building forms occur: some species are found in lenticular coral-beds. It has been observed that although the character of the sea-bottom varied greatly over the British area contemporaneously and successively, the general characters of a coral sea constantly prevailed in the Oolitic period;[2] and it has been suggested that certain outlying masses of oolite derived their present form not mainly from denudation, but from original formation. Of course Coral-reefs may stand up in isolated masses amid sedimentary deposits; and if ultimately preserved, the structure would suggest an unconformity or fault;[3] but while there can be no doubt that such reefs existed during Oolitic times, we have no clear proof of their being preserved.

Our Oolitic rocks, in fact, were to a large extent derived from the waste of Coral-reefs, the Oolite itself, as Mr. W. H. Hudleston has pointed out, being for the most part granulated coral-mud. The well-known Coral-sand of the West Indies, while it resembles oolite, is mainly composed of rolled fragments of coral. On the other hand, the grains of oolite frequently exhibit an internal radiate structure, and are made up of concentric rings of carbonate of lime; while the material of which they are chiefly composed has been deposited chemically around nuclei, such as Foraminifera, or minute fragments of Corals, Echinoderms, and Mollusca, or very fine grains of quartzose sand. There are instances where the oolitic structure seems to be independent of any nucleus, and where it must have been produced by chemical changes in the soft mud, or subsequently when the deposit had become solidified.[4] Marly clay, as well as limestone, may be oolitic; and sometimes the entire mass of the rock is made up of oolitic grains, but then the rock is usually false-bedded, indicating that the grains must have been drifted and heaped up by currents in comparatively shallow

[1] In reference to the fossils of the Oolites, see the works of the Palæontographical Society:—Reptilia and Mammalia, by Sir R. Owen; Corals, by H. Milne Edwards and J. Haime, with Supplements by Dr. P. M. Duncan; Echinodermata, by Dr. T. Wright; Brachiopoda, by Dr. T. Davidson; Great Oolite Mollusca, by Prof. J. Morris and Dr. Lycett; Trigoniæ, by Dr. Lycett, etc.; see also Palæontology of the Yorkshire Oolites, by W. H. Hudleston, G. Mag. 1880, 1882, 1884, 1885. (See also references, *ante*, p. 254.)

[2] P. M. Duncan, Q.J. xxvi. 62.

[3] See W. O. Crosby, G. Mag. 1879, p. 296.

[4] J. Phillips, Geol. Oxford, etc., p. 396; H. C. Sorby, Address to Geol. Soc. 1879.

water. Portions of the Great Oolite and the Forest Marble are conspicuously false-bedded. The formation of oolite has been thus explained by Mr. Hudleston, by reference to modern Coral-reefs :—

"The coral is being perpetually ground down to the finest powder, which is held suspended in the sea like ordinary sediment ; but as it falls towards the bottom, it encounters an acid stratum of water, due to the quantity of carbonic acid generated by the decomposition of organic matter and the respiration of animals. This slightly attacks the calcareous sediment, and forms the usual soluble bicarbonate, which is again precipitated as calcic carbonate amongst the interspaces of the slowly settling mud, thus cementing the whole into a mass of most compact rock, and gluing up all the shells." "From this type of rock, to a regular oolite with very little paste, there is every gradation."[1]

Oolitic rocks, although characteristic of the series, by no means constitute its bulk: they are interstratified with sands and clays, and seemingly in places in so regular a sequence of sand, clay, and limestone, that much remark has been made upon the subject.[2] But this repetition of a ternary or tripartite series is after all very local and unreal; the divisions that appear in the south of England do not correspond lithologically with those in the north of Oxfordshire and the southern part of Northamptonshire, nor with those made in the northern part of Northamptonshire and Lincolnshire; whilst a comparison between the 'Yorkshire Oolites' and those of the Cotteswold Hills shows more strikingly the changes undergone by the strata, for in Yorkshire the beds are essentially arenaceous. It must, however, be borne in mind that the deposits presented to our view are but local sediments.

Prof. Hull has put forward reasons for concluding that all the Lower Jurassic formations exposed in the western and central counties die out towards the south-east; that this attenuation is due to the increase of distance from the sources of supply, and the consequent failure of sedimentary materials which were derived from land occupying the region of the North Atlantic.[3] Such attenuation may in some cases, as pointed out by Mr. Topley and Mr. Lucy, modify our estimates of the dip.[4] (See Fig. 43.)

As before observed, the character of the different subdivisions of the Oolitic strata varies much; the development of the oolites and sandy strata being more restricted than that of the clays, for the Inferior Oolite, the Great Oolite, and the Corallian Beds, die out in places or are represented by strata of a different sedimentary character. The Cornbrash may be cited as being the most persistent of the calcareous strata. Fissile sandy limestones, locally known as 'slates,' occur at various horizons in the Lower Oolitic series.

The Oolitic strata rest conformably upon the Liassic sediments, and while the entire Jurassic series exhibits many variations, the absence of individual members in certain places may be due to

[1] Proc. Geol. Assoc. v. 431.
[2] E. Hull, G. Mag. 1868, p. 143; Q. J. xviii. 133; Phillips, Geol. Oxford, p. 393; Lyell, Student's Elements, 1871, p. 342.
[3] Q. J. xvi. 63; see also Physical History of the British Isles.
[4] Q. J. xxx. 186; and Proc. Cottesw. Club, 1869, p. 7.

local changes of condition, and in some cases perhaps to paucity of sediment; for there are no positive evidences over any extensive area of the removal of any absent division, by denudation in Oolitic times.

Most of the strata are truly marine in the western and midland counties, but there are in Yorkshire especially, evidences of estuarine conditions pointing to the proximity of rivers; and, as observed by Prof. Phillips, in that county the strata give evidence of a true coal-field in the Oolitic era, produced by the interposition of vast quantities of sedimentary deposits brought down by floods from the land, between the more exclusively marine strata of the ordinary Oolitic type. Thus while in the midland and southern counties the Oolites yield many famous building-stones, in Yorkshire the beds are rich in ironstone, layers of coal, beds of gritstone, and shale.

The Oolitic strata of the south of England were taken as the types by William Smith;[1] but even in 1822 Conybeare and Phillips questioned whether these divisions could be traced throughout the course of the Oolites.[2] The following are the main divisions:—

Upper Oolitic.	Purbeck Beds. Portland Beds. Kimeridge Clay.
Middle Oolitic.	Corallian Beds. Oxford Clay and Kellaways Rock (Callovian).
Lower Oolitic.	Great Oolite Series (Bathonian). Inferior Oolite Series (Bajocian).[3]

The distinct groupings and nomenclature adopted for the Lower Oolites in different parts of the country will be noted further on. The divisions into Upper, Middle, and Lower Oolites are simply made for convenience, as they do not mark any sharply-defined groups.

The Oolites stretch across the country from Yorkshire to Dorsetshire, forming often fine and bold hills, such as the Hambledon and Howardian Hills in Yorkshire, the Cliff in Lincolnshire, and the Cotteswold Hills in Gloucestershire. The stone-beds stand out in prominent ridges, above the vales of clay; and perhaps the series of escarpments formed by the Portland Beds, Corallian Rocks, Forest Marble, Fullers Earth Rock, and Inferior Oolite, is nowhere better marked in succession than in the country traversed by the London and South-Western Railway between Dinton, west of Salisbury, and Yeovil. Excellent sections of the strata are exposed in the cliffs of Yorkshire and Dorsetshire. In Yorkshire the hilly

[1] See Rev. Joseph Townsend, The Character of Moses, 1813; W. Smith, Strata Identified by Organized Fossils, 1816; Stratigraphical System of Organized Fossils, 1817.

[2] Outlines of the Geol. England and Wales, p. 202; see also Fitton, T. G. S. (2), iv. 208.

[3] The term Bajocian, from Bayeux (Bajocea) in Calvados, was applied by D'Orbigny to the Inferior Oolite and Fuller's Earth.

ground is to a large extent moorland, while in the midland and southern counties the Oolites form a rich tract of corn land and pastures.

In composition the Oolitic limestones contain, as a rule, from 90 to 95 per cent. of carbonate of lime.[1] In colour they are generally pale yellow or brown, when seen in open quarries; but when dug at great depths or otherwise obtained at points where they have not been exposed to atmospheric influences, all the Oolitic rocks exhibit an almost uniform deep-blue tint, which is apparently communicated to them by a diffusion through their substance of small quantities of sulphide of iron.[2]

LOWER OOLITIC.

The subdivisions of the Lower Oolitic strata of England will be best understood from the accompanying diagram (p. 286).

Our knowledge of the strata, especially in the south-west of England, is largely owing to the labours of William Smith, followed by Lonsdale (T.G.S. (2) iii. 241). In the midland counties the classification is mainly due to the researches of Prof. J. W. Judd (Geol. Rutland, etc.), Prof. J. Morris (G. Mag. 1869, p. 446), and Mr. S. Sharp (Q.J. xxix. 285). In Yorkshire we owe our knowledge of the strata chiefly to Prof. John Phillips (Geol. Yorkshire, Part 1), Mr. W. H. Hudleston (P. Geol. Assoc. iii. 283, iv. 353, v. 378), and Mr. C. Fox Strangways (Explan. Sheets 93 N.E., 95 N.W., S.W., and S.E., 96 N.E. and S.E. Geol. Survey.)

It will be most convenient to arrange the descriptions of the rocks under three headings:—1. South-west of England, 2. Midland Counties, and 3. Yorkshire.

SOUTH-WEST OF ENGLAND.

Inferior Oolite Series.

This Series is divided as follows:—

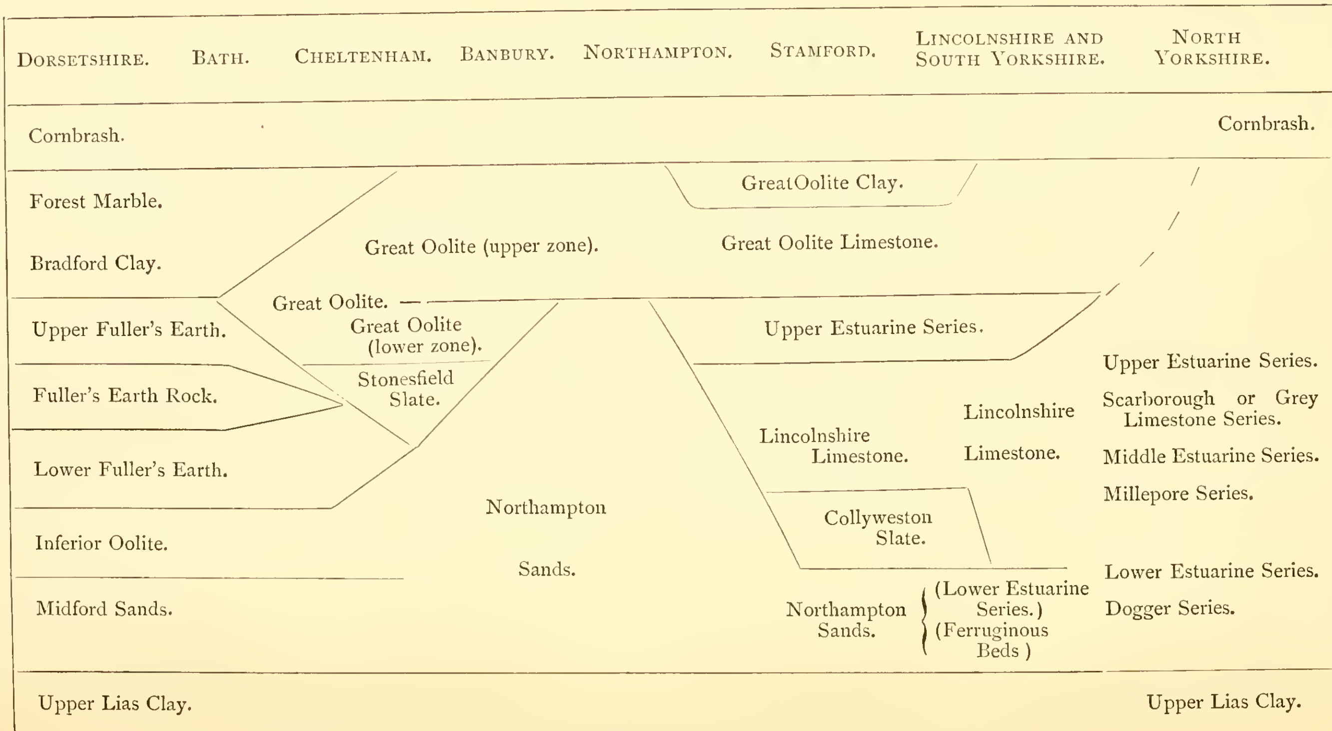
	ZONES.
Inferior Oolite.	*Ammonites (Cosmoceras) Parkinsoni.*
	,, (*Stephanoceras*) *Humphriesianus.*
	,, (*Harpoceras*) *Murchisonæ* [including sub-zone of *A.* (*Harpoceras*) *Sowerbyi*].
Midford Sands.	,, (*Harpoceras*) *opalinus.*
	,, (*Lytoceras*) *Jurensis.*

MIDFORD SANDS.

The term Midford Sands was given in 1871 by Prof. Phillips to the sands which occur between the Upper Lias Clay and the Inferior Oolite.[3] Midford is a little hamlet about three miles south of Bath, and it was there that William Smith first studied the Sands, and called them the 'Sand of the Inferior Oolite.'

[1] Prof. A. Voelcker. Q. J. xiv. 120.
[2] Judd, Geology of Rutland, etc., p. 115; Phillips, Geol. Oxford, p. 396.
[3] Geol. Oxford, p. 118.

Table showing the Subdivisions of the Lower Oolitic Rocks.



They consist of micaceous yellow sands, with occasional beds or concretionary masses of calcareous sandstone or sandy limestone, locally known as 'sand bats' or 'sand burrs,' which frequently contain organic remains. They are capped in Gloucestershire by a brown marly iron-shot limestone, one to three feet thick, which yields numerous species of Ammonites, Belemnites, and Nautili, whence the bed was termed the 'Cephalopoda-bed' by Dr. Wright. The beds attain a thickness of from 25 to 200 feet.

The Cephalopoda-bed and the upper portion of the Sands yield *Ammonites Aalensis*, *A. radians*, *A. hircinus*, *A. variabilis*, *A. opalinus*, *Belemnites compressus*, *B. irregularis*, *Gresslya abducta*, *Hinnites abjectus*, etc. Amongst the fossils of the Cephalopoda bed and Sands *Ammonites Jurensis* is conspicuous: hence the formation has been termed the zone of *A. Jurensis* by Dr. Wright, but the zone is sometimes restricted to the lower portions of the Sands. *Rhynchonella cynocephala* is another characteristic fossil: hence the term 'Cynocephala stage' used for the series by Dr. Lycett.[1] The sands contain also *Terebratula Stephani*, *Rhynchonella plicatella*, *Cucullæa ferruginea*, *Gervillia Hartmanni*, *Pholadomya fidicula*, *Perna rugosa*, *Trigonia formosa*, *Myacites arenacea*, *Myoconcha crassa*, *Pecten* (several species), *Serpula*, etc.

The fossils belong partly to the Lias and partly to the Inferior Oolite, and Professor Phillips has well observed that 'before the Liassic life has come to an end, the Oolitic life has begun.' Such being the case, the term Midford Sands is better than Upper Lias Sands proposed in 1856 by Dr. Wright,[2] or than Inferior Oolite Sand, or than Supra-Liassic Sands.[3] Between the Sands and the beds both above and below, there is evidence in places of transition, but perhaps the sands are on the whole more nearly allied to the Oolite above. In the neighbourhood of Yeovil the concretions in the lower part of the sands are blue and shaly, and the passage into the Lias appears to be very gradual; but in other localities there is a passage into the Oolites, and as a rule the base of the sandy beds is indicated by a line of springs thrown out by the Lias clays, and by a marked feature in the conformation of the ground. As before mentioned, the sands in the upper part of the Middle Lias in Dorsetshire are of much the same character as the Midford Sands.

To the east of Bridport Harbour there is a fine coast-section of the Sands, which are there seen to attain a thickness of nearly 150 feet, and, as the base is not visible, they may reach 200 feet. On the other side of the Harbour the Sands likewise occur, faulted almost directly against the Fuller's Earth. (See Fig. 40, p. 252.) The junction with the Inferior Oolite is seen in a road-cutting south of Burton Bradstock, as well as in the cliffs east of the river Bredy.

[1] J. Lycett, Handbook, Cotteswold Hills, 1857; Proc. Cottesw. Club, ii. 142.

[2] Q. J. xii. 292. See also J. Buckman, Q. J. xiv. 102; and E. Witchell, Geology of Stroud, p. 30.

[3] The term Aalenian, from Aalen in Wurtemburg, has also been applied to the strata by Karl Mayer (1864).

Rhynchonella cynocephala occurs in the sands. The yellowish-brown cliffs present a picturesque appearance, the many bands of sandy limestone standing out in relief from the softer sands, which more readily yield to the destructive influence of the weather. Here and there a smooth face of cliff may tell of recent slips, the tumbled masses of which are soon removed by the sea. A slight inward dip helps to keep the cliffs perpendicular.

The basement-beds of the Inferior Oolite, which occur on top of the Sands, and which were grouped by Dr. Wright as the 'Cephalopoda-bed,' were regarded by Prof. Buckman as palæontologically equivalent to the Gryphite-grit near the top of the Inferior Oolite at Leckhampton; while the Dorset Sands (in his opinion) in part represent the Lower Freestones of Gloucestershire.[1] It may be observed that strictly speaking the whole of the Inferior Oolite near Bridport is a 'Cephalopoda-bed,' and as this is now known to include the zones of *A. Parkinsoni*, *A. Humphriesianus*, and *A. Murchisonæ*, the Sands below unquestionably represent the Sands at the base of the Inferior Oolite in the Cotteswold Hills.

The Sands are well exposed in the deep lanes near Beaminster, in the lanes and railway-cuttings near Crewkerne and Yeovil, and at Babylon Hill, between Pen Mill and Bradford Abbas. These have been spoken of as the Yeovil Sands by Mr. Hudleston, and their thickness is about 150 feet. Occasional shelly limestones are met with in the sands at Yeovil Junction and Babylon Hill, and these develope into the celebrated building-stone at Ham Hill, near Martock. Here the section is as follows:[2]—

	ft.	in.
Ochre beds, yellow sands and sandstone	30	0
Yellow beds, closely-bedded stone	50	0
Grey bed, stone	8	2
Bottom bed, hard nodular bed (base of quarry)	1	4
Yellow "Brim Sands," with concretionary beds of sandstone	80	0

The yellow and grey beds are worked. The stone is almost entirely made up of comminuted shells, but specimens of *Pecten* and *Rhynchonella cynocephala* are to be recognized occasionally. Mr. Hudleston recently observed one of these shelly beds in the Sands in a quarry at Stoford, near Yeovil Junction. It was probably about 30ft. or 40ft. below the base of the Inferior Oolite Limestone, and was rich in fossils, including *Ammonites Moorei*, *A. radians*, *Trigonia angulata*, and *Tancredia*.[3]

The Sands cap the summit of Glastonbury Tor (Fig. 39, p. 250) and Brent Knoll, south of the Mendips, where their maximum thickness is about 160 feet. North of the Mendips the thickness is very variable, and the Sands disappear entirely in places. At Bath their thickness is about 40 feet; they have been well exposed in the tunnel under Combe Down, and in cuttings near Midford.

In Gloucestershire the Sands and Cephalopoda-bed (the Ammonite and Belemnite Bed of the Rev. P. B. Brodie, the Ammonite Sands of Prof. Hull, and Cotteswold Sands of Mr. E. Witchell) are persistent, and have a thickness of from 30 to 150 feet. The

[1] Q.J. xxxiii. 1, xxxv. 737.
[2] C. Moore, Proc. Somerset Arch. Soc. xiii.; see also Buckman, *Ibid.* vol. xx.
[3] P. Geol. Assoc. ix. 190.

Cephalopoda-bed (4 to 16 feet) is sometimes bored by *Lithodomus*. The beds are very well developed at Nailsworth and Frocester (150 feet), and the names of these places have been locally used to designate the Sands. They are also to be seen at Wotton-under-Edge, Crickley Hill, Haresfield, and other localities.[1] (See Fig. 44.)

The soil on the Midford Sands is generally fertile. Some of the concretionary masses are used for building-purposes, and Dr. Wright has stated that the sands are "well adapted for foundry purposes, as they receive sharp impressions of bodies impressed upon them."

The Ham Hill Stone is one of the best building-stones in the west of England, and has been quarried for many centuries. It is of a light brown colour, due to the presence of carbonate of iron. Montacute House and Brympton Hall near Yeovil, as well as most of the churches in the neighbourhood, are fine examples of buildings constructed of this stone. Similar stone is quarried at North Perrot, near Crewkerne.

The Sands form conspicuous grassy knolls in the neighbourhood of Bridport, Colmer's Hill to the west of that town being a prominent feature; Glastonbury Tor and Brent Knoll are still more striking examples. (See remarks on sandy lanes, in sequel.)

INFERIOR OOLITE.

The Inferior Oolite consists of buff and brown oolitic and iron-shot limestone, with marly and sandy layers, and occasional beds of compact limestone. It is generally darker in colour than the Great Oolite, and was termed the Under Oolite by William Smith in 1812, and the Inferior Oolite by James Sowerby in 1815. In thickness it varies from 15 feet on the Dorsetshire Coast to over 230 feet near Cheltenham. The fossils of the Inferior Oolite vary much in different localities, but from Gloucestershire to Dorsetshire the four Ammonite-zones may at intervals be determined. The succession is well borne out, and yet sometimes one or more zones may be absent, or the beds may be unfossiliferous. Occasionally *A. Parkinsoni*, and *A. Humphriesianus* may be met with together. By some authorities the zone of *A. Sowerbyi* is regarded as a subzone of that of *A. Murchisonæ* (a species named in honour of Lady Murchison). In some quarries Cephalopods are very abundant, in others Lamellibranchs, or Brachiopods are the prevailing forms; but Ammonites and Brachiopods are perhaps the most characteristic of particular horizons.

In the zone of *Ammonites Parkinsoni* there occur *A. subradiatus*, *Terebratula globata*, *T. sphæroidalis*, *T. perovalis*, *T. Phillipsii*, *Rhynchonella spinosa*, *R. subtetrahedra*, etc. In the zone of *A. Humphriesianus* we find *A. Blagdeni*, *A. Martinsii*, *Waldheimia carinata*, etc. In the zone of *A. Murchisonæ* there are *A. Sowerbyi*, *A. concavus*, *Terebratula fimbria*, *T. simplex*, *T. plicata*, *Rhynchonella subobsoleta*, etc.

Among the other fossils are Sponges; also the Corals, *Isastræa*, *Latimæandra*, *Montlivaltia*, etc., and the Echinoderms, *Holectypus*

[1] P. B. Brodie, Q. J. vii. 210; T. Wright, P. Geol. Assoc. iv. 168; E. Witchell, Geology of Stroud.

hemisphæricus, *H. depressus*, *Collyrites ringens*, *Cidaris Bouchardii*, etc. The large specimens of *Clypeus Plotii* (*sinuatus*), called poundstones or quoitstones, were in old times not unfrequently employed as a pound-weight by dairywomen.[1] They occur in the upper beds at Stroud, Naunton and Stow-in-the-Wold, and appear to be represented in Dorsetshire by *C. altus*.

Several species of *Serpula* are met with, also Polyzoa, and spicules of Holothuroids. Among the Mollusca, the species of *Trigonia* are very abundant: they include *T. formosa*, *T. costata*, *T. signata*, etc. The Inferior Oolite was indeed termed 'the metropolis of the Trigoniæ' by Dr. Lycett. There also occur, among the Lamellibranchs, *Ostrea gregaria*, *O. Marshii* (*flabelloides*), *Lima pectiniformis* (*proboscidea*), *L. Etheridgii*, *Pecten demissus*, *Trichites*, *Astarte excavata*, *A. obliqua*, *Ceromya Bajociana*, *Modiola Sowerbyana*, *Hinnites abjectus*, *Myacites tenuistriatus*, *M. Jurassi*, *Gresslya abducta*, *Myoconcha crassa*, etc. Among the Gasteropods species of *Pleurotomaria* are numerous; *Amberleya*, *Chemnitzia*, *Natica*, and other genera occur, also *Nerinæa* and *Alaria*, which appear for the first time in this country. *Belemnites giganteus*, *B. canaliculatus*, etc., and *Nautilus truncatus*, and other species are met with. Remains of Fishes, *Strophodus* and *Acrodus*, have rarely been noticed; bones of Saurians have also been met with. Plant-remains are exceedingly rare, but *Araucaria* has been determined.

In describing the Corals of the Inferior Oolite near Crickley and Stroud in Gloucestershire, Mr. R. F. Tomes observes that one bed in the Oolite Marl has the appearance and character of a true reef.[2] Four distinct Coral-beds have been observed near Stroud by Mr. Wi chell.

The Inferior Oolite is best developed in the Cotteswold Hills in Gloucestershire. At Leckhampton Hill, south of Cheltenham, it admits of the following divisions (see Fig. 43):[3]—

6. Upper Ragstone } and Clypeus bed with *C. Plotii*.	38 feet	Zone of *A. Parkinsoni*.
5. Lower Ragstone }		,, ,, *Humphriesianus*.
4. Upper (flaggy) Freestone	27 ,,	,, ,, *Sowerbyi*.
3. Oolite Marl	7 ,,	
2. Lower Freestone	110 ,,	,, ,, *Murchisonæ*.
1. Pea Grit Series	38 ,,	

Prof. Hull estimated the total thickness of the Inferior Oolite at this locality to be 264 feet; Mr. Witchell, whose figures are quoted above, estimates it at 236 feet. The Upper Freestone is so intimately connected with the Oolite Marl, that Mr. Witchell would group them together. Ammonites are not abundant in the beds.

The beds 5 and 6 are sometimes divided as follows:—

Clypeus Grits or Pholadomya Grit, with *P. Heraulti* and *Homomya gibbosa*.
Upper Trigonia Grit, with *T. costata*.
Gryphite Grit, with *Gryphæa sublobata* (*Buckmani*).
Lower Trigonia Grit, and Chemnitzia Grit with *C. procera*.

[1] Phillips, Life of William Smith, p. 3.
[2] Q. J. xxxviii. 411; G. Mag. 1886, p. 385.
[3] E. Hull, Geol. Cheltenham; J. Lycett, The Cotteswold Hills, 1857; J. Buckman, Q. J. xiv. 107; T. Wright, Q. J. xvi. 5; Murchison, Geol. Cheltenham, edit. by J. Buckman and H. E. Strickland, 1845.

All these subdivisions of 5 and 6 have been collectively grouped by Dr. Lycett as the Spinosa stage, characterized by *Rhynchonella spinosa*. No. 3 has been termed the Fimbria stage, being characterized by *Terebratula fimbria*; it contains also *Rhynchonella subobsoleta*, etc. The term "Grit" has locally been applied to rubbly oolitic stone, often a hard ragstone or limestone unfit for building-purposes. *Trigonia signata* (*decorata*) occurs in the Upper Trigonia Grit.

The Pea Grit Series includes certain beds of coarse ferruginous oolite and freestone[1] (Lower Limestone), which occur below the Pea-grit, at Stroud, etc. A variety of *Rhynchonella cynocephala* has been found in this Series and also in the Oolite Marl.

The Pea-grit or Pisolite is composed of flattened spheroidal masses about the size of a pea, and one-fourth or one-fifth of an inch in diameter. Many of the ovules consist of layers of carbonate of lime, aggregated around some organic or inorganic fragment: some appear to be small rolled fragments of limestone. This division is very fossiliferous: it contains *Terebratula simplex*, *T. plicata*, etc. It extends from Leckhampton, by Birdlip and Stroud to Selsley and Nailsworth.

The beds which rest on the Pea-grit are, according to Prof. Hull, frequently pierced by *Lithodomus attenuatus*: the upper bed of the Ragstone is also bored by Lithodomi.

Between Cheltenham and Chipping Campden the Inferior Oolite covers an extensive area; and it occurs on Bredon Hill. Near Bourton-on-the-Hill the Clypeus grit (36 feet) is underlaid by freestone bored by Annelides, and is not far removed from the Upper Lias.

East of Cheltenham the Inferior Oolite rapidly diminishes in thickness. (See Fig. 43.) It is represented in the neighbourhood of Woodstock by only 5 to 10 feet of the highest member of the series. At Sarsden the thickness is about 20 feet; at Fawler, near Stonesfield, 10 feet; at Enstone there is only a trace; and along the valley of the Cherwell it is altogether absent.

To the south and south-west of Cheltenham the Inferior Oolite also diminishes in thickness; at Haresfield Beacon, west of Painswick, it is about 90 feet,[2] but the full thickness near Stroud is about 150 feet. The beds may be well studied at Stroud Hill and at Rodborough Hill to the south of Stroud. At Dundry Hill, where the zones of *A. Parkinsoni*, *A. Humphriesianus*, and *A. Murchisonæ* are represented, the Oolite is upwards of 40 feet; and at Bath it is about 25 feet thick, but here *Ammonites* are by no means abundant. From Dundry a specimen of *A. subradiatus* obtained with its operculum *in situ*, was described by Dr. S. P. Woodward.[3]

In thickness and lithological character the Inferior Oolite varies much in Somersetshire; near Radstock and Frome it is a pale oolite, very cherty in places near the latter town.[4] In the combes near Frome, at Vallis, Whatley (see Fig. 41, p. 253), Nunney, Holwell, and Little Elm, the Inferior Oolite rests sometimes on the Rhætic Beds, sometimes directly on the Carboniferous Limestone or Old Red Sandstone; and it is in places conglomeratic, containing pebbles of quartz from the Old Red Sandstone, etc.

[1] E. Witchell, Geology of Stroud, 1882, and Q. J. xlii. 264; see also P. B. Brodie, Q. J. vii. 210.
[2] J. Buckman, Q. J. xxxv. 737.
[3] Geologist, iii. 328.
[4] J. McMurtrie, Proc. Bath Nat. Hist. Club, 1883.

De la Beche observed on the top of the hill between Holwell and Leighton, oyster-shells of the date of the Inferior Oolite, adhering to the old surface of Carboniferous Limestone, which was occasionally pierced by *Lithodomus*.[1]

Near Bruton the Inferior Oolite is exposed in the railway-cutting west of the station, and in many pits, between the town and Castle Cary. *Rhynchonella spinosa* is abundant in this neighbourhood, and here, as well as at Bath, it occurs low down in the Inferior Oolite.[2]

The two well-defined divisions of the Inferior Oolite of the south of England are thus described by Dr. Holl:[3]—

> *Upper Ragstone*, consisting of light-coloured, coarse-grained, thin-bedded or flaggy oolite, containing few fossils, and those chiefly in the form of casts (near Bath, etc.).
>
> *Lower Ragstone*, consisting of hard, brown, ferrruginous limestone, often much speckled with ovoid grains of peroxide of iron, and abounding in fossil remains.

Broadly speaking the upper beds correspond with the zone of *Ammonites Parkinsoni*, the lower beds comprise those of *A. Humphriesianus*, etc. Such is the case in Dorsetshire and parts of Somersetshire, although the beds vary to some extent, and the zones are not always to be identified. Much discussion has taken place concerning the correlation of the beds by Dr. Wright and Prof. J. Buckman, but more recent work, especially that of Mr. S. S. Buckman, has made it clear that the four Ammonite zones are developed in the neighbourhood of Sherborne and Yeovil, and that the 'Dorsetshire Cephalopoda-bed' is part of the Inferior Oolite, the representative of the Gloucestershire Cephalopoda-bed being the upper part of the Yeovil and Bridport Sands that underlie the Inferior Oolite.[4] (See p. 288.)

The quarries in the neighbourhood of Sherborne and Yeovil have long been known to collectors, for the beds are rich in fossils. It is, however, very remarkable, as shown by Mr. S. S. Buckman and Mr. Hudleston, that the fossil-beds occur at different horizons in different localities. Thus at Oborne the zone of *A. Humphriesianus* is the richest bed, while at Bradford Abbas and Half-way House this zone is hardly represented, and the zones of *A. Parkinsoni*, *A. Sowerbyi*, and *A. Murchisonæ* yield the fossils. At Bradford Abbas *Terebratula Morieri* was discovered by Mr. J. F. Walker at the base of the zone of *A. Parkinsoni*. At Oborne *Ammonites Sauzei* is found below the zone of *A. Humphriesianus* in a layer termed the *Sauzei*-bed; the upper part of that zone has been termed the *Cadomensis*-bed, from the occurrence in it of *A. Cadomensis*.[5]

The following section of the East Hill Quarry at Bradford

[1] Mem. Geol. Survey, i. 289.
[2] See Sir W. V. Guise, Proc. Cottesw. Club, ii. 170.
[3] Q. J. xix. 306.
[4] Q. J. xxxvii. 588.
[5] W. H. Hudleston, P. Geol. Assoc. ix. 193; Walker, G. Mag. 1878, p. 552.

Abbas (known as Prof. Buckman's quarry) was noted by Mr. Hudleston:—

Zone	Subzone	Bed	Ft.	In.
Zone of *Ammonites Parkinsoni.*		*a.* Whitish limestone in beds which are not very fossiliferous, though *A. Parkinsoni* occurs rarely, and mostly towards the base	6	6
		b. Marl bed with *Terebratula Morieri* and *Rhynchonella parvula*	0	6
? Zone of *A. Humphriesianus.*		*c.* The "rotten-bed" with large *Astarte.* Very small ammonites; thickness variable. About	0	6
Zone of *A. Murchisonæ.*	Subzone of *A. Sowerbyi.*	*d.* Irony stone	0	6
		e. The great shell-bed of Bradford Abbas with *A. concavus* in abundance, and many specimens of *A. Sowerbyi*, etc. Full of univalves. A yellowish ironshot oolite	2	0
		f. The Pavingstone or *Murchisonæ*-bed proper	1	1
		g. The "Dew-bed"	1	2
		Total thickness in quarry	12	3

The neighbourhood of Bridport, like that of Sherborne, is exceedingly rich in Inferior Oolite fossils, and here again the "fossil beds" now occur in the zone of *A. Parkinsoni*, and now in that of *A. Humphriesianus*, while the lower zones are generally well developed and rich in specimens of *A. concavus*, etc. In this district have been obtained most of the fine examples of *Ammonites Parkinsoni*, of which cut and polished specimens are to be seen in many collections.

The quarries near Beaminster, at Powerstock, Loders, Chideock, and Bridport are well known to collectors; but perhaps the cliffs and quarries at Burton Bradstock, east of Bridport Harbour, have been chiefly examined. Here the Inferior Oolite, altogether about 15 feet in thickness, rests on the yellow sands which form such striking features in the cliffs. The Oolite has been divided as follows (see Fig. 40, p. 252):[1]—

Pale and brown oolite with *Ammonites Parkinsoni*, *A. subradiatus*, *Terebratula Phillipsii*, *Collyrites ringens*, *Holectypus hemisphæricus*, etc.
Brachiopoda-bed: containing in great abundance *Terebratula sphæroidalis*; also *Waldheimia carinata*.
Brown and iron-shot oolite, with *A. concavus*, representing the zones of *A. Humphriesianus*, *A. Sowerbyi*, and *A. Murchisonæ*.
Sands representing the zones of *A. opalinus* and *A. Jurensis*.

The zone of *Ammonites Humphriesianus*, which is to be found in some quarries east of Bridport, does not appear to be distinctly developed at Burton Bradstock, although the species is met with in the cliffs and road-cutting. Dr. M. Poignand, who visited the

[1] Wright, Q. J. xii. 312, xvi. 47; R. Damon, Geol. Weymouth, etc. (1884) p. 226, with notes by R. Etheridge. See also Rev. G. F. Whidborne, Q. J. xxxix. 487; Prof. W. J. Sollas, *Ibid.* 541; and T. Davidson, Proc. Dorset Nat. Hist. Club, 1877.

neighbourhood while the road-cutting was being made, obtained from it as well as from the cliffs, *Ammonites Martinsii*, *A. Parkinsoni*, *A. Humphriesianus*, *A. subradiatus*, *A. fuscus*, *A. dimorphus*, *A. polymorphus*, *A. Gervillei*, *A. Garantianus*, *A. concavus*, a variety like *A. Aalensis*, *A. Murchisonæ*, *A. Sowerbyi*, and *A. confusus*.[1]

Near Banbury, according to Mr. E. A. Walford, the Inferior Oolite is represented by 12 to 20 feet of sands with occasional bands of stone, containing numerous plant-remains: these rest on the Upper Lias Clay. In the railway-cutting half a mile south of Hook Norton a good section of the Inferior Oolite has been exposed: it consists of flaggy and sandy limestones about 30 feet thick, and rests on Upper Lias Clay: here the zone of *Ammonites Humphriesianus* has been identified. At Chipping Norton the upper beds of the Oolite (about 30 feet) consist of freestone and siliceous limestone, termed by Mr. Hudleston the Chipping Norton Limestone. These may perhaps represent the Fuller's Earth of the south. They rest on marly and sandy limestones with *Ammonites Parkinsoni*, and *Trigonia signata* (in the upper part), while rubbly oolitic limestones with *Clypeus Plotii* come below.[2] At Chipping Norton, as Mr. Hudleston has remarked, we have the conventional namesake of the Northampton Sand, superposed on the *Clypeus*-grit, or *Parkinsoni* zone![3] (See sequel.) The Inferior Oolite extends by Charlbury to Fawler, near Stonesfield, where its thickness is from 5 to 10 feet. It contains *Ammonites Parkinsoni*, etc.[4]

Economic products, etc.

The stone is extensively quarried for building-purposes, for road-metal, and for lime-burning. Where the Great Oolite is developed and the Inferior Oolite is the poorer stone, it has been termed Bastard Freestone.

The Cheltenham Freestone[5] is largely quarried in many places along the Cotteswold Hills. The Lower or Building Freestone yields the principal building-stone quarried at Bourton, Broadway, Guiting, Stanley Hill, Cleeve Cloud, Dowdeswell, Leckhampton Hill, Painswick Hill, Birdlip, Uley Bury, Nailsworth, etc. The stone when first removed can usually be cut by the saw; it hardens upon exposure. The freestone is oolitic, and largely composed of comminuted shells. The Upper Freestone is oolitic, and has been worked at Stinchcombe, Wotton-under-Edge, and other places in the Cotteswold Hills.

Further south the Inferior Oolite is quarried at Dundry, Radstock, Frome, etc. One of the best examples of stone is obtained from Doulting, east of Shepton Mallet. The rock is a white and brown sandy and sparry stone, slightly oolitic in places, and with few fossils. Wells Cathedral and Glastonbury Abbey were largely constructed of Doulting Stone. The so-called Druidical remains, known as the

[1] See P. Geol. Assoc. ix. 204.

[2] Walford, Q. J. xxxix. 224, xli. 38.

[3] P. Geol. Assoc. v. 382. Churchill, near Chipping Norton, was the birthplace of William Smith.

[4] A. H. Green, Geol. Banbury, p. 11.

[5] The term Freestone is generally applied to a rock which can be cut into blocks in any direction: but is not always applied to a limestone.

Rollwright (or Rollerich) stones, near Little Rollwright, not far from Chipping Norton, are formed of Inferior Oolite.[1]

Analysis of the Inferior Oolite shows about 90 per cent. of carbonate of lime, with small portions of silica, alumina, etc.

The soil is reddish-brown and brashy ; the character of the ground is hilly, and sometimes comparatively barren. The higher grounds, especially on the Cotteswold Hills, are largely devoted to sheep-walks ; but where the soil is deep, it is fertile, and forms good corn land.

FULLER'S EARTH.

The term Fuller's Earth was applied geologically by William Smith, in 1816, to a thick deposit of grey clay and marl, with occasional nodules of earthy limestone; this is divided near the middle, in some localities, by beds of soft argillaceous limestone, called the Fuller's Earth Rock. The formation is characterized by the presence (south of Bath) of beds of blue and yellow Fuller's Earth, a marly clay, which is of a brown or yellowish colour near the surface, and blue deeper down. As described by Mr. Bristow, this Fuller's Earth is of commercial value, has a greasy feel, and an earthy fracture; it yields to the nail, and affords a shining streak; it scarcely adheres to the tongue; becomes translucent when placed in water, and falls into a pulpy impalpable powder, without forming a paste with it.[2]

The maximum thickness of the Fuller's Earth formation may be as much as 400 feet. It rests conformably on the Inferior Oolite, and is overlaid by the Great Oolite or Forest Marble. The Fuller's Earth Rock is from 20 to 30 feet in thickness, and may be described as a blue marly limestone weathering pale-grey or yellowish-grey. According to Mr. Bristow it is feebly developed in the neighbourhood of Bath, but becomes of importance between Kilmersdon in Somerset and Beer Hackett and Thornford, in Dorset.

The Fuller's Earth is characterized by *Ostrea acuminata*, *Terebratula* (*Waldheimia*) *ornithocephala*, and *Rhynchonella varians* (*media*).

Among other fossils may be mentioned *Ammonites subcontractus* (*modiolaris* of Wm. Smith), *A. macrocephalus*, *Belemnites parallelus*, *Ostrea Sowerbyi*, *Pecten vagans*, *Pholadomya truncata*, *P. deltoidea*, *Goniomya angulifera*, *G. literata*, *Homomya gibbosa*, *Isocardia concentrica*, *Ceromya plicata*, *Lima duplicata*, *Placunopsis socialis*, *Modiola Sowerbyana*, *M. gibbosa*, *Terebratula globata*, *T. perovalis* and *Serpula tetragona*.[3] *Glyphea* has been met with, and many species of Entomostraca and Foraminifera have also been obtained.[4] Some

[1] P. Geol. Assoc. v. 179.

[2] Glossary of Mineralogy, 1861.

[3] See Phillips, Geol. Oxford, etc., p. 166; W. Smith, Strata Identified, 1816; E. Witchell, Geol. Stroud, p. 69.

[4] T. R. Jones and C. D. Sherborn, G. Mag. 1886, p. 272.

Plant-remains have been recorded, including *Pterophyllum*, *Zamites*, and *Palæozamia*.

Professor R. Tate regarded the Fuller's Earth as the uppermost zone of the Inferior Oolite;[1] but the fossils indicate that it is closely connected with the Great Oolite, and in Dorsetshire the Upper Fuller's Earth seems to replace that formation.

The thickness of the Fuller's Earth in Somersetshire varies from 120 to 180 feet. At Scale Hill, near Bruton, the following section was noted by De la Beche:[2]—

Upper Fuller's Earth	133 feet.
Fuller's Earth Rock	25 ,,
Lower Fuller's Earth	21 ,,

Lamyat Beacon is a conspicuous outlier of Fuller's Earth Clay and Rock. The Fuller's Earth is largely developed in Dorsetshire (400 feet). A good section (about 90 feet) of grey crumbling marl is shown in the somewhat treacherous cliffs of Watton Hill, between Eype and Bridport Harbour, where the beds, overlaid by the Forest Marble, are faulted on the west against the Middle Lias and on the east against the Midford Sands. In both cases the faults run in an easterly and westerly direction. The junction of Fuller's Earth and Inferior Oolite is shown in the cliff at Burton Bradstock. (See Fig. 40, p. 252.) The Fuller's Earth contains beds of impure limestone, and (near the faults) layers of fibrous carbonate of lime, like the "Beef" of the Purbeck Beds. Bivalves of the genera *Lucina*, *Myacites*, *Nucula*, etc., are met with in the marl. A bank almost entirely composed of specimens of *Ostrea acuminata* is exposed on the borders of the Fleet, south of Langton Herring, near Weymouth. Fossils have also been obtained from a cutting at Smokeham, near Poorstock.[3]

The Fuller's Earth Rock is well exposed in the railway-cuttings east of Milborne Port, and between Wincanton and Cole, near Shepton Montague. In this neighbourhood it makes a conspicuous escarpment. In Gloucestershire the Fuller's Earth has a thickness of 130 feet at Wotton-under-Edge, 70 feet at Stroud and Sapperton Tunnel, while it occurs only as a thin band at Cheltenham. The upper layers in this district are frequently interstratified with beds similar to Great Oolite. (See Fig. 44, p. 280.) Fossils have been obtained at Cubberly, near Cheltenham, at Sapperton, etc.[4]

The Fuller's Earth soon disappears when traced beyond Gloucestershire; but it is represented by a few feet of clay at Chipping Norton, and at Sherborne near Burford on the borders of Oxfordshire.

[1] Quart. Journ. Science, 1870, vii. 68.
[2] Mem. Geol. Survey, vol. i. p. 280.
[3] See T. Wright, Q. J. xii. 310; R. Damon, Geol. Weymouth, 1884, p. 223.
[4] E. Hull, Geol. Cheltenham (Geol. Surv.), p. 52.

Economic products, etc.

The following section by Lonsdale exhibits the general type of the Fuller's Earth near Bath :[1]—

	Feet
4. Blue and yellow clay, with nodules of indurated marl	30 to 40
3. Bad Fuller's Earth	3 to 5
2. Good Fuller's Earth	$2\frac{1}{2}$ to 3
1. Clay containing beds of bad Fuller's Earth, and layers of nodular limestone and indurated marl	100

An old analysis of Fuller's Earth showed about 73 per cent. of silicate of alumina, and 27 per cent. of carbonate of lime ; some ferruginous matter was also present.[2]

Mr. H. W. Bristow has observed that the blue Fuller's Earth is frequently of as good quality as the yellow for particular purposes, as in fulling coarse cloths, but the yellow is usually esteemed the better. The general thickness of the veins is from 18 inches to four feet. If good, a vein 18 inches in thickness could be worked with profit, but not if of less thickness. Sometimes the vein ends suddenly ; at others it gradually thins out.

The economic Fuller's Earth has been worked along the outcrops of the strata at Dunkerton, Odd Down, near Midford, Wellow, and Box. Shafts with levels are sometimes sunk to a depth of thirty feet or more. The earth has been much used in fulling at the cloth mills at Bradford-on-Avon, Frome, and in Gloucestershire. It is still worked in the district near Bath. In Gloucestershire the earth is only occasionally represented by an impure and useless bed.

The Fuller's Earth rock is quarried for building-purposes, for road-metal and for lime-burning. Bricks and tiles are sometimes made from the Fuller's Earth clay, as at Maperton, south-west of Wincanton ; and the clay is also burnt for ballast between Toller Porcorum and Poorstock.

The soil is not, as a rule, very fertile, the land being heavy and wet. On the slopes of the Cotteswold Hills the soil on the Inferior Oolite is sometimes largely made up of slipped Fuller's Earth, and its fertility is thereby improved.

The Fuller's Earth throws out copious springs, and has caused numerous slips on the declivities of the hills around Bath and other places.

Great Oolite Series.

The Series is divided as follows :—

Cornbrash.
Forest Marble and Bradford Clay.
Great Oolite. { *Upper Zone.*
{ *Lower Zone.* Stonesfield Slate and Northampton Sand (upper part).

GREAT OOLITE.

The Great or Bath Oolite consists of a series of shelly limestones (rags) and fine oolites or freestones, often exhibiting much false-

[1] T. G. S. (2) iii. 249 ; see also Geol. East Somerset (Geol. Surv.), p. 125.
[2] C. Boyd, Letters, etc., Bath and West of England Soc. (1810) xii. 379.

bedding, and generally of a yellowish-white colour.[1] Layers of sandy marl occasionally form partings between the beds of stone.

The Great Oolite is rich in univalve Mollusca, such as *Alaria*, *Cylindrites*, *Nerinæa Voltzii*, *Nerita*, *Patella cingulata*, *P. rugosa*, *Chemnitzia*, *Cerithium quadricinctum*, *Natica*, *Trochotoma obtusa*, *Purpuroidea Morrisii*, *Pteroceras Wrightii*; amongst the bivalves are *Cardium Stricklandi*, *Macrodon Hirsonensis*, *Ceromya*, *Cypricardia*, *Gervillia*, *Trigonia imbricata*, *T. Moretoni*, *Pholadomya*, *Tancredia brevis*, *Astarte excavata*, *Arca*, *Ostrea gregaria*, *Pecten lens*, *P. vagans*, *Lima cardiiformis*, *L. duplicata*, *Modiola imbricata*, *Pachyrisma grande*, and *Opis lunulatus*. Cephalopoda are not abundant; they include *Ammonites subcontractus*, *Nautilus*, and *Belemnites*. Among the Brachiopoda are *Rhynchonella concinna*, *Terebratula perovalis*, *T. maxillata*, *Waldheimia digona*, etc.[2] The Coral *Calamophyllia* (*Eunomia*) *radiata*, is common near Bath; other species occur at various horizons, including *Isastræa*, *Convexastræa*, *Thamnastræa*, etc., and the 'Button-stone,' *Anabacia orbulites*.[3] Among Echinodermata are *Hemicidaris*, *Acrosalenia hemicidaroides*, etc., of which many spines and plates are found, also *Millericrinus Pratti*. *Diastopora ventricosus* is not uncommon. Fragments of Crustacea (*Glyphea*) are sometimes met with. Of Fishes, we find the large quadrangular palatal teeth of *Strophodus*, spines and teeth of *Hybodus*, and the small spherical teeth of *Lepidotus* (sometimes termed 'Fishes' eyes'). Teeth and bones of Saurians (*Cetiosaurus*, etc.) are occasionally met with. Some Reptilian eggs found in the Great Oolite at Hare-bushes quarry, near Cirencester, were described by Prof. Buckman, who named them *Oolithes Bathonicæ*.[4] Fragments of lignite occur in places. In many localities the Great Oolite appears destitute of fossils, or the organic remains are so broken up that not a single perfect specimen can be obtained.

The thickness of the Great Oolite varies from 50 to 150 feet.

The Great Oolite in the neighbourhood of Bath was thus divided by Lonsdale:[5]—

		Feet
Upper Rags.	1. Coarse, shelly limestones 2. Tolerably fine oolites (Scallet) 3. Tough, brown, argillaceous limestone	20 to 55
Fine freestones (Weatherstone, etc.)		10 to 30
Lower Rags, Coarse, shelly limestones		10 to 40

Beds of Coral and shell-beds with small Gasteropods occur in the upper beds at Farley Down, at Murrel (Murhill) near Winsley, and Ancliff (Avoncliff) near Bradford-on-Avon, as noted by Mr.

[1] The formation was termed the Great Oolite of Bath, or Upper Oolite, by William Smith, in 1815.

[2] See J. Lycett, The Cotteswold Hills, J. Phillips, Geol. Oxford, etc. In the Oxford area we owe our knowledge of the fossils of the Great Oolite Series largely to collections made by Mr. J. Whiteaves, Rep. Brit. Assoc. 1860, Sections, p. 104.

[3] R. F. Tomes, Q. J. xxxix. 170; xli. 170.

[4] Q. J. xvi. 107, xiv. 117; W. Carruthers, Q. J. xxvii. 447.

[5] T. G. S. (2), iii. 250, 254.

W. H. Wickes. The Corals in the opinion of Mr. Tomes are drifted.

The Great Oolite forms the summits of Lansdown and of the principal hills south and east of Bath. It occurs at Bradford-on-Avon; but it thins away entirely in the district north of Frome, between Wellow and Norton St. Philip,[1] and is therefore not present in Dorsetshire.

In the northern part of the Cotteswold district Prof. Hull found it convenient to divide the Great Oolite as follows:[2]—

Upper Zone	"White limestone," compact white marly limestones, seldom oolitic, and marls or clays; about 100 feet at Burford.	
Lower Zone	White oolitic freestone, false-bedded. Stonesfield Slate..................	12 to 80 feet

The Upper Zone, as Prof. Judd states, possesses a distinctive fauna, in which *Myidæ*, *Ostreidæ*, and Echinodermata are especially noticeable; it may be traced from the northern end of the Cotteswolds, through Oxfordshire and Northamptonshire to Lincolnshire. In the neighbourhood of Bath it is represented by the Upper Rags. (See p. 298.)

The Lower Zone contains remains of terrestrial organisms and indicates the littoral conditions under which it was deposited. Traced towards the Midland counties, the Lower Zone is represented by sandy beds (Northampton Sand, upper part), and still further north by estuarine clays (Upper Estuarine Series). The Bath freestone and beds beneath belong to the Lower Zone.[3]

The Lower Zone of the Great Oolite includes the Stonesfield Slate, which was shown by Lonsdale to lie at the base of the Great Oolite.[4] It comprises not only flags and tilestones, but also white shelly oolites, which in some places overlie the flags, and in others replace them. These oolites or freestone beds, which attain a thickness of from ten to nearly forty feet, are worked at Minchinhampton, Burford, Tainton, and Windrush.

In the neighbourhood of Banbury the beds become sandy, and there they have been included in the Northampton Sands, although their true position as part of the base of the Great Oolite was recognized by Mr. T. R. Polwhele.[5] (See Diagram, p. 286.) *Terebratula maxillata*, *Rhynchonella concinna*, *Cypricardia Bathonica*, and other fossils were obtained from these Sands near Deddington.

At Minchinhampton extensive sections have been opened in the

[1] The inlying mass at Wanstrow, between Bruton and Frome, represented on the Geological Survey Map as Great Oolite, is in reality Fuller's Earth.

[2] Geology of Cheltenham, p. 53; Judd, Geology of Rutland, etc., p. 10.

[3] Hull, Explan. Sheet 34 (Geol. Surv.), p. 13.

[4] Proc. G. S. i. 414; see also Dr. W. H. Fitton, Zool. Journ. 1828, iii. 412.

[5] A. H. Green, Geol. Banbury, etc. p. 11; see also Judd, Geol. Rutland, etc. p. 25.

Great Oolite, and the following general section was noted by Dr. J. Lycett:[1]—

	feet	in.
"Planking." Coarse shelly oolitic limestone, false-bedded. *Purpuroidea*, *Pteroperna*, *Macrodon* and other large shells	10	0
Thin-bedded pale oolite, with sandy partings: more compact at base. *Ostrea*, *Tancredia*, etc.	12	0
False-bedded yellowish oolite. *Lithodomus inclusus*	6	0
"Weatherstone." Greyish-brown oolite full of shells	6	0
Hard argillaceous limestone, and flaggy oolite. *Ostrea*.		9
Fuller's Earth.		

From the quarries in the neighbourhood Dr. Lycett obtained upwards of 300 species of Mollusca. The beds of Oolite here are grouped with the Lower Zone, the Upper Zone being scarcely represented at this locality: at the same time it is worthy of remark that in this district there often appears to be no positive line of separation between the Great Oolite and the Forest Marble.[2] Sections showing the two zones of Great Oolite have been exposed at Yatton Keynell, near Corsham, and east of Castle Combe.[3]

Other fossiliferous localities are Bussage, west of Chalford; near the Seven Springs, to the west, and Windrush and Sherborne Park to the east of Northleach; Cirencester; Burford; and Andoversford.

At Sapperton Tunnel the thickness of the Upper Zone of white limestones is about 30 feet; but the total thickness of the Upper Zone of Great Oolite is from 60 to 80 feet. The beds are blue when reached at some depth, but they weather white, and hence are locally known as the white limestones. They contain plant-remains and jet, in some localities. In a quarry by the railway south of Cirencester station, beneath the Bradford Clay, there is a marly bed of Great Oolite crowded with specimens of *Acrosalenia pustulata*, to which attention was drawn by Mr. F. Bravender. The total thickness of the Great Oolite at Cirencester has been proved to be 120 feet; at Coln St. Dennis, the beds have a thickness of 145 feet. The beds may be seen also at Brackley, and Whittlewood Forest, north of Buckingham, and around Towcester. (See sequel.)

Economic products, etc.

At Tainton, near Burford, the Great Oolite yields excellent building-stone, known as the Tainton stone, which was much used in Oxford, and in the construction of Blenheim Palace.[4] The beds are also quarried near Cirencester, Kemble, Tetbury, etc. At Minchinhampton there are extensive quarries (Hampton stone), showing thirty to forty feet of rock. The beds are also worked

[1] The Cotteswold Hills, p. 93; see also E. Witchell, Geol. Stroud, p. 73.
[2] Hull, Geol. Cheltenham, p. 65; see also A. H. Green, Geol. Banbury, p. 17.
[3] Hull, Geol. parts of Wilts, etc., p. 14.
[4] Hull, Explan. Sheet 45 S.W. (Geol. Survey), p. 16.

at Chalford, Bisley, and other localities; they vary much in character in different places.

The Bath stone hardens and becomes whiter on exposure, after it has been quarried. In its natural bed it is soft and moist, and it has been proved that a cubic foot of the stone will absorb one gallon of water. The beds are largely quarried, or mined, near Bath (on Odd Down, Combe Down, and Monkton Farley Down), at Box, Corsham, Limpley Stoke, and Bradford-on-Avon. Stone was formerly quarried on Bath Hampton Down. This stone is known as Combe Down Stone, etc. Some of the beds, called Weather-stones (brown oolitic limestones), are specially valuable for outside work, etc.; the Scallet is of superior quality for carving, being of very fine and uniform texture, but it is seldom worked. Analysis of the stone shows about 95 per cent. of carbonate of lime.[1]

The action of the weather, by means of rain, frost, and carbonic acid, is very obvious in these calcareous rocks. Thus not only are the beds broken up at the surface into a rubble; but the surfaces of the rocks are often pitted and eroded in very fantastic hollows, with branching ridges, and crests.[2] The Dagham Stone, of Daglingworth Down, north of Cirencester, is a well-known example.

The soil on the Great Oolite is a thin stone-brash. It is suited to the growth of turnips and barley, but much wheat is also cultivated.

The Great Oolite generally forms a well-marked feature in the neighbourhood of Bath, in Gloucestershire, and the borders of Oxfordshire; but north of Minchinhampton, the Inferior Oolite forms the main escarpment of the Cotteswold Hills.

Stonesfield Slate.

The Stonesfield Slate consists of fissile calcareous sandstones or flags, which, splitting readily along the planes of bedding, produce the so-called 'slates' of Stonesfield, west of Woodstock, in Oxfordshire. False-bedding is of frequent occurrence in the beds.

The formation is rich in fossil Plants, Molluscs, Insects, Fishes, Reptiles, and Mammals. Corals, Echinoderms, and Crustacea are also met with. The occurrence of Mammalia was first recognized by Cuvier in 1818, from a specimen obtained by Mr. W. J. Broderip; but for many years afterwards there was much controversy concerning the mammalian characters of the fossil and the antiquity of the deposit.

The Mammals include the *Amphitherium*, *Phascolotherium*, and *Stereognathus*. The Reptiles include *Megalosaurus Bucklandi*, *Rhamphorhynchus* (a Pterosaurian), *Teleosaurus*, *Testudo Stricklandi*, and the reptilian eggs *Oolithes sphæricus*.[3] The Fishes include *Pholidophorus*, *Lepidotus*, *Pycnodus*, *Ganodus*, *Hybodus*, *Strophodus*, *Nemacanthus*, *Ceratodus*, etc. Among Crustacea, *Pollicipes Ooliticus* is the oldest known pedunculated Cirripede. Among the Insects are a Dragon-fly, *Libellula*, and a Butterfly, *Palæontina*. Among the Mollusca are *Rhynchonella concinna*, *Trigonia impressa*, *Gervillia acuta*, *Pholadomya acuticosta*, *Ostrea gregaria*, *Ammonites gracilis*, *Belemnites fusiformis*, *B. bessinus*, etc. The Plant-remains include

[1] See Mem. Geol. Survey, vol. ii. part 2, p. 690.
[2] Phillips, Geol. Oxford, etc. p. 143.
[3] W. Carruthers, Q. J. xxvii. 447.

Algæ, Ferns, Cycads, and Conifers; among the genera are *Pterophyllum*, *Pecopteris*, *Tæniopteris*, *Thuytes*, *Araucarites Brodiei*, etc.

According to Prof. Phillips, the beds were probably laid down in a lagoon with bordering marshes and drier land, while the organic remains present remarkable affinities with forms now living in Australia.[1]

The flaggy beds are quarried in the Evenlode Valley, at Sarsden, Stonesfield, and Woodstock, also on Sevenhampton Common, Eyeford, near Naunton, Bisley, etc.[2]

The deposit worked for 'slates' is sometimes only a foot in thickness, but it generally consists of two fissile beds of a buff-coloured or grey oolitic limestone called *pendle*, each about two feet thick, separated by a bed of loose calcareo-siliceous sandstone called *race*, about the same thickness. Concretions are frequent in the latter, and are called *whinstones* or *pot-lids*; they are partially oolitic, and vary from six inches to two feet in diameter; their form is generally that of a flattened sphere; they break into parallel planes, and often contain shells. The pendle, after being quarried, is suffered to lie exposed to the action of a winter's frosts, and the blocks being then struck on their edge with a mallet, freely separate into slates sufficiently thin to afford a light material for roofing. The quarries are principally situated immediately to the south of Stonesfield village, in the valley which branches off eastwards from that of the Evenlode. The mode of working is by driving horizontal galleries about six feet high into the side of the hill, and then extracting the two strata of pendle laterally, piling up the refuse masses of the intermediate bed of race, so as to support the roof: deep perpendicular shafts communicate with these galleries. These workings have been carried on from remote times to a considerable extent, so that both sides of the valley are completely honey-combed by them. Beautiful plumose stalactites are often found in the fissures of the rock, and are called *tallow* by the workmen.[3]

FOREST MARBLE.

This formation was named by William Smith in 1815, from the Forest of Wychwood, between Burford and Woodstock, in Oxfordshire. It comprises thick beds of clay and shale, also sand, sandstone, and oolite, but its characteristic rock is a fissile[4] shelly and oolitic limestone, which has been polished in some localities for ornamental purposes. Few formations are more changeable in character within short distances; and the stone-beds are conspicuously false-bedded and wedge-bedded. These beds are usually overlaid and underlaid by shaly and marly clays, that contain thin layers or films of calcareous sandstone.

The thickness of the Forest Marble in north Dorsetshire has been estimated at 450 feet by Mr. Bristow, but it diminishes northwards, being about 100 feet near Bath and Cirencester. The main mass of the stone-beds is seldom more than thirty feet in thickness, but occasional beds of shelly limestone are found at all horizons in

[1] G. Mag. 1866, p. 99; Geol. Oxford, etc., pp. 168, 237; Owen, Brit. Fossil Mammalia; Brodie, Fossil Insects; Brodie and Buckman, Q. J. i. 220.

[2] Hull, Geol. Cheltenham (Geol. Survey), p. 53; Hull, Explan. Sheet 45 S.W. p. 18; and A. H. Green, Geol. Banbury, etc. (Geol. Survey), p. 13.

[3] Conybeare and Phillips, Outlines of the Geol. England and Wales, p. 204.

[4] A term applied to beds capable of being split up into flags.

the series. The beds rest conformably on the Great Oolite in Gloucestershire and Somersetshire, and on the Fuller's Earth in the southern part of Somersetshire and in Dorsetshire.

The lowest portion of the Forest Marble is sometimes distinguished by the name of the Bradford Clay. The shelly limestones are largely made up of comminuted shells of *Ostrea*, *Pecten*, etc.

The Mollusca include *Ostrea Sowerbyi*, *Pecten vagans*, *P. lens*, *P. annulatus*, *Trigonia Moretoni*, *Cyprina Loweana*, *Lima cardiiformis*, *L. duplicata*, as well as some Gasteropods. The Brachiopods include *Terebratula maxillata*, *Waldheimia digona*, *W. cardium*, *Rhynchonella varians*, *R. concinna*, *R. obsoleta*, etc. Most of the species are, however, identical with those found in the Great Oolite and Cornbrash. One Ammonite, *A. discus*, has been recorded from Tetbury. The Echinoderms include *Apiocrinus Parkinsoni* (*rotundus*), and species of *Acrosalenia*, *Echinobrissus*, etc. Corals and Sponges are not abundant. The oldest known British Crab, *Palæinachus longipes*, has been obtained from the Forest Marble of Malmesbury.[1] Palatal and other remains of the Fishes *Lepidotus* and *Strophodus*, and bones of Saurians, are occasionally met with.

Ripple-marks, worm-tracks, and other curious trailings abound on the surfaces of some of the thin beds of calcareous sandstone.[2] Lignite is abundant in the limestone beds. Hence the beds were evidently deposited in shallow water, not far from land.

Bradford Clay.

This is a deposit of pale-grey or yellowish-grey marly clay, sometimes containing seams of limestone and laminæ of grit, identical in character with beds in the Forest Marble. It was originally termed the 'Clay over Upper Oolite' by William Smith, as it rests in places on the Great Oolite; its fossiliferous character, however, caused it to receive a separate name from its occurrence at Bradford-on-Avon. Lonsdale, to whom we are indebted for the first particular account of the Bradford Clay, regarded it as simply a portion of the Forest Marble, and the same view was taken by Prof. Hull.[3]

The thickness of the Bradford Clay is about ten feet in the immediate neighbourhood of Bradford, but it may be somewhat thicker at Farleigh. The fossil-bed to which it owes its importance occurs at the base. Where the Great Oolite has disappeared south of Frome, the Bradford Clay and Fuller's Earth come together, and it is not easy to separate the two; while, on the other hand, where the Bradford Clay is wanting, it becomes in some localities difficult to distinguish the upper beds of the Great Oolite from the lowest of the Forest Marble.

Fossils were noticed early in the present century by the Rev.

[1] Dr. H. Woodward, Q. J. xxii. 493.
[2] G. P. Scrope, Proc. G. S. i. 317, and Journ. Roy. Inst. i. 538.
[3] T. G. S. (2), iii. 255, and Hull, Geol. Cheltenham, p. 69.

Benjamin Richardson, at Berfield, to the north of Bradford;[1] and subsequently a most extensive collection of the characteristic 'Bradford Encrinites' was made by Dr. J. Chaning Pearce.[2] These fossils are known also as Pear Encrinites, 'Peg-tops' and 'Coach-wheels,' from the fancied resemblance of the body and portions of the stalk of the Crinoid to those objects: they form parts of the *Apiocrinus Parkinsoni*, which evidently attached itself to the surface of the Great Oolite.

Among the fossils, Brachiopoda are conspicuous, and the bed has been termed the zone of *Terebratula* (*Waldheimia*) *digona*: perhaps the more characteristic form is *Terebratula coarctata* (*decussata*); *T. maxillata*, *T. Bradfordiensis*, *Waldheimia cardium*, *Rhynchonella varians*, *R. concinna*, and other forms occur; also *Avicula costata*, *Ostrea gregaria*, *O. Sowerbyi*, *Mytilus asper*, *Serpula*, *Acrosalenia*, *Cidaris*, and *Antedon prisca* (one of the *Comatulæ*).[3]

Although the Bradford Clay is generally considered to be a local deposit in the district between Bradford-on-Avon and Cirencester, the fauna is represented in Dorsetshire, from specimens collected by Mr. J. F. Walker, Mr. Darell Stephens, and Mr. R. Damon, at Radipole, near Weymouth, etc.[4] At West Cliff, Bridport Harbour, the upper part of the cliff is formed of Forest Marble, exhibiting a mass of shell-limestones ten or twelve feet in thickness, overlaid by thirty feet of clays, shaly and thin flaggy limestones, and underlaid by similar beds about fifty feet in thickness. At the base of these lower clays is a hard brown sandy marl, one foot or more in thickness, containing many fossils. The same bed occurs east of Burton Bradstock, and at Herbyleigh, near Weymouth; and it appears to represent the Bradford Clay. At Eype a conspicuous band of hard pale marl occurs below this bed, marking the junction with Fuller's Earth. (See Fig. 40, p. 252.) *Rhynchonella Boueti*, *Terebratula intermedia*, var. *Langtonensis*, *Waldheimia obovata*, as well as *R. varians*, *T. coarctata*, *T. maxillata*, *W. digona*, etc., are found at these localities.

Mr. Walker has obtained a variety of *Rhynchonella spinosa* from the road-cutting below the Great Western Railway at Tetbury Road, near Cirencester.[5] In this neighbourhood the Bradford Clay is represented by three to ten feet of yellow marl, and from it Dr. S. P. Woodward obtained 105 species of fossil marine organisms.[6]

The Forest Marble forms a prominent escarpment in Dorsetshire, at Lillington Hill south of Sherborne, and to the west of Stalbridge and Wincanton.

[1] Townsend, Character of Moses, p. 268.
[2] Proc. G. S. i. 484; see also P. Geol. Assoc. ix. 165.
[3] P. H. Carpenter, Q. J. xxxvi. 54.
[4] Damon, Geol. Weymouth, 1884, p. 15; T. Davidson, Supp. to Jurassic Brachiopoda (Palæontogr. Soc.), p. 156; T. Wright, Q. J. xii. 310; see also P. Geol. Assoc. ix. 207.
[5] G. Mag. 1870, p. 299.
[6] Proc. Cotteswold Club, i. 6; J. Buckman, Q. J. xiv. 117.

The following divisions of the beds in Somersetshire and Wiltshire were made by Lonsdale:[1]—

		Feet.
Forest Marble.	6. Clay with occasional laminæ of grit	15
	5. Sand and Grit = Hinton Sand and Sandstone of W. Smith, at Charterhouse Hinton, near Bath[2]	40
	4. Clay, with thin slabs of stone, and laminæ of grit	10
	3. Shelly limestone or coarse oolite	25
	2. Sand or sandy clay and grit	10
	1. Bradford clay.	

The Hinton Sand contains large concretionary masses of hard sandstone, sometimes in the form known as 'pot-lids.' These beds occur also at Norris Hill, north-west of Westbury.

Many fossils have been obtained from the neighbourhood of Atford, between Bath and Melksham, and in the railway-cutting west of Laycock. Northwards the beds extend by Corsham and Castle Combe, to Badminton, Tetbury, Malmesbury, and Cirencester. Here and there beds of sand with pot-lids occur.

In Oxfordshire the thickness averages twenty-five feet. At Blenheim Park the thickness is fourteen or fifteen feet. Prof. Hull has observed that owing to the rapid inclosure of Wychwood Forest, many quarries have been opened, showing the lower beds (resting on the Great Oolite) to consist of false-bedded shelly oolite, splitting into slabs and flags, and composed of enormous quantities of broken oyster-shells; they are about thirty feet in thickness. The higher beds consist of bluish clays and marls, with thin flagstones and roofing-slates, from twenty to thirty feet in thickness. Towards Witney the Forest Mable becomes very thin; but the beds have been traced to near Bucknell, north-west of Bicester, and west of Pattishall, north-west of Towcester.[3] As remarked by Prof. Judd, in Oxfordshire the limestones thin out and disappear altogether, and the clays with occasional shelly bands become so thin that the beds cannot be separated from the Great Oolite. In North Northamptonshire and Lincolnshire the beds of clay again thicken, but they do not include any of the characteristic shelly limestones: hence they have been grouped as the Great Oolite Clay.[4] The Alwalton Marble near Peterborough may however be a representative of the Forest Marble. (See p. 316.)

Economic products, etc.

Some of the beds furnish coarse roofing-slates and flagstones, as at Poulton, west of Fairford, Cirencester, and Chavenage, near Tetbury.

Near Milborne Port the beds are worked at Bowden, and known as Bowden Marble; they are also quarried at North Cheriton and Bratton, near Wincanton, Frome (Frome stone), and many other places.

[1] T. G. S. (2), iii. 255.

[2] Memoirs of W. Smith, by John Phillips, p. 59; Q. J. xiv. 87.

[3] Geol. Woodstock (Geol. Survey), p. 22; and A. H. Green, Geol. Banbury, p. 26.

[4] Geology of Rutland, etc., p. 9.

Mr. Bristow informs me that at Long Burton in the neighbourhood of Sherborne (Dorset), beds of Forest Marble are sometimes polished for ornamental purposes: this has been called the Yeovil Marble. As a rule, however, it is too much impregnated with ochreous galls to be useful as marble. Slabs of Forest Marble are employed to form the sides of piggeries and cattle-sheds. The smaller pieces broken up form a very durable material for road-making. Some of the thicker blue-centred slabs are used for building-purposes, for which (especially in the shape of rough ashlar) they are admirably adapted, as they readily form even courses of a somewhat regular thickness. As a soil, the Forest Marble is usually poor, but capable of great improvement by draining and cultivation.[1] Some of the flaggy beds are used for paving; and at Bothenhampton (B'ampton Stone), near Bridport, and other localities eastwards to near Weymouth, the more calcareous beds have been burned for lime. The Forest Marble is, however, rarely burnt for lime where Cornbrash is readily to be obtained. It is probable that iron-pyrites has originally been the colouring material of the blue bands of the Forest Marble, and that the yellowish-brown exterior is due to the oxidation of the pyrites.[2] Saline waters have been met with in the Forest Marble at Swindon (well), and other places in Wiltshire.[3]

CORNBRASH.

The Cornbrash, so named by William Smith, consists of pale earthy and rubbly limestones, sometimes shelly, sometimes of a pasty or marly consistency. The beds, where not exposed to atmospheric influences, are compact, blue in colour, and often sufficiently hard to be used for rough building-purposes, as near Malmesbury, and at Radipole, near Weymouth. The thickness of the formation varies from 5 to 40 feet.

As a rule the formation is very fossiliferous, bivalve Mollusca being most plentiful. The more abundant species are *Avicula echinata*, *Pholadomya bucardium* (*deltoidea*), *Gresslya peregrina*, *Myacites securiformis*, *M. decurtatus*, *Waldheimia* (*Terebratula*) *obovata*, *Terebratula lagenalis* (allied to *W. ornithocephala*), *Rhynchonella concinna* and *Echinobrissus* (*Nucleolites*) *clunicularis*. The Cornbrash and Forest Marble have been grouped together as the zone of *Terebratula lagenalis*. *Ammonites macrocephalus* (*Herveyi*) is abundant in the Midland Counties, but rarer in the south; *A. discus* and *Nautilus* are also found. *Belemnites* are not known. Polyzoa occur; and among other fossils we may mention *Ostrea Marshii* (*flabelloides*), *O. Sowerbyi*, *Lima duplicata*, *Pecten vagans*, *Isocardia*, *Trigonia costata*, *Homomya gibbosa*, *Modiola Sowerbyana*, *Ceromya concentrica*, *Goniomya*, *Terebratula intermedia*, *Rhynchonella Morierei*, *Holectypus depressus*, *Acrosalenia spinosa*, *Anabacia orbulites*, *Bathycœnia*, etc.

Some irregular forms of *Ostrea* (*O. irregularis*) are found in the Cornbrash (as well as other formations), which have imitated the forms or markings of different organisms.[4]

[1] J. Buckman, Bath and W. of Eng. Agric. Journ. xiii.
[2] A. H. Church, Q. J. Chem. Soc. (2), ii. 379.
[3] Q. J. xlii. 287.
[4] Judd, G. Mag. 1871, p. 355.

Remains of Fishes (*Strophodus*, etc.), Saurians (*Steneosaurus*), and Lignite are occasionally met with. Many of the Mollusca are similar to those in the Inferior Oolite or Fuller's Earth Rock.[1]

In the South of England the Cornbrash is not oolitic; it is well developed in Dorsetshire and Somersetshire. Among localities are Radipole and West Chickerel, near Weymouth, Ryme, Yetminster, Closeworth, Stalbridge, Henstridge, Cheriton, Wincanton, South Brewham, and Road, near Frome. The maximum thickness in this district, according to Mr. Bristow, is forty feet.[2]

In Wiltshire the beds may be seen at Trowbridge, Corsham, Chippenham, Stanton St. Quintin, Malmesbury, and near Cricklade. At Swindon the thickness was proved to be eighteen feet in a well-sinking. In Gloucestershire the beds occur at Fairford, and south of Cirencester.

In Oxfordshire, near Woodstock, the Cornbrash, six to fifteen feet in thickness, consists of shelly limestones. Prof. A. H. Green has noticed that here and there clay-beds occur which cause the formation to swell out to more than double its average thickness; these clays are irregular, and never extend beyond small areas.[3] The outcrop of the Cornbrash extends from Bicester to Buckingham and Newport Pagnell. In Bedfordshire it has been termed the Bedford Limestone.

The Cornbrash occurs as a rather ferruginous limestone in the Nene Valley, near Oundle, and Peterborough; here its thickness is about fifteen feet. Rushden, south of Higham Ferrers, in Northamptonshire, is a noted locality for fossils, and there the Rev. A. W. Griesbach collected an interesting series.[4] The Cornbrash occurs at Irchester, also at Overton Longville and other places between Chesterton and Peterborough, and at Stilton in Huntingdonshire.

In north-west Lincolnshire the Cornbrash is shown by Appleby Station, where it consists of a fossiliferous brown rag. Sudbrook Park, near Lincoln, is a good locality for fossils.[5] (See Fig. 42, p. 278.)

The Cornbrash of Yorkshire is a grey, marly, rubbly, and sometimes ironshot oolitic limestone, overlaid by *Avicula*-shales or 'clays of the Cornbrash,' finely laminated grey shales, containing *Avicula echinata*, and these pass upwards into yellow sandy mudstones, that occur at the base of the Oxford Clay. It is well developed in Newtondale (10 to 14 feet), where (says Mr. Hudleston) its ferruginous character tempted a speculator to work it for iron, while in a secluded nook of the same lovely valley there yet stands (1874) what was meant to have been a colliery—the shaft was sunk to a considerable depth, in the expectation of

1 J. Buckman, Q. J. xiv. 119; Proc. Cotteswold Club, i. 262.
2 See R. Damon, Geol. Weymouth, 1884, p. 17.
3 Geol. Banbury (Geol. Surv.), p. 30; see also J. Phillips, Geol. Oxford, p. 239.
4 G. Sharman, in Judd's Geology of Rutland, p. 220.
5 Rev. J. E. Cross, Q. J. xxxi. 122, 125; Jukes-Browne, Geol. South-west Lincolnshire, p. 62.

winning the real north-country coal! The shales vary from eight to fifteen feet in thickness, and seem to form a connecting link between the true Cornbrash and the Oxford Clay.[1] (See Fig. 47.)

The Cornbrash is exposed at Gristhorpe and Scarborough, where it is from two to fifteen feet in thickness. It is seen on the North Shore and Castle Hill, and Red Cliff (Cayton Bay). It is a very shelly rock, and has yielded a large suite of species, for our knowledge of many of which we are indebted to Mr. J. Leckenby. The Cornbrash has not been identified in the Howardian Hills.

The Cornbrash is used for road-mending, and for building walls, etc.; it is also burnt for lime. As the name implies, the rubbly or 'brashy' soil (especially in the South-West of England) is well suited to the growth of corn; according to Prof. Buckman it contains more phosphate of lime than the subordinate Oolitic formations. Analysis shows about 90 per cent. of carbonate of lime. In Northamptonshire it makes a red soil, and is not reckoned so fertile.

In the South of England its outcrop is marked by a line of villages which are due, as Prof. Buckman remarks, not only to the fertility of the Cornbrash, but to the circumstance that this porous rock, resting on the impervious Forest Marble, is a collecting ground for water, which is kept up by the latter formation.[2]

In the deep boring at Richmond, clayey and sandy beds, and oolitic limestones 87 feet in thickness, were proved to belong to the Great Oolite Series; similar beds having a thickness of 64 feet occurred in the boring for Meux's Brewery, in London.[3]

MIDLAND COUNTIES.

Inferior Oolite Series.

This series is divided as follows:—

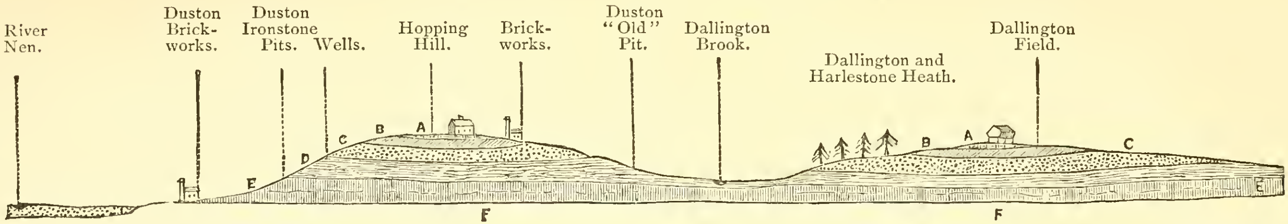
		Zones.
Lincolnshire Limestone		*Ammonites Sowerbyi.*
Collyweston Slate		
Northampton Sands.	Lower Estuarine Series.	,, *Murchisonæ.*
	Ferruginous Beds	,, *opalinus.*

Northampton Sands.

This Series, which derives its name from the town of Northampton, comprises beds of ferruginous sand and sand-rock, which in that neighbourhood include the zones of *Ammonites Murchisonæ* and *A. opalinus*, thus representing the base of the Inferior Oolite

[1] P. Geol. Assoc. iii. 321, iv. 360. See also W. C. Williamson, T. G. S. (2), vi. 145; and C. F. Strangways, Explan. Sheet 95 S.W. and S.E. (Geol. Survey), p. 11.
[2] Journ. Bath and W. Eng. Soc. xiv., Q. J. xiv. 98.
[3] J. W. Judd, Q. J. xl. 748.

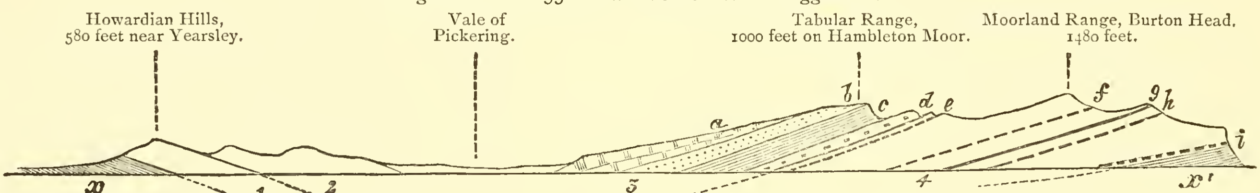
FIG. 46.—SECTION FROM DUSTON TO DALLINGTON, NEAR NORTHAMPTON. (S. Sharp.)



C. Sand.
D. Variable Beds. } Northampton Sands.
E. Ironstone }
F. Upper Lias Clay.

X. Alluvium.
A. Great Oolite Limestone.
B. Great Oolite Clay.

FIG. 47.—SECTION ACROSS THE JURASSIC ROCKS OF YORKSHIRE. (W. H. Hudleston.)
Length of section 33 miles. Vertical scale exaggerated.



x. Lias of the Vale of York.
x.[1] Lias of Robin Hood's Bay, and the Peak.
1, 4. Lower Oolites.
2, 3. Middle Oolites.
a. Coralline Oolite (including Upper Calcareous Grit) of Pickering.
b. Lower Calcareous Grit of Newtondale.
c. Oxford Clay of Newtondale, and Hole of Horcum.
d. Kellaways Rock of Newtondale.
e. Cornbrash of Newtondale.
f. Grey or Scarborough Limestone of Maybecks.
g. Approximate position of the principal Moorland Coal.
h. Representative of the Millepore Series.
i. Dogger Series of the Peak, etc.

and the top of the Midford Sands. The term Northampton Sand was proposed in 1860 by Messrs. W. T. Aveline and R. Trench.[1]

Traced northwards and eastwards from the Cotteswold area, the Inferior Oolite assumes sandy characters, and it has been shown by the Geological Survey that the lower zone of the Great Oolite (which includes the Stonesfield Slate) undergoes similar changes. Thus, as Prof. Judd has remarked, the two series of sandy beds are brought together, and as the higher series is almost always unfossiliferous, it was found impracticable, as a rule, in the Oxfordshire area, to separate the sands of the Great Oolite from those of the Inferior Oolite: hence the term Northampton Sands has unfortunately in that area been applied to the whole mass of variable sandy strata which intervene between the Upper Lias Clay and the upper zone of the Great Oolite.[2] (See p. 299.)

In the northern part of Northamptonshire and in Lincolnshire, the Northampton Sands include the Lower Estuarine Series of Prof. Judd, and occur beneath the Collyweston Slates and Lincolnshire Limestone (Inferior Oolite). Prof. Judd has observed that the Northampton Sands sometimes rest on an eroded surface of the Upper Lias Clay, and in some localities there is no evidence that any part of the Midford Sands is represented. The thickness of the Northampton Sands and Lower Estuarine Series varies from twenty to eighty feet. The following divisions of the beds have been made in the Northampton district (see Diagram, p. 286):[3]—

	Feet.	
4. White or grey sand and sandstone, containing a plant-bed	12	*Lower Estuarine Series.*
3. Thin beds of ferruginous sandstone and shelly calcareous beds—very variable, being sometimes entirely calcareous, at others consisting of white sand and sandstone	30	*Ferruginous Beds.*
2*b*. Coarse oolitic limestone with fossils 2*a*. Slaty bed	4	
1. Ironstone-beds containing *Rhynchonella variabilis*, *R. cynocephala*, etc.	35	
Upper Lias Clay.		

Amongst other fossils from the Northampton Sands are *Terebratula perovalis*, *Avicula Braamburiensis*, *Gervillia acuta*, *G. Hartmanni*, *Lucina Wrightii*, *Pholadomya fidicula*, *Gresslya peregrina*, *Isocardia cordata*, *Hinnites abjectus*, *Lima duplicata*, *Ostrea gregaria*, *Pecten personatus*, *P. demissus*, *Astarte elegans*, *Cardium Buckmani*, *Ceromya Bajociana*, *Cucullæa cancellata*, *Trigonia costata*, *Nerinæa cingenda*, *Nautilus*, *Belemnites giganteus*, and *Ammonites Murchisonæ*. The Lower Estuarine Series contains thin seams of lignite and occasionally *Cyrena*.

Amongst the localities where the beds may be observed are Kingthorpe, Northampton, Duston (slaty beds), Blisworth, and Gayton. (See Fig. 46.) At Lincoln the thickness of the sandy

[1] Explanation of Quarter-sheet 53 S.E. (Geol. Survey), p. 8.
[2] Geology of Rutland, etc., p. 30.
[3] Sharp, Q. J. xxvi. 358; xxix. 285. See also Morris, G. Mag. 1869, p. 101; and Jukes-Browne, Geol. S. W. Lincolnshire, p. 45.

and ironstone beds is twelve feet; at Banbury also the beds are twelve feet in thickness.

The Ironstone-beds yield a number of fossils, many of them, as Mr. Sharp points out, cast, as it were, in iron, so that the introduction of the ore must have taken place subsequently by infiltration and replacement.

Economic products, etc.

The iron-ore is worked at Duston, Blisworth, Gayton, Wellingborough, Cranford, Stamford, etc., and there are blast-furnaces at Neville Holt. The ore yields 40, and sometimes 55 per cent. of pig-iron. The iron-ore has also been worked in several places north and south of Lincoln. According to Prof. Judd, the iron-ore has been formed chiefly by infiltration of waters containing carbonate of iron in solution.[1] Allophane has been met with near Northampton.

In places the Northampton Sand contains hard calcareous sandstone which has been used for building-purposes; while some beds are sufficiently calcareous for lime-burning. The White Sands are dug for making mortar. Clay-beds in this series have been worked for brick-making, and for Terra-cotta in the neighbourhood of Stamford-Baron. Concretionary masses of sandstone called 'Pot-lids' are met with in the sands. At Duston, near Northampton, beds of fissile sandy limestone were formerly dug for roofing-purposes under the name of the "Duston Slate."

Capt. Macdakin mentions that immediately over the Upper Lias Clay south of Lincoln there is a curious bed (three inches in thickness) of phosphatic nodules, with masses of pyrites, which the country people carry off as decorations for their chimney pieces.[2] The Northampton Sand forms a rich soil.

Collyweston Slate.

At Collyweston, south-west of Stamford, certain fissile calcareous sandstones, or sandy limestones, which, after exposure, split up horizontally and form flagstones or tilestones, have been quarried for roofing-purposes, and are termed the Collyweston Slates. Where thickest the beds are a little over eighteen feet. Prof. Judd observes that sometimes the sands which alternate with these lower beds of sandy limestone at the base of the Lincolnshire Oolite are full of calcareous concretions, the associated limestones exhibiting broad mammillated surfaces, which give rise to the masses known to quarrymen as "pot-lids."[3]

The Collyweston Slates overlie the Northampton Sands, and are overlaid by the Lincolnshire Limestone; and as there is a general resemblance between these Collyweston tilestones and the Stonesfield Slate, they were at one time confounded. The Collyweston Slates may partly represent the Lower Estuarine beds which overlie the Dogger in Yorkshire.[4]

[1] Geol. Rutland, etc. (Geol. Survey), p. 113.
[2] G. Mag. 1877, p. 406.
[3] Geol. Rutland, etc., p. 140.
[4] J. Morris, G. Mag. 1869, p. 104.

The fossils of the Collyweston Slates include *Pecten pumilus*, *Avicula Braamburiensis*, *Pinna cuneata*, *Gervillia acuta*, *Trigonia compta*, *Pholadomya fidicula*, *Ceromya Bajociana*, *Goniomya literata*, *Perna rugosa*, *Modiola Sowerbyana*, *Lucina Wrightii*, *Myacites Scarburghensis*, *Pterocerns Bentleyi*, *Alaria Phillipsii*, etc. They do not, however, yield remains of Mammals, etc., like the Stonesfield Slate. The surfaces of the slates exhibit the proximity of the shore, in ripple-markings, worm-tracks, and burrows, as well as by numerous plant-remains.

At Dene Brickyard the section, according to Prof. Judd, is:—

Lincolnshire Limestone	9 feet.
Bed with siliceous concretions (Collyweston Slate)	3 ,,
Northampton Sands	20 ,,
Upper Lias Clay.	

The following section at Easton shows the succession of beds from the Lincolnshire Limestone to the Northampton Sands:[1]—

	Feet	in.
Oolitic limestone, sandy in places. *Lincolnshire Limestone*	12	0
Sand with siliceous concretions	4	0
Limestone, partially oolitic	2	6
Indurated sand, with concretionary masses	1	6
Siliceous limestone	2	0
Finely-laminated, calcareous sandstone beds, which weather into "slates"	2	0
Hard flaggy, siliceous beds, with mammillated surfaces (pot-lids, etc.)	0	6
Sands	6	0
Ironstone-beds ("Red-rock"). *Northampton Sands.*		

The Collyweston Slate has been largely employed as a roofing-material, but Prof. Judd observes, that excepting for ecclesiastical and other Gothic buildings, and for strictly local purposes, there is now little demand for the slate. A considerable number of pits are still worked, but over a large area the 'slate' has been exhausted. The pits commence east of Collyweston, and extend to Easton. The beds are quarried at those localities, and also at Dene, Kirby, and Wittering. There is only a single bed of stone (the lowest hard bed of the series) which is used for making tiles: this varies greatly in thickness,—from six inches to three feet, while not unfrequently the bed is absent and represented by sand. The slates are worked either in open quarries or by drifts (locally called "fox-holes") carried for a great distance under ground, in which the men work by the light of candles. One of the deepest quarries at Collyweston showed eighteen feet six inches of alternations of sand, bluestone, and slate. The slate when first raised is a hard and solid stone; on exposure to moisture and frost it becomes fissile. The work of quarrying is carried on only in winter, for, if dried by the summer sun and wind, the rock hardens and will not split. The holes are blocked up in spring, and the quarrymen then employ their time in the preparation of the 'slate.' The splitting is partly aided by the presence of organic remains; but the fissile character is local, as in some places the beds become worthless for roofing-purposes. "Slate-mines" have been opened since the time of Henry VII.

[1] Judd, Geol. Rutland, etc., pp. 156, 182. See also Ibbetson and Morris, Rep. Brit. Assoc. 1847, Trans. of Sections, p. 127; Sharp, Q. J. xxix. 243; P. Geol. Assoc. iii. 243; and Phillips, Geol. Oxford, etc., p. 408.

Lincolnshire Limestone.

This formation comprises beds of compact cream-coloured and marly limestone and shelly oolitic ragstone, and was named by Prof. Judd, from its development in Lincolnshire.[1] The beds rest on the Collyweston Slate near Stamford, and on the Northampton Sands in other localities. Some of the beds are largely made up of Corals, which usually have been converted into masses of finely crystallized carbonate of lime. Among the genera noticed are *Thamnastræa*, *Cladophyllia*, *Isastræa*, *Thecosmilia*, etc.

Among other fossils are the Mollusca *Ammonites Murchisonæ*, *A. subradiatus*, *Natica cincta*, *Tancredia axiniformis*, *Pteroperna*, *Nerinæa cingenda*, *Ceromya Bajociana*, *Pholadomya fidicula*, *Pinna cuneata*, *Modiola Sowerbyana*, *Astarte elegans*, *Pecten pumilus*; the Brachiopoda, *Terebratula submaxillata*, *T. perovalis*, etc.; also the Plants *Pecopteris*, *Pterophyllum*, and *Palæozamia*.

The Lincolnshire Limestone and the Collyweston Slate are placed on the horizon of the Inferior Oolite, a position for the limestone which was first suggested by the Rev. P. B. Brodie and Dr. Lycett. Prof. Judd groups the Limestone as the zone of *Ammonites Sowerbyi*.

In Lincolnshire the oolitic limestones which constitute the formation attain a thickness of about 200 feet, forming the "Cliff" escarpment: they thin out near Kettering, being only eight feet at Raven Wood near Glendon, two miles from that town. At Stamford the thickness is about eighty feet. Prof. Morris has remarked that in some quarries, as near Ketton, a line of separation is marked in the Oolitic rocks by borings of *Lithodomi*, which lived in the partly consolidated rocks previous to the deposition of the Upper Estuarine Series.

At Oundle and Higham Ferrers the Northampton Sand is directly overlaid by the Upper Estuarine Series (base of Great Oolite). Mr. Sharp thus grouped the beds:[2]—

		Stamford.	*Oundle.*
Inferior Oolite		Lincolnshire Limestone with Collyweston Slate.	(dies out.)
	Northampton Sand.	Lower Estuarine Series.	Lower Estuarine Series.
		Ironstone Rock.	Ironstone Rock.

Prof. Judd considers that the Lincolnshire Limestone was deposited under moderately deep-sea water conditions, but there are evidences in its lower portion of littoral accumulations.

North of Lincoln about eighteen feet of limestone is exposed, the upper part flaggy, and containing a shelly limestone with many small Gasteropods; below are compact creamy and blue-hearted

[1] Geology of Rutland, etc., pp. 33, 139. See also J. Morris, Q. J. ix. 317, G. Mag. 1869, p. 102; S. Sharp, Q. J. xxix. 225; P. B. Brodie, Proc. Cottesw. Club, i. 52, ii. 132; Ann. Nat. Hist. 1857 (2), xix. 56; G. Mag. 1869, p. 236; and Jukes-Browne, Geol. S.W. Lincolnshire, p. 52.

[2] Q. J. xxix. 283.

limestones, shelly in places. In the north-western part of Lincolnshire the Rev. J. E. Cross divides the beds as follows:—

Lincolnshire Limestone, 36 feet.
Santon Oolites, containing *Hinnites abjectus*, *Gervillia acuta*, etc., with soft ferruginous bed at base (Dogger).[1]

Mr. W. A. E. Ussher has locally divided the beds as follows:—

Ponton Beds. White and cream-coloured oolite. 20 to 30 feet.
Kirton Beds. Bluish-grey limestone, oolitic in places. 30 to 40 feet.
Basement Beds, consisting of band of hydraulic limestone, and shale (Lower Estuarine Series of Yorkshire); these beds would be about 15 to 20 feet thick, including ferruginous beds of the Dogger Series or Northampton Sand.

Economic products, etc.

The Barnack Rag, a light brown shelly oolite, is said to have been quarried by the Romans, and the quarries exhausted four hundred years ago, although a great deal of stone has in recent years been sold as Barnack Rag.[2] Peterborough Cathedral and Crowland Abbey were in part constructed of this stone. The Ketton Stone, a cream-coloured oolite, about eleven feet thick, was used in the construction of modern works in Peterborough and Ely Cathedrals, and in many buildings in Cambridge, for St. Dunstan's Church in Fleet Street, London, etc. The beds yield valuable building-stone also at Casterton, Geeston, Collyweston, Morcot, Denton, Corby, Weldon (twenty-five feet of stone), Geddington, Pipwell Abbey, etc.

The "silver bed" of Ponton was used in the construction of Lincoln Cathedral; the "roe-stone" bed is also employed for building. The beds are worked at Haydor, near Grantham, and in the railway-cutting at Ancaster.

The Stamford Marble, as seen in Tinkler's quarry, Stamford, is described by Prof. Judd as a hard blue-hearted limestone, one foot to eighteen inches in thickness, containing Corals, also *Nerinæa cingenda*, *N. triplicata*, and other shells, teeth and palates of *Pycnodus* and *Strophodus*. When polished, it is a favourite material for chimney-pieces.[3]

North of Lincoln the stone is worked at the Dean and Chapter pit, and other places; here the lowest and best bed is called the "silver bed." At Maidwell, north of Northampton, the stone (Maidwell Limestone) has been worked. The beds, besides being largely used for building-purposes, are used for road-metal and burnt for lime. The term Northamptonshire Lime was applied to the beds in 1788 by the Rev. John Michell.

The soil on the Lincolnshire limestone is light and not very productive; but good barley is grown in some places.

[1] Q. J. xxxi. 121.
[2] Porter, Geol. of Peterborough, p. 114.
[3] Geol. Rutland, etc., p. 160.

MIDLAND COUNTIES.

Great Oolite Series.

This Series is divided as follows :—

Cornbrash (see p. 307).
Great Oolite Clay.
Great Oolite Limestone.
Upper Estuarine Series, and Northampton Sand (upper part, local).

Upper Estuarine Series.

This division, named by Prof. Judd in 1867, consists of light-blue, grey, and variegated clays, sometimes very sandy, together with laminated marls, shales, and irregular beds of limestone, and "beef" (fibrous carbonate of lime). The beds are from fifteen to thirty feet in thickness, and contain wood and other plant-remains, and also shelly bands with marine and freshwater mollusca. At the base is a thin band of nodular ironstone, rich in fossils, which marks the junction between the Great and Inferior Oolite Series; and, in Prof. Judd's opinion, affords evidence of a break, accompanied by slight unconformity, between these two Series in the Midland area.

Mr. Sharp observes that the Upper and Lower Estuarine series occur together in vertical juxtaposition throughout a large part of Northamptonshire and in Oxfordshire. In Oxfordshire he observes that the Upper Estuarine Series is traceable to the Stonesfield Slate, and the difficulty of separating the two Estuarine Series led formerly to the whole of the Northampton Sand (Lower Estuarine, etc.), being regarded as the equivalent of the Stonesfield Slate. Among the fossils are species of *Pholadomya*, *Modiola*, *Ostrea*, *Cyrena*, *Unio*, etc.; remains of *Ceteosaurus* also occur in the beds.

All the characters presented by the Upper Estuarine Series, according to Prof. Judd, point to the conclusion that the beds were accumulated under an alternation of marine and freshwater conditions, such as occurs in the estuaries of rivers.[1]

The beds may be seen at Ketton and Casterton, near Stamford, and in the Essendine and Danes Hill cutting of the Great Northern Railway;[2] also near Duston and Dallington, west of Northampton.

The Clays in this series are worked for brick-making, at Stamford, Little Bytham, and other places; at Wakerley a fire-clay occurs which has been used in the manufacture of terra-cotta. The soil is comparatively barren, being stiff and cold.

Great Oolite Limestone.

The Great Oolite Limestone, so named by Prof. Judd, consists of alternate beds of compact white marly limestone and clay, with

[1] Geol. Rutland, etc., p. 32; Jukes-Browne, Geol. S.W. Lincolnshire, p. 61.
[2] J. Morris, G. Mag. 1869, p. 103.

seams made up of the shells of small oysters.[1] Oolitic structure is seldom developed. The Great Oolite Limestone occurs in Lincolnshire and the northern part of Northamptonshire.

Among the fossils are *Nautilus subtruncatus*, *Natica textata*, *Ostrea subrugulosa*, *O. Sowerbyi*, *Homomya gibbosa*, *Ceromya concentrica*, *Modiola imbricata*, *M. cuneata*, *Myacites crassiusculus*, *Pholadomya lyrata*, *Pecten annulatus*, *Terebratula maxillata*, *Rhynchonella concinna*, *Clypeus Mülleri*, *Acrosalenia hemicidaroides*, *Isastræa*, also bones of *Cetiosaurus*, and some Fish-remains, *Hybodus*, *Pycnodus*, etc. The compact limestones are sparingly fossiliferous, but the intervening shaly or marly beds afford a number of species, many of which have been obtained at Tadmarton near Banbury.[2]

The Great Oolite Limestone, which attains a thickness of about twenty-five feet, is a continuation of the Upper Zone of the Great Oolite, and perhaps in part of the Forest Marble. It extends from Towcester, over Salcey Forest, to Northampton. (See Fig. 46.) Fossils have been obtained at Chadlington Down, near Chipping Norton, and at the Fox quarry, near North Ashton, by Mr. T. Beesley and Mr. E. A. Walford.

The limestone beds (White Limestone) are worked for building-purposes, road-metal, and lime-burning, at Holcot, Kettering, Higham Ferrers (Stanwick Ragstone), Kingthorpe, etc. At Blisworth, where the limestone is quarried, one of the beds is called Pendle. At Stamford both Great Oolite and Lincolnshire Limestone occur.

At Alwalton, near Peterborough, shelly flag-stone, which takes a good polish, was formerly quarried. It was termed the Alwalton (or Allerton) Marble. Flaggy beds occur also at Castor, etc. These beds have been regarded as Forest Marble, and very likely they do represent it. Many of the pilasters in Peterborough Cathedral are composed of the Alwalton Marble.

Great Oolite Clay.

This clay, termed Blisworth Clay by Mr. Sharp,[3] and Great Oolite Clay by Prof. Judd, occurs at the top of the Great Oolite Series in Northamptonshire, resting on the Great Oolite Limestone. In thickness it varies from two to twenty feet, and it comprises a series of variegated, blue, green, yellow, and purplish clays, often containing bands of irregular white or pale-green calcareous concretions, and sometimes septaria. It contains *Ostrea subrugulosa*, *O. Sowerbyi*, *Placunopsis socialis*, etc. In part the beds seem to be of estuarine character.[4] They may be seen near Northampton, Oundle and Wansford. (See Fig. 46.)

In the north-western part of Lincolnshire the Rev. J. E. Cross has described beds of greenish clay about forty feet in thickness underlying the Cornbrash and resting upon the Lincolnshire Lime-

[1] Geology of Rutland, etc., pp. 186, 201 ; S. Sharp, Q. J. xxvi. 354.
[2] T. Beesley, G. Mag. 1872, p. 279.
[3] Q. J. xxvi. 380.
[4] Judd, Geol. Rutland, etc., p. 186.

stone. They contain the two species of *Ostrea*, etc.; also Fish-remains. This Ostrea-clay is seen near Appleby Station.

It is open to question whether the clay occurs in Yorkshire, but doubtless it represents, in part, the Forest Marble of the south-west of England.

The clay is employed for brick-making at Bedford Purlieus, and New England, near Peterborough. At Bottlebridge, near Overton Longville, some ironstone has been raised on the estate of the Marquis of Huntly; but owing to the large amount of waste material, the works were discontinued. The soil is by no means fertile.

YORKSHIRE.

Great and Inferior Oolite Series.

These two Series are divided as follows:—

		Zones.
Great Oolite Series.	Cornbrash. (See p. 307.)	
	Upper Estuarine Series.	
Inferior Oolite Series.	Scarborough or Grey Limestone Series.	*Ammonites Humphriesianus.*
	Middle Estuarine Series.	
	Millepore Series.	,, *Sowerbyi.*
	Lower Estuarine Series.	
	Dogger Series.	,, *Murchisonæ.*

The total thickness of the Inferior Oolite Series, including the Upper Estuarine beds, varies from about 250 to over 600 feet.

The Oolitic series is best studied on the coast, and in the Hambleton and Howardian hills above Thirsk.

We owe our knowledge of the strata to the labours of the Rev. George Young and John Bird,[1] John Phillips,[2] W. H. Hudleston, and C. Fox Strangways, as well as to the collections made by J. Leckenby, W. Reed, Sir Charles Strickland, and others. (See p. 285.)

Dogger Series.

Resting upon the Alum Shale (Upper Lias) of Yorkshire is the series known as 'Dogger,' a term used by Young and Bird (1822).

The Dogger is a sandy and oolitic ironstone, but the series is sometimes taken to include not only the Dogger proper, but the grey and yellow sands which underlie it. The total thickness of the series is about 95 feet.

Mr. Hudleston remarks that it is not certain whether the Dogger (sometimes termed the Scar of Whitby) has received its name from the lines of nodules, so characteristic of it, or from the peculiar

[1] A Geological Survey of the Yorkshire Coast, 1822.
[2] Geol. Yorkshire, Part I.; Q. J. xiv. 84.

appearance which the rock assumes owing to the rounding off of the huge oblong blocks, produced by the arrangement of the jointing; but the word Dogger, in the patois of the district, is applied to any rounded stone. The beds may be studied at Peak (Blue Wyke),[1] Glaisdale, Sandsend, High Whitby, and Saltwick. (See Fig. 47.)

The Upper Lias passes gradually upwards into the beds above, which are classed as follows:—

		Feet.
Dogger Beds.	Yellow sandstone and ironstones (Dogger) including the Nerinæa Bed (*N. cingenda*)	30
	Yellow sands and sandstone, with Terebratula Bed (*T. submaxillata*)	20 to 25
Blue Wyke Sands.	Grey sands and Sandstones, containing a Serpula Bed, and Lingula Bed (*L. Beanii*)	20 to 25
	Passage beds, Sandy Shales yielding *Ammonites striatulus* (Striatulus Beds). Zone of *Ammonites Jurensis.*	

The Dogger, according to Mr. W. H. Hudleston, contains *Gervillia tortuosa*, *G. lata*, *Macrodon Hirsonensis*, *Trigonia denticulata*, *T. v-costata*, *T. spinulosa*, *Cardium acutangulum*, *Astarte elegans*, *Ceromya Bajociana*, and *Rhynchonella subobsoleta*. In the sands beneath occur *Ammonites Aalensis*, *A. comensis*, *Discina reflexa*, *Rhynchonella cynocephala*, and *Terebratula trilineata*.[2]

The Dogger is placed on the horizon of the Inferior Oolite, in the zone of *Ammonites Murchisonæ*, so that the sands below are probably homotaxial with the Midford Sands, and represent the zone of *A. opalinus*.

The Dogger itself has been much worked for iron-ore, which contains from 30 to 50 per cent. of the metal. The magnetic iron-ore of Rosedale is worked in this series; and Prof. Phillips considers that this ore and those of Thirsk and Kirkham are the equivalents of the Northamptonshire iron-ores.[3]

Lower Estuarine Series.

This series was described by Phillips, in 1829, as the Lower Carbonaceous Sandstone and Shale. It rests upon the Dogger, and comprises alternating beds of sands, false-bedded sandstone, and shale, with cement-stone, oolitic ironstone, thin seams of impure coal, and much carbonaceous matter. It attains a thickness of from 100 to 280 feet. The beds, as a rule, contain no marine shells, but many plant-remains, including *Zamia gigas*, *Equisetites columnare*, *Otopteris*, etc. One marine bed with *Pholadomya* has been noticed by Mr. Hudleston; this may be about the same horizon as the Eller Beck Bed, first noticed by Mr. G. Barrow in Eller Beck,

[1] Wyke means a hollow of the sea-coast or small bay. The locality is sometimes termed Blue Wick and Blea Wyke.

[2] G. Mag. 1882, p. 147, P. Geol. Assoc. iii. 293; Wright, Q. J. xvi. 1.

[3] Geol. Eskdale, Rosedale, etc., by C. F. Strangways, C. Reid, and G. Barrow, p. 21.

near Goathland, which yields *Nucula*, *Astarte minima*, etc.[1] This bed is about 15 feet thick.

Mr. Hudleston observes that the group thins out towards the south and west of the Oolitic area; it, however, constitutes a large portion of the Staintondale Cliffs, where, in certain layers of nodular ironstone, many species of ferns are nicely preserved.[2] The beds appear in the cliffs from Robin Hood's Bay to Huntcliff; and they may be studied at Whitby and Blue Wyke.

The 'Great Sandrock,' 50 to 100 feet, occurs at or near the base of the series: it is largely used for building-stone. Whitby Abbey was constructed of this stone, which has been worked for building-purposes in Eskdale. A coal-seam was formerly worked to the north of Yearsley and Grimston Moors. Cement-stone (hydraulic limestone) has been burnt for lime at Terrington. Ironstones have been worked at Kirkham and Mount Pleasant, near Castle Howard.

Millepore Series.

This series of beds, so named by Dr. Wright, from the occurrence of *Cricopora* (*Millepora* or *Spiropora*) *straminea*, occurs as an impure limestone in Gristhorpe Bay; nearer Scarborough it is obliquely laminated and arenaceous, and it is still more sandy at Cloughton Wyke. In places the rock is oolitic; and the characteristic fossil *Polyzoon* is displayed on the weathered surfaces of the beds. Dr. Wright correlates the Whitwell oolitic limestones of the Howardian Hills with this series, which is from 8 to 30 feet in thickness. It may be seen also at Osgodby. It is continued in the Cave Oolite and Lincolnshire Limestone, and, as Mr. Hudleston considers, may therefore, with the Whitwell and Cram Beck Limestone, be the chief representative of the Inferior Oolite in Yorkshire.

The beds yield *Lima duplicata*, *Gervillia Hartmanni*, *G. lata*, *Modiola imbricata*, *Trigonia reticosta*, *T. conjungens*, *Pinna cuneata*, *Ceromya Bajociana*, *Myacites recurva*, *Cardium Buckmani*, *Isocardia cordata*, *Terebratula submaxillata*, and *Pygaster semisulcatus*. Most of the fossils have been obtained from Sycarham, near Cloughton Wyke. *Natica cincta*, which occurs here, is also found in the Oolite Marl of the Cotteswolds. *Pleurotomaria*, which is abundant in the South of England, is comparatively rare in Yorkshire. At Sycarham the rock is a ferruginous grit seen in reefs along the shore, and it contains Kaolinite.[3] Mr. Hudleston has traced the Millepore Bed near Goathland, otherwise the Middle and Lower Estuarine Series are not separable in parts of north-east Yorkshire.

Middle Estuarine Series.

This group, known as the Middle Shale and Sandstone, consists of shales and sandstones (Block Sand rock), from about 30 to 100

[1] G. Mag. 1877, p. 552; Explanation of Quarter-Sheet 95 N.W. (Geol. Survey), p. 33; 96 N.E. p. 29.
[2] P. Geol. Assoc. iii. 307; J. Phillips, Q. J. xvi. 119.
[3] Hudleston, G. Mag. 1882, p. 147.

feet in thickness, and it contains many plant-remains, ironstone-nodules, thin seams of coal, and sometimes impure jet.

It includes the main seams of Moorland coal, developed on Grimston Moor, which vary from a few inches to eighteen inches in thickness. Mr. Hudleston observes that the thickest seam is of little economic value, but it is remarkable for its persistency over a large area, extending from the coast inland as far as Castleton and Coxwold. The coal rests on the soils which supported the plants from which it was formed. (See Fig. 47.)

At Gristhorpe the plant-bed has yielded many cycads, including the cycadean fruit *Beania*, and ferns such as *Sphenopteris*, *Pecopteris*, *Neuropteris*, etc., also *Equisetites columnaris*, *Zamia*, *Otozamites*, etc. Plant-remains have also been found at Cloughton Wyke.[1] Casts of *Pteroperna* and *Ostrea* have been noticed, also *Estheria concentrica*.

Hard and siliceous sandstone near the top of the series is quarried for road-stone at Harwood-dale. Soft jet was formerly worked at Gate Holm Wood, and High Normanby, in the Hawsker district.

Scarborough Limestone.

This formation comprises a series of blue and grey shaly limestones ('Grey limestone' of Phillips), with occasional ironstones, shales and mudstones, 3 to 100 feet in thickness. The beds are not oolitic, although they have been termed the 'Oolite of Gristhorpe.'

The fossils include *Belemnites elongatus*, *B. giganteus*, *Ammonites Humphriesianus*, *A. Blagdeni*, *Avicula Braamburiensis*, *Gervillia acuta*, *Perna rugosa*, *Pecten lens*, *Pinna cuneata*, *Trigonia costata*, *T. signata*, *Gresslya peregrina*, etc. Many species have been obtained at Hundale.

According to Mr. Hudleston the beds are feebly developed at Gristhorpe Bay (8 feet), but make a better show at White Nab and in Scarborough Bay. They are best developed at Cloughton Wyke (Hundale). These beds represent part of the Inferior Oolite; Phillips originally placed them with the Great Oolite.[2] They are not recognized in the southern part of Yorkshire, where the entire series above the Cave Oolite consists of sands and clays. (See Fig. 47.)

Stonecliff Wood Series.—This series, named by Mr. Hudleston, consists of sands containing towards the base and upper part intercalated beds and lenticular masses (pot-lids) of arenaceous and siliceous limestone; it is altogether about thirty feet in thickness.[3] The beds form a sort of escarpment on the steep bank of Stonecliff Wood, facing the Derwent Valley. Some of the stone-beds are used for building-purposes. The fossil remains link the beds with the Scarborough Limestone.

[1] C. J. F. Bunbury, Q. J. vii. 179; J. Leckenby, Q. J. xx. 76; W. H. Hudleston, P. Geol. Assoc. iii. 310.

[2] Q. J. xiv. 85.

[3] P. Geol. Assoc. iii. 329, 292; see also Strangways, Explan. Sheet 93 N.E. (Geol. Survey), p. 17.

The Brandsby Stone is a hard siliceous limestone, sufficiently fissile to have afforded roofing-slates, for which purpose it was largely used in former years. The beds are worked for road-metal, and are locally known as the Brandsby road-stone. Locally the rock is also known as Pier stone, as the harbour-pier at Scarborough was largely built of it.

Upper Estuarine Series.

These beds, known also as the Upper Sandstone and Shale, consist chiefly of shales with thin bands of ironstone and much carbonaceous matter, together with irregular beds of false-bedded sandstone. The sandstones are developed more prominently in the lower portion of the series. The formation (as described by Mr. Hudleston) is remarkable for the quantity of hard siliceous rock, which is sometimes bedded with it, and sometimes occurs in enormous concretions or 'doggers.' These are probably the 'Crow-stones' of Young and Bird, who state that of this material several of the ancient rude monuments have been made.

The beds rest on the Grey Limestone Series at Scarborough, and may be well studied in the Spa cliffs, and at White Nab; under Wheatcroft the thickness is estimated at about 220 feet, and at Gristhorpe Bay 120 feet. The beds contain *Anodon*, *Ostrea*, and a few Plant-remains, *Cyclopteris*, *Pecopteris*,[1] etc.

Mr. Strangways includes this Upper Estuarine Series of Yorkshire with the Inferior Oolite, observing that the bed must not be confounded with the Upper Estuarine Series of Rutland, etc. There is, however, no positive evidence for correlating the beds either with the Inferior or Great Oolite. As Mr. Hudleston remarks, we have no palæontological indications in Yorkshire either of the zone of *Ammonites Parkinsoni*, or of the Great Oolite; and the Upper Shale and Sandstone may represent any of the strata between that zone and the Cornbrash.

Scarbroite (a hydrous silicate of alumina) occurs in crevices of the rocks. Some of the clay-beds are worked near Scarborough for manufacture into tiles and drain-pipes.

A massive layer of false-bedded sandstone, termed the Moor Grit, is quarried at Cloughton, while at Sneaton it supplies the district with flagstones. It is well seen in the cliffs about Cloughton and Staintondale, forming a conspicuous feature in the hills above Robin Hood's Bay.[2] Its thickness is 40 feet, at Blue Wyke, where it rests on the Grey Limestone Series. In places it is a hard quartzose grit, but near Stonegate it is a fine-grained siliceous rock.

[1] G. Mag. 1882, p. 147; P. Geol. Assoc. iii. 318.

[2] C. F. Strangways and G. Barrow, Explan. Quarter-sheet 95 N.W. (Geol. Survey), p. 44; 96 N.E. p. 42; 95 S.W. and S.E. p. 9; see also W. C. Williamson, T. G. S. (2), vi. 143.

MIDDLE OOLITIC.

OXFORD CLAY.

The Oxford Clay consists of dark-blue, purplish, yellowish, and slate-coloured clay and shale. Calcareous and bituminous varieties are met with here and there. It contains much iron-pyrites and selenite, and many septaria. The name is derived from the county in which it is well developed; originally it was termed the 'Clunch Clay and Shale,' by William Smith.[1] The name Oxford Clay was used by Conybeare in 1822. Near its base there occur in places beds of sand and calcareous sandstone, sometimes of a concretionary nature and very fossiliferous, termed the Kellaways (or Kelloway) Stone or Rock, by W. Smith, in 1815, from Kellaways, north-east of Chippenham, in Wiltshire.

The thickness of the Clay varies from 300 to 600 feet; and that of the Kellaways Rock from 5 to 80 feet, and upwards. The term Oxfordian, proposed by D'Orbigny, is sometimes used for the strata. Some authorities are disposed to rank the Kellaways Rock as a distinct division, termed the Callovian by D'Orbigny in 1852. This may be useful on the Continent, but in this country the Kellaways Rock must be regarded as the irregular basement-bed of the Oxford Clay; for it is not a persistent bed, and the sandy sediments run up irregularly into the Oxford Clay.

The beds are sometimes (palæontologically) divided as follows :—

3. Beds with Ammonites belonging to the '*Cordatus*' group (*A. cordatus*, *A. Lamberti*, etc.).
2. ,, ,, Ammonites belonging to the '*Ornatus*' group (*A. Jason*, *A. ornatus*, *A. athleta*, etc.).
1. ,, ,, *Ammonites Calloviensis*, *A. macrocephalus*, *Ancyloceras Calloviense*. (Kellaways Rock).

The fossils of the Oxford Clay include the Coral *Anabacia orbulites*; the Annelide *Serpula vertebralis*; and the Echinoderms, *Extracrinus* and *Acrosalenia spinosa*, etc. ; but as with other clay formations like the Lias and the Kimeridge Clay, there are few Urchins. Among other fossils, there are *Avicula inæquivalvis*, *Gryphæa dilatata* abundant, *Ostrea Marshii* (*flabelloides*), *Pecten fibrosus*, *Cucullæa concinna*, *Modiola bipartila*, *M. cuneata*, *Nucula nuda*, *Thracia depressa*, *Trigonia clavellata*, *T. elongata*, *T. irregularis*; *Waldheimia* (*Terebratula*) *impressa*, *Rhynchonella varians*, *Discina latissima*; *Ammonites excavatus*, *A. vertebralis*, *A. Bakeriæ*, *A. Mariæ*, *A. Gowerianus*, *A. Jason*,[2] and other species previously noted; *Nautilus hexagonus*, *Belemnites hastatus*, and *B. Owenii* (*puzosianus*) which attains large dimensions.

Fossil coniferous wood has been found, also leaves of *Zamia*. Remains of the Reptiles *Ichthyosaurus*, *Ophthalmosaurus*, *Plesio-*

[1] Clunch is a provincial term for any coarse clay.

[2] *A. Duncani*, *A. Gulielmi*, and *A. Elizabethæ* have been regarded as varieties of *A. Jason*.

saurus, and *Pliosaurus*, and of Fishes, such as *Lepidotus*, *Hybodus*, *Ischyodus*, etc., are occasionally met with.

Among the fossils of the Kellaways Rock are *Belemnites Owenii*, *Ammonites Koenigi*, *A. Gowerianus*, *A. modiolaris (sublævis)*, *Gryphæa bilobata*, *Isocardia tenera*, *Modiola pulchra*, *Avicula inæquivalvis*, *Waldheimia obovata*, and the species previously mentioned from this division; but there is no very definite palæontological or lithological boundary between the Kellaways Rock and the Oxford Clay.

The Oxford Clay occurs near Weymouth (300 feet or more), and extends across the Vale of Blackmore by Witham Friary, Trowbridge, and Melksham to Chippenham. Small nodules, called Kidney-stones, composed of reddish-brown ironstone with veins of Calc-spar, are frequently found in the Oxford Clay in the cliffs and on the shore north of Weymouth. Here large specimens of *Gryphæa dilatata* are abundant. Fossils may also be obtained in the low cliffs of Oxford Clay bordering Radipole Lake and the Fleet. *Ophioderma Weymouthiensis* and many other species have been obtained by Mr. R. Damon.[1] The Kellaways Rock has not been observed in Dorsetshire, but it was proved in a boring near South Brewham, in Somersetshire.

In Wiltshire the Oxford Clay is upwards of 420 feet in thickness. Christian Malford, about four miles north-east of Chippenham, is a well-known locality for fossils; and there, in 1841, when the cuttings were made for the Great Western Railway, Dr. J. Chaning Pearce obtained many fossils from bands of laminated clay alternating with sandy clay. These included *Ammonites Jason*, as well as *Belemnoteuthis*, and other Cephalopoda, the soft parts of which, together with the ink-bag, were beautifully preserved.[2] Many fossils have also been obtained in the neighbourhood of Trowbridge.[3]

The Kellaways Rock of Kellaways between Chippenham and Christian Malford is a bed of calcareous sandstone near the bottom of the Oxford Clay, from three to five feet in thickness, and crowded with organic remains. Lonsdale observed that the fossils are occasionally so numerous as to constitute nearly the whole of the stratum, but are often wanting. He gave the following section of a quarry at Christian Malford:[4]—

Pale lead-coloured clay, streaked with yellow.	
Rubbly stone, highly charged with oxide of iron, and inclosing a few organic remains	5 feet.
Sandstone, abounding with fossils	3 ,,
Sand	4 ,,
Clay.	

Alternations of sandstone, sand and clay, representing the Kellaways Rock, and attaining a thickness of 62 feet, were met

[1] Geol. Weymouth, etc., 1884, and Supplement with figures of fossils.

[2] Proc. G. S. iii. 592; London Geol. Journ. p. 75; W. Cunnington, *ibid.* 97; S. P. Pratt, Ann. Nat. Hist. 1841, viii. 161; Owen, Phil. Trans. cxxxiv. 65; Egerton, Q. J. i. 229; Morris, Ann. Nat. Hist. xv. 30.

[3] R. N. Mantell, Q. J. vi. 310.

[4] T. G. S. (2), iii. 260.

with in a deep well-sinking at the Great Western Railway-works, Swindon: there the overlying Oxford Clay was 510 feet thick.[1]

The Oxford Clay forms a broad tract of low-lying country from Chippenham and Wootton Bassett to Purton, Cricklade, Lechlade, and Oxford. South of Cirencester, the Kellaways Rock is represented by yellowish sands and calcareous sandstone, highly fossiliferous in places.[2] The best section of the Rock that has been exposed in the South of England is that opened up in the railway-cutting north of South Cerney, and which has been described by Prof. Allen Harker.[3] Here the sands contain huge concretionary masses or "doggers" of calcareous sandstone, much like those in the Corallian beds (Bencliff grits) near Weymouth. The Kellaways Rock occurs also near Malmesbury.

Near Oxford, according to Prof. Phillips, we have the following succession of Ammonites in the Oxford Clay:[4]—

4. *Ammonites vertebralis.*
3. ——— *Lamberti.*
2. ——— *Duncani* (*Jason*).
1. Kellaways Rock, etc., of Wiltshire.

The Kellaways Rock, however, is not known in Oxfordshire, although some of its characteristic Ammonites have been found in the lower part of the Oxford Clay. The Oxford Clay is exposed in the St. Clement's Pits. It extends from Oxford (300 feet) by Fenny Stratford to Bedford, Kimbolton, and Huntingdon, and forms the substratum of much of the western portion of the Cambridgeshire fens and those which border on Huntingdonshire. It may be studied at Eynsbury, St. Neots, and in brick-pits near St. Ives. A bed of rock which has been noticed by Prof. Seeley at St. Neots may be on the horizon of the Kellaways Rock.[5] This rock has also been observed near Wellingborough.

In the Northampton district Prof. Judd has noted the following principal divisions in the Oxford Clay:[6]—

6. Clays with Ammonites of the group of the '*Cordati*.'
5. Clays with Ammonites of the group of the '*Ornati*.' Dark-blue clays with much iron-pyrites, and pyritic *Ammonites*. *A. ornatus*, *A. Duncani*, *A. athleta*.
4. Clays with *Belemnites hastatus*.
3. Clays with *Belemnites Owenii*. *Gryphæa dilatata* appears to commence in these beds.
2. Laminated blue shales with *Nucula nuda* and compressed *Ammonites*.
1. Kellaways Sands, Sandstones, and Clays, with *Gryphæa bilobata*, *Avicula inæquivalvis*, and *Belemnites Owenii*.

[1] Q. J. xlii. 287.
[2] E. Hull, Explanation Sheet 34 (Geol. Survey), p. 19. See also J. Buckman, Q. J. xiv. 125.
[3] Proc. Cottesw. Club, 1883-84, p. 176.
[4] Geol. Oxford, p. 298.
[5] Geologist, iv. 553; see also T. G. Bonney, Cambridgeshire Geology, p. 10; Penning and Jukes-Browne, Geol. Cambridge (Geol. Survey), p. 5.
[6] Geol. Rutland, etc., p. 232; see also Dr. H. Porter, Geology of Peterborough, 1861.

The Kellaways Beds may be traced between Bourn and Folkingham in Lincolnshire, and other divisions of the Oxford Clay have also been noted in that county.[1]

In Yorkshire the Oxford Clay, consisting chiefly of grey shale, attains a thickness of from 120 to 150 feet on the coast, but is much less inland. It occurs at Castle Hill, Scarborough, Gristhorpe Cliffs, Cunstone Nab, etc. (See Fig. 47, p. 309.)

The Kellaways Rock comprises a variable set of beds of sandstone, calcareous grit and shale, whose thickness varies from 30 to 70 or 80 feet, and even 120 feet. Where seen at the southern extremity of Gristhorpe Bay, the beds are about 30 feet thick, and the fossiliferous band (only 5 inches) occurs at the top, the beds below being destitute of organic remains. In other places the base of the rock is fossiliferous. The rock is exposed at the North Cliff and Castle Hill, Scarborough, Red Cliff in Cayton Bay, Newtondale, Cave, Hackness, etc.[2] It has also been exposed at Drewton on the Hull and Barnsley Railway.[3] Mr. Hudleston observes that the Kellaways Rock in Yorkshire is a more comprehensive formation than in Wiltshire. Taking the whole of the Yorkshire area, the Kellaways Rock, Oxford Clay, and Lower Calcareous Grit, replace one another to a considerable extent, and must be viewed simply as varying parts of one great formation known elsewhere as the Oxford Clay.[4] The following fossils characterize the divisions of the Clay:—

Upper Beds. *Ammonites perarmatus* (rarely).
Middle Beds. Small Ammonites, *A. crenatus*, etc.
Lower Beds. *Belemnites Owenii*, *A. Lamberti*, *A. athleta*, *A. crenatus*, etc.

Varieties of *A. cordatus* occur throughout the Clay. In the Kellaways Rock the species include *A. Jason*, *A. athleta*, *A. Gowerianus*, *A. Koenigi*, *A. macrocephalus*, etc. At Coney Birks, in the valley of the Riccal, in Yorkshire, the Kellaways Rock becomes quite a coarse grit, and covers the hill-side with large fallen blocks, one of which measured 27 feet in length by 9 feet in breadth.[5]

The Oxford Clay has been reached in the Sub-Wealden boring, near Battle, at a depth of over 950 feet; and also at Dover. (See Fig. 31, p. 202.)

Economic products, etc.

The Oxford Clay is difficult and expensive to cultivate; it requires draining, and is mostly under permanent pasture. The 'Dorset-blue' and the North Wilts cheeses, and that of Stilton, in Huntingdonshire, are among the products of the dairy-farms. (See p. 270.) The old Forest of Braydon (Wilts) was situated on the Oxford Clay.

[1] Jukes-Browne, Geol. South-west Lincolnshire, etc. (Geol. Survey), p. 70.
[2] J. Leckenby, Q. J. xv. 4; C. F. Strangways, Explan. Sheets 95 S.W. and S.E. (Geol. Surv.), p. 12; 95 N.W. p. 45; 96 S.E. p. 9.
[3] W. Keeping and C. S. Middlemiss, G. Mag. 1883, p. 219.
[4] P. Geol. Assoc. iv. 355, 410; G. Mag. 1882, p. 147; 1884, p. 146.
[5] C. F. Strangways, Explan. Sheet 96 S.E. (Geol. Survey), p. 9.

Septaria have been polished as marble at Weymouth, and at Melbury Osmond, near Yetminster (Melbury Marble), and other places in Dorsetshire, where they are locally termed 'turtle-stones' or 'pudding-stone.' They there contain veins of semi-transparent yellow calc-spar.

The Oxford Clay is largely worked for brick- and tile-making; and the clay associated with the Kellaways Rock is also worked, at Oundle and other places.

Beds of bituminous shale and lignite have led to futile searches for coal in many tracts where the Oxford Clay is exposed; as near Malmesbury,[1] and near South Brewham, north-east of Bruton.[2] At Studley, south of Trowbridge, bituminous shale has been met with that emitted a brilliant gas when burnt.[3]

The Kellaways Rock is used for building-purposes in some places, also for road-mending. At Hackness in Yorkshire, the compact brown sandstones (Hackness rock) are quarried. In this district the Kellaways Rock contains clayey sandstone and ironstone, and the Killing Pits in Goathland Beck are considered to be the remains of rude mining operations in the beds.

The Oxford Clay is a retentive formation, and to obtain well-water it is necessary to penetrate it, or to sink into the Kellaways Rock. Saline waters have been met with at Salt's Hole, between Cricklade and Purton.[4]

CORALLIAN BEDS.

To this series the name 'Coral Rag and Pisolite' was given by William Smith in 1815, on account of the local abundance of Corals and the presence of pisolitic beds in Wiltshire; but the term Corallian, a modification suggested by D'Orbigny, is now usually adopted. Originally the beds were divided by John Phillips (1829) into:—

3. Upper Calcareous Grit.
2. Coral Rag or Coralline Oolite (Oxford Oolite of Fitton, 1827[5]).
1. Lower Calcareous Grit.

This classification was taken from the strata in Yorkshire, and applied, so far as possible, to the rocks that extend thence to the Dorsetshire coast near Weymouth. The beds are extremely variable; but taking Yorkshire as their type, the following general divisions have been made in the series by Messrs. W. H. Hudleston and J. F. Blake, to whom we are most largely indebted for our knowledge of these rocks:[6]—

F. Upper Calcareous Grit.	
E. Coral Rag. Sub-zone of *Cidaris florigemma*.	Zone of *Ammonites plicatilis*.
D. Coralline Oolite.	
C. Middle Calcareous Grit.	
B. Lower Limestone.	Zone of *Ammonites perarmatus*
A. Lower Calcareous Grit.	

[1] J. Buckman, Q. J. xiv. 125; Geologist, i. 185.
[2] Memoirs of W. Smith, by J. Phillips, p. 66; Conybeare and Phillips, Geol. Engl., p. 195.
[3] R. N. Mantell, Q. J. vi. 312.
[4] Q. J. xlii. 300.
[5] See T. G. S. (2), iv. 208.
[6] Q. J. xxxiii. 389.

Some of these divisions are local. The entire thickness in Yorkshire varies from 200 to 250 feet.

The Upper beds contain *Ostrea deltoidea*, and pass up into the Kimeridge Clay; and the lower beds contain *Gryphæa dilatata*, and pass down into the Oxford Clay. The term 'grit,' applied to these rocks, is not usually appropriate, as they are ferruginous marly sandstones, with cherty limestone, in Yorkshire; and occasionally the 'grits' are oolitic. Clays occur in the lower beds in Yorkshire, and are conspicuously developed in the series in Dorsetshire.

Among the fossils are the Corals *Thecosmilia annularis*, *Thamnastræa arachnoides*, *T. concinna*, *Isastræa explanata*, *Comoseris irradians*, *Stylina De la Bechei*, *S. tubifera*, etc., and these sometimes, as in parts of Wiltshire, form a kind of reef, and retain the position in which they grew. In their forms, as remarked by Lyell, they more frequently resemble the reef-building Polyparia of the Pacific than do the Corals of any other member of the Oolitic series. The Coral Rag is in fact made up of coral-reefs, and more especially the debris of coral-reefs, shell-beds, huge sand-banks, and mud deposits. The fossils naturally vary in different places, and at different horizons. The Mollusca include *Ammonites vertebralis*, *A. cordatus*, *A. plicatilis*, and *A. perarmatus* (*catena*), the casts of whose chambers are not uncommon in the lower beds in Berks and Wilts; *Belemnites abbreviatus*, which attains a large size; *Gervillia aviculoides*, *Pholadomya paucicostata*, *Ostrea solitaria*, *O. gregaria*, *O. Marshii*, *Myacites securiformis*, *Lima pectiniformis*, *Trigonia clavellata*, *T. monilifera*, *Perna quadrata*, *Pinna lanceolata*, *Goniomya literata*, *G. v-scripta*, *Pecten fibrosus*, *Opis corallina*, *Natica clio*, *Nerinæa Goodhalli* (sometimes upwards of a foot in length), *Chemnitzia Heddingtonensis*, *Pleurotomaria Münsteri*, and *Phasianella striata*. Sea-Urchins are abundant, they include *Cidaris florigemma*, *Echinobrissus* (*Nucleolites*) *scutatus*, *Pygaster umbrella*, *Hemicidaris intermedia*, *Acrosalenia decorata*, and *Pseudodiadema versipora*. Other fossils are the Annelides *Serpula intestinalis*, and *S. tricarinata*; the Crustacean *Glyphea rostrata*; Fishes, *Asteracanthus*, *Gyrodus*, etc., and Saurians, *Megalosaurus*, etc.

The more detailed divisions of the Corallian Beds of Yorkshire, as noted by Mr. W. H. Hudleston, are as follows:[1]—

F. Upper Calcareous Grit or Supracoralline Beds. 15–40 feet.	Upper calcareous grit ("Red rock") flanking the western part of the Vale of Pickering, Kirkby Moorside, Helmsley. Argillo-calcareous beds (cement-stone or 'Throstler') of the Vale of Pickering. Argillo-calcareous beds (Cement stones) of the Howardian Hills.
E. Coral Rag. 12–40 feet.	Rag of Scarborough district, Cayton, Brompton, etc. *Cidaris-florigemma*-rag of the Vale of Pickering, and Langton Wold, Helmsley. Hildenley limestone and North Grimston limestone.

[1] P. Geol. Assoc. iv. 359, v. 410; G. Mag. 1880, p. 246; 1882, p. 146; see also Q. J. xxxiii. 315, and Phillips, Geol. Yorkshire, part 1.

D. Coralline Oolite. 20–35 feet.	Oolites of Scarborough district. *Chemnitzia*-limestones with *Trigonia*-beds at base, Pickering, Kirkdale, etc. Oolites of the Howardian Hills (in part), Malton, etc.
C. Middle Calcareous Grit. 10–45 feet.	Calc-grit of Filey Brigg, Pickering, etc., Wass Moor Grit.
B. Lower Limestones or Hambleton Oolite. 20–120 feet.	Oolites of the Tabular Hills, Hambleton Hills, Kepwick, etc., and (in part) of the Howardian Hills. Limestones of Scarborough Castle, Hackness (Lower Coral Rag), etc.
A. Lower Calcareous Grit. 80–150 feet.	Hard blue calcareous grits, alternating with yellowish calcareous sandrock. Whitestonecliff, Cayton Bay, Gristhorpe Cliffs, etc.

The Lower Calcareous Grit is described by Mr. C. Fox Strangways as a massive yellow calcareous sandstone, becoming more shaly towards its lower portion, where it passes into the Oxford Clay. He observes that the upper part of the rock is marked by about ten feet or more of soft sandy beds containing lines of siliceous nodules, which have weathered out from the main mass and form very prominent objects in the cliffs at Scarborough Castle, and near Filey; these rest on a much harder bed, which, although only about three feet thick, stands out in the cliff in a well-marked ridge, and, as suggested by William Smith, it is probably owing to the great regularity of this bed and its greater hardness that the tabular form of these hills in the interior is due.[1]

Mr. Strangways remarks that a curious feature of this formation are the numerous spurs or 'nabs' into which it has been denuded by the springs and small streams issuing from the Oxford Clay below.[2] On Levisham Moor the rock has been excavated into numerous "griffs" or narrow gullies with vertical sides; they are often 30 or 40 feet deep and only a few yards wide, like miniature cañons.[3]

Between the Lower Limestone and the Lower Calcareous Grit, there is locally a division known as the Greystone or Passage Beds. The central portion, locally known as Greystone, consists of fissile calcareous sandstone, 20 to 30 feet in thickness. This passes down into loose sandy beds, and it is overlaid by calcareous gritty and oolitic beds. At Scarborough these rocks are very accessible, and can be easily examined on the north side of the Castle Hill, where the upper portion is so full of *Gervillia aviculoides* as to well merit the name of the "Gervillia beds." The Greystone beds are to be seen north of Ebberston and Snainton, and in Thornton Dale.[4]

The Coralline Oolite and Coral Rag are grouped together as Upper Limestone; and at Hackness their thickness is 100 feet. In places the upper part becomes a true Coral Rag, having, as Mr. Strangways remarks, a peculiar rubbly aspect without a trace of bedding, and being largely composed of crystallized carbonate of lime, abounding with corals.

Dr. Sorby has pointed out that part of the calcareous grit, just below the Coralline Oolite of the Yorkshire coast, contains numerous agatized shells and minute organisms converted into agate, which at first sight present the appearance of grains of sand.[5]

The Corallian beds have not been traced far south of Malton, in Yorkshire. In Lincolnshire the Oxford and Kimeridge Clays

[1] Explan. Sheets 95 S.W. and S.E. p. 15. The Tabular Hills are a range of flat-topped hills, extending from Scarborough westwards to near Thirsk. See Sorby, Geol. Polytech. Soc. W. Riding, iii. 169.

[2] Explan. Sheet 95 N.W. (Geol. Survey), p. 47.

[3] Explan. Sheet 96 N.E., by C. F. Strangways, C. Reid, and G. Barrow, p. 47.

[4] C. F. Strangways, Explan. Sheets 95 S.W. and S.E. (Geol. Survey), p. 18.

[5] Q. J. vii. 1.

seem to be one continuous formation, and to be bound together by many forms in common.[1] Further south in Huntingdonshire, Cambridgeshire, Bedfordshire, and Buckinghamshire, the Corallian series is, as a rule, absent; and it is not until we approach Wheatley in Oxfordshire that the series is again persistently developed. The Calcareous grit has, however, been observed at Houghton Hill, between Huntingdon and St. Ives, and at Papworth St. Edward, south-east of Huntingdon. This absence, which causes the Kimeridge and Oxford Clays to come directly together, by no means proves any unconformity, for most calcareous rocks occur in great lenticular masses. Prof. Sedgwick has observed that the large area of fen-land, occupying the Bedford Level and a considerable portion of Lincolnshire, rests on a deposit of clay of great but unknown thickness. The lower portion of this deposit belongs to the Oxford Clay, and the higher portion to the Kimeridge Clay; and there is no indication of any break between these formations. For this great 'Pelolithic' formation, as it has been termed, Prof. Seeley proposed the name of Fen Clay in 1861.[2] The Sub-Wealden exploration at Battle proved the absence of Corallian rock-beds; but Prof. J. F. Blake has suggested that the 'Supra-coralline beds' may be represented by 390 feet of strata, and the Corallian beds by 90 feet.[3] (See Fig. 31, p. 202.)

Actual representatives of the Corallian series are met with in what has been called the "Cambridge reef," at the hamlet of Upware, between Ely and Cambridge. Here north of the Inn termed "Five miles from anywhere" are two quarries in the Upware Limestone. The rock in the southern pit is regarded by Messrs. Blake and Hudleston as representing the Coral Rag (zone of *Cidaris florigemma*), and the northern pit as representing a lower horizon, the Coralline Oolite.[4] (See Fig. 68.)

The researches of Professors Sedgwick and Seeley have shown that at Elsworth, near St. Ives, dark-blue iron-shot limestone about 14 feet in thickness occurs near the top of the Oxford Clay. (See Fig. 68.) It contains *Ammonites vertebralis*, *A. perarmatus*, etc. Also at St. Ives a rock termed the Red Rock of St. Ives, which immediately overlies fossiliferous Oxford Clay, has yielded *Pecten fibrosus*, *Ostrea gregaria*, *Cidaris florigemma*, etc. The rocks of Elsworth and St. Ives are sometimes grouped with the "Lower Calcareous Grit;" they probably represent portions of the Corallian Series of other parts of England.

Prof. Seeley has observed that the Corallian Beds are replaced in parts of Huntingdonshire, Cambridgeshire, etc., by a clay which is well seen in the cuttings on the Bedford and Luton Railway near Ampthill, where the Oxford and Kimeridge Clays are displayed below and above it. This clay he terms the Ampthill Clay, and it

[1] J. F. Blake, Q.J. xxxi. 216; see also Hudleston, P. Geol. Assoc. v. 409.
[2] Geologist, iv. 552.
[3] P. Geol. Assoc. vii. 358. See also Topley, Geol. Weald, p. 44.
[4] G. Mag. 1878, p. 90; Q. J. xxxiii. 313. See also H. Keeping, G. Mag. 1868, p. 273; and T. G. Bonney, Cambridgeshire Geology, p. 19.

is the same as that previously called Tetworth Clay by Sedgwick, from Tetworth near St. Neots: this clay rests on the Elsworth Rock in places, and is surmounted by the Boxworth Rock, a hard, dark blue, flaggy and shelly limestone.[1]

In Oxfordshire the Corallian Beds are exposed in the quarries at Wheatley, and may be studied at Headington, Faringdon and other places. The following divisions have been made:[2]—

	Feet
Upper Calcareous Grit, consisting of variegated sand and clay	5
Coral Rag and Coralline Oolite, oolitic shelly limestone and pisolite	10 to 30
Lower Calcareous Grit, hard grit and soft brown sands........................	20 to 80

Fossils are most abundant in the Coral Rag division; they include *Cidaris florigemma;* and in places a Trigonia-bed with *T. perlata* and *T. Meriani* is found. A Natica-bed with *N. marchamensis* occurs in the Lower Calcareous Grit; and in this division *Ammonites perarmatus* is met with, and fine specimens occur in the same beds at Marcham, Seend and Calne.[3] At Studley, between Islip and Brill, the Lower Calcareous Grit comprises sands with a hard bed of calcareous grit at the base.

In Wiltshire the Corallian Beds have been thus divided:[4]—

	Feet.
Upper Calcareous Grit, ferruginous sand and clay, slightly oolitic.....	20
Coral Rag and Coralline Oolite, rubbly and shelly oolite, and pisolite, with beds of corals	120
Lower Calcareous Grit, sands, and calcareous sandstone	25 to 50

Sometimes a thick bed of clay overlies the Lower Calcareous Grit. The beds are exposed at Highworth, Wootton Bassett, Hillmarton, Calne, and Westbury.

At Westbury the uppermost beds are of considerable economic value, on account of the iron-ore which is developed directly under the Kimeridge Clay. These beds contain *Ammonites Berryeri*, *A. pseudocordatus*, *A. decipiens*, *Ostrea deltoidea*, etc.

At Steeple Ashton numerous Corals have been obtained, but they have been collected chiefly from the ploughed fields, especially from one field "on the north side of a road that turns off to the south-east from the high road between Steeple Ashton and Bratton."[5]

In the Calne district Messrs. Blake and Hudleston observe that "at Westbrook we have a fine coral reef, the first in our journey northwards that we have been able to examine *in situ*. Layer upon

[1] Seeley, Index to Fossil Remains of Aves, etc. p. 109; Ann. Nat. Hist. (3), x. 101; Geologist, iv. 552; Blake and Hudleston, Q. J. xxxiii. 313; Bonney, Cambridgeshire Geology, p. 11; Penning and Jukes-Browne, Geol. Cambridge (Geol. Survey), p. 6; Green, Geol. Banbury, p. 45.

[2] Hull, Explan. Sheet 13 (Geol. Surv.), p. 5; Phillips, Geol. Oxford, p. 298.

[3] Blake and Hudleston, Q. J. xxxiii. 301.

[4] Lonsdale, T. G. S. (2), iii. 261; Hull, Explan. Sheet 34 (Geol. Surv.), p. 20.

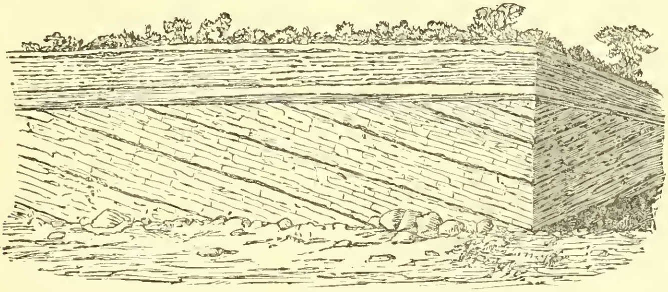
[5] Blake and Hudleston, Q. J. xxxiii. 286.

layer of large masses of *Thamnastræa concinna* and *Isastræa explanata*, bored by the characteristic *Lithodomus inclusus*, and changed not seldom into crystalline limestone, in which the organic structure is no longer visible, here spread over the surface, resting immediately upon a bed of sand, which is itself not far removed in elevation from the Oxford Clay."[1]

The Lower Calcareous Grit is exposed near Conygre Farm, and the Coralline Oolite is quarried near the Union Workhouse, at Calne. I am informed by Mr. W. A. Baily that many of the Echinoderms (*Hemicidaris intermedia*, etc.) for which this locality is noted were obtained from beds exposed to the east of the church.

The Corallian rocks occur at Cucklington, east of Wincanton, whence they stretch southwards to Marnhull and Sturminster Newton. The quarries south-west of Todbere show about twelve feet of remarkably false-bedded oolitic limestone (Coralline Oolite) overlaid by rubbly, shelly, and oolitic limestone. (See Fig. 48.) The section furnishes evidence of contemporaneous erosion. Pisolitic beds have been traced by Mr. Bristow in the lower portion of the Corallian series in this neighbourhood.

FIG. 48.—SECTION BETWEEN TODBERE AND MARNHULL, NEAR STURMINSTER NEWTON. (Prof. J. F. Blake.)



Corallian Beds. { Flaggy oolites, resting on / False-bedded oolites.

The Corallian Beds are well shown near Weymouth (Weymouth sands and grit), in the cliffs extending from the Nothe to Sandsfoot Castle; and again to the north, east and west of Osmington, having a thickness of about 200 feet. The various divisions originally described by Sedgwick,[2] and later on by Buckland and De la Beche,[3] have been worked out in great detail by Prof. Blake and Mr. Hudleston.[4] The beds are divided as follows (the letters refer to the grouping on p. 327):—

E. F. {
8. Upper Coral Rag and Abbotsbury Ironstone. The former seen near Osmington, and the latter at Abbotsbury.
7. Sandsfoot Grits, 25 feet. Ferruginous fucoidal grits, seen at Sandsfoot Castle, Linton Hill, etc.
6. Sandsfoot Clay, 40 feet. *Ostrea deltoidea*, etc.

[1] Q. J. xxxiii. 288.
[2] Ann. Phil. xi. 339.
[3] T. G. S. (2), iv. 1.
[4] Q. J. xxxiii. 262.

D.	5. *Trigonia*-beds, 28 feet. Gritty and shelly limestones, well seen in ledges on foreshore south of Bencliff, Weymouth, and near Osmington, where there is a pavement of rock crowded with specimens of *Trigonia clavellata* (also *T. monilifera*). *Nerinæa*-bed with *N. Goodhallii* near Weymouth.
	4. Osmington Oolite, 22 feet. Fine-grained (occasionally pisolitic) oolites and oolitic marls, well shown under Bencliff, at Wyke, and Osmington.
C.	3. Bencliff Grit series, 20 feet. Calcareous grit, sand, and laminated sandy clays, with 'doggers' of indurated calcareous sandstone, Bencliff and Osmington. Few fossils.
B.	2. Nothe Clays, 40 feet. Weymouth Bay. *Gryphæa dilatata*, etc.
A.	1. Nothe Grits, 12 to 30 feet. Calcareous sands and grits seen at Nothe Fort, Weymouth, near Osmington, etc. *G. dilatata*, etc.

The term 'Kimeridge Grit' was applied by Mr. R. Damon to a very fossiliferous layer of pale gritty limestone about eight inches in thickness which occurs a few feet above the Sandsfoot Grits, at Osmington and Ringstead Bay.[1] It contains *Isastræa Greenoughi*, *Thamnastræa concinna* and *Thecosmilia*, *Ammonites mutabilis*, *Pecten vimineus*, *Lima pectiniformis*, *Phasianella striata*, etc.; this is the Upper Coral Rag, and on this horizon comes the Ironstone series of Abbotsbury, attaining a thickness of about 35 feet. The iron-ore is oolitic, and is well developed around Abbotsbury, where many fossils are to be found in it, especially in the red lane to the north of the village. They include *Ammonites decipiens*, *Exogyra virgula*, *Rhynchonella corallina*, *R. inconstans*, *Terebratula subsella*, *Waldheimia lampas*, *W. Dorsetensis*, *Echinobrissus scutatus*,[2] etc. The fossils of this Ironstone as well as of the Kimeridge Grit have been described as Kimeridge Passage-beds, but they are most properly included in the Corallian series.

Large slabs of the Trigonia-bed, containing 60 or 70 specimens, have been sometimes obtained from Osmington, near Weymouth.[3]

Economic products, etc.

The iron-ore (hydrous oxide of iron) of Abbotsbury, in Dorsetshire, is developed around the village, on St. Catherine's Hill, etc., where the deep red colour of the soil is very conspicuous. It yields about 43 per cent. of ferric oxide in mass, although the oolitic granules contain about 73 per cent. of ferric oxide. The matrix, however, contains a good deal of silica (42 per cent.), which lessens the commercial value of the ore.[4] (See Fig. 49.)

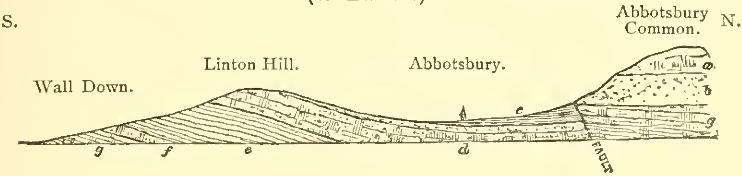
At Westbury in Wiltshire there is "an oolitic ironstone more or less mixed up with black argillaceous ore. It is almost free from grit, and exists partly as ferrous carbonate and partly as hydrated peroxide." The ore is of a bluish-green colour, weathering reddish-brown. It appears to be of limited extent, and varies from 11 to 14 feet in thickness; it yields 37 to 42 per cent. of

[1] Damon, Geology of Weymouth, 1884, p. 65.
[2] J. F. Blake and W. H. Hudleston, Q. J. xxxiii. 272.
[3] J. Buckman, Trans. Dorset Nat. Hist. Club, ii. 19; Damon, Geol. Weymouth, etc., *frontispiece*.
[4] Damon, Geology of Weymouth, 1884, p. 48.

iron. The usual yield of ore per diem at these works is 300 tons, which are smelted at the fine blast-furnaces adjoining.[1]

In Yorkshire the Lower Calcareous Grit yields building-stone and road-metal; there are quarries at Castle Howard, etc. The Lower Limestone is extensively quarried and burnt for lime. The Greystone is quarried for building walls and for road-metal; near Hackness it is known as Wallstone; and at Gaterley it is burnt

FIG. 49.—SECTION FROM ABBOTSBURY TO THE WEST FLEET, DORSETSHIRE. (R. Damon.)[2]



e. Oxford Clay.
f. Cornbrash.
g. Forest Marble.

a. Chalk.
b. Upper Greensand.
c. Kimeridge Clay.
d. Corallian Beds.

for lime. The Middle Calcareous Grit has been quarried at Pickering, and Wass Moor. The Upper Limestone is quarried at Pickering for lime-burning and as a flux for smelting iron-ore; it is also used for road-metal. Mr. Strangways mentions that the old cavern of Kirkdale is almost quarried away.

Near Oxford, the Headington Stone, which consists of 12 feet of Oolitic freestone, has been worked for building-purposes; the stone is also quarried at Faringdon, Cumner, and Wheatley; it is, however, nowhere very durable. Many of the Colleges at Oxford were built of Headington Stone. At Calne (Calne freestone), Goat Acre, north of Hillmarton, again near Gillingham, Todbere (Todbere stone) and Marnhull, stone has also been worked for building-purposes, or road-metal. At Westbrook north of Seend, the stone (Westbrook rag), has been burnt for lime; and at Westbury the limestone is quarried as a flux for smelting the iron-ore. Near Weymouth clay-beds are worked for brick-making. The Sands are dug in many places.

The Corallian series furnishes a light sandy and brashy arable soil; the pasture is poor and the soil unproductive in some localities. The Corallian beds as a rule are water-bearing strata. In some places, as in a well-boring at Swindon, and near Wootton Bassett, saline waters have been met with.[3]

UPPER OOLITIC.

KIMERIDGE CLAY.

The Kimeridge Clay consists of dark bluish-grey shaly clay, which is sometimes bituminous. Crystals of selenite are not uncommon. The clay is occasionally calcareous; it contains nodules of argillaceous limestone or septaria, and sometimes sandy beds

[1] Blake and Hudleston, Q. J. xxxiii. 284; A. C. Cruttwell, Geology of Frome, p. 18.
[2] Geol. Weymouth, etc., p. 52. See also De la Beche, T. G. S. (2), iv. plate ii.
[3] Q. J. xlii. 298.

and clay ironstone near the base. The name was adopted by Conybeare and Phillips in 1822; and the term Kimeridgian was subsequently used by D'Orbigny. The name is taken from Kimeridge, in the so-called Isle of Purbeck, where the beds of bituminous shale have been used as fuel, and called Kimeridge Coal; and where the dark cliffs form striking features in the coast scenery. (See Fig. 45.) The thickness is upwards of 600 feet in Dorsetshire, about 500 feet near Swindon, only 100 feet near Oxford, but upwards of 500 feet in Yorkshire. Prof. J. F. Blake has divided the Kimeridge Clay into two sections; the upper of which consists of paper-shales, bituminous shales, and cement-stones, with a maximum thickness of 650 feet or more; and the lower of blue sandy clay with ferruginous concretions or '*doggers*,' having a thickness of from 300 to 500 feet, typically developed in Lincolnshire; but the greatest developments of these sections are *not known in the same area*. Near the junction with the Corallian series the beds become sandy and the line of demarcation is indistinct.

Palæontologically the Kimeridge Clay on the Continent has been divided as follows:[1]—

Upper.—Virgula beds, with *Exogyra virgula*.
Middle.—Pteroceras beds, with *Pteroceras Oceani*.
Lower (passage-beds).—Astarte beds, with *Astarte supracorallina*.

Prof. Blake has not definitely recognized the Middle zone in England, although he identifies the Virgulian and Astartian beds.[2]

Amongst the fossils are *Exogyra* (*Gryphæa*) *virgula*, *E. nana*, *Ostrea deltoidea* (abundant in the lower beds), *Cardium striatulum*, *Astarte supracorallina*, *A. lineata*, *A. ovata*, *Arca rhomboidalis*, *Thracia* (*Panopæa*) *depressa*, *Pecten nitescens*, *Lucina minuscula*, *Pleurotomaria reticulata*, *Trigonia Voltzii* (and other species), *Rhynchonella inconstans*, *Discina* (*Orbicula*) *latissima*, *Lingula ovalis*, *Belemnites excentricus*, *B. explanatus*, *B. nitidus*, *B. abbreviatus*, *Ammonites biplex*, *A. mutabilis*, *A. triplex*, with the problematical *Aptychi* or opercula called *Trigonellites*, of which *T. latus* is abundant east of Kimeridge; also *Serpula tetragona*, *S. intestinalis*, a few Crustacea, Echinodermata, and many Foraminifera.

Saurian remains have been found in many localities, they include *Ceteosaurus*, *Dakosaurus*, *Omosaurus*, *Pterodactylus*, *Plesiosaurus*, *Pliosaurus*, *Ichthyosaurus*, *Steneosaurus*, *Teleosaurus*, etc. Testudinate remains also occur, *Pelobatochelys*, etc. The Fishes include *Asteracanthus*, *Gyrodus*, *Lepidotus*, *Pycnodus*, etc.

Mr. Hudleston has remarked that there is no formation in the whole Jurassic system, as developed in England, which is more difficult to tabulate or understand than the Kimeridge Clay,[3] for the palæontological divisions made in one locality do not seem to correspond with those in another. In Dorsetshire the Lower

[1] Oppel, Die Juraformation. See also Dr. C. Struckmann, G. Mag. 1881, p. 556.
[2] Q. J. xxxi. 196. See also Judd, Q. J. xxiv. 239.
[3] Reports of sub-committees Internat. Geol. Congress, Cambridge, 1885, p. 88.

Kimeridge beds yield *Rhynchonella inconstans*, *Ostrea deltoidea*, *Exogyra virgula*, *Ammonites longispinus*, etc.; the Upper beds yield *Lucina minuscula*, *Discina latissima*, *Lucina lineata*, *Ammonites biplex*, etc. The Kimeridge Clay is best shown on the Dorsetshire coast in the cliffs between St. Albans Head and Gad Cliff, and again south of Weymouth and in Portland[1] (see Fig. 50). It forms the foundation of the Isle of Portland, being exposed at the northern end. The cliffs at Ringstead Bay, Kimeridge, and Chapman's Pool, near Encombe, are good localities for fossils.[2] The 'Kimeridge Grit' of Mr. Damon is generally regarded as the top of the Corallian series (see p. 332). The Kimeridge Ledges (Broad Bench, etc.) are formed by the layers of cement-stone.

Northwards the Kimeridge Clay may be examined near Gillingham, and south of Mere. Thence in Wiltshire it forms a wide expanse of country (North Wilts Clay), between Westbury and Devizes. Mr. J. K. Shopland has obtained some fine Saurian remains from the brickyards at Swindon. Here *Exogyra virgula* characterizes the upper beds, and *Ostrea deltoidea* the lower.[3]

In Oxfordshire (100 feet) the beds are exposed near Culham and Headington.[4]

In Buckinghamshire there are brick-pits at Aylesbury, Stone, and Hartwell (Hartwell Clay). In Cambridgeshire the beds are well exposed at Roslyn Hole, near Ely. At Knapwell and Littleport thin courses of limestone have been observed. (See Fig. 68.)

In Norfolk the beds have been exposed at Southrey near Downham Market, and they were penetrated in a well-boring at Lynn.

In Lincolnshire the beds extend from Horncastle and Fulletby to Market Rasen and Brigg. Beautiful iridescent Ammonites and many other fossils have been obtained at Market Rasen.

In Filey Bay, Yorkshire, and in the Vale of Pickering, the Kimeridge Clay is represented at the base of the Speeton Clay. (See sequel.) The clay may be seen at Hildenley, and near Kirkby Moorside. Its thickness at Knapton has been estimated at 500 feet.

In the Sub-Wealden boring the clay was reached at a depth of nearly 300 feet: its thickness appears to be about 660 feet; and here Prof. Blake has suggested that the Pterocerian zone may be present.[5] (See Fig. 31, p. 202.)

At South Willingham in Lincolnshire there is hard inflammable shale, locally known as "dice."[6]

[1] Termed the Weymouth Clay by Fitton, T.G.S. (2), iv. 212.

[2] Damon, Geol. Weymouth, 1884; Dr. W. Waagen, Versuch einer allgemeinen Classification der Schichten des oberen Jura, Munich, 1865.

[3] See J. Buckman, Q. J. xiv. 127.

[4] Phillips, Geol. Oxford, etc. p. 324.

[5] P. Geol. Assoc. vii. 358.

[6] The term 'Dicey' is sometimes employed to indicate clay or marl that breaks up into cuboidal masses.

Economic products, etc.

The so-called Kimeridge Coal has for a long period been worked on the coast by Little Kimeridge and north of Hen Cliff. The shales here are more or less bituminous, but the best or Black Bed is dug out of the cliffs 12 to 14 feet from the top. The bituminous matter is probably of animal origin. It has for many years been used by cottagers in the neighbourhood as fuel, and is still so employed, but it emits an unpleasant smell while burning. About the year 1768 it was regularly worked and sold at 6*s.* a ton. At times it has been employed in making naphtha, candles, and even gas.[1] A company is now engaged in digging or mining it, with works near Wareham, where not only mineral oils, but tar, animal charcoal, and carbolic disinfectants are prepared. Bituminous shale has been dug for fuel at Portland, south of Chesilton: this shale may be distinguished from non-bituminous or feebly bituminous shale, by the peculiarity that a thin paring curls up in front of the knife, and shows a brown lustrous streak.[2]

Messrs. Buckland and De la Beche state that near Portland Ferry a portion of the Kimeridge Clay at one time "presented the appearance of slate burnt to the condition of red tiles," evidently due to the "pseudo-volcanic phenomena" that were in 1829 exhibiting themselves in the same stratum at Holworth Cliff, Ringstead Bay. Here combustion began in September, 1826, and during a period of many months, considerable volumes of flame were emitted, probably originating in the heat produced by the decomposition of the iron-pyrites with which this shale occasionally abounds. The extent of the surface of clay which was burnt did not exceed 50 feet square. Within this space many small fumaroles exhaled bituminous and sulphureous vapours, and some of them were lined with a thin sublimation of sulphur.[3]

Alum is said to have been formerly made from the shales in the parish of Kimeridge.

Many fruitless trials for coal have been made in this formation, in Oxfordshire, Berkshire, and Dorsetshire.

Bricks and tiles are made in many places. The cement-stones of Kimeridge have been manufactured into cement, and perhaps from their being used in the neighbourhood (Weymouth) they may have given rise to the name Portland cement. Such cement is now made from the Kimeridge cement-stones at Sandford, near Wareham.

Near Smedmore, in the parish of Great Kimeridge, there is found what the country people call '*Coal-money*,' generally in the soil on the top of the cliffs, two or three feet below the surface. This 'money' consists of circular pieces of shale, from two inches to three and a half in diameter, and a quarter of an inch thick, on one side flat and plain, on the other convex with mouldings; on the flat side are two or three small round holes, and sometimes one square hole. It is considered probable that the Kimeridge coal-money may be simply the refuse from which rings or armlets have been turned in a lathe, or they may be the bases of vases or bowls.[4]

The Kimeridge Clay forms broad vales which are naturally unproductive, the soil being cold and stiff. Most of the land is in meadow or pasture. Oaks grow well upon it; hence the name 'Oak Tree Clay,' applied by William Smith. There are no springs, excepting those which break out along lines of fault.

[1] Damon, Geology of Weymouth, 1884, p. 58; J. C. Mansel-Pleydell, Geol. Dorset, G. Mag. 1873, p. 407.

[2] A. Geikie, Text-Book of Geology, edit. 2, p. 173.

[3] T. G. S. (2), iv. 22.

[4] J. Evans, Ancient Stone Implements, p. 418; Conybeare and Phillips, Geol. England and Wales, p. 177.

PORTLAND BEDS.

The Portland Beds, deriving their name from the Isle of Portland, are generally divided into:—

Portland Stone,
Portland Sand.

The name Portland Stone has been in use ever since the stone has been quarried; perhaps the earliest geological description is that of Webster in 1816.[1] The name Portland Sand was introduced by Fitton in 1827.[2] The term Portlandian has been used by D'Orbigny.

The Portland Stone consists of white shelly and oolitic limestones, with layers and nodules of chert,[3] attaining a thickness of 60 feet and upwards at Portland, where the beds are largely quarried. The beds beneath consist of brown and yellow sands, clays and marls, with bands and nodules of calcareous sandstone, sometimes full of green glauconitic grains, and they attain a thickness of about 80 feet. Nodular concretions of calcareo-siliceous grit occur in the sandy beds in Oxfordshire, which, as Conybeare remarked, from their size and grotesque appearance, formerly attracted the notice of every one who ascended Shotover in following the old London road. The term Pot-lids is applied to these concretionary masses of sandstone, when of a lenticular form.

In the Isle of Purbeck the thickness of the Portland Sands has been estimated at from 120 to 240 feet, but as there is a gradual passage downwards into the Kimeridge Clay, there is no definite line.

Amongst the fossils, many of which occur in the shape of casts, are *Ammonites giganteus* (known in Portland as 'Conger Eels'), *A. biplex*, and *A. boloniensis*. Belemnites are exceedingly rare. Brachiopoda are also rare, but *Rhynchonella Portlandica* and *Discina* have been obtained from the Sands, and *Waldheimia* from the top beds on the Dorset coast. The more abundant Mollusca are *Cardium dissimile*, *Lucina Portlandica*, *Trigonia gibbosa*, *T. incurva*, *Perna mytiloides*, *Ostrea expansa*, *O. solitaria*, *Exogyra bruntrutana*, *Myoconcha Portlandica*, *Pecten lamellosus*, *Lithodomus Portlandicus*, *Cyrena rugosa*, *Buccinum naticoides*, *B. angulatum*, *Pleurotomaria rugata*, the 'screw' or *Cerithium Portlandicum*, *Natica elegans*, *N. incisa*, etc. *Isastræa oblonga* (the Tisbury 'star' or coral) generally occurs in chert. Remains of the Reptiles *Ceteosaurus*, *Goniopholis*, and *Steneosaurus*; of Fishes, *Pycnodus*, etc.; and fragments of coniferous wood are sometimes met with.

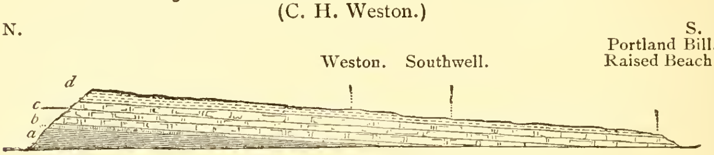
[1] Sir Henry C. Englefield's Isle of Wight. The term Portland Lime was used by the Rev. John Michell in 1788.

[2] Phil. Mag. (1827), i. 139; see also T. G. S. (2), iv. 103.

[3] Chert is an impure kind of flint, of varied colour, often breaking with a flat or splintery, and seldom with a conchoidal fracture.

Below the freestone-beds at Portland there is a bed so full of *Serpula gordialis* as almost to merit the title of Serpulite.[1] *Ostrea duriuscula* is also met with in the sands, as well as *Lima rustica*, and *Trigonia gibbosa*.

FIG. 50.—SECTION OF THE ISLE OF PORTLAND. (C. H. Weston.)



d. Purbeck Beds. *b*. Portland Sand.
c. Portland Stone. *a*. Kimeridge Clay.

The Portland Stone has been designated as the zone of *Trigonia gibbosa* and *Ammonites giganteus*.

The Portland Beds are well exposed in the so-called Isle of Portland, dipping gently to the south, so that, while the Kimeridge Clay is exposed on the northern slopes, the stone-beds descend to the sea-level at the Bill.[2] Purbeck Beds cover the greater part of Portland to the south of the Vern Fort. (See Fig. 50.[3])

The freestone-beds are subject to great variation in thickness and in quality. The accompanying general section (see Fig. 51, p. 339) gives the local names applied to the beds.[4]

The junction between the Portland and Purbeck strata, which formerly was taken at the Dirt-bed, is now taken below the Caps and on top of the Roach, as Dr. Fitton showed that by their fossil contents (*Cyprides*, etc.), the Cap-beds belong more properly to the Purbeck series.[5] Nevertheless, the most important local break appears in the great Dirt-bed. The Caps often form a marked feature, presenting in many places a rolling or undulating, and very irregular appearance, distinct from the more regular beds of Portland Stone beneath; yet in some places it is not easy at a glance to determine the junction, as near Tilly Whim and Durlston Head.

Minute Gasteropods (*Cerithium*, *Delphinula*, *Nerita*, etc.) were discovered by Mr. A. M. Wallis, in the Whit and Curf Beds.[6]

The stone-beds are much interrupted by fissures called "lets" or "gullies," over or into which the superincumbent Purbeck strata are generally tumbled. One of these gullies is represented in Fig. 51.

The Whit Bed and the Base Bed are the chief beds of Portland Stone worked for

[1] J. F. Blake, Q. J. xxxvi. 192.

[2] The Race of Portland is partly due to the agitation of the water caused by a subjacent mass of Portland Stone.

[3] See also Horizontal Sections, Sheet 20 (Geol. Survey), by H. W. Bristow.

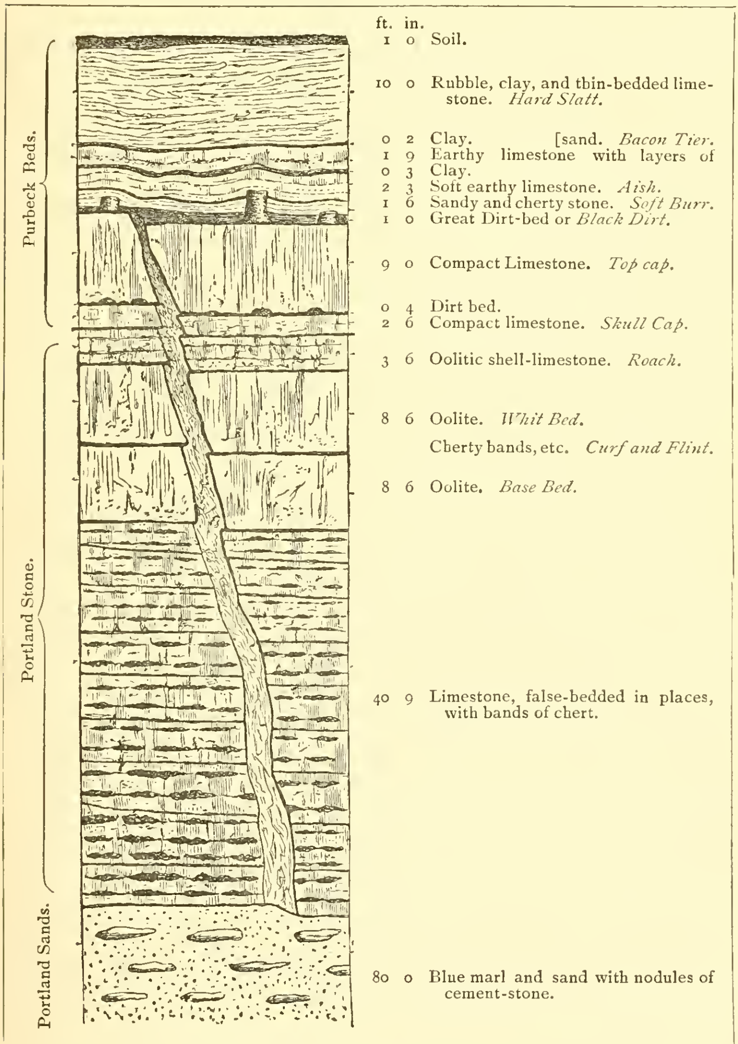
[4] Damon, Geol. Weymouth, 1884, p. 81.

[5] Buckland's Bridgewater Treatise, Pl. 57; Buckland and De la Beche, T.G S. (2), iv. 17; Fitton, *Ibid.* iv. 219; Webster, *Ibid.* ii. 37.

[6] Damon, Geology of Weymouth, 1884; the species have been found elsewhere and figured by MM. De Loriol and E. Pellat, Mem. Soc. Phys. etc. Genève, xix. 192.

building-purposes, etc. The Curf is, in places, a hard and sometimes oolitic limestone with much flint or chert, which separates the two beds of freestone. In it occur many specimens of *Ammonites giganteus.* The Roach is an oolitic shell-

Fig. 51.—Section of Strata, Isle of Portland.
(H. W. Bristow.)

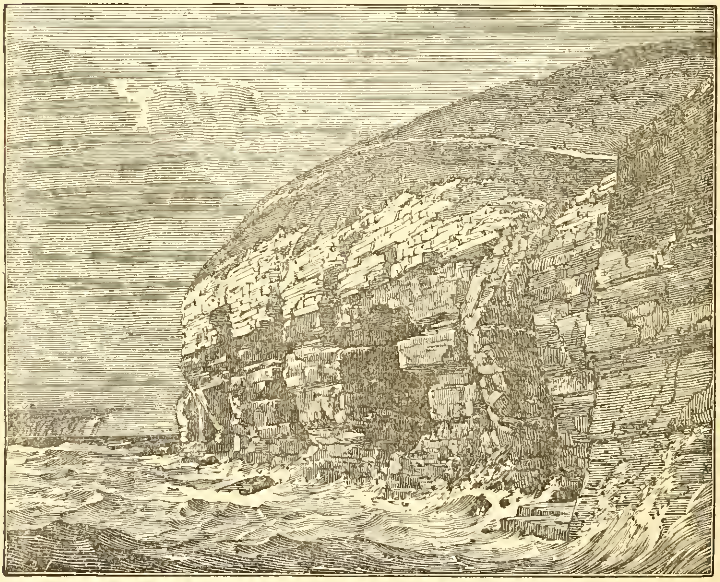


limestone, containing casts of *Cerithium Portlandicum*, *Trigonia*, etc. ; it merges into the Whit Bed. It has been used in the construction of Harbours, Breakwaters, Piers, etc., but as a rule is not removed from the Quarries. The Whit and

Base beds are used for building, for columns, sinks, troughs, rollers, etc. Some of the beds are burnt for lime. About the year 1623, in the reign of James I., the Portland stone appears to have first attracted attention. St. Paul's Cathedral, and many of the churches and other large buildings erected in the reign of Queen Anne, were constructed with stone said to be more durable than that now generally employed.[1] The stone was then obtained on the margin of the Island, and transported by vessels. London Bridge was also in part constructed from this stone.

The Portland Rocks form the grand cliffs between Durlston Head and St. Aldhelms or St. Albans Head, also Gad Cliff, and portions of the cliffs east and west of Lulworth Cove, and Durdle Door.[2] These cliffs are for the most part

FIG. 52.—PORTLAND BEDS AT ANVIL POINT, DURLSTON HEAD, NEAR SWANAGE.



abrupt and inaccessible, and it may be useful to warn the rambler that he cannot travel along the foot of Gad Cliff to Worbarrow. From Swyre Head (667 feet), east of Kimeridge, a spur of Portland Sand, a most extensive view is to be obtained overlooking on the east the picturesque valley of Encombe, called 'the Golden Bowl.'

The stone quarried in the Isle of Purbeck is locally known as 'Purbeck Portland.' The old quarries of Tilly Whim, near Durlston Head, are well known to visitors to Swanage; the good beds of stone having been worked out in tunnels and galleries. The stone here is said to be harder than that of Portland; it was last worked about the year 1812.

[1] R. Hunt and F. W. Rudler, Guide to Museum Pract. Geol., edit. 4, p. 38.

[2] See C. E. Robinson, Picturesque Rambles in the Isle of Purbeck, 1882, p. 145; and Sir Henry C. Englefield, Picturesque Beauties, etc., of the Isle of Wight, 1816, with geological sketches of the Dorset Coast, etc., by T. Webster.

There are several quarries along the coast at Dancing Ledge, Seacombe, and Windspit. There is generally worked an upper and lower freestone, shaped into blocks for building and into troughs, etc. The general section of the beds is as follows:[1]—

Shrimp-bed, fine-grained compact limestone	9 feet.
Oyster-bed, with *Ostrea solitaria*, *Perna Bouchardi*, etc.	6 ,,
Freestone, in two beds	35 ,,
Cherty series.	

At Upway, north of Weymouth, the Portland Stone is a white chalky-looking rock (white freestone), with nodules of black chert, and it so much resembles the Chalk, that one might readily imagine oneself to be in a Chalk-pit, until some of the fossil Mollusca are noticed. Prof. Jones has observed Cretaceous Entomostraca in this chalky rock.[2] Here the beds are highly inclined to the north, forming the northern slope of the Weymouth anticlinal.

The Portland Beds of the Vale of Wardour, well shown in the quarries of Chilmark ravine, north of Chicksgrove, are thus divided by the Rev. W. R. Andrews:[3]—

	Feet.
Upper Cyrena-beds, white fine-grained oolitic limestone, in which the fossils occur as casts. *Cerithium Portlandicum*, *Cyrena rugosa*, *Cardium*, *Lucina*, *Pecten*, etc. *Neritoma sinuosa* occurs sparingly	18
Chalky series with flints (marine). *Ammonites boloniensis*, *Trigonia gibbosa*, *Pecten*, etc.	24
Lower Cyrena-beds or Ragstones (estuarine). *Cyrena rugosa*, *Neritoma sinuosa*, *Cerithium*, *Lucina*, *Cardium*, etc.	8 to 10
Freestones or main building-stones, 4 or 5 beds of gritty limestone or calcareous sandstone with much glauconite, and sponge-spicules	18
Basement Beds, impure sands, sandy limestones, and clay, with *Trigonia gibbosa*, *Mytilus jurensis*, etc.	38

The Chalky beds may represent the 'Base bed' of Portland. They have been used for hearthstones.

The building-stones are known by the following local names (in descending order): Trough Bed, best building-stone, Green Bed, Pinney Bed, Hard Bed, and Fretting Bed. Analysis of the Trough bed showed 10 per cent. of silica, and 79 per cent. of carbonate of lime.

Mr. Hudleston was of opinion that there was some unconformity between the Portland and Purbeck beds near Tisbury, but this appearance may be due to the irregular nature of the several divisions of the Portland beds.

The Upper Cyrena-beds were formerly quarried and used in the west front of Salisbury Cathedral. The Chilmark freestone was used in the construction of Salisbury Cathedral, Wardour Castle, Romsey Abbey, Rochester Cathedral, and Wilton Abbey. At Chicksgrove, Wockley, Fonthill, and Tisbury, the beds are worked in places. A band of chert opened up near Fonthill Giffard has supplied many of the beautiful Corals (*Isastræa oblonga*), polished specimens of which are to

[1] W. H. Hudleston and J. Morris, P. Geol. Assoc. vii. 382; Damon, Geol. Weymouth, 1884, p. 87.

[2] Q. J. xxxvi. 236; see also Fitton, T.G.S. (2), iv. 225.

[3] Proc. Dorset Nat. Hist. Club, v. 57; see also Fitton, T.G.S. (2), iv. 249; W. H. Hudleston, G. Mag. 1881, p. 387, P. Geol. Assoc. vii. 173; J. F. Blake, Q. J. xxxvi. 200.

be seen in geological collections.[1] Its precise horizon appears to be at the top of the chief Building-stones. Many specimens are obtained from ploughed fields north-west of Tisbury.

The Portland Sands are exposed to the south of Devizes, and further north the Portland Beds occur for the most part in straggling outliers.

At Swindon the Portland limestone is about eight feet in thickness, and contains casts of shells, like the Roach of the Isle of Portland. The sands beneath (25 feet thick) contain irregular beds of hard calcareous sandstone (Swindon stone); and another bed with casts of shells, and two layers of hard limestone occur below. It has been stated that evidence of an alternation of marine (Portland) and freshwater (Purbeck) conditions is to be observed at Swindon, but the evidence has been questioned by Prof. J. F. Blake, who points out that the two series are locally unconformable.[2] The beds are exposed in quarries to the west of the old town of Swindon, and also at Coate, to the south-east, where the beds of stone have been termed the Coate beds. At Bourton south of Shrivenham, chalky oolite (eight feet) rests on hard blue fossiliferous limestone, grouped by Sir A. Ramsay with the Portland Sands,[3] and as equivalent to the lower shelly bed at Swindon.

The beds are developed in Buckinghamshire and Oxfordshire, where the sands have a thickness of 50 to 80 feet.[4] At Shotover the Portland Sands are overlaid by the Iron Sands of the Lower Greensand. (See sequel.) The stone-beds have been worked near Garsington, Great Hazeley, Thame, Long Crendon, Brill (20 feet), Quainton Hill, and Hartwell near Aylesbury. At Hazeley the stone is about eight feet in thickness, and consists of white limestone resting upon grey sandy oolite. The Aylesbury limestone is a marly and shelly limestone, worked at Hartwell and other places south-east of Aylesbury. Aylesbury is situated on Portland Beds, which occur also at Bierton, and at Whitchurch, not far off.[5] At Hartwell many Ammonites and other fossils have been preserved by Dr. John Lee in the walls that border the squire's park.

Further north the beds are not developed, unless we include the somewhat doubtful representatives at Speeton,[6] which consist of clay containing Portland fossils, but the beds are not well exhibited. A band of coprolites in the clay was formerly worked at New Closes Cliff.

In the Sub-Wealden boring, sandy beds and sandstone, containing chert-nodules, having a thickness of 110 feet, and commencing at a depth of 180 feet, have been classed as Portland

[1] Fitton, T.G.S. (2), iv. 255; Etheldred Benett, Catal. of Organic Remains of Wiltshire, 1831, p. iv.

[2] See Godwin-Austen, Q. J. vi. 464; Morris, Proc. Geol. Assoc. iv. 548; and J. F. Blake, Q. J. xxxvi. 203, 209.

[3] Explan. Sheet 34 (Geol. Survey), p. 27.

[4] See Fitton, T. G. S. (2), iv. 272.

[5] Phillips, Geol. Oxford, pp. 326, 413.

[6] J. Morris, P. Geol. Assoc. iv. 547; Judd, Q. J. xxiv. 231, xxvi. 326; Strangways, Geol. Oolitic Rocks, etc. S. of Scarborough, p. 23.

Beds. Prof. Blake has, however, suggested a different reading of the section as follows [1]:—

Portlandian	60 feet.
Bolonian	660 ,,

The Bolonian is a division recognized in the Boulonnais, and usually regarded as the uppermost stage of the Kimeridgian (Kimeridge Clay).

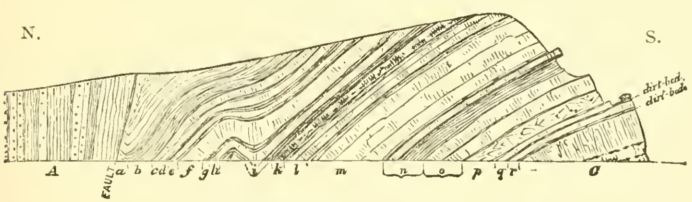
The fissures in the beds at Portland and Tisbury contain stalactitic deposits, called "congealed water," and beautiful yellow crystals of calcite called "sugar candy stone." Fuller's earth has been found in the Portland Stone at Brill. The Portland Stone forms bold hills, usually devoted to sheep-walks. The soil is a 'poor stone-brash.' Water is held up or thrown out at the base of the Sands by the Kimeridge Clay.

PURBECK BEDS.

This name was given from the great development of the beds in the 'Isle,' or more properly peninsula, of Purbeck. It probably originated from the extensive use of the Purbeck stone at Swanage, and the name has been applied in a geological sense since 1816, when it was used by T. Webster.

The formation is essentially of freshwater origin, but it contains a few estuarine or marine beds, which serve to link it with the Oolitic group. It consists of an alternating series of limestones, clays, and marls. The various sections at Durlston Bay, Worbarrow Bay, Lulworth Cove, and Ridgway Hill, show much

FIG. 53.—SECTION ON THE EAST SIDE OF LULWORTH COVE, DORSETSHIRE.[2]
(H. W. Bristow.)



A. Wealden Beds.
a to *r*. Purbeck Beds. (See p. 344.)
C. Portland Beds.

variation in thickness, both in the mass and in the divisions. The greatest thickness measured by Mr. Bristow at Durlston Bay is upwards of 360 feet, at Mewps Bay the beds are less by about 100 feet, and at Ridgway Hill, measured by the Rev. O. Fisher [3] and Mr. Bristow, the beds show further diminution.

[1] P. Geol. Assoc. vii. 358.
[2] Damon, Geol. Weymouth, 1884, p. 120.
[3] Trans. Camb. Phil. Soc. ix. 574.

The Purbeck Beds of Dorsetshire were divided as follows by Prof. E. Forbes and Mr. H. W. Bristow (see Fig. 53) :[1]—

Upper Purbeck Beds. 50 to 60 feet.	*a.* Paludina clays with Purbeck Marble containing *Paludina carinifera.*
	b. Cypris clays and shales.
	c. Unio beds, greenish shaly limestone with *Unio*, *Cyclas*; Crocodile-bed at Durlston Bay, with Turtle, Crocodile, etc.
	d. Broken-shell limestones, with comminuted shells, *Cyrena*; Fish-remains, etc.
Middle Purbeck Beds. 50 to 150 feet.	*e.* Beef beds, shales, etc., with fibrous carbonate of lime (Beef),[2] selenite, etc.
	f. Corbula beds, with *Corbula*, *Melania*, *Asteracanthus.*
	g. Scallop beds, with *Pecten.*
	h. Intermarine beds, with *Corbula*, *Ostrea*, *Cyclas*, *Hemicidaris Purbeckensis*; (Swanage Stone).
	i. Cinder bed made up of *Ostrea distorta*; when weathered, it presents a rough cindery appearance.
	Dirt-bed (local).
	k. Cherty freshwater bed, limestone with nodules of chert, *Limnæa*, *Physa Bristovii*, *Planorbis*, *Valvata*, etc.
	Carbonaceous bed at Durlston Bay, with Insectivorous Mammals.
Lower Purbeck Beds. 95 to 160 feet.	*l.* Marly freshwater beds.
	m. Soft cockle beds; chiefly marl, with gypsum and pseudomorphous crystals of rock-salt in places.
	n. Hard cockle beds, sandy and calcareous beds.
	o. Cypris freestone, slaty limestones, etc.
	p. Broken bands, beds made up of broken fragments of calcareous slate and bituminous limestone, squeezed together, with fragments of chert, etc.
	q. Soft cap, sandstone and bituminous limestone.
	Dirt-bed, with pebbles or fragments of limestone.
	r. Hard cap, bituminous limestone, etc., botryoidal in places.
	Dirt parting in places.
Portland Stone.	

The Dirt-beds, which consist of sandy carbonaceous clay, with rounded fragments of limestone from the underlying beds, occur at various horizons, but usually towards the base of the Purbeck strata. At Portland the principal bed lies above the Caps (see p. 339), and is full of the fossil silicified stools and prostrate trunks of coniferous and cycadean trees. There it is known as the Black Dirt, and it was first described by Thomas Webster.[3] It contains rounded fragments of limestone, which Mr. Horace Brown has suggested are due to the superficial weathering in Purbeck times of the underlying beds. Many limestones weather in a rubbly form at the surface, and similarly the Purbeck Caps may have weathered during the formation of the old soil or Dirt-bed. The stools of the trees, some of which are known as "Bird's Nests," stand out in more or less circular ridges, as sketched by Prof. Henslow in 1832, and they evidently mark old terrestrial soils, and the remains of contemporaneous land-surfaces.

Mr. J. C. Mansel-Pleydell has remarked that the most easterly evidence of the Purbeck forest is at Gad Cliff; good examples occur also about a quarter of a mile east of Lulworth Cove. The

[1] Vertical Sections (Geol. Survey), No. 22; and Horizontal Sect. No. 56.

[2] Termed 'Horseflesh' in the Isle of Portland.

[3] T. G. S. ii. 42. See also Buckland and De la Beche, T. G. S. (2), iv. 11; and Fitton, Proc. G. S. ii. 185.

tree-stumps are still erect, with their roots in the soil, but they are broken off a short distance from the ground. He observes that a submergence, or change of level, converting the lands on which the trees grew into a morass, would inevitably cause the destruction of the forest, and occasion a rapid decay, especially at the bases of the trees, and, thus weakened, they would yield to the force of wind or flood, and break off a few inches from the root.[1]

The Cycads include *Yatesia gracilis*, *Bennettites Portlandicus*, *Mantellia nidiformis*, *M. intermedia*, *M. microphylla*, and *M. pygmæa*.[2] The plants include also the Conifer, *Dammarites Fittoni*, and seed-vessels of *Chara*.

In 1854 Messrs. Wilcox and W. R. Brodie of Swanage discovered the Mammal *Spalacotherium tricuspidens*, in a thin carbonaceous bed at the base of the Middle Purbeck beds at Durlston Bay. Later on, in 1856, chiefly owing to the labours of Mr. S. H. Beccles, who opened a quarry in the cliffs, many remains of marsupial Mammalia (insectivorous, predaceous, and herbivorous) were found. These include *Amphitherium*, *Plagiaulax*, *Stylodon*, etc. Altogether thirteen genera and twenty-four species of Mammals have been identified by Sir Richard Owen and Dr. Falconer.[3] More recently (1880), from the same pit, known as 'Beccles' Quarry,' Mr. E. W. Willett obtained a specimen of *Triconodon mordax*.[4] The Reptiles obtained from the Purbeck Beds include the Swanage Crocodile, *Goniopholis crassidens*, also *Macrorhynchus*, the Lacertilian *Nuthetes destructor*, and *Pterodactylus*; as well as the Turtles *Pleurosternon concinnum*, *Chelone obovata*, etc. These occur in the Upper and Middle divisions of the Purbeck Beds. Fish-remains are not uncommon in the same divisions; they include *Lepidotus minor*, *Microdon radiatus*, *Hybodus strictus*, *Asteracanthus*, *Pholidophorus granulatus*, etc. Batrachian remains have also been recorded.

The principal Mollusca have been previously noted, as well as the *Hemicidaris* discovered by Prof. E. Forbes. Among other fossils the Isopod *Archæoniscus* is abundant in some localities; and Ostracoda are also of frequent occurrence. *Cypridea punctata* characterizes the Upper Purbeck Beds; *C. granulosa*, var. *fasciculata*, the Middle Beds; and *Cypris Purbeckensis* the Lower Beds.[5] A fresh-water sponge (*Spongilla*), from the Purbeck Beds at Lulworth, has been described by Mr. J. T. Young.[6]

Insect-remains are plentiful in the Middle and Lower Purbeck strata; they include chrysalides of Lepidoptera, Wings of *Libellula*, and of Dipterous and Hemipterous insects, and elytra of beetles.

[1] Proc. Dorset Nat. Hist. Club, ii. 1; see also G. Mag. 1873, p. 410.

[2] Carruthers, T. Linn. Soc. xxvi. 675. The old genera identified as *Zamites* and *Cycadites* are now regarded as *Mantellia*.

[3] See Owen, Fossil Mammals (Palæontograph. Soc.); Falconer, Q. J. xiii. 261. An animal allied to *Plagiaulax* has been found in the Jurassic rocks of Wyoming, and in the Lower Eocene of Rheims.

[4] Q. J. xxxvii. 377.

[5] T. R. Jones, Q. J. xli. 311.

[6] G. Mag. 1878, p. 220.

These remains are abundant both in Dorsetshire and in the Vale of Wardour.[1]

The Purbeck Beds, as a rule, rest conformably upon the Portland strata, although local symptoms of unconformity have been observed.[2] They were included with the Wealden Beds by Fitton and Mantell,[3] and as part of the Purbeck-Wealden Series by Topley[4] (1875); but they were first grouped with the Oolitic series on the suggestion of Edward Forbes.[5]

The beds pass upwards, as Mr. H. W. Bristow has shown, into the variegated Wealden Strata. This is well exhibited in the section at Mewps Bay, east of Lulworth Cove, on the Dorsetshire coast, which is generally regarded as the most complete section of the Purbeck strata. The junction-beds are as follows :—

		ft.	in.
Wealden Beds.	White siliceous sand with lignite Red and grey sandy clay, etc.	7	0
Upper Purbeck Beds.	Purple green and grey Marls with *Paludina*	11	0
	Paludina Marble	0	6
	Red and green Marls with *Paludina*	4	0
	Paludina Marble	0	9
	Grey clay with *Paludina*	2	7
	Paludina Marble	6in. to 1	0

The Purbeck strata may be regarded as passage-beds between the Portland and Wealden series, for no rigid boundary-lines mark their limits. Indeed it has been considered that the northerly portions of the Purbeck Beds were to some extent contemporaneous with the Portland Beds further south.[6]

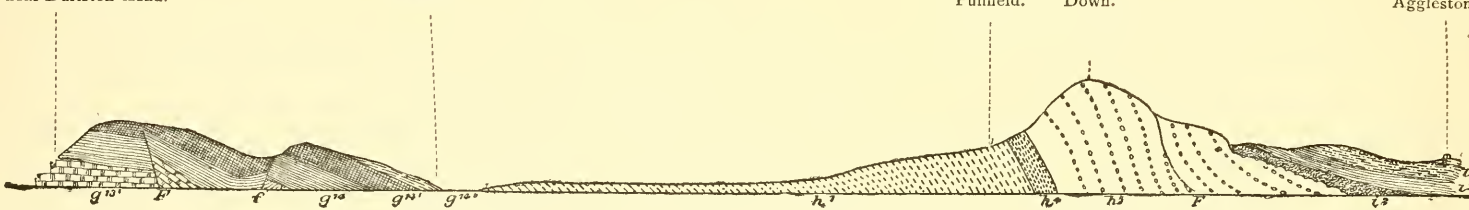
It has been questioned whether the Purbeck and Portland Beds ever extended far beyond their present limits;[7] but the Wealden and Purbeck Beds, as remarked by Sir A. Ramsay, represent the delta and lagoon deposits of an immense river, which in size may have rivalled the Ganges or the Mississippi.

The highly inclined and contorted strata at Lulworth form interesting subjects for study. At Stair Hole or Cove the sea has forced its way inland by three tunnels through Portland rocks, perhaps originally joints and fissures; and this process indicates the probable way in which Lulworth Cove and Worbarrow Bay were formed. The 'Broken Beds' noticed by Mr. Bristow along the coast are remarkable. On Portland such beds may in most cases be clearly traced to the "gullies" in the Portland rocks, but this explanation is quite inadequate to explain the disturbance of the beds along the Isle of Purbeck. The effects of weathering along the inclined edges of the strata may have had some influence, and there may have been some crushing of the beds during the great disturbances to which they have been subjected, when the Chalk and other strata of Dorsetshire and Hampshire were

[1] Brodie, Fossil Insects, 1845, Q. J. x. 475 ; H. Goss, P. Geol. Assoc. vi. 116.
[2] J. F. Blake, Q. J. xxxvi. 204.
[3] Isle of Wight, ed. 3, p. 42 (table). See also Dr. C. Struckmann, G. Mag. 1881, p. 556.
[4] Geology of the Weald (map).
[5] Rep. Brit. Assoc. 1850.
[6] Godwin-Austen, Q. J. vi. 478 ; see also Blake, Q. J. xli. 330, 352 ; Phillips, Geol. Oxford, p. 410.
[7] J. Morris, G. Mag. 1867, p. 462 ; Judd, Q. J. xxvii. 222.

Fig. 54.—Section across part of the East End of the Island of Purbeck. (H. W. Bristow.)

Length about $3\frac{1}{2}$ miles.



N.B.—This section is drawn a little inland of the actual coast, but so as to express its chief geological features. The upper part of h^1 contains the "marine band" of the "Punfield Beds," and the uppermost Lower Greensand. At the base of h^4 are dark clays, which represent part of the Gault. The junction of Chalk with Tertiaries is marked by a series of funnel-shaped pits, or "pot-holes."

$g^{14''}$ Upper, $g^{14'}$ Middle, g^{14} Lower — Purbeck Beds.
g^{13} Portland Beds.
F Faults.

i^4 Lower Bagshot Beds.
i^3 London Clay.
i^2 Reading Beds.
h^5 Chalk.
h^4 Upper Greensand, etc.
h^1 Wealden Beds.

uptilted. The beds may also have been subject to atmospheric influences during Purbeck times.[1]

The Purbeck Beds of the Vale of Wardour are well exposed in the railway-cutting west of Dinton Station and in quarries near Teffont Evias, Wockley, and Chilmark. The Rev. W. R. Andrews, who has paid much attention to the beds, remarks that they are only 60 or 70 feet in thickness, and belong to the Lower and Middle divisions. They rest conformably on the Portland series, and are overlaid by Wealden strata. "Whether the Upper Purbecks were ever deposited here it is impossible to say," but Mr. Andrews is of opinion that the Wealden Beds were laid down on an eroded surface of the Purbeck Beds.[2] The beds are as follows:—

Wealden.—	Yellow and red sandy clays. *Endogenites erosa.*
Middle Purbeck.	Hard marls, clays and limestones. *Archæoniscus Brodiei.* Cinder Bed with *Ostrea distorta*, *Trigonia densinoda* and *T. gibbosa.* Hard limestones and sandy rock.
Lower Purbeck.	Clay, marl. (Insect-beds, etc.)

So abundant are remains of *Archæoniscus*, that 250 specimens have been obtained on a slab not larger than one foot square.

Traces of Purbeck Beds occur at Brill in Buckinghamshire; consisting chiefly of argillaceous beds having a thickness of 10 feet.[3] Purbeck Beds, with a thickness of 4 feet, occur at Shotover Hill. The term Pendle is applied to fissile argillaceous limestones that occur near the base of the Purbeck Beds at Hartwell and other localities in the neighbourhood; they yield Fish-remains, Insects, Cyprides, Ferns, etc.

Near Swindon the Purbeck Beds are represented by hard cream-coloured marly limestones and clays (with *Paludina*, *Bithynia*, etc.), about 12 feet thick. Here Mr. C. Moore obtained remains of Mammals, and also of the oldest known Frog.[4]

In Sussex the Purbeck Beds occur near Battle, where they were formerly classed with the Ashburnham (Wealden) Beds. The total thickness of these Purbeck Beds is stated by Mr. Topley to be about 400 feet. The Sub-Wealden boring passed through 180 feet of this formation, consisting of limestone, shale and marl, with beds of gypsum. The higher beds consist chiefly of shales, with two groups of limestones, the upper termed the 'Greys,' and the lower the 'Blues.' *Cyrena* and other Mollusca, and *Cypridea Valdensis* occur sometimes abundantly in the shales. *Paludina* is rare, and *Ostrea* has only occasionally been met with.[5]

[1] See also Rev. O. Fisher, Trans. Cambr. Phil. Soc. ix.

[2] Q. J. xxxvii. 251; see also Rev. O. Fisher, Q. J. x. 476; J. F. Blake, Q.J. xxxvi. 200; Brodie, Foss. Insects, p. 3.

[3] Rev. P. B. Brodie, Q. J. xxiii. 197; see Phillips, Geol. Oxford, p. 415; J. F. Blake, Q. J. xxxvi. 215.

[4] Proc. Geol. Assoc. iv. 544.

[5] W. Topley, Geol. Weald, pp. 16, 30, 408. A full account of the literature is there given.

Economic products, etc.

Swanage is noted for the "chipping and shipping" of stone. In the Middle Purbeck Beds near Swanage there are numerous quarries where the Purbeck stone is raised. There are many beds used for building, paving, and roofing; and some are serviceable as kerb-stones. The quarries, of which there are (or have been) upwards of a hundred on the hill that stretches from the south of Swanage to Kingston, might be termed mines, for they are reached by a sloping tunnel 30 or 40 feet deep, according to the position and dip of the beds. The beds are worked underground to avoid removing the useless stone which forms the greater mass of the strata. (See Fig. 55.) The Langton freestone is Purbeck stone dug at Langton Maltravers. At Ridgway Hill (Upway), the workable stone occurs in the Lower Purbeck Beds.

The Purbeck Marble (Marble Rag) which occurs in the Upper Purbeck strata, is exhibited at Peveril Point, and has been worked about 700 years, inland along the Purbeck ridge, near the junction with the Wealden strata. Quarries are to be seen at Easton, and at Woody Hyde and West Orchard near Kingston.[1] The beds are usually from 6 to 9 inches in thickness, and are mostly made up of specimens of *Paludina*, which stand out in relief on the weathered surfaces of the stone. Much of the Marble is of a grey colour, but red and green varieties are sometimes obtained. Formerly it was much employed for making the slender shafts in Gothic churches; but the introduction of foreign marbles has decreased the demand for it. Stone has been worked at Teffont Evias, near Dinton, for building-purposes and lime-burning; and south of Chilmark the Purbeck beds have been raised in slabs for tiling, etc.

A bed called the Burr stone, a soft sandy limestone, occurs in the lower strata at Portland; it stands fire, and has been used for chimney-work and fire-places. Shell-limestones, also termed Burr stone, occur in the upper beds at Swanage, and have been employed for building-purposes. The Aish bed at Portland has been used for holystone.

Gypsum occurs in the Lower Purbeck Beds at Durlston Bay, and masses have been collected from the beach. It is worked now near the site of the Sub-Wealden Boring, at Limekiln Wood, near Battle. The limestones were at one time largely quarried, mostly by shafts, in the Purbeck area, north-west of Battle. Hard calcareous sandstones are worked in places for road-metal.

[1] See also Rev. J. H. Austen, Guide to Geol. I. of Purbeck, 1852.

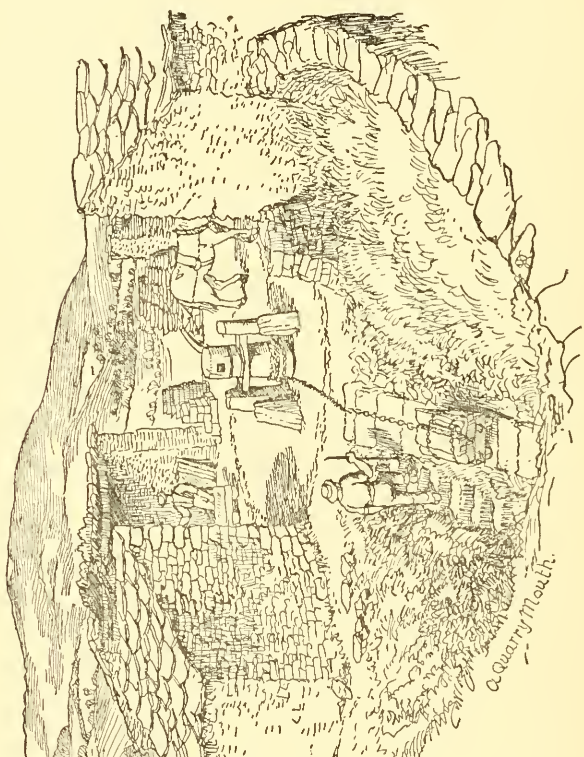


Fig. 55.—Purbeck Stone-quarry, Swanage.

CRETACEOUS.

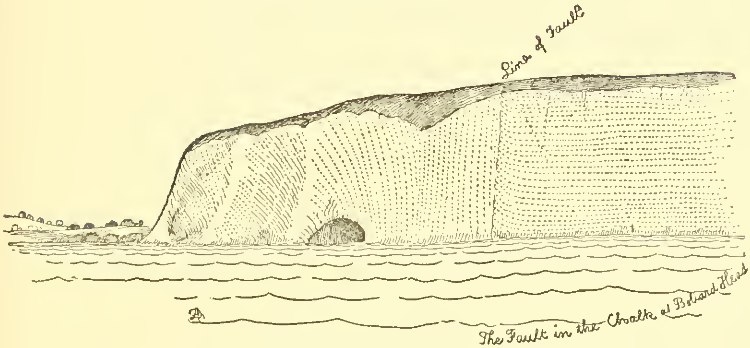


FIG. 56.—CHALK CLIFF AT BALLARD HEAD, NORTH OF SWANAGE.

The Cretaceous system is composed of a series of rocks that exhibit varied phases, both in their lithological characters and method of formation; the series is mainly composed of sands and clays, but it includes the Chalk, and on that account the name was applied by Dr. W. H. Fitton.[1] The following are the main divisions in this system :—

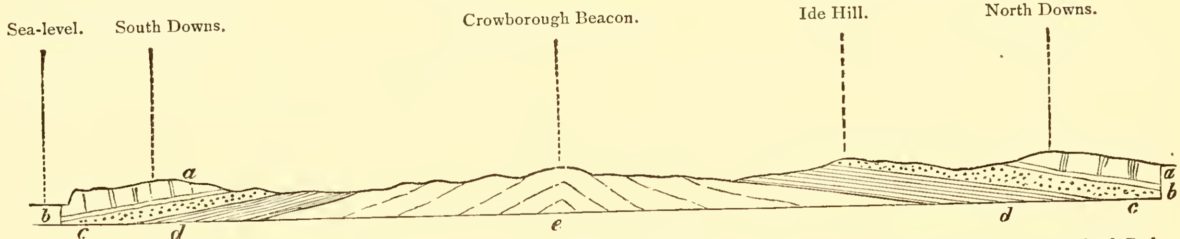
Upper Cretaceous.	Chalk Upper Greensand Gault	
Lower Cretaceous.	Lower Greensand Wealden Beds	Neocomian of some authors.

Considerable difference of opinion has been expressed regarding the nomenclature and the grouping of the beds; but on the whole it appears best to divide them into an upper and a lower series as above indicated. For this system the term Anglian was proposed by Prof. Hughes in 1879.[2]

The term Neocomian, introduced into England by Mr. Godwin-Austen in 1843,[3] has been generally used as a synonym for our Lower Cretaceous strata. It was

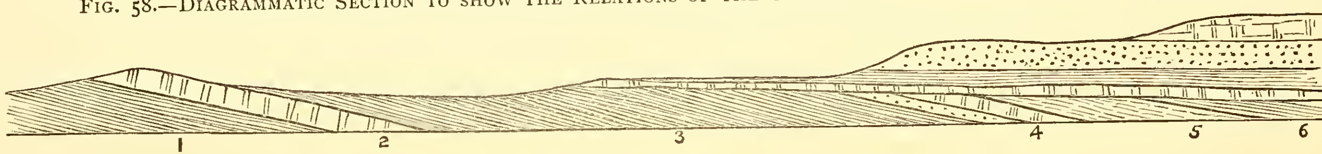
[1] Ann. Phil. (2), viii. 382; see also pp. 365, 458.
[2] Proc. Cambridge Phil. Soc. iii. plate vi.
[3] Proc. G. S. iv. 170; Q. J. vi. 478.

FIG. 57.—GENERALIZED SECTION ACROSS THE WEALDEN DISTRICT.



a. Chalk.
b. Upper Greensand and Gault.
c. Lower Greensand.
d. Weald Clay.
e. Hastings Beds; and Purbeck Beds (not exposed at surface).

FIG. 58.—DIAGRAMMATIC SECTION TO SHOW THE RELATIONS OF THE OOLITIC AND CRETACEOUS STRATA IN WILTSHIRE.



5. Purbeck Beds.
4. Portland Beds.
3. Kimeridge Clay.
2. Corallian Beds.
1. Oxford Clay.

10. Chalk.
9. Upper Greensand.
8. Gault.
7. Lower Greensand.
6. Wealden Beds.

proposed by Jules Thurmann about the year 1832 (mainly through the labours of Auguste de Montmollin) for certain strata which are developed near Neuchâtel (Neocomum) in Switzerland, and correspond in age with our Wealden Beds. In this country, however, the term has been used to embrace not only the Wealden, but also the Lower Greensand; while latterly some authorities have been disposed to restrict the name Neocomian to the Lower Greensand, or to those strata that occur above the Wealden and below the Gault! Moreover, on the Continent, Neocomian has been applied in different senses;[1] hence on the whole it is a very unfortunate term.

The organic remains of the Cretaceous Rocks include among Plants, remains of Fuci, Coniferæ, and Cycadaceæ; also many Sponges and Foraminifera. Corals are not abundant, and, as Dr. Duncan remarks, "There are no traces of any Coral reefs or atolls in the British Cretaceous area, and its Corals were of a kind whose representatives for the most part live at a depth of from five to six hundred fathoms."[2] The Echinoderms are conspicuous among Cretaceous fossils, and include *Salenia*, *Diadema*, *Micraster*, *Holaster*, etc. Among the Annelides we find *Vermicularia*, and the Crustacea comprise Cirripedes, Ostracoda, and Podophthalmia. The Brachiopoda include *Crania* and other forms; the Mollusca are well represented by the Lamellibranchiata, *Ostrea*, *Pecten*, *Inoceramus*, *Arca*, *Pectunculus*, etc., while the Gasteropoda include forms like *Aporrhais*, *Turritella*, *Solarium*, *Scalaria*, etc., which foreshadow Tertiary life. Of Cephalopoda there are species of *Ammonites*, *Turrilites*, *Scaphites*, *Hamites*, and *Baculites*, also *Belemnites* and *Belemnitella* (found in the Chalk). The Vertebrata include many Fishes, *Lamna*, *Otodus*, *Ptychodus*, *Beryx*, *Ischyodus*, etc. Among the Saurians we find the Lacertilian genus *Mosasaurus* (essentially Cretaceous), so that the term Mosasaurian was applied to the system by John Phillips. Dinosaurians and Chelonians are also conspicuous forms. Birds, including *Enaliornis* and *Pelagornis*, have been found in the Cambridge "Greensand"; and another genus *Palæornis* has been obtained from the Wealden Beds. No Mammals have been recorded from Cretaceous rocks in this country.[3]

The divisional line between the Cretaceous and Jurassic systems, like that taken between some other systems, is one of convenience, and not one indicating any great physical break, for the Wealden and Purbeck Beds are intimately connected. The Purbeck Beds mark the commencement of those freshwater conditions which

[1] A. J. Jukes-Browne, G. Mag. 1886, p. 311; see also Judd, *Ibid.* 1870, p. 225, 1886, p. 382.

[2] Duncan, Supp. to Brit. Fossil Corals (Palæontogr. Soc.), Part II. No. 2, 1870.

[3] See works by Owen, Sharpe, Davidson, and others (Palæontograph. Soc.); also A. D. D'Orbigny, Paléontol. Francaise, Terrain Crétacé.

attended the deposit of the Wealden sediments; and the two groups of strata have sometimes been classed together. (See p. 346.) The Lower Greensand, Gault, Upper Greensand, and Chalk indicate marine conditions of varying character;[1] and although locally we have indications of transition from the Wealden deposits upwards to the Chalk, yet over large portions of our area the Lower Greensand rests unconformably on the Wealden and Upper Oolitic strata beneath.[2] (See Fig. 58.)

In the Wealden area the Gault rests conformably on the Lower Greensand, although, as Mr. Topley remarks, there is a great palæontological break between them.[3] In other parts of England, as in Wiltshire, the Gault overlaps the Lower Greensand and rests on older beds; and this general overlap of the Upper Cretaceous beds over the Lower beds, and their overstep across different members of the Jurassic system, is well marked in the south of England, in the Midland Counties, in Lincolnshire and Yorkshire.[4] We see, in fact, evidence of a plain of marine denudation, that was commenced during the Lower Greensand period, and continued in Upper Cretaceous times.

In Yorkshire the Wealden Beds are represented in part by a series of marine clays included under the general name of Speeton Clay.

The Cretaceous Rocks were mapped for the Geological Survey, in the south and south-west of England, chiefly by W. T. Aveline, H. W. Bristow, H. Bauerman, and W. Whitaker; in the south-eastern area, by H. W. Bristow, F. Drew, W. Whitaker, C. Gould, C. Le Neve Foster, and W. Topley; and in the eastern and north-eastern counties, by W. Whitaker, W. H. Penning, C. Fox Strangways, F. J. Bennett, A. J. Jukes-Browne, A. Strahan, and the writer.

[1] See S. V. Wood, Jun. On the Form and Distribution of Land-tracts during the Secondary and Tertiary Periods, Phil. Mag. 1862; C. J. A. Meyer, G. Mag. 1866, p. 13; J. S. Gardner, Q. J. xl. 122.

[2] See also Fitton, T. G. S. (2), iv. plate 10*a*, and p. 189; and Judd, Q. J. xxvii. 221.

[3] Geology of Weald, p. 3.

[4] Conybeare, Phil. Mag. (2), i. 118; Phillips, Geol. Oxford, p. 422; J. W. Judd, Q J. xxiii. 242; C. E. De Rance, G. Mag. 1874, p. 246.

Table to Show the General Relations of the Lower Cretaceous Strata.[1]

	Wealden Area.	Isle of Wight.	Midland Counties.	Lincolnshire.	Yorkshire.	S. E. France.[2]	
Lower Greensand.	Folkestone Beds.	Shanklin Sands.	Faringdon Beds, Woburn Sands, Potton and Wicken Beds, and Shotover Sands?	Carstone?	Upper Speeton Clay.	Aptian.	Neocomian (of some authors).
	Sandgate Beds.						
	Hythe Beds.	Walpen Sands.		Tealby Beds.	Middle Speeton Clay.		
	Atherfield Clay.	Atherfield Clay and Punfield Beds of Dorset.		Donnington Clay.		Rhodanian.	
Wealden Beds.	Weald Clay.	Wealden Beds.		Spilsby Sandstone.	Lower Speeton Clay.	Urgonian and Neocomian.	
	Hastings Beds.						

[1] See A. J. Jukes-Browne, G. Mag. 1886, p. 317; Judd, Q. J. xxvii. 223; C. J. A. Meyer, G. Mag. 1866, p. 15.

[2] The term Aptian, given by D'Orbigny, is derived from Apt in Vaucluse; Rhodanian, given by Renevier, from the Rhone valley; Urgonian, given by D'Orbigny, from Orgon, Bouches des Rhone; Neocomian, see p. 351.

LOWER CRETACEOUS.

Wealden Series.

This term is a modification of Weald Measures, introduced in 1812 by J. Middleton. Our earliest information respecting the strata is mainly due to Mantell (1822) and Fitton (1824); but the name Wealden appears to have been first used by P. J. Martin, in 1828.[1]

The Wealden area, as understood by geologists, embraces all the rocks bounded by the Chalk escarpment of the North and South Downs; but the Wealden rocks proper constitute the old district of the Weald, and with these we have now principally to deal.

The Wealden Beds are developed over a considerable part of Surrey, Sussex, and Kent, between Haslemere, Hythe, and Pevensey; they are also found in Dorsetshire and the Isle of Wight. These rocks comprise a series of clays, loose sands, sandstones, and shelly limestones, indicating by their fossils that they were accumulated in an estuary or lake, where freshwater conditions prevailed.[2] In the upper part of the series we find in places indications of fluvio-marine conditions. The Plant-remains include Coniferæ, Cycads, and the Ferns, *Pecopteris*, *Sphenopteris*, *Lonchopteris*, etc. The Ostracoda include *Cypridea Fittoni*, *C. Valdensis*, etc. Many remains of Insects are found.[3] The Mollusca comprise species of *Cyrena*, *Unio*, *Melanopsis*, *Paludina*, etc. Among the Fishes are *Lepidotus*, *Hybodus*, etc., and the Reptiles include several forms of Dinosauria, and other orders.

The Iguanodon was discovered in the Wealden Beds of Tilgate Forest in 1822 by Mrs. Mantell, and named three years later by Dr. G. A. Mantell. Its length from snout to end of tail has been estimated at upwards of 40 feet.

Among other forms are *Hylæosaurus Owenii* and *Megalosaurus Bucklandi*. The *Hylæosaurus* ("Forest" or "Wealden Lizard"), was discovered in 1832, and its estimated length was 25 feet. The *Megalosaurus*, as restored in 1854, in the gardens of the Crystal Palace, by Mr. B. Waterhouse Hawkins, measures 37 feet long and 22 feet 6 inches in girth.[4] *Pterodactylus* also occurs in the Wealden Beds, as well as *Cetiosaurus*, *Streptospondylus*, etc. Speaking of the great quadrangular dorsal scutes of the *Goniopholis* of the Wealden and Purbeck formations, Sir R. Owen says, "No knight of old was encased in jointed mail of better proof than these Crocodiles

[1] See W. Topley, Geol. of the Weald (Geol. Survey), 1875; Mantell, Geol. S. E. of England; Fitton, T. G. S. (2), iv. 103; P. J. Martin, Memoir on Western Sussex, 1828.

[2] C. J. A. Meyer. Q. J. xxviii. 243.

[3] W. R. and H. Binfield, Q. J. x. 171; H. Goss, P. Geol. Assoc. vi. 116.

[4] See Owen, Geology and Inhabitants of the Ancient World, 1854; Morris, P. Geol. Assoc. v. 377.

of an older world."[1] Remains of *Chelone*, *Platemys*, and *Tretosternon* (*Trionyx*), have been found, as well as a Reptilian egg, discovered by the Rev. T. Fox, at Brixton in the Isle of Wight, and named *Oolithes obtusatus*.[2] Remains of the Bird *Palæornis* have likewise been met with.

The Wealden Beds are divided as follows:[3]—

2. Weald Clay.
1. Hastings Beds.

Their total thickness is about 1500 feet. While the beds extend uninterruptedly over the Wealden area, they do not extend far north, and are not even present beneath the Chalk at Chatham.

HASTINGS BEDS.

The lower portion of the Wealden Beds consists for the most part of sands, with subordinate beds of clay; these are well shown in the cliffs at Hastings, and hence the name Hastings Sands was proposed by Dr. Fitton in 1824. The several members of the series are very variable in thickness (attaining a total of 700 feet), and at the same time there is great similarity in the clays and sands that occur at different horizons in it. It is hardly possible to regard the divisions as marking changes that occurred uniformly over the area, and although it is convenient to make lithological divisions, yet the correlation of these in different parts of the district must always be open to doubt as regards contemporaneity. Indeed, in the lowermost division it has been determined that the Fairlight Clays are represented in other localities by sandy beds belonging to the Ashdown Series. Mr. Topley has well observed that such divisions can only be made out, and their relations determined, by actual mapping.

In the Hastings Beds occur the deposits of iron-ore for which the Wealden district was noted from early British and Roman times down to about the year 1720. Hence the term 'Iron Sand and Carstone' used by old writers. In the time of Queen Elizabeth, Sussex was full of iron-mines and furnaces, for the casting of cannon, etc.[4]

The fossils of the Hastings Beds have been generally noted under the heading of Wealden, and they will be referred to under the various divisions. *Endogenites erosa* is met with in the lowest beds, and *Equisetites Lyellii* more generally.

[1] Q. J. xxxiv. 422.
[2] W. Carruthers, Q. J. xxvii. 447.
[3] F. Drew, Q. J. xvii. 271.
[4] Camden's Britannia, 1586.

FIG. 59.—SECTION ALONG THE CLIFFS OF HASTINGS AND FAIRLIGHT.
(From the Geological Survey.)

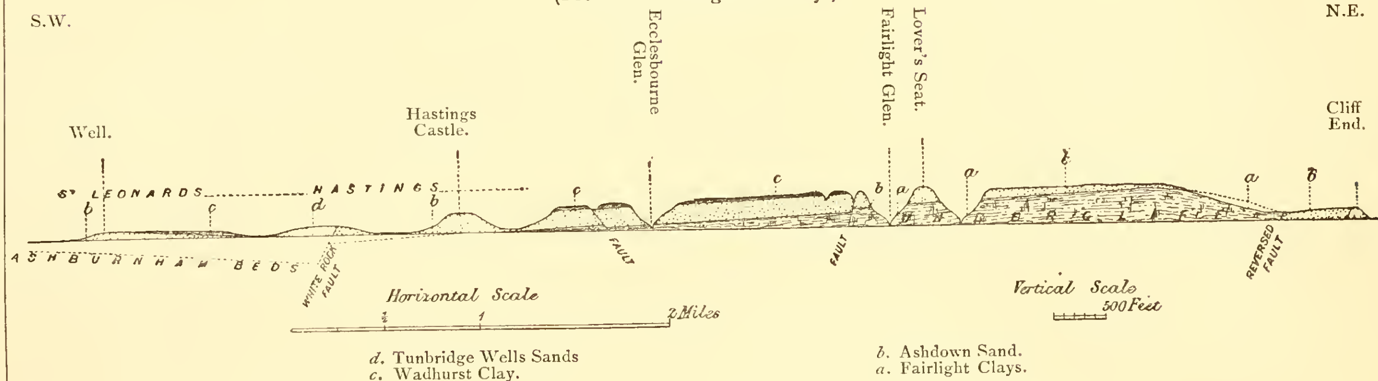
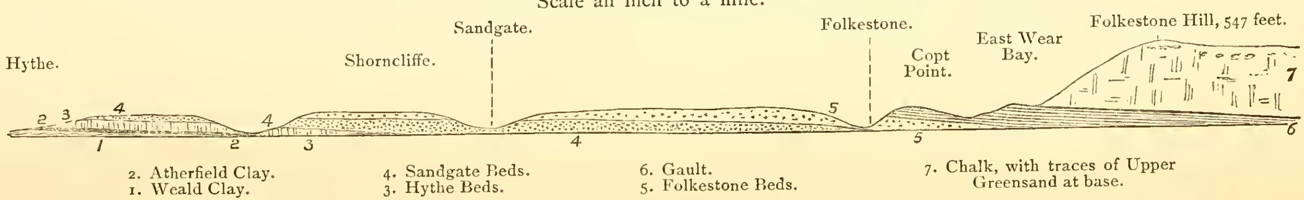


FIG. 60.—SECTION ALONG THE CLIFFS FROM HYTHE TO FOLKESTONE HILL. (W. Topley.)
Scale an inch to a mile.



The Hastings Beds have been divided as follows by Mr. F. Drew (1861):[1]—

Tunbridge Wells Sands.	Upper Tunbridge Wells Sand with Cuckfield Clay. Grinstead Clay. Lower Tunbridge Wells Sand.
Wadhurst Clay.	
Ashdown Sand....	Ashdown Sand and Fairlight Clays.

Ashdown Sand.

This formation consists of sand and soft buff or white sandstone, with bands of loam, blue clay and lignite, having a total thickness of 400 or 500 feet. The term 'Ashdown Sand' was proposed by Mr. F. Drew, on account of the great development of the beds (400 feet) in Ashdown Forest, south-west of Tunbridge Wells. The sands form very high ground, as at Crowborough Beacon, and are spread over a large area. The term Worth Sandstone was used by Mantell, but the sandstone at Worth itself, near Three Bridges, belongs to the Lower Tunbridge Wells Sand. In the upper part, near Hastings, there are sometimes beds of calcareous sandstone or ironstone ('Tilgate Stone'), and quartzose conglomerate. Near Tunbridge Wells the beds are about 100 feet thick; they are well developed at Heathfield. (See Fig. 57.)

Fairlight Clays.—In the neighbourhood of Hastings and Fairlight, clays, frequently mottled, predominate in the lower part of the Ashdown Beds. These clays were formerly termed the Ashburnham Beds by Mantell;[2] they were subsequently termed the Fairlight Clays by Mr. C. Gould, from Fairlight Glen, where the mottled clays give colour to the cliffs, and they represent the lower part of the Ashdown Sand as it appears further west. They attain a thickness of 360 feet, the bottom not being seen; the sands above, to which the term Ashdown Sand is locally restricted, are here about 150 feet thick. Many beds of sandstone are included in the Fairlight Clays; one curious bed—called the Tesselated Sandstone—is 4 feet in thickness. The sands are often false-bedded, a feature well seen in the cliffs east of Ecclesbourne glen. (See Fig. 59.)

The Ashdown Sand yields *Endogenites erosa*, which chiefly occurs in a bed of shale not far from the top of the formation. *Araucarites* and *Sphenopteris* have also been met with. Tracks of Birds? (*Ornithoidichnites*) were observed in the Hastings Beds west of St. Leonards by Mr. S. H. Beckles;[3] and Dr. Fitton noticed a bed of

[1] Q. J. xvii. 283.

[2] The Ashburnham Beds of Mantell include the lower part of the Ashdown Sand (the Fairlight Clays), the Purbeck limestone-beds near Battle, and also the shelly bed at the bottom of the Wadhurst Clay. The name was given from Ashburnham, west of Battle. W. Topley, Geology of the Weald, p. 6.

[3] Q. J. viii. 396, x. 457.

grit with freshwater shells, *Cyclas*, *Paludina* and *Unio*, in the White Rock Cliff, where rocky ledges run out to sea.

The old town of Hastings is built entirely on Ashdown Sand, whilst St. Leonards is mainly built on Tunbridge Wells Sand, the two series being brought together by the "White Rock Fault." (See Fig. 59.) The Ashdown Sand forms the fine cliffs on which the Castle is built; here the beds consist of compact white rock-sand, resting on beds somewhat more clayey in nature. The uppermost beds are generally massive, and form a range of bare rocks around the Hastings and Ecclesbourne valleys. The East Cliff is composed almost entirely of sandstone like the Castle Cliff, but in going eastwards the beds contain intercalated beds of clay; hence the cliffs at Hastings weather into vertical faces, whilst those nearer Fairlight present a succession of steps. The top of the East Cliff from Hastings to Fairlight is composed of Wadhurst Clay, and the lower part of Fairlight Clays.[1]

White pipe-clay occurs in the beds at East Cliff, Hastings. In 1801 a block of jet or lignite was obtained between Heathfield and Waldron, east of Uckfield. Lignite has also been found at Bexhill, west of Hastings, and the occurrence gave rise to fruitless searches for coal. The Crowborough stone is dug in places in Ashdown Forest.

Wadhurst Clay.

This deposit was named by Mr. F. Drew from the village of Wadhurst south-east of Tunbridge Wells. It consists of clay and shale, with a bed of sand towards the base near Rye, and at Icklesham, west of Winchelsea; it also contains, near the bottom, lignite and nodules and bands of clay-ironstone, which furnished the chief supply of iron-ore to the old furnaces of the Weald. The top of the clay is commonly of a bright red colour, as around Tenterden, etc.

The beds sometimes contain calcareous sandstone—the Tilgate Stone of Dr. Mantell—which Mr. C. Gould has noticed at irregular intervals throughout the series, either in large detached rounded masses or in continuous layers. When unweathered and freshly broken, it is of a bluish colour; occasionally it passes into a conglomerate. As pointed out by Mr. Topley, the 'Tilgate Stone' of Dr. Mantell occurs at different horizons in different localities.

Sections of Wadhurst Clay may seen in the cliffs on either side of Ecclesbourne Glen, on Telham Hill, south-east of Battle, etc. The thickness of the deposit at Pembury is about 160 feet, and near Goudhurst about 180 feet; at Rye and Fairlight it is about 120 feet.

This formation is rich in fossil Plants, and freshwater Molluscs, together with the Fishes *Hybodus*, *Lepidotus Mantelli*, etc.

The Tilgate Stone is noted for its Reptilian remains: it becomes

[1] W. Topley, Geol. Weald, p. 54; see also Webster, T. G. S. (2), ii. 31; Fitton, Geology of Hastings (1833); T. G. S. (2), iv. 163, plate x*b*; and S. H. Beckles, Q. J. xii. 288.

a regular bone-bed in places. These remains include Dinosauria, *Iguanodon Mantelli;* Crocodilia, *Goniopholis crassidens;* Pterosauria, *Pterodactylus Cliftii;* and Chelonia. Remains of *Iguanodon* have been obtained near Hastings. There also the fern *Oleandridium Beyrichii* was discovered by Mr. Charles Dawson.[1]

Mr. Topley informs me that the only fossiliferous band which can be considered at all characteristic of any horizon in the Hastings Beds occurs near the base of the Wadhurst Clay. It is composed mainly of shells of a small *Cyrena*, and varies from one to four inches in thickness. Generally there is only one band, but occasionally there are two or even three layers of shelly limestone (Ashburnham Beds, in part, of Mantell).

The Tilgate stone has been much quarried for road-material at Calverley Quarry, near Tunbridge Wells, and other places. The 'Hastings granite' is a local variety of Tilgate stone belonging to the Wadhurst Clay. At Beech Green, near Penshurst, it is called Beech Green stone. The shale has been largely dug for 'marl.'

The iron-ore which in old times was so extensively worked, is a clay-ironstone that occurs in nodules and thin beds towards the bottom of the Wadhurst Clay. Mr. Topley remarks that the ore was worked mainly by means of bell-pits, about six feet in diameter at the top, and widening towards the bottom. They were usually shallow, rarely more than twenty feet deep; sometimes they were connected by levels. Great numbers of these pits ("mine-pits") still remain in the woods, and they are generally full of water. The clay-ironstone contains about thirty-five per cent. of iron. Iron-ore was worked at Ashburnham, Lamberhurst, Wadhurst, etc. The iron railings at St. Paul's were made at Lamberhurst, east of Tunbridge Wells, and many iron "tombstones" still remain in churchyards. The earliest historical record of the Iron-mines dates back to the time of Henry III. The last furnace, that at Ashburnham, was extinguished in 1828. An effort to revive the mining was commenced in 1857, and abandoned a year later.[2] Bricks are made in places from the Wadhurst Clay.

Tunbridge Wells Sands.

The term 'Tunbridge Wells Sand' was first suggested by Mr. F. Drew, because the beds are well developed in the neighbourhood of that town, where grey and yellow sandstones belonging to the series form the rocks of Mount Ephraim and other places.

The Horsted Sand of Mantell, corresponds generally with the Tunbridge Wells Sands, and so also does the Worth Sandstone of Mantell, at Worth. The Tilgate Beds of Mantell belong generally to the upper part of the Tunbridge Wells Sand, although he included in this division beds both lower and higher in the series, as those in the Wadhurst Clay of Hastings, and certain beds at Loxwood in the Weald Clay.[3]

The Tunbridge Wells Sands much resemble the Ashdown Sand; and Mr. Drew remarks that the two can only be separated by regarding their positions with respect to the Wadhurst Clay. The Tunbridge Wells Sands consist of loose sand, false-bedded rock-

[1] J. E. H. Peyton, Q. J. xxxix. (Proc.), 3.

[2] Topley, Geol. Weald, pp. 329, 334; see also W. B. Dawkins, Trans. Internat. Congr. Prehistoric Arch. 3rd series.

[3] W. Topley, Geol. Weald, p. 6.

sand, and loam of a yellowish or white colour. In the neighbourhood of Hastings they consist of soft yellow and white sand, hard ferruginous sandstone, and shale, having a thickness of 140 or 150 feet. The beds are exposed at Little Horsted, and in the railway-cutting north of Worth. In the neighbourhood of Tunbridge Wells their total thickness is about 180 feet.

They contain *Lepidotus Fittoni*, *Unio*, *Cyrena*, *Paludina*, *Cypridea*, etc., and among Plants, *Carpolithes*, *Sphenopteris*, *Zamiostrobus*, and *Clathraria Lyellii*.

Some hard beds of ferruginous sandstone are dug for road-metal. Lignite has been found at Newick Old Park, near Cuckfield, and was known as the Newick Coal; it has very much the character of jet.

Grinstead Clay.—The Tunbridge Wells Sands in the western part of the Wealden district, are divided into an Upper and Lower Series by a band of clay which has been mapped by the Geological Survey under the name of Grinstead Clay. The name was suggested by Mr. Drew, because on the north side of East Grinstead the clay occupies a considerable area, and its relations with the Sands beneath may be well seen.

The Grinstead Clay attains a thickness of 50 feet or more in places; at Rye and Fairlight it is only 10 feet in thickness.

It is not quite certain, as Mr. Topley observes, whether this clay as mapped on the south side of the Weald, is always on the same horizon. He observes that the clay is generally loamy and nearly always mottled; sometimes it is stiff and shaly. The mottled variety is usually known as 'catsbrains'; but there is no positive character whereby to distinguish it from the Wadhurst Clay. It sometimes occurs only thirty feet above the base of the Sands; it contains *Paludina*, *Cyrena*, etc.

Prof. T. R. Jones has noticed sand-worn or polished pebbles in the Upper Tunbridge Wells Sandstone.[1]

Near Lindfield a bed of conglomerate occurs at the top of the Lower Tunbridge Wells Sand; here Mr. Topley found a fragment of an *Ammonite*, and he would infer that although the pebbles are apparently mostly derived from Palæozoic rocks, yet the Wealden rocks were also partly derived from the waste of Secondary strata.[2]

In the neighbourhood of Cuckfield the Upper Tunbridge Wells Sand contains a bed of clay called the Cuckfield Clay, about 15 feet in thickness, which is described by Mr. H. W. Bristow as a sandy and mottled clay, sometimes shaly. In this district the beds occur as follows:—

		Feet.
Upper Tunbridge Wells Sand.	Sand and sandstone with layers of Tilgate stone at the top	115
	Cuckfield Clay	15
	Sand and Sandstone	70
Grinstead Clay		80
Lower Tunbridge Wells Sand		100

[1] G. Mag. 1878, p. 287.
[2] Topley, Geol. Weald, p. 84.

It was from the Cuckfield district, generally spoken of as Tilgate Forest, that Dr. Mantell obtained most of his Saurian remains, *Iguanodon Mantelli*, etc. (see p. 356). The larger number were obtained from the quarry at Whiteman's Green, north of Cuckfield. William Smith also in previous years collected many reptilian bones from this quarry. The bones often occur in a rolled state in a conglomeratic band, interstratified with beds of sandstone and calciferous grit (Tilgate stone).

The High Rocks to the south-west and Penn's and Harrison's Rocks (the Eridge Rocks), south of Tunbridge Wells, are formed of the Tunbridge Wells Sand. There is also the Toad Rock on Rusthall Common west of that town, and there are other rocks at West Hoathly and Buxted. Their form is partly owing to the varied induration of the sand-rock, and to the effects of weathering along old joints, by rain, frost and wind.[1] Near Tunbridge Wells the rocks are so smoothed, polished and striated by human agency as to present the appearance of *roches moutonnées*!

WEALD CLAY.

The term Weald Clay was introduced by Conybeare in 1822. The beds consist for the most part of clay or shale, generally brown or blue, containing in places layers of shelly limestone, and sometimes sand, sandstone, and nodules of clay-ironstone and iron-pyrites. Among the fossils are Plant-remains, *Pterophyllum*, etc.; Elytra of Coleoptera; Ostracoda, *Cypridea Valdensis*; Mollusca, *Ostrea distorta* (in top beds), *Cyrena media*, and other species, *Unio*, *Corbula*, *Melanopsis*, *Paludina elongata*, etc.; and Fish-remains, *Lepidotus Fittoni*, *Hybodus dubius*, etc.

The limestones (called Sussex Marble) are composed almost entirely of *Paludina* of two or more species, large and small. The lowest bed of marble is seen near Biddenden, Staplehurst, and Crowhurst; another kind, with *P. Sussexiensis*, has been worked near Chiddingfold; while still higher in the series is the most constant bed, containing *P. fluviorum*, known as Petworth and Bethersden Marble, and Laughton Stone. Bethersden lies to the south-west of Ashford.

The thickness of the Weald Clay has been estimated at 1000 feet in the neighbourhood of Leith Hill. Mr. Topley states that extremely few junction-sections with the Atherfield Clay above are to be seen; and those with the Tunbridge Wells Sands below are not frequent.

The Weald Clay forms a low-lying tract of country, extending from Romney Marsh to Ashford and Tunbridge, and thence south of Reigate, by Ockley to the west of Haslemere, and again from Petworth to Hailsham and Pevensey Level.

The Weald Clay forms wet and rather poor land: much of it is in pasture. It was in former times extensively covered with forests; hence many of the village names end in *hurst*. It was termed Oak-tree Clay by William Smith, although

[1] See Topley, *op. cit.* p. 246.

this term was more generally used by Smith for the Kimeridge Clay, but sometimes also for the Gault. The oak was chiefly used in obtaining charcoal for the old iron-furnaces. Many hop-yards are situated on the Weald Clay between Tunbridge and Headcorn. The beds have in many places been dug as 'marl,' and the ironstone has been largely smelted, particularly in the western part of the area. Calcareous grit occurs in places, often as lenticular masses in the clay; this and the limestone-beds were formerly much dug for mending roads, and still are to some extent; they have also been used for building-purposes. Some of the beds are used for brick- and tile-making, as at Pluckley, St. John's Wood, near Lindfield, at Ockley, Holmwood, etc. The Bethersden Marble has been used extensively for building, and for making long narrow causeways, necessary in wet weather, along the muddy roads of the Wealden area.

Horsham Stone.—About 120 feet above the base of the Weald Clay there is locally a bed of calcareous sandstone capable of being split into slabs, which are used for building, paving, and roofing. Associated with it are beds of sand and sandstone not calcareous, and there is always some interbedded clay. The stone is often strongly ripple-marked, and contains footprints of *Iguanodon*. It has been worked near Itchingfield, West Grinstead, etc.[1]

In the Isle of Wight, beds identified with the Weald Clay occur between Cowleaze Chine and Compton Bay, and again at Sandown Bay. The upper portions consist of dark grey shaly clay (included in his Punfield formation by Prof. Judd); the lower of variegated marls, clays, and sandstones. Mr. Bristow observes that the Wealden strata in this district are extremely irregular, and that the thick beds of sandstone which form conspicuous objects in the cliffs occasionally thin out rapidly, as may be observed between Brixton and Barnes Chines.[2] Many Reptilian remains, also Plants (*Pinites*), have been obtained from the Wealden beds of Brook, where the lowest beds are exposed on the shore.

Between Cowleaze and Barnes Chines, the higher portions of the series were separated by Prof. Judd under the name of the Punfield formation (see sequel), of which locally he made two groups:—

2. Cowleaze series, chiefly shales with bands of limestone, 180 feet.
1. Barnes series (Barnes's Sand-rock),[3] false-bedded yellow sands, and sandstone with subordinate beds of clay, about 50 feet.

These beds attain a maximum thickness of 230 feet at Atherfield, and are exposed between Atherfield Point and Barnes High; and also in Compton and Sandown Bays.

The Cowleaze beds yield *Ammonites Deshayesii*, *Paludina*, *Exogyra sinuata*, *Ostrea*, *Modiola*, *Cyrena*, *Unio*, etc. They are overlaid by the Perna-beds of the Lower Greensand, and underlaid by the variegated Wealden beds, 300 to 400 feet thick. The Barnes series contains *Cyrena*, *Unio*, *Cardium*, and *Trigonia*; and has also yielded many Reptilian bones, including a Dinosaurian *Hypsilophodon Foxii*, obtained by the Rev. W. Fox.[4] The limestones

[1] See W. Topley, Geol. Weald, pp. 102, 252, 399; and Journ. R. Agric. Soc. (2), viii. 241.

[2] Geol. Isle of Wight (Geol. Survey), p. 5; see also Judd, Q. J. xxvii. 207; Meyer, Q. J. xxviii. 243.

[3] Fitton, T. G. S. (2), iv. 199.

[4] T. H. Huxley, Q. J. xxvi. 3; see also Buckland, T. G. S. (2), iii. 425.

of the Cowleaze series are used locally for rough paving. Mr. C. J. A. Meyer regards the Punfield Beds of the Isle of Wight as essentially part of the Wealden formation. (See p. 357.)

In Dorsetshire the Wealden Beds are represented by alternations of red and purple coloured clays, white and yellow sands, and occasional beds of quartzose sandstone or grit, with lignite towards the base. The occurrence of this lignite on the foreshore gave rise to the notion of a submerged forest in Swanage Bay. (See Fig. 54, p. 347.) In Swanage Bay the thickness of the beds has been estimated at 1800 feet; at Worbarrow Bay 725, at Mewps Bay 660, at Lulworth Cove 462, and at Man of War Cove 172 feet, showing a remarkable attenuation of the beds which takes place towards the west; but this may in part be due to faulting, for at Mewps Bay the Wealden Beds are faulted against the Greensand, etc.[1] The Wealden Beds occur at Ridgway,[2] and they are also to be seen at Dinton, west of Wilton, where fragments of *Endogenites erosa* have been obtained by the Rev. W. R. Andrews. (See p. 348.)

In Oxfordshire the lower portions of the Iron-sands of Shotover contain freshwater shells, and by some authorities the beds have been grouped as Wealden, but they are now usually regarded as Lower Greensand. (See sequel.)

In Lincolnshire the Wealden Beds are represented in part by the Spilsby Sandstone. (See Fig. 62.) In Yorkshire the Speeton Clay contains marine representatives of the Wealden Beds, and Prof. Judd has traced beds of this age at Reighton, West Heslerton, and Knapton in the Vale of Pickering.[3] (See sequel.)

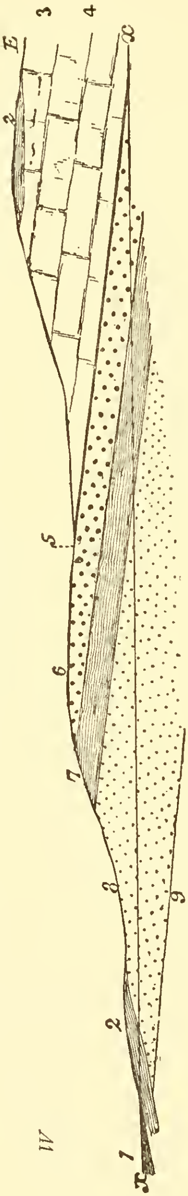
LOWER GREENSAND.

Among earlier writers much confusion arose between the Iron-sands of the Wealden series and those of the Lower Greensand; the latter term was, however, proposed by Webster in 1824, and finally came into general use, though not without protest from Fitton in 1827, and from other geologists at various subsequent times.[4]

Although the term Lower Greensand is in many respects unsatisfactory, it is so well known that more inconvenience is likely to arise from a change of name than by adhering to Lower Greensand, even if the distinction between it and the Upper Greensand is greater than the terms would seem to imply. The name Vectian, recommended in 1885 by Mr. A. J. Jukes-Browne, was previously applied by John Phillips to the Fluvio-marine Tertiary Strata of the Isle of Wight,[5] while

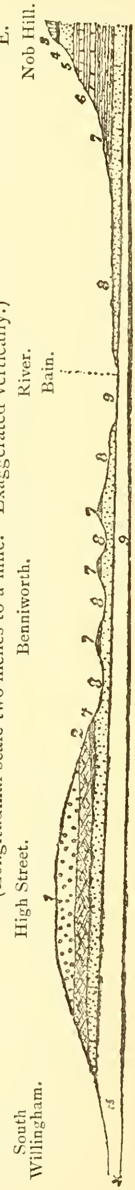
[1] Judd, Q. J. xxvii. 222; J. C. Mansel-Pleydell, G. Mag. 1873, p. 410.
[2] C. H. Weston, Q. J. iv. 245, v. 317.
[3] Q. J. xxvi. 326.
[4] See Judd, G. Mag. 1870, p. 223, 1886, p. 384; Topley, Geol. Weald, p. 15.
[5] Guide to Geology, edit. 5, p. 199.

FIG. 61.—DIAGRAM-SECTION OF THE COUNTRY NEAR SNETTISHAM SOUTH OF HUNSTANTON.
(W. Whitaker.)



x. Sea-level.
1. Alluvium.
2. Boulder Clay.
3. Chalk with Flints.
4. Hard Chalk without Flints.
5. Red Chalk.
6. Carstone.
7. Clay and Loam. } Lower Greensand.
8. Sand.
9. Probable position of Kimeridge Clay.

FIG. 62.—DIAGRAM-SECTION FROM SOUTH WILLINGHAM TO THE CHALK WOLDS NEAR DONNINGTON IN LINCOLNSHIRE.
(A. Strahan.)
(Longitudinal scale two inches to a mile. Exaggerated vertically.)



X Sea Level.
1. Boulder Clay.
2. Glacial Sand and Gravel.
3. Chalk.
4. Red Chalk.
5. Carstone.
6. Tealby Limestone.
7. Donnington Clay. } Lower Cretaceous.
8. Spilsby Sandstone.
9. Kimeridge Clay.

the name of 'Vectine' (from Insula vectis of the Romans) was suggested by Fitton in 1845.[1]

In Surrey, Kent, Sussex, and part of Hampshire the Lower Greensand has been divided by Mr. F. Drew as follows:—

4. Folkestone Beds.
3. Sandgate Beds.
2. Hythe Beds.
1. Atherfield Clay.

These divisions are well seen in the cliffs between Hythe and Folkestone, where their united thickness is about 250 feet; but westwards they attain a thickness of 450 feet and more. In the Isle of Wight and other parts of England, different divisions have been made. (See p. 355.) From Reigate westwards the beds are chiefly arenaceous, eastwards calcareous beds occur in places.

The organic remains of the Lower Greensand comprise Plants, Sponges, and Corals, Echinoderms, Annelides, and Cirripedes. The Mollusca include *Belemnites*, *Nautilus plicatus*, *Ammonites Deshayesii*, *Ancyloceras (Scaphites) gigas*, *Diceras Lonsdalei*, *Trigonia caudata*, *T. alæformis*, *Gervillia anceps*, *Perna Mulleti*, *Ostrea frons*, *Exogyra (Gryphæa) sinuata*, *Panopæa Neocomiensis*, *P. plicata*, *Thetis Sowerbyi*, *Pecten orbicularis*, *Arca Raulini*, *Cyprina angulata*; and the Brachiopoda include *Terebratula sella*, *Rhynchonella sulcata*, *R. Gibbsiana*, *Terebratella oblonga*, etc. Remains of Fishes are uncommon, they include *Strophodus*; among Reptiles are *Ichthyosaurus*, *Iguanodon*, *Plesiosaurus*, *Polyptychodon*, and *Protemys*.

In the South of England the Lower Greensand (and the Punfield Beds where these beds have been identified) rests directly on the Wealden Beds, from Kent westwards to Dorsetshire. Traced northwards the Lower Greensand overlaps the Wealden strata and rests on the Kimeridge Clay and Corallian rocks near Devizes and Calne, and on the Kimeridge Clay near Swindon, and on the Purbeck and Portland Beds in Buckinghamshire.[2] (See Fig. 58.)

WEALDEN AREA.

Atherfield Clay.

This name was given by Dr. Fitton to certain strata which overlie the Wealden Beds at Atherfield, on the south-western coast of the Isle of Wight.[3] (See sequel.)

The formation consists essentially of clay, with, in places, concretionary beds of shelly rock and calcareous bands. In thickness it varies from 60 feet at Godalming to 20 or 30 feet between Hythe and Sandgate. At Hythe it rests on shales with Cyprides, the upper part of the Weald Clay (or Punfield Beds), while the junction

[1] Q. J. i. 189.
[2] Morris, G. Mag. 1867, p. 462.
[3] Fitton, Proc. G. S. iv. 200; Godwin-Austen, *Ibid*, 171.

with the beds above, may be seen at very low tides at the base of Shorncliffe (see Fig. 60). The Atherfield Clay has also been recognized near Maidstone, Sevenoaks, Redhill, and Guildford. It has not been determined in the eastern part of Sussex, but it has been observed at Petersfield and Pulborough.

The beds display the incoming of marine conditions, for they contain *Panopæa*, *Exogyra sinuata*, *Astarte substriata*, *Arca Raulini*, *Perna Mulleti*, *Gervillia alæformis* (*anceps*), *Corbis corrugata*, *Cyprina angulata*, *Panopæa plicata*, *Trigonia caudata*, *T. dædalea*, *Aporrhais robinaldina*, *Terebratula sella*, the Coral *Holocystis elegans*, etc. Phosphatic nodules occur in the Atherfield Clay at Stopham, near Pulborough.

Hythe Beds.

These beds were named by Mr. Drew in 1861, from Hythe, on the coast of Kent. They consist of limestones, sandstones, and sands, with iron-sandstone and chert. The limestone is of a greyish-blue colour, and contains fine grains of quartz; it is known as 'rag' (Kentish Rag), hence the name Kentish Rag Series used at one time by Fitton. The beds which alternate with the 'rag' are known as 'hassock' or 'calkstone,' being sometimes a soft calcareous stone, sometimes coarse impure sand or soft sandstone.

Among the fossils of the Hythe Beds we find Plant-remains, *Chondrites*, *Pinites*, etc.; Annelides, *Serpula variabilis*; Brachiopoda, *Terebratella oblonga*, *Terebratula sella*, *Waldheimia tamarindus*; Mollusca, *Plicatula placunea*, *Exogyra sinuata*, *Lima Cottaldina*, *Gervillia anceps*, *Pecten orbicularis*, *Trigonia alæformis*, *T. spinosa*, *Ammonites Deshayesii*, *A. Martini*, *A. furcatus*, *Ancyloceras gigas*, *A. Hillsii*; Fishes, *Strophodus*; Reptilia, *Iguanodon*, etc.

Some beds in this division are largely made up of the detached spicular remains of siliceous sponges.[1] Many fossils have been obtained from quarries north-east of Hythe. (See Fig. 60.)

The Hythe Beds form the elevated and picturesque tract extending from Liphook, Haslemere, and Hindhead, to Leith Hill (967 feet above sea-level), Limpsfield, Tilburstow Hill, and Sevenoaks.

The thickness of the Hythe Beds is at Hythe 60 feet, Maidstone about 80 feet, at Sevenoaks 160 feet, at Bletchingley near Nutfield 180 feet, at Leith Hill 200 feet, around Godalming and Guildford 240 feet, and at the Devil's Punch Bowl in the Hindhead district probably as much as 300 feet. The beds occur also at Petworth.

To the south-west of Dorking the beds comprise sand, sandstone, a few layers of chert and concretions of ironstone, and in the higher part of the series there is a calcareous sandstone or grit, known as Bargate Stone, which contains *Avicula pectinata*. This stone occurs near Wotton and Abinger, on the top of the sands, and is largely quarried near Godalming. Here, at Holloway Hill,

[1] Dr. G. J. Hinde, G. Mag. 1885, p. 324; Phil. Trans. 1885.

the Hythe Beds comprise about 30 feet of false-bedded sand with Bargate Stone, resting on 46 feet of buff calcareous sand.[1] Mr. C. J. A. Meyer has described the Lower Greensand of the neighbourhood of Godalming in detail. His classification differs somewhat from that adopted by the Geological Survey, inasmuch as he places the Bargate Stone and the underlying pebbly beds with the Folkestone Beds, and he regards portions of the lower strata (here spoken of as Hythe Beds) as Sandgate Beds.[2]

The pebble-beds of Godalming, beneath the Bargate stone, consist of quartzose sand with pebbles of quartz, lydian stone, ironstone, etc., and the beds are from a few inches to ten or twelve feet in thickness. They contain also extraneous Oolitic and Liassic fossils; as well as Spines of Echinoderms, *Vermicularia concava*, and other Lower Greensand fossils, including *Terebratella Fittoni*, etc. Mr. Meyer traces the beds at Guildford, Dorking, Nutfield, and Sevenoaks, and also at Folkestone and Shanklin.[3] The beds may be compared with those of Faringdon and Seend.

At Leith Hill, Cold Harbour, etc., the Hythe Beds comprise false-bedded yellow and brown sands and sandstone, speckled with green particles of glauconite, together with a few layers of chert.

Mr. F. Drew observes that above Maidstone the Hythe Beds consist entirely of Kentish Rag with hassock between the layers; the beds worked are thirty or forty feet or even more in thickness. In the rag dark phosphatic and carbonaceous masses called "Molluskite" occur; they are supposed to be the soft parts of Mollusca petrified. The most interesting remains are those of the *Iguanodon* obtained in 1834 by Mr. W. H. Bensted.[4]

Economic products, etc.

The Iguanodon-quarry near Maidstone is one of the largest quarries in Kent, the stone being worked to a depth of 75 feet, and comprising 21 layers of building- and road-stone alternating with hassock.

The Kentish Rag and sometimes also the Hassock are used for building-purposes and road-metal. The Rag is quarried at Preston Hill, and Barming Heath, near Maidstone, Hythe, etc. Most of the old churches and castles of Kent have been constructed of this stone. It is also burnt for lime, and, according to Mr. Bensted, in the same way as Chalk, more fuel, however, being required. Hence, although superior to chalk-lime, it is more costly. An analysis showed the following composition :—

Carbonate of lime with a little magnesia	92·6
Earthy matter	6·5
Oxide of iron	·5
Carbonaceous matter	·4
	100·0

[1] Topley, Geol. Weald, p. 122.
[2] P. Geol. Assoc. 1869 (paper separately printed).
[3] G. Mag. 1864, p. 249 ; 1866, p. 18 ; Geologist, vi. 53 ; Topley, Geol. Weald, p. 124.
[4] Proc. Geol. Assoc. i. 57 ; Geologist, v. 300.

The Kentish Rag limestone is in some parts replaced by dark chert. At Sevenoaks there is a bed of chert above the Kentish Rag called the Sevenoaks Stone, which is much used for road-mending. Chert (locally called 'whinstone') has been dug near Petworth ; at this locality and at Pulborough, hard sandstones (Pulborough Stone) in the Hythe Beds have been worked since the time of the Romans.

Fuller's Earth occurs in places ; it has been dug at Tillington. Phosphatic nodules occur in the Hythe Beds near Godalming.

The soil as a rule is light, stony, and sandy, and in many places is particularly adapted to the growth of Hops. Over large areas there is much wood- and common-land covered with heath and fir.

Sandgate Beds.

This term was proposed by Mr. Drew in 1861, from the development of the beds at Sandgate, near Folkestone. (See Fig. 60.) It has been remarked that the beds form a low cliff of a blackish green colour between Folkestone and Sandgate, and they extend inland to Hythe. They consist of dark clayey sand and clay; the dark colour is due to green particles of glauconite (hydrous silicate of iron, potash and alumina). At the junction with the Hythe beds there is occasionally a band of phosphatic nodules and pebbles, with fragments or casts of fossils and bored wood.

At Sandgate the beds are 80 feet in thickness, and comprise the following strata :—

Brownish clays.
Yellowish-green sands.
Black clayey sand.
Dark greensand.
Black sands (zone of *Rhynchonella sulcata*).[1]

The Sandgate Beds contain Coniferous wood; the Annelide *Vermicularia concava;* Brachiopoda, *Rhynchonella Gibbsiana*, etc. Mollusca, *Gervillia anceps*, *Cucullæa glabra*, *Panopæa* (*Myacites*) *plicata*, *Cytherea parva*, etc. Bones of *Ichthyosaurus campylodon* have also been found.

The Sandgate Beds are not persistent over the Wealden area; at Maidstone their thickness is fourteen feet, and they are not with certainty represented at Godalming. (See p. 369.) At Pulborough they attain 100 feet, as sand and shale; and at Petersfield they are represented by about seventy-five feet of sand capped by dark sandy clay.

Some discussion has arisen concerning the position of the Fuller's Earth, whether it should be grouped with the Hythe Beds or even with the Folkestone Beds, but it is placed with the Sandgate Beds by the Geological Survey. The typical district of the Fuller's Earth is near Nutfield and Redhill or Reigate. Here, it is true, the beds do not resemble the Sandgate Beds of the coast, a circumstance which has led to some doubt as to their exact position in the series.

[1] F. G. H. Price, P. Geol. Assoc. iv. 137.

Mr. Topley, however, states that they are upon the same horizon as the Fuller's Earth of Maidstone, and this has been traced continuously eastwards into the typical Sandgate Beds of East Kent.[1]

The following account of a Fuller's Earth pit west of Nutfield Church is by Mr. Whitaker:[2]—

Folkestone Beds.	Grey and ironshot sand	15 feet or more.
Sandgate Beds.	Buff sandy clay, with bed of clayey greensand, about	15 ,,
	Soft sandstone	4 ,,
	Greenish sandy clay	½ ,,
	Sandstone	12 ,,
	Fuller's Earth, the upper part discoloured to a buff tint (by infiltration of water, and consequent peroxidation of iron), the lower part blue	8 ,,
	Soft sandstone (Hythe Beds?)	

The thickness of the Fuller's Earth is sometimes twelve feet. The beds have been worked for a long period, the blue and yellow varieties being equally valuable. An analysis showed the composition as follows:[3]—

Silica	53·00
Alumina	10·00
Peroxide of Iron	9·75
Magnesia	1·25
Lime	0·50
Potash	trace
Chloride of Sodium	0·10
Water	24·00
	98·60

The amount of magnesia, lime, and soda is sometimes larger.

The soil on the Sandgate Beds is variable: in Kent it is loamy, and heavier than other divisions of the Lower Greensand, while in Sussex the soil is light and poor.

Folkestone Beds.

This term was proposed by Mr. Drew in 1861, because the beds are well exposed at Folkestone, in the cliffs below and east of the town, whence they descend beneath the Gault. Westwards they extend towards Hythe. (See Fig. 60.)

The Folkestone Beds consist of sand generally false-bedded and 'Carstone,' having an average thickness of 100 feet; and they were termed the Ferruginous Sands by P. J. Martin in 1829. At Godalming the thickness is estimated at 160 feet; at Folkestone 70 to 90 feet; at Petersfield 100 feet; and at Eastbourne at about 70 feet.

[1] Topley, Geol. Weald, p. 130; C. J. A. Meyer, G. Mag. 1866, p. 15; P. Geol. Assoc. vi. 373.

[2] Geol. Weald, p. 132. See also Meyer, P. Geol. Assoc. v. 159.

[3] Bristow, Glossary of Mineralogy, p. 145.

Four divisions are noted at Folkestone by Mr. F. G. H. Price:[1]—

Sands and conglomeratic bed, about 7 feet. Zone of *Ammonites mammillaris*. (Junction-bed with Gault.)	
Calcareous sandstone (Folkestone Stone) and sand, made up largely of Sponges	60 feet.
Clayey sandstone	2 ,,
Brown ferruginous sandstone with phosphatic nodules	1 ,,

In places there occur beds of greenish clayey sandstone, which owe their colour to the deposition of glauconite in the interior of shells of Foraminifera, etc. The upper (or Junction) bed comprises coarse grit, composed of quartz, jasper, etc., with phosphatic nodules, and contains *Ammonites mammillaris*, *Exogyra conica*, etc. M. Gaudry in 1859 proposed to place this bed with the Gault.[2]

The Folkestone Beds contain *Arca Raulini*, *Lima elongata*, *Ostrea frons*, *Lucina Arduenensis*, *Avicula pectinata*, *Panopæa plicata*, *Pecten (Janira) quinquecostatus*, *P. orbicularis*, *Exogyra sinuata*, *Terebratula biplicata*, *T. sella*, *Rhynchonella depressa*, *Waldheimia pseudo-jurensis*, *Serpula filiciformis*, and *Ichthyosaurus campylodon*.

The beds are not as a rule fossiliferous, but specimens have been found at Copt Point, Folkestone. The Folkestone Beds form a very persistent stratum beneath the Gault in the Wealden district.

The term Carstone is applied to a ferruginous grit of irregular nature, which is largely quarried for road-metal at Pulborough, Fittleworth, Trotton Common, etc. In Woolmer Forest it is termed the Forest Stone. At Ightham hard green grit is found in large masses on the Common, and called the Ightham Stone.

Sometimes phosphatic nodules occur in the upper part of the series, at the junction with the Gault: they have been worked at Farnham. They occur also at the base of the Folkestone Beds.

Glass-sand is often dug from the Folkestone Beds; large quantities of white sand are obtained for this purpose at Reigate (Reigate Sand), and also in Kent at Aylesford (25 feet), Berstead (Berstead Sand), White Heath near Hollingbourn, and elsewhere.

Mr. Topley observes that the Folkestone Beds form an exceedingly sterile soil, especially where they spread over a wide tract or make high ground, as on Albury, Black, and Farley Heaths. The escarpment of the Folkestone Beds, overlooking the lower ground of the Sandgate Beds, is well marked in many places.[3]

In the Kentish Town boring, and at Tottenham Court Road, London, there was no trace of Lower Greensand, while at Richmond it was proved to have a thickness of about ten feet, at Caterham twenty feet, and at Chatham forty-one feet.[4]

[1] P. Geol. Assoc. iv. 138.

[2] Bull. Soc. Géol. Fr. (2), xvii. 32; G. Mag. 1882, p. 92; C. Barrois, Ann. Soc. Géol. du Nord, iii. 23.

[3] Geol. Weald, p. 258.

[4] Whitaker, Geol. London, ed. 4, p. 20; Judd, Q. J. xl. 744; Prestwich, Q. J. xxxiv. 909.

ISLE OF WIGHT AND SOUTH-WESTERN COUNTIES.

In the Isle of Wight the following divisions of the Lower Greensand, seen in succession between Atherfield Point and Rocken End, were noted by Dr. Fitton :[1]—

		Feet.	In.
Shanklin Sands.	Variously coloured sands and clays	118	4
	Upper clays and Sand-rock	118	0
	Ferruginous sands of Blackgang Chine	20	6
Walpen Sands and Crioceras Beds.	Sands of Walpen and Blackgang Undercliff	97	0
	Laminated clay and sand	25	0
	Cliff-end sands, with concretions	20	0
	Upper Gryphæa (Exogyra) group, with *Exogyra sinuata*	16	0
	Walpen and Ladder sands	42	0
	Upper Crioceras group, sand with nodules and *C. Bowerbankii*	46	2
	Walpen clays and sands	57	0
	Lower Crioceras group, sand with nodules and *C. Bowerbankii*	16	3
	Scaphites group, brown sand with *Ancyloceras* (*S.*) *Hillsii*, *A. gigas*	50	4
	Lower Gryphæa (Exogyra) group, brown sand, with *Exogyra sinuata*	32	0
Atherfield Beds.	The 'Crackers,' sandy clay	85	0
	Atherfield clay	60	0
	Perna Mulleti Bed, sandy clay and sand	5	3
		808	10

The 'Crackers' bed contains two layers of ferruginous sandy nodules, so called from the noise produced by the waves in dashing over the ledges formed by them on the shore.

The Lobster Clay of Atherfield occurs in the lower portion of the 'Crackers' division : it yields *Astacus Vectensis* and *Meyeria magna*.

The Atherfield Clay is exposed also at Red Cliff, and the other divisions may be seen in Sandown Bay.

Punfield Beds.—Prof. J. W. Judd suggested in 1871 that a distinctive name, taken from Punfield Cove, on the north of Swanage Bay, should be applied to certain strata previously grouped with the upper part of the Wealden Beds and the base of the Lower Greensand; and he indicated the occurrence of these Punfield Beds, not only in Dorsetshire, but in the Isle of Wight (see p. 364), at Hythe, and perhaps also at Leith Hill.[2]

The beds consist of an alternation of yellow sands and clays, with limestones, marls, seams of "beef," and layers (made up of small oysters) resembling the 'Cinder-bed' of the Purbeck series. Their fauna is brackish or fluvio-marine, hence they differ from the

[1] T. G. S. (2), iv. 195; Q. J. iii. 289; Mantell, Geol. Excursions Round the Isle of Wight, edit. 3, 1854; Simms, Q. J. i. 77; Ibbetson and Forbes, Q. J. i. 190; C. J. A. Meyer, G. Mag. 1866, p. 15; H. W. Bristow, Geol. I. of Wight, p. 10.

[2] Q. J. xxvii. 211.

main mass of the marine Lower Greensand above, and from the freshwater Wealden below. Among the fossils noted by Prof. Judd from the Punfield Beds are *Exogyra sinuata*, *E. Boussingaultii*, *Corbula striatula*, *Cardium subhillanum*, *Anomia lævigata*, *Vicarya*, *Cerithium*, *Ammonites Deshayesii*, etc.; these occur in the Marine band. The Punfield Beds attain a thickness of 65 feet at Worbarrow Bay, but they have not been noticed further west. Traces of laminated clays and sands, probably on the same horizon, were opened up in a cutting by Corfe railway-station.

The sequence of beds below the Gault at Punfield is as follows:—

			Feet.	Ins.
	Grey clays alternating with ferruginous sandy beds. *Exogyra sinuata*, *Panopæa Neocomiensis*		60	0
Punfield Beds.	Grey laminated shales with bands of limestone (Cypridiferous Beds), *Cyrena media*, *Ostrea*, etc., about		6	0
Punfield Beds.	Grey and ash-coloured sands, with interlaminated clays and lignite, and seams and bands of ironstone. Bands near middle with *Ostrea*, etc.		100 to 150	0
Punfield Beds.	Hard, laminated, micaceous sandstone Bed of oysters Blue shelly limestone	Marine Bed.	1	9
	Blue clay with *Arca*, and the marine Crustacean (Atherfield lobster) Clays with many Lower Greensand fossils Line of ironstone nodules		about 100	0
Wealden.	Dark clays, with *Cypris*		7	6
Wealden.	Grit-band, with *Cypris* and Fish-remains.			
Wealden.	Blue Cypridiferous shales and clays.			
Wealden.	Variegated clays and sands, etc.			

The beds marked above as Punfield Beds were so grouped by Prof. Judd, but afterwards Mr. C. J. A. Meyer obtained evidence of marine shells below the 'Marine Bed,' and he regards the entire series between the Wealden Beds and Gault as a littoral facies of Lower Greensand.[1] The section was subsequently studied by Members of the Geologists' Association, and some further important particulars have been incorporated above, which tend to corroborate the views of Mr. Meyer.[2] (See Fig. 54, p. 347.)

The thickness of the Lower Greensand at Worbarrow Bay has been estimated at 36 feet, excluding the Punfield Beds. At Mewps Bay the Lower Greensand is faulted against the Wealden Beds, and it is not seen at Lulworth Cove.[3] Mr. Etheridge has stated that it is represented by a bed of Carstone, 1 to 2 feet thick, at Black Ven, Lyme Regis:[4] but westwards beyond this somewhat doubtful representative, no Lower Greensand has been traced, although at one time it was supposed that the Blackdown Greensand included portions of it. Its abrupt termination near Lulworth is due in part to faulting, but also to attenuation, and overlap by the Upper Cretaceous strata.

In Wiltshire the Lower Greensand consists of ferruginous beds

[1] Q. J. xxviii. 250; xxix. 70.
[2] W. H. Hudleston, P. Geol. Assoc. vii. 388.
[3] Judd, Q. J. xxvii. 211; see also Godwin-Austen, Q. J. vi. 455; xii. 69.
[4] Q. J. xxxviii. 93; xli. 26.

which are paralleled with the Faringdon Beds, and with the Sandgate and Folkestone beds. The series has a thickness of from 25 to 30 feet, and consists of red, yellow, and grey sands, containing, according to Lonsdale, the following beds in descending order:[1]—

Calcareous grit with sandy clay.
Sandstone.
Quartzose conglomerate.
Ironstone-nodules.
Chert (comparatively rare).

The quartzose conglomerate yields pebbles of quartz, lydian stone, slate, oolite, etc. It was regarded by Mr. Godwin-Austen as true littoral shingle. The pebbles of quartz, etc., may have been derived from the Corallian Beds (Lower Calcareous Grit); the 'lydian stone,' in Prof. Bonney's opinion, is for the most part chert from the Carboniferous Limestone, and these and other pebbles may perhaps have been derived from Triassic rocks, directly or indirectly.[2] (See Fig. 58, p. 352.)

Diceras (*Requienia*) *Lonsdalii* occurs at Stock Orchard, south of Calne, at Lockswell Heath, to the east of Bowden Hill, and at other localities near Devizes and Seend. Among other fossils are *Terebratella Menardi*, *Terebratula depressa*, *Pecten interstriatus*, *Nucula impressa*, *Opis Coquandiana*, *Emarginula Neocomiensis*, etc. At Seend, where the beds rest on the Kimeridge Clay, they comprise false-bedded brown ferruginous sands, sandstone, and quartzose sand. Ochreous nodules occur, and veins of ironstone traverse the beds vertically and horizontally, while here and there greenish sands and laminated sandy clays occur.[3] Mr. W. Cunnington has pointed out that at Seend the upper part of the Kimeridge Clay contains septaria bored by *Lithodomus* of the Lower Greensand.[4]

The iron-ore at Seend has been largely worked; and beds of quartzose sandstone from this locality were used in ancient times for making querns. Quartzose conglomerate occurs also near Swindon. Beds of sand and ironstone are developed west of Devizes, at Poulshot Green, Rowde and Bromham. Fine white quartzose sand has been extensively worked at Sands Farm, east of Calne. In the Vale of Wardour the beds have not been clearly exposed.[5]

MIDLAND COUNTIES.

Faringdon Beds.—To the south of Faringdon, in Oxfordshire, are the celebrated 'Sponge-Gravels' of Little Coxwell. The beds are from 25 to 40 feet thick, and form a plateau based on Kimeridge Clay and Corallian rocks. The gravels are capped in places by dark ironsand, and their total thickness has been estimated at from seventy to one hundred feet. The gravels consist of quartzose

[1] T. G. S. (2), iii. 266.
[2] Address to Geol. Sect. Brit. Assoc. 1886.
[3] T. R. Jones and C. D. Sherborn, G. Mag. 1886, p. 274.
[4] Q. J. vi. 453.
[5] Fitton, T. G. S. (2), iv. 248.

conglomerate and sand, with fossils (calci-sponges, etc.), mostly hardened by a ferruginous cement. The surface of this deposit is sometimes curiously weathered and "piped." There has been much dispute as to the age of this gravel, but it is now generally referred to the Lower Greensand. Pebbles of slate, quartz and crystalline rocks, as well as Oolitic rocks, occur, and the beds are evidently the continuation of those exposed at Seend and other parts of Wiltshire. They contain the same species of *Nucula*, *Opis*, *Emarginula*, and *Terebratula*; and also some species derived from Oolitic beds (mostly from the Kimeridge Clay and Corallian rocks); the Brachiopoda are similar to those met with at Wicken, etc. (See sequel.) The derived fossils are chiefly the remains of Vertebrates; the Lower Greensand species comprise Sponges, Polyzoa, Echinoderms, Brachiopoda, and bivalve Mollusca, the rarity of univalves being remarkable. The Sponges are most important, both as forming a large part of the gravel and from their good preservation. They have been carefully studied by Dr. G. J. Hinde, and include *Tremacystia* (*Verticillopora* or *Verticillites*) *anastomans*, *Peronella* (*Scyphia*) *ramosa*, *Elasmocœlia* (*Tragos*) *Faringdonensis*, *Corynella* (*Scyphia*) *foraminosa*, *Synopella* (*Manon*) *pulvinaria*, *Elasmostoma consobrinum* (*Manon peziza*), *Raphidonema* (*Manon*) *Faringdonense*, *R. macropora*, etc.

Overlying the Sponge-gravels there is a series of clays and sands with ironstone bands, developed on the Furze Hills and at Cole's Pits, east of Little Coxwell. 'Cole's Pits' are old excavations, upwards of 270 in number, extending over fourteen acres. They have, by some, been regarded as the remains of early British habitations; and the largest has been pointed out by tradition as the castle of 'King Cole,' but as Mr. Godwin-Austen has observed, "Geology can countenance no fictions except its own, and Cole's Pits are evidently the remains of the open workings for the ironstone overlying the mass of sand." [1]

Some of the hard beds in the Lower Greensand near Faringdon have been made into millstones, and they are used for road-metal, for building walls, etc.

Shotover Sands.—The Ironsands of Shotover have attracted the attention of many geologists since the time of William Smith, Conybeare, Buckland and Fitton; but in the early days of geology there was, as before mentioned, much confusion between the Ironsand of the Wealden and that of the Lower Greensand.

In ascending Shotover from Oxford we pass over Oxford Clay, Corallian Rocks, Kimeridge Clay, Portland Beds, and then come upon the Ironsand and Ochre series at the top of the hill. This series, 80 feet in thickness, comprises white and yellow, and sometimes brown or black sands, sandstones occasionally cherty, blue and white clay, fuller's earth, ironstone, oolitic iron-ore and ochre. Organic remains occur in these beds, especially in the ferruginous layers; they were discovered in 1833 by the Rev. H. Jelly, of Bath, but they have not been noticed in the uppermost

[1] Godwin-Austen, Q. J. vi. 453; Archæologia, v. 7; D. Sharpe, Q. J. x. 176; J. Phillips, Geol. Oxford, p. 431; E. C. Davey, Trans. Newbury Field Club, 1874, vol. ii.; W. T. Aveline, Explan. Sheet 34 (Geol. Survey), p. 28; J. Morris and C. J. A. Meyer, P. Geol. Assoc. iv. 554; Geologist, vii. 5; G. Mag. 1866, p. 16; G. J. Hinde, Catalogue of Fossil Sponges, 1883.

sandstones, 20 feet thick. They include *Unio Stricklandi*, *Cyrena media*, *Paludina elongata*, *P. Sussexiensis*, etc. None of the marine forms usual in Lower Greensand have been met with, and the fossils are suggestive of Wealden beds. At Great Hazeley, and other places south-east of Shotover, the beds rest on Portland or Purbeck strata, while near Woburn the equivalent beds are overlaid by Gault. Although distinct from the marine deposits of Seend, Faringdon, etc., these beds are now usually regarded as an estuarine deposit of Lower Greensand age.[1]

At Brill the Ironsand series (fifty or sixty feet) rests on the Purbeck Beds, and comprises brown ferruginous sandstone, with *Cyrena*, and white and yellow sands ; at Quainton, also, remains of *Cyclas* and *Paludina* occur in the lower beds.[2]

At Hartwell and Stone, near Aylesbury, the Purbeck Beds are covered with brown ferruginous and white sand, with pebbles of quartzite, quartz and lydian stone. The white sand of Hartwell (eight feet) has been used for glass-making, and sent to Birmingham ; the lower beds contain hard siliceous concretions called "Bowel-stones," used as ornaments in the neighbourhood. At the base of the sands of Hartwell, according to Prof. Morris, but not *in situ*, are blocks of compact brown sandstone, containing casts of *Unio*, *Cyrena*, *Paludina*, and traces of Plants. The sands themselves contain impressions of *Lima*, *Pecten*, *Exogyra sinuata*, etc. Near Stone, at the base of the sands, *Unio* and *Paludina* were also met with, as well as *Endogenites erosa*, suggesting the former existence over this area of Wealden Beds, which were subsequently removed by denudation, previous to or during the deposition of the sands above.[3] At Round-hill pit, near Stone, the sands are covered by beds of impure fuller's earth and coarse iron-sandstone, containing casts of *Pecten*, *Ostrea*, etc. In this neighbourhood the beds yield a good water-supply.

Woburn Sands, Potton and Wicken Beds.—The Lower Greensand is well exposed near Leighton Buzzard, at Little Brickhill in Buckinghamshire, between Fenny Stratford and Woburn, at Sandy and Potton, and at Wicken and Upware south-west of Soham. It consists of iron-sands, etc., and contains near its base a variable band of gravel or nodule-bed (6 in. to 2 feet in thickness) full of fossils, mostly water-worn, including many bones and teeth of Saurians, Fish-remains, and 'coprolites.' Pebbles of quartz, quartzite, lydian stone, and ironstone occur in the bed, which is sometimes cemented into a hard rock by carbonate of lime. Most of the fossils are derived from the Wealden and Upper Oolitic strata. Some indigenous fossils are found, and they indicate that the beds are of the age of the Lower Greensand. Among derived fossils, *Ammonites biplex* is very abundant. The indigenous fossils

[1] See Phillips, Geol. Oxford, p. 111 ; Q. J. xiv. 236, xvi. 309 ; Fitton, T. G. S. (2), iv. 272 and plate x*a*. ; E. Hull, Explan. Sheet 13 (Geol. Survey), p. 15 ; see also J. J. H. Teall, The Potton and Wicken Phosphatic Deposits, p. 32.

[2] A. H. Green, Explan. Sheet 45 (Geol. Surv.), p. 50.

[3] G. Mag. 1867, p. 459.

include *Waldheimia tamarindus*, *W. Woodwardi*, *Terebratula depressa*, *Rhynchonella latissima*, *Ostrea macroptera*, *Trigonia alæformis*, *Opis Neocomiensis*, *Cyprina Sedgwickii*, *Pleurotomaria gigantea*, and (at Upware) the Sponge *Elasmostoma acutimargo*.[1]

Iron-ore was formerly worked in the sands in the neighbourhood of Leighton Buzzard; and this locality has yielded *Cycadites Yatesii*, (described by Mr. Carruthers).[2] *Pinites* has been obtained from the Potton Beds.

Prof. Bonney observes that the 'coprolites' consist of wood, mineralized by phosphate, casts of Mollusca, bones, and shapeless lumps; they are worked for manure. The Potton phosphatic nodules, to which attention was first directed by the Rev. P. B. Brodie, yield from 30 to 50 per cent. of phosphate of lime, while those of the Cambridge 'Greensand' yield 58 to 61 per cent. The occurrence of phosphatic nodules at the base of the sands at Brickhill was made known in 1873 by Mr. Teall. The Upware district was first described by Mr. J. F. Walker, and there phosphatic nodules occur in the Lower Greensand and also at the base of the Gault.[3]

In the neighbourhood of Woburn the Woburn Sands (termed by the Rev. John Michell in 1788 the 'Sand of Bedfordshire') are about 220 feet in thickness, and here at Wavendon and other places fuller's earth has been dug for the past 150 years.[4] The fuller's earth occurs rather below the middle part of the sand, as follows:—

Sand	130 feet.
Fuller's Earth	12 ,,
Sand ... about	80 ,,

The fuller's earth is now obtained by sinking shafts, at Aspley Heath. The water thrown out by this bed is said to be very pure and sweet, and Mr. A. C. G. Cameron states that blocks of the earth have been placed in wells to purify the water. At Ampthill the thickness of the Lower Greensand is upwards of 30 feet, while at Potton it is over 100 feet; at these localities, as well as at Sandy and Woburn, the Lower Greensand contains much iron-ore in the form of ochre, etc.

Prof. Bonney remarks that at Sandy, in Bedfordshire, the Lower Greensand strata form a remarkably picturesque escarpment on the right bank of the Ivel; between that place and Potton, they are cut through by, and well seen from the railway between Bedford and Cambridge. They consist of Carstone and buff or ochreous brown sand, often showing false-bedding, and with many cakes and concretions of brown iron-oxide. So sterile is the land in places that it can support little but the Scotch fir; still the extraordinary productiveness of the market-gardens in the Ivel valley above Sandy is largely due to the admixture of this light warm sand in the alluvial soil.[5]

[1] J. F. Walker, Ann. Nat. Hist. (3), xviii. 31, 381, xx. 118; H. G. Seeley, *Ibid*, xviii. 111, xx. 23; and Index Woodwardian Museum, p. ix; Brodie, G. Mag. 1866, p. 153; J. J. H. Teall, The Potton and Wicken Phosphatic Deposits; Bonney, Cambridgeshire Geology, p. 22.

[2] G. Mag. 1867, p. 199.

[3] G. Mag. 1867, p. 454; 1868, p. 399. See also W. Keeping, The Fossils, etc., of Upware and Brickhill, 1883.

[4] Fitton, T. G. S. (2), iv. 295; Rev. B. Holloway, Phil. Trans. xxxii. 419 (1723); Conybeare and Phillips, Geol. Eng. and Wales, p. 138; A. C. G. Cameron, G. Mag. 1885, p. 91, Brit. Assoc. 1885.

[5] Cambridgeshire Geology, p. 22.

EASTERN COUNTIES.

In Cambridgeshire the Lower Greensand consists of brown and yellow false-bedded sands, with ironstone concretions and occasional beds of loam; its total thickness is about seventy feet.[1] At Ely it rests on the Kimeridge Clay, and is there only about nine feet in thickness, and at Haddenham it is fifteen feet thick.

The Lower Greensand of Norfolk consists of alternating beds of red and white sand, sandstone and clay, from seventy to one hundred feet in thickness. Some of the beds, as in the cliff at Hunstanton, are conglomeratic, containing pebbles of quartz, lydian stone, etc. (See Frontispiece.) The hard beds, locally termed Carstone, ('gingerbread stone,' or Quern stone), are quarried for building-purposes at Snettisham, while the white sand of Snettisham and Castle Rising has been used in the manufacture of glass. The occurrence of 'Carstone,' as remarked by Mr. Whitaker, is a local feature, dependent on the presence beneath the sand of beds of clay which have arrested the percolation of ferruginous waters.[2] (See Fig. 61, p. 366.) On the foreshore at Hunstanton clayey beds (at one time thought to be Kimeridge Clay) have been described as the Perna-bed by the Rev. T. Wiltshire, containing *P. Mulleti*, *Ancyloceras gigas*, and *Ammonites Deshayesii*; Mr. Teall, however, considers that the bed cannot be properly correlated with the Atherfield Clay, as it may represent a higher subdivision of the Lower Greensand. In all probability the strata here rest upon the Kimeridge Clay, as they do further south at Lynn. The Lower Greensand contains one or two impersistent beds of clay, worked for brick-making at Heacham, Ingoldsthorpe, and Sandringham warren. At Heacham, Mr. Teall obtained *Ammonites Deshayesii*, *Pecten orbicularis*, and *Trigonia*, from ironstone-nodules in the clay. These also contain fine specimens of iron-pyrites. At Ingoldsthorpe the Lower Greensand is said to contain a bed of Fuller's Earth; here Dr. Fitton obtained some fossils.[3]

The sands form a fine and picturesque escarpment extending from Heacham to Sandringham; they were termed Sandringham Beds by Mr. F. W. Harmer.[4] Where the hard beds of Carstone appear on the fore-shore at Hunstanton, they form a pavement which has been separated into isolated masses by the sea eroding along the lines of joints.

Tealby Series, etc.—In Lincolnshire the following beds occur beneath the Red Chalk:—

Carstone.	
Tealby Limestone	Tealby Series.
Donnington Clay........................	
Spilsby Sandstone	

Mr. A. Strahan has lately pointed out that the Carstone in this area rests on different members of the Tealby series, and presents

[1] Penning and Jukes-Browne, Geol. Cambridge, p. 11; see also Penning, G. Mag. 1876, p. 218.

[2] P. Geol. Assoc. viii. 139.

[3] T. G. S. (2), iv. 306, 313; see also J. J. H. Teall, The Potton and Wicken Phosphatic Deposits, p. 17; Wiltshire, Q. J. xxv. 189; Judd, Q. J. xxiv. 236.

[4] "Testimony of the Rocks" in Norfolk, 1877.

a strong contrast to them in lithological character, and in being, except for the derived fauna, entirely unfossiliferous. It is composed of such materials as would result from the "washing" of the Tealby beds. In general it is a reddish-brown grit, made up of small quartz-pebbles, flakes and spherical grains of iron-oxide, with rolled phosphatic nodules. Towards the south, where it is thick, the nodules are small and sporadic; but northwards, as the Carstone becomes thinner, they increase in size and abundance, so as to form a "coprolite-bed," and have yielded specimens of *Ammonites Speetonensis*, *A. plicomphalus*, *Lucina*, etc. When the Carstone finally thins out, the conglomeratic character invades the Red Chalk, similar nodules being then found in this rock. The presence of these nodules, with their organic remains, taken in connexion with the character of the materials of the Carstone, points to considerable erosion of the Tealby beds. On the other hand, there is a passage from the Carstone up into the Red Chalk, as noticed by Mr. C. J. A. Meyer.[1] Hence in Mr. Strahan's opinion the Carstone should in this area be regarded as a "basement-bed" of the Upper Cretaceous rocks.[2]

The Carstone was described by Prof. Judd under the name of the Upper Ferruginous Sands, and is from 20 to 40 feet in thickness. The term Langton Sand, from Langton, near Spilsby, has been used by Mr. Jukes-Browne.

The Tealby Series, so named by Prof. Judd, from Tealby north-east of Market Rasen, consists of beds of limestone (greystone), and sandy clay, from 40 to 50 feet thick;[3] underlaid by beds of sand and sandstone, from 30 to 40 feet thick. These beds are now divided into the Tealby Limestone, the Donnington Clay, named by Mr. Strahan from Donnington, south-east of Louth; and the Spilsby Sandstone, named by Mr. Strahan from the town of that name. The Tealby series yields *Pecten cinctus* (9 to 12 inches in diameter), *P. orbicularis*, *Exogyra sinuata*, *Ostrea frons*, *Belemnites semicanaliculatus*, *Rhynchonella parvirostris*, etc. The fossils obtained from the Spilsby Sandstone at Bolingbroke, etc., include many Oolitic forms.[4]

Iron-ore composed of oolitic grains of hydrated peroxide of iron has been worked in the Tealby Beds, at Claxby and Nettleton, and pisolitic iron-ore was formerly worked at Walesby.[5] The coarse sandstone of the series has been used for building-purposes.

Speeton Clay.—The Speeton Clay, so named by Prof. Phillips in 1829, consists of a series of black and dark-blue clays, sometimes bituminous, pyritic, or slaty, and it attains a thickness of 500 feet. It was termed the Upper Shale by Young and Bird in 1822.

The section of Speeton Clay occurs on the coast to the north of Flamborough Head, where the strata are much disturbed and obscured by slips; the clay extends inland to Knapton, etc. The

[1] G. Mag. 1869, p. 13.
[2] Q. J. xlii.; P. Geol. Assoc. viii. 386.
[3] Q. J. xxiv. 236. See also W. H. Dikes and J. E. Lee, Mag. Nat. Hist. i. 560.
[4] Jukes-Browne, Geol. E. Lincolnshire (Geol. Surv.), 1886.
[5] Morris, G. Mag. 1867, p. 460; see also H. Keeping, Q. J. xxxviii. 239.

beds are overlaid unconformably by the White Chalk and Red Chalk, and they rest on the Kimeridge Clay and Portland Beds, which were formerly included with them. The Speeton Clay represents the Lower Greensand and Wealden Beds, but no portion of it appears to be of the age of the Gault.[1] A section near Givendale Church, described by Prof. J. F. Blake, showed conglomerate, and variegated sandstone, not unlike the Carstone of Norfolk, overlaid by Red Chalk, etc.[2]

Prof. J. W. Judd has made the following divisions in the Speeton Clay:[3]—

Speeton Clay (Lower Cretaceous or Neocomian).	*Upper Beds.* 150 feet.	Black and dark-blue clays, 120 feet.
		Cement-beds, 30 feet. Light-blue clay containing regular layers of large septaria.
	Middle Beds. 150 feet.	Dark-blue clays, 80 feet, with a few septaria.
		Zone of *Pecten cinctus*, 40 feet, dark-blue clays. (Shrimp-bed in lower part: nodules containing *Meyeria* (*Astacus*) *ornata*.)
		Ancyloceras-beds, 30 feet, dark-blue clay with layers of septaria.
	Lower Beds. 200 feet.	Blue Clays. Zone of *Ammonites Speetonensis*, 100 feet.
		Clays. Zone of *Am. Noricus*, 50 feet.
		Pyritic clays. Zone of *Am. Astierianus*, 50 feet.
		Coprolite-bed. Phosphatic nodules and Saurian remains.
	Portland Beds.	Fish-bed.
		Clays and hard dark-coloured rock-bands.
	Kimeridge Clay.	Laminated bituminous clays and slaty beds.
		Light-blue sandy and dark-blue pyritic clays, with jet.
		Dark-coloured clays.

Among the fossils recorded by Prof. Judd are the following:—*Ancyloceras*, *Ammonites Deshayesii*, *Aporrhais* (*Rostellaria*) *Parkinsoni*, *A. bicarinata*, *Trochus granulatus*, *Nucula obtusa*, *Isocardia angulata*, *Panopæa Neocomiensis*, *Thracia Phillipsii*, *Pecten orbicularis* (Upper Beds); *Meyeria ornata*, *Belemnites jaculum*, *Ancyloceras Duvalii*, *A. Emericii*, *Exogyra sinuata*, *Pecten cinctus* (Middle Beds); *Belemnites lateralis*, *Ammonites Speetonensis*, *A. Astierianus*, *Exogyra Couloni* (Lower Beds); *Ammonites rotundus*, *Lucina Portlandica* (Portland Beds); and *Belemnites nitidus*, *Ammonites rotundus*, *A. biplex*, *Exogyra virgula*, *E. nana*, *Discina latissima*, and *Lingula ovalis* (Kimeridge Clay).

The Septaria are used in the manufacture of Portland cement; upwards of 1000 tons being annually sent to Hull. Some of the light-coloured clays in which the cement-stones occur, produce a fine quality of the same cement. The Coprolite-bed is worked also for artificial manure. Inland the clays are worked for brick-making.

[1] Godwin-Austen, Proc. G. S. iv. 197; J. Leckenby, Geologist, ii. 9; Rev. T. Wiltshire, *Ibid.* 264; Phillips, Geol. Yorkshire, Part 1, edit. 3, p 99.

[2] G. Mag. 1874, p. 363.

[3] Q. J. xxiv. 218; see also C. F. Strangways, Explan. Sheets 95 S.E. and S.W. (Geol. Surv.), p. 25.

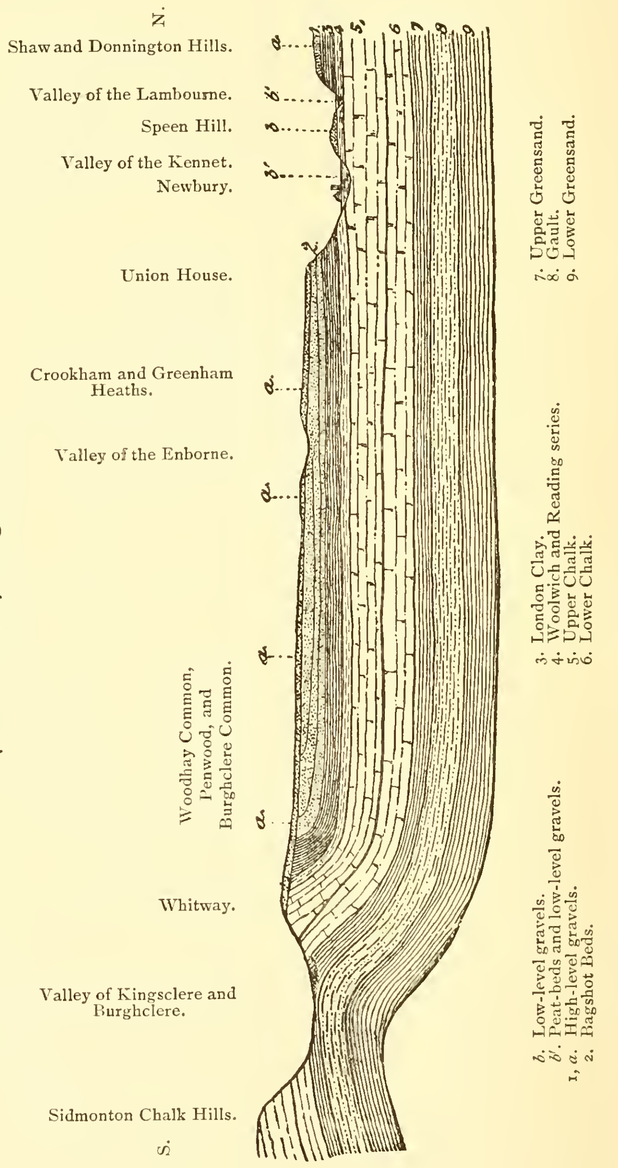


FIG. 63.—SECTION FROM THE VALLEY OF KINGSCLERE TO THE HILLS NORTH OF NEWBURY.

(H. W. Bristow.) Length 8 miles.

UPPER CRETACEOUS.

The Upper Cretaceous strata are divided as follows:—

3. Chalk.
2. Upper Greensand.
1. Gault.

These strata are intimately connected, for it is frequently difficult to fix any divisional line between the Chalk and Upper Greensand, and between the Gault and Upper Greensand.[1] In Devonshire the Blackdown Beds probably represent littoral deposits of the age of the Gault, as well as Upper Greensand.

GAULT.

The term Gault (spelt also Galt or Golt) is a local name in Cambridgeshire for unctuous clay, and from its application in that district to the strata now under consideration, the term came to be restricted to them; it was used as early as 1788 by the Rev. John Michell. The term Blue Marl was used by William Smith (1812): and the name Albian given by D'Orbigny (from the department of the Aube) is sometimes applied.

The Gault may be described as a stiff blue or pale bluish-grey clay, sometimes calcareous or sandy and micaceous, and now and then containing indurated nodules and small septaria. Nodules and crystals of iron-pyrites are abundant, and many of the fossils are pyritic: small crystals of selenite are not uncommon. A layer of iron-grit occurs at its base in parts of Sussex; but in this position there is generally found a band of phosphatic nodules.

The thickness of the Gault is at Folkestone 100 feet, at Maidstone 150 feet, and in the boring at Chatham, 193 feet. At Caterham, a thickness of 343 feet was proved in a well. In Wiltshire it varies from 70 to 100 feet; in Oxfordshire and Berkshire it is about 250 feet; and in Buckinghamshire upwards of 200 feet. Near Cambridge it varies from 115 to 180 feet, and between Arlesey and Ashwell, and at Hitchin, from 180 to over 200 feet. Near Downham Market it may be about 60 feet; it was proved in a well sunk at Holkham, near Wells, in Norfolk, 10 feet; and at Norwich (Carrow Well), about 38 feet. In deep borings at Harwich it was 61 feet thick, and at Kentish Town, London, 130 feet.

The Gault at Folkestone (Folkestone Marl) has always been a famous collecting-ground for fossils; since the formation may be well studied at Copt Point, and its brilliantly-coloured fossils may be seen exposed at low tide on the fore-shore of East Wear Bay. The organic remains, being mostly pyritic, are liable to rapid decay, and although abundant, it requires care and patience to collect a good

[1] W. Whitaker, P. Geol. Assoc. v. 497; Godwin-Austen, Q. J. vi. 461; Judd, Q. J. xxvii. 222; J. S. Gardner, Q. J. xl. 122; A. J. Jukes-Browne, G. Mag. 1877, p. 363.

series of specimens.[1] Many of the gems of private collections have been obtained by John Griffiths of Folkestone. (See Fig. 60, p. 358.)[2]

The Gault of Folkestone has been divided into the following zones:[3]—

		Feet	ins.
Upper Gault (about 72 feet).	Zone of *Ammonites rostratus* (*A. inflatus*). Clay with seam of greensand	56	3
	,, *Kingena lima*. Pale grey marl	5	1
	,, *Ammonites varicosus* (*Inoceramus sulcatus* bed). Pale grey marly clay	9	5
Junction bed.	,, ,, *cristatus* (Nodule bed). Clay with nodules	0	9
Lower Gault (about 28 feet).	,, ,, *auritus* (Dark bed). Dark clay	6	2
	,, ,, *denarius* (Mottled bed). Dark mottled clay	1	0
	,, ,, *lautus* (Coral bed with *Smilotrochus*). Mottled clay	1	6
	,, ,, *De la Ruei*. Clay	0	4
	,, Crustacea (*Palæocorystes*) (Crab bed). Fawn-coloured clay	4	6
	,, *Ammonites auritus*, var. Dark clay, iridescent fossils	4	3
	,, ,, *interruptus*.—Dark clay with phosphatic nodules; Dark greensand; Nodules of iron-pyrites	10	1
Lower Greensand.	,, ,, *mammillaris*. Coarse grit and phosphatic nodules. (See p. 372.)		

The Upper Gault is sometimes termed the Zone of *A. inflatus*, and the Lower Gault the Zone of *A. lautus*.

The fossils of the Gault include *Pinites* and other Plant-remains; a few Sponges; Foraminifera; Corals; Echinodermata, *Hemiaster*, *Pentacrinus*; Annelides, *Serpula articulata*; Crustacea, *Pollicipes*, *Necrocarcinus*, etc. The common Mollusca of the Gault are *Nautilus Clementinus*, *Hamites intermedius*, *Ammonites splendens*, *Ancyloceras spinigerum*, *Belemnites minimus*, *Aporrhais* (*Rostellaria*) *carinata*, *Dentalium decussatum* (*ellipticum*), *Solarium ornatum*, *Inoceramus sulcatus*, *I. concentricus*, *Plicatula pectinoides*, *Nucula ovata*, *N. pectinata*, etc. The Fishes include *Otodus*, and *Saurocephalus*;

[1] All fossils from clay strata, but especially those from the Gault, the Oxford Clay, and the Lias, require almost daily care and attention for the first few weeks after they are removed from the bed in which they occur, or the entire surface will flake off in drying. A judicious application of very dilute gum, mixed with one-fourth part glycerine or sugar, is found to give the necessary tenacity to these delicate remains; but the practised fossil-collector prefers treating such objects with thin gelatine as a more durable hardening material.—Dr. H. Woodward, G. Mag. 1866, p. 11.

[2] See also Fitton, T. G. S. (2), iv. Plate 8; and F. Drew, Geol. Folkestone, etc. (Geol. Survey).

[3] F. G. H. Price, The Gault, 1879; Q. J. xxx. 342; C. E. De Rance, G. Mag. 1868, p. 163; S. J. Mackie, Geologist, iii.; W. Topley, Geol. Weald, p. 145; W. Whitaker, G. Mag. 1864, p. 213.

besides which there are remains of Saurians (*Pterodactylus*, etc.), and Chelonia. Prof. T. R. Jones has noticed an Annelide-bed in the Gault near Charing, Kent. In his opinion the Foraminifera indicate that the beds were deposited in a depth of about one hundred fathoms.[1]

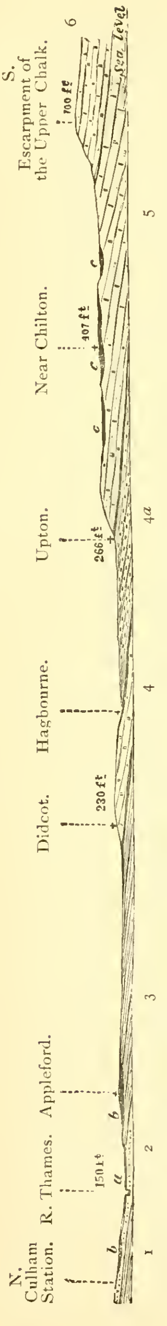


Fig. 64.—General Section from Culham, near Abingdon, to near East Ilsley, in Berkshire. (Prof. J. Prestwich.) Distance, 9 miles.

4a. Light-coloured greensand } Upper
4. Compact greenish sandstone } Greensand.
3. Gault.
2. Lower Greensand.
1. Kimeridge Clay.

a. Alluvium.
b. Valley Gravel, with mammalian remains, and river-shells.
c. Angular Drift, with mammalian remains, and land-shells.
6. Upper Chalk.
5. Lower and Middle Chalk.

To the west of Reigate the Gault appears much reduced in thickness, although the breadth of its outcrop is naturally diminished by the higher inclination of the strata.[2] A section of Gault has been exposed at the Varnes, on the banks of the Medway, near New Hythe. Many fossils have been obtained at Bletchingley. In East Sussex fossils have been found in the neighbourhood of Ringmer; and the railway-cutting near Alton has also yielded specimens.

In the Isle of Wight the Gault has received the name of the 'blue slipper,' from the tendency of the overlying strata to slip or slide over its surface; and in this way the beautiful scenery of the Undercliff has been mainly produced. It has a thickness of 100 feet in Compton Bay.[3]

In Swanage Bay the Gault is seen on the shore near Punfield Cove, and is there represented by about thirty feet of bluish-green sandy clay. (See Fig. 54, p. 347.) It may be traced in Mewps Bay, and was noticed in Lulworth Cove by Dr. Fitton, where it is represented by dark, greenish, sandy strata, with large concretionary nodules.[4] It has also been recognized at White Nore, further west, though, from the accumulation of tumbled rock, it is not always visible.[5]

The Gault has been traced in places as far as Black Ven, Lyme

[1] Geol. Mag. 1876, p. 118.
[2] See also C. J. A. Meyer, G. Mag. 1866, p. 17.
[3] H. W. Bristow, Geol. Isle of Wight, p. 22.
[4] C. J. A. Meyer, Q. J. xxx. 382.
[5] R. Damon, Geology of Weymouth, 1884, p. 129.

Regis, where it rests upon the Lias Clays; it is from eighteen to twenty-five feet thick according to Mr. C. Reid; and consists of dark blue micaceous sandy clay, which appears to represent the Lower Gault. Among the fossils are *Cucullæa carinata*, *Inoceramus concentricus*, *Lima parallela*, *Pecten orbicularis*, *Pinna tetragona*, *Aporrhais carinata*, *Ammonites splendens*, etc.[1] Here the collector must be careful, as fossils from the Gault and Lias are commingled in the talus of the upper portion of the cliffs. (See Fig. 40.) Mr. De Rance has noticed the deposit as occurring not only at Black Ven, Golden Cap, and Stonebarrow Hills, but also at Pinhay Cliff;[2] westwards in the coast-section the Gault thins out towards Sidmouth. In 1874, Mr. Ussher noticed in the railway-cutting at Wilmington, near Honiton, clayey beds at the base of the Greensand, which seem to be referable to the Gault; and this view has been confirmed by the Rev. W. Downes, who has procured a number of fossils from the beds.[3]

The Blackdown Beds have by some geologists been regarded as for the most part of Gault age, and placed in the zone of *Ammonites inflatus*; but, as Mr. Downes remarks, there is no boundary between Upper Greensand and Gault in the West of England.

Inland in Dorsetshire the Gault is well developed below the Upper Greensand of Shaftesbury; in the Vale of Wardour the Gault is about 75 feet thick, and it has been exposed near Dinton, Fovant, and at Ridge, south-east of Chilmark. The Gault appears as an inlier at Crockerton, south of Warminster, and it has been traced from Westbury (Eden Vale brickyard) to the neighbourhood of Potterne and Devizes, resting indifferently on the Oxford Clay, Corallian rocks, Kimeridge Clay, Portland Sands, and Lower Greensand. (See Fig. 58.) It forms a continuous band stretching into Oxfordshire, and occupying a broad tract around Tetsworth, south-west of Thame. At Towersey near Thame, and Culham near Abingdon, many fossils have been obtained.[4] (See Fig. 64.)

In Cambridgeshire the Gault (brickearth of Cambridge) appears as a stiff pale bluish-grey clay, and may be studied in the brick-pits around Barnwell, also west of Soham. Phosphatic nodules occur in the Gault at Upware, but the principal accumulations of phosphate occur in the Lower Greensand, and at the base of the Chalk. (See p. 377, and sequel.)[5] The formation is not known in Lincolnshire or Yorkshire, while much of the so-called Gault of Norfolk may be Chalk Marl. (See sequel.)

The Gault forms what may be termed an unproductive soil, but it is well adapted for pasture. It is sometimes called 'black land,'[6] and there is a village named Blackland, south-east of Calne, which is partly situated on Gault. It forms a flat

[1] E. T. Newton, Cat. Cret. Fossils (Geol. Surv.), 1878; Rev. W. Downes, Q. J. xli. 23.
[2] G. Mag. 1874, p. 252. See also Fitton, T. G. S. (2), iv. 233.
[3] G. Mag. 1886, p. 308.
[4] J. Phillips, Q. J. xvi. 309; Geol. Oxford, p. 427.
[5] H. Keeping, G. Mag. 1868, p. 272.
[6] H. W. Bristow, Explan. Sheet 13 (Geol. Surv.), p. 5.

and sometimes marshy tract; but in many places oaks grow well upon it. (See p. 363.) The beds are much used in the manufacture of bricks and tiles. There are large brickyards at Cambridge, at Arlesey, south of Biggleswade; also at Aylesford and Burham in Kent. The Burham bricks are white. At Chipstead, north-west of Sevenoaks, Gault and overlying Pleistocene brickearth are worked for brick-making. At Folkestone, Portland cement is manufactured from Gault clay mixed with finely levigated Chalk. Coprolites have been worked at Towersey.

UPPER GREENSAND.

The Upper Greensand consists of greenish-grey sand and sandstone, the typical green beds generally being charged with glauconite (hydrous silicate of iron, alumina, and potash); pale calcareous sandstone and chert also occur.

The term Greensand was used by William Smith in 1812, and was originally applied to the sands overlying the Gault (Blue Marl). Later on the sands below the Gault came to be termed Greensand, and much confusion resulted. The term Upper Greensand was used by Murchison in 1825. The terms Firestone and Malm Rock have in old times been applied to this Greensand, from the local use of the prominent beds of pale calcareous sandstone: the firestone being developed at Merstham and Reigate, and the malm rock in West Surrey, Hants and Sussex. These beds appear to represent one another, but the malm rock has a more chalky appearance. The term Chloritic Sands, suggested by Godwin-Austen and adopted by Lyell, is open to objections on the grounds that the term merely indicates a colour which is far from predominant; and that the green beds are charged with glauconite (not chlorite). It was shown by Ehrenberg, and more recently by Carpenter, that the green grains are very frequently internal casts of the chambers of Foraminifera in glauconite.[1]

The thickness of the Upper Greensand is about 60 feet on the average in the Wealden district. At Petersfield it is 80 feet, at Eastbourne 40 feet, at Godalming 50 feet, and at Wallingford 70 feet.

The Upper Greensand contains the Echinoderms *Discoidea* (*Galerites*) *subuculus* ('Button stone'), *Salenia*, *Goniaster*, *Hemiaster*, *Cardiaster suborbicularis*, *Pseudodiadema*, etc.; Mollusca, *Pecten* (*Janira*) *quinquecostatus*, *P. quadricostatus*, *P. asper*, *P. orbicularis*, *Cardium Hillanum*, *Exogyra conica*, *E. columba*, *E.* (*Gryphæa*) *vesiculosa*, *Ostrea frons* (*carinata*), *Plicatula inflata*, *Trigonia alæformis*, *Ammonites varians*, *A. rostratus*; Brachiopoda, *Rhynchonella Grasiana*, *R. latissima*, *Terebratella pectita*, *Terebratula biplicata*; Annelides, *Vermicularia concava*; Corals, *Micrabacia coronula*; and Sponges. *Siphonia* and other Sponges are met with particularly in the beds at Warminster and Blackdown, while at the Blackdown and Haldon Hills and other localities, some beds are largely made up of the detached spicular remains of siliceous sponges.[2] Teeth of Fishes and bones of Saurians also occur.

[1] Q. J. vi. 470.
[2] Dr. G. J. Hinde, Phil. Trans. 1885, p. 403, Ann. Nat. Hist. (5), x. 185; E. Parfitt, Trans. Devon Assoc. 1870; H. J. Carter, Ann. Nat. Hist. (4), vii.

Mr. Carruthers has identified a Tree fern (*Caulopteris punctata*) from the Upper Greensand of Shaftesbury, Dorset.

The Upper Greensand is sometimes divided as follows:—

2. Zone of *Pecten asper*.
1. ,, ,, *Exogyra conica*.

The Upper Greensand is somewhat doubtfully represented north of Folkestone with a thickness of less than twenty feet, as the beds here are sometimes grouped with the Chalk Marl; it rapidly thins away inland.[1] At Aylesford about eighteen inches of greenish-grey marly sand has been classed as Upper Greensand, but it belongs properly to the base of the Chalk; at Snodland, near Maidstone, the Greensand beds are also absent, but near Westerham they begin to acquire importance. (See sequel.)

In the neighbourhood of Godstone, Merstham (Merstham Beds), Reigate (Reigate Stone), and east of Dorking, the firestone beds are largely worked.

Mr. Webster observed that "The quarries of Reygate stone were formerly considered of such consequence that they were kept in the possession of the Crown, and a patent of Edward III. exists, authorizing them to be worked for Windsor Castle. Henry the Seventh's chapel at Westminster was also built of the stone procured from them, as is also the church at Reygate. These ancient quarries were situated between the town of Reygate and the chalk hills to the north, and traces of them may still be seen in several places, as at Gatton park, Colley farm, and Buckland green, which latter place is the most westernly spot where the stone has been found."[2] The firestone has been used for the floors of furnaces, for hearths, etc. (hence its name).

The following section taken in a quarry about a mile and a half east of Merstham was noted by Mr. Whitaker:[3]—

	Chalk Marl, with fossils, the lower part sandy, and passing into beds below	about 15 feet.
Upper Greensand.	Greyish-green sand, with calcareous nodules and fossils: the lower part of the rock is a soft sandstone	15 ,,
	Stone	2 ,,
	Soft, greenish-grey sandstone	5 ,,

Near Betchworth beds of hearth-stone are worked; this rock is a soft calcareous sandstone about eleven feet in thickness, and it occurs above the firestone, and beneath the 'roof-bed.'

In Sussex the Upper Greensand comprises beds of greenish-grey calcareous sandstone (20 feet), and they may be seen north of Beachy Head, in the neighbourhood of Eastbourne. (See Fig. 66.) The sandstone has been quarried, and was used in the construction of Pevensey Castle. Fossils have been found near Hamsey and Bignor. The malm rock was used and occasionally polished for work in the Roman villa at Bignor; it occurs also at Hartley and Selborne, south-east of Alton.[4]

In the Isle of Wight the Upper Greensand, as described by Mr. Bristow, appears in the cliffs at Compton Bay, and extends across

[1] F. W. Simms, Proc. Geol. Soc. iv. 206.
[2] T. G. S. v. 353.
[3] Topley, Geology of the Weald, p. 154.
[4] H. W. Bristow, Explan. Sheet 12 (Geol. Surv.), p. 5.

the island at the southern base of the Chalk hills to Sandown Bay; and it is exposed again to the south between Chale Down and Dunnose. It consists of calcareous sandstones, chert-beds, and yellowish-grey micaceous sands, having a thickness of about 150 feet. The higher beds have been quarried on the north side of Shanklin Down, and in other places, for building-stone; while the cherty strata furnish an excellent stone for road-mending.[1]

The following section at Ventnor was noted by Mr. Mark W. Norman:[2]—

Chalk.	Chloritic Marl	8	feet.
Upper Greensand.	Chert and sandstone	24	,,
	Sandstone and rag beds	62	,,
	Yellow sands	30	,,
	Rag	1	,,

The Upper Greensand about Wantage and Wallingford, in Berkshire, consists of soft dark-green sands (20 or 30 feet in thickness), resting upon white siliceo-calcareous strata.[3] The total thickness of the formation at Woolstone is 60 feet, and at Didcot upwards of 70 feet; while at Cuxham, near Watlington, in Oxfordshire, it is 70 feet. (See Fig. 64.)

Near Prince's Risborough, Mr. Whitaker describes the Upper Greensand as consisting almost wholly of a soft white crumbling sandstone, sometimes calcareous, overlaid by a thin deposit of clayey greensand. The formation is not exposed further in a north-westerly direction than West-end Hill, near Cheddington, and Ivinghoe, in Buckinghamshire.[4] In Cambridgeshire and adjoining counties the 'coprolite' beds (Cambridge Greensand) were at one time considered to represent the Upper Greensand, but while carrying on the Geological Survey in Bedfordshire and Hertfordshire, Mr. Whitaker concluded (in 1868) that the nodule-bed was really the base of the Chalk Marl, an opinion which has been corroborated by the researches of Mr. Jukes-Browne. (See sequel.)

In the deep boring at Harwich the thickness of the Upper Greensand has been estimated to be about 20 feet, and in the Carrow boring, Norwich, about 7 feet; but its presence in these localities is considered somewhat doubtful. In the Kentish Town well-section the thickness, according to Mr. Whitaker, is 13 feet 9 inches.[5]

In Wiltshire the Upper Greensand has a thickness of from 60 feet at Swindon to 150 feet further south; in the upper part it consists of sandstone and chert, and in the lower of light brown and grey sands with glauconitic grains. Near Wroughton the boundary of the Gault and Upper Greensand is much obscured by landslips.[6] The Green-

[1] Geol. I. of Wight, p. 24.
[2] G. Mag. 1882, p. 440.
[3] E. Hull, Explan. Sheet 13 (Geol. Survey), p. 18.
[4] Jukes-Browne, Q. J. xxxi. 265.
[5] Guide to Geol. London, ed. 4, p. 20.
[6] W. T. Aveline, Explan. Sheet 34 (Geol. Survey), p. 34; see also Godwin-Austen, Q. J. vi. 461.

sand fringes the Marlborough Downs from a little south of Swindon to Cherhill and Devizes, spreading out eastwards in the Vale of Pewsey (or Pusey) and appearing again in the inliers of Shalbourn, south-west of Inkpen, and of Burghclere and Kingsclere.[1] (See Fig. 63, p. 382.) South of Devizes, the Greensand extends by Market Lavington to Westbury and Warminster, and thence by Heaven's Gate in Longleat Park to Maiden Bradley and Alfred's Tower at Stourton. It borders the Vale of Wardour, being exposed at Fonthill on the north side, and at Fovant on the south ;[2] and still further south it forms a fine escarpment, about 800 feet high at Shaftesbury.

Our earliest knowledge of the Wiltshire fossils is largely due to the labours of Miss Etheldred Benett, who had made sketches of the Warminster Sponges as early as 1816.[3] The Sponges include *Siphonia tulipa* (*pyriformis*), *Hallirhoa* (*Siphonia*) *costata*, *H. agariciformis*, *Jerea* (*Siphonia*) *Websteri*, *Chenendopora fungiformis*, etc.[4] They have mostly been obtained from pits on the west of Warminster. The Plant *Sequoiites Woodwardi* has also been found in this neighbourhood. Many specimens of Mollusca were obtained by Miss Benett from a field named Brimsgrove at Shute (or Chute) Farm, south of Shirewater in Longleat Park, near Warminster.

The term Warminster beds was used by Mr. C. J. A. Meyer in 1874 for the upper beds of the Greensand of this neighbourhood ; and from the fact that many of the fossils are found in the so-called Chloritic Marl of the Isle of Wight and of Chardstock, he further proposed to group the Warminster beds with that formation.[5] (See sequel.)

The Upper Greensand is exposed in small quarries and road-cuttings south and south-east of Warminster, where the beds consist of greensand with indurated beds and chert. The chert-beds, which are worked for road-metal, are largely composed, as Dr. Hinde points out, of spicules of lithistid and tetractinellid sponges.[6] Many Echinodermata (*Salenia*, *Diadema*, etc.) have been found in the Greensand of Warminster; and a large number of the fossils, as at Blackdown in Devonshire, are replaced by chalcedony.

In Dorsetshire the Upper Greensand, consisting of glauconitic sand with concretions, about 70 feet thick, may be seen at Punfield Cove, north of Swanage, where many fossils have been obtained.[7] (See Fig. 54, p. 347.) Greenish sand and sandstone crop out beneath the Chalk along the Purbeck Chalk range, and may be seen at Church Knowle, west of Corfe Castle and other places between Swanage and Worbarrow Bay. The beds form a fertile strip of ground below the downs. Beneath the Chalk at White

[1] T. R. Jones, Geol. History of Newbury, 1854, p. 34.
[2] Fitton, T. G. S. (2), iv. 246.
[3] A Catalogue of the Organic Remains of the county of Wilts, 1831 ; see also Phillips, Geol. Oxford, p. 432.
[4] Dr. G. J. Hinde, Catalogue of Fossil Sponges, 1883.
[5] Q. J. xxx. 371 ; G. Mag. 1878, p. 547.
[6] Phil. Trans. 1885, p. 419.
[7] H. G. Fordham, P. Geol. Assoc. iv. 511.

Nore (or White Nose) Cliff the Upper Greensand has a thickness of about 100 feet, and consists of green sandy beds and chert; many fossils may be obtained here.[1]

Yellow sands and chert-beds are very conspicuous at Stonebarrow Hill, east of Charmouth, and at Golden Cap (Gilten Cup), to which from their colour they give the name. (See Fig. 40, p. 252.) They crown the conspicuous hills of Pillesdon Pen and Lewesdon (called by sailors the 'Cow and Calf,' and by some the 'Alps of Dorset'), also Shipton Beacon, east of Bridport; while northwards they form the base of the Chalk Downs between Crewkerne and Beaminster, at Cerne Abbas, etc. The following divisions of the Greensand have been determined near Lyme Regis.:[2]—

	Feet.
Hard calcareous sandstone with quartz grains	3
Yellowish-brown sandstone, with chert seams in lower part	40
Yellowish-brown sand (Fox-mould)	60 to 80
Greensand and sandstone containing indurated nodules called 'Cow stones'	40 or 50

The total thickness probably does not exceed 180 feet.

In the cherty beds *Pecten asper* and *P. quinquecostatus* are abundant, and in the sandy beds below *Exogyra conica* is frequently met with at different horizons. The Cow stones, according to Mr. De Rance, contain *Hoploparia longimana*.

The beds are shown on the top of Black Ven (yellow sand 75 feet, overlaid by chert gravel), and westwards at various points among the landslips towards Axmouth. (See Fig. 40, p. 252.)

The general succession of the Greensand strata at and near Beer Head, west of Seaton in Devonshire, has been worked out in detail by Mr. C. J. A. Meyer as follows, the species (except those in brackets) being taken to mark zones:[3]—

	Feet.	In.
12. Compact nodular bed, with green grains and quartz grains in a chalky paste. *Ammonites Rothomagensis*, *Scaphites æqualis*, *Holaster subglobosus*, *Catopygus carinatus*. [Chloritic Marl.]	2	0
11. Yellowish quartzose grit in a chalky paste. *Rhynchonella dimidiata*, *Terebratula pectita*, *Exogyra columba*	3	0
10. Rubbly, yellowish, quartzose grit, in a chalky paste. *Siphonia*, *Nautilus lævigatus*, *Discoidea subuculus*	15	0
9. Buff-coloured saccharine sandstone, with green grains and layers of quartzose grit. (*Rhynchonella Schlœnbachii*)	20	0
8. Buff-coloured sands. *Exogyra digitata*, *Orbitolina concava*	10	0
7. Shingle bed of sandstone pebbles (with *Ostrea*)	2	0
6. Light-coloured sand and sandstone. *Exogyra digitata*	2	6
5. Light-coloured sand, with chert in nodules or layers. *Exogyra columba*, *Pecten* (*Janira*) *quadricostatus*	20	0
4. Yellowish marly sands with irregular concretions. *E. columba*, *Pecten quadricostatus*, *P. orbicularis*, (*P. elongatus*, *Vermicularia umbonata*)	20	0

[1] Damon, Geol. Weymouth, 1884, p. 129.

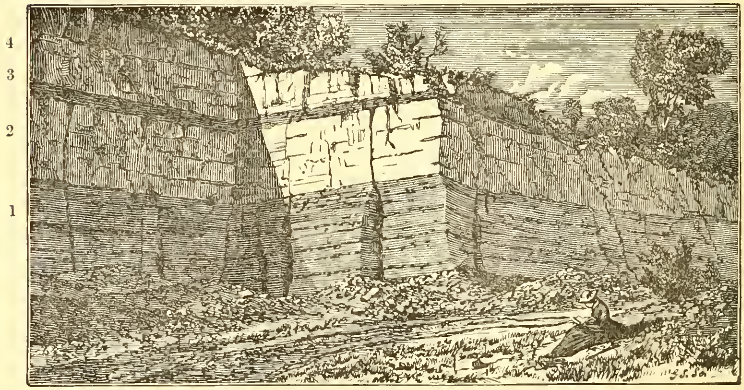
[2] De la Beche, Report Geol. Cornwall, etc., p. 237; T. G. S. (2), ii. 113; De Rance, G. Mag. 1874, p. 247. See also C. J. A. Meyer, G. Mag. 1866, Plate 2, p. 18.

[3] Q. J. xxx. 393. See also Fitton, T. G. S. (2), iv. 234; De la Beche, *Ibid.* ii. 115.

		Feet.	In.
3.	Greyish marly sand, with nodular concretions. *Exogyra conica*, *E. lævigata*	30	0
2.	Sands, with green earth (argillaceous). *Inoceramus sulcatus*	25	0
1.	Greenish-grey sands and grit-bed. *Exogyra conica* (*Vermicularia concava*)	3	6

The beds 1-9 are grouped as Upper Greensand and Gault by Mr. Meyer, the Blackdown beds being regarded as the equivalents of beds 1–4, including Gault and base of Upper Greensand. The beds 10 to 12 are all grouped as Chloritic Marl by Mr. Meyer, but the term should be restricted to bed No. 12.[1] The Warminster beds are grouped as equivalent to beds 10–12, but Mr. Jukes-Browne has questioned the propriety of this correlation, for the Warminster beds are below the Chloritic Marl.[2]

FIG. 65.—SECTION AT SNOWDOWN, CHARD.



4. Chalk (13 feet shown).
3. Chloritic Marl, 1 foot to 18 inches. } Lower Chalk.
2. Calcareous Sandstone, with quartz grains, 7 feet 8 inches
1. Chert Beds (15 feet shown). } Upper Greensand.

The Greensand of the neighbourhood of Chard consists in its upper part of calcareous sandstone and chert beds (20 to 30 feet), and lower down of sands of varied hue, green, brown, and yellow (about 120 feet). The topmost beds of calcareous sandstone or grit generally crop out in the roads and lanes and along the scarps of the hills. (See Fig. 65.) At Dalwood, north of Axminster, the sands yield *Exogyra conica*, *Pecten orbicularis*, etc.

The nodules of chert frequently weather sandy on the exterior, and they may be found exhibiting only a small internal nucleus of chert ; while sandy concretions may be obtained near Honiton, which appear to exhibit the formation of chert from a centre.

Near Widworthy (at the base of the Chalk), according to Dr. Fitton, there is a siliceous bed called 'Grizzle' by the quarrymen, about five feet in thickness, and containing greenish particles. It has been much used for building-purposes.

[1] See also H. G. Fordham, P. Geol. Assoc. iv. 515.
[2] G. Mag. 1877, p. 358. See also Barrois, Ann. Soc. Géol. du Nord, iii. 7.

The Chert-beds which form the high grounds west and south-west of Chard are generally much broken up on the surface, the soil is often a drift-clay with angular stones, and it becomes wet and boggy in many places. The sands are not usually fertile, and much of the country occupied by them is covered with plantations of fir, or with gorse and heather.

Blackdown Beds.—During the past 50 years much attention has been paid to the fossils obtained from the sands with hard concretions, exposed at the whetstone pits of Blackdown, which is a projection of the Blackdown Hills west of Dunkeswell, in Devonshire. Whetstones or scythe-stones have been worked for many a year in the escarpment between Blackborough Hill and Hembury Fort, including Punchey Down and Upcott Pen, near Kentisbere and Broadhembury. Indeed, as pointed out by the Rev. W. Downes, so extensive have been the burrowings or tunnels driven into the hills for the purpose of working the stone, that considerable subsidences have occurred, whereby Blackborough (or Mortal Pen Beacon) has lost quite thirty feet of its height.[1] Hence opportunities have occurred for obtaining large collections of fossils from the sands. These are preserved in chalcedony, and being derived from sands beneath the Chert beds (which have been denuded), the 'Blackdown fauna' represents only a part of the Upper Greensand of the district, and the term Blackdown Beds is similarly restricted.

The exact age of these strata has formed the subject of considerable dispute among palæontologists, inasmuch as representatives not only of Upper Greensand, but also of Gault and even Lower Greensand, have been considered to be present. The Blackdown Beds were described long ago by Fitton, and the age of the fossils has been discussed by D. Sharpe,[2] Godwin-Austen, E. Renevier,[3] and others, and more recently by the Rev. W. Downes.

The Upper sands at Blackdown, according to Mr. Downes, are characterized by *Pecten quadricostatus*, then come sands with *Pectunculus sublævis* and *Trigonia affinis* (*excentrica*); beneath in a bed called the "Red rock," *Cyprina cuneata* and *Exogyra conica* are abundant; lower down *Turritella granulata*, and *Siphonia tulipa* (*pyriformis*) are found; while *Pectunculus umbonatus*, *Trigonia alæformis* and *Inoceramus sulcatus* occur more or less plentifully in the lowest beds. Mr. Downes concludes that we do not find exclusively Upper Greensand fossils at the top of the series, Gault fossils in the middle, and Lower Greensand forms at the base, and on the whole it is best to regard the Blackdown Beds as Upper Greensand, restricting the term Gault to the clay wherever it occurs below that Greensand.[4]

The scythe-stones or whetstones are known also as Devonshire Batts, and in Dorsetshire as Rubber-batts or Balkers. Dr. Fitton remarked that the strata

[1] Trans. Devon Assoc. 1880.
[2] Q. J. x. 186.
[3] Bull. Soc. Vaudoise des Sc. Nat. v. 51 (Q. J. xii. part 2, p. 21); see also Barrois, L'âge des couches de Blackdown, 1875.
[4] Q. J. xxxviii. 75, xli. 27.

which afford the whetstones are about eighty feet below the top of the hill, and the scythe-stones are shaped from concretions of very irregular form, embedded in looser sand, but marks of the stratification of the sand can be traced on their outside. The masses of stone vary from six to about eighteen inches in diameter, and the beds which afford them attain a total thickness of about seven feet, of which about four are fit for that purpose, the looser stone at the top and bottom being employed for building.[1]

At Penzlewood (Pen Selwood) near Stourton, similar beds (Penstone) have been worked for scythe-stones at the Pen pits.[2]

From the neighbourhood of Seaton the Upper Greensand extends westwards in outlying masses to Sidmouth and the Haldon Hills in Devonshire. A shingle bed was noticed by Mr. Godwin-Austen in the lower part of the Greensand on Salcombe Hill.[3]

A yellow sandstone belonging to the Greensand, and known as the Salcombe sandstone, was, until about 1860, largely employed for building-purposes. The old quarries (I am informed by Mr. P. O. Hutchinson) were worked on the side of the hill east of Salcombe Regis church, near Sidmouth. Much of Exeter Cathedral (it is believed) was built of this stone.

The Upper Greensand on Little Haldon is about 70 feet in thickness; there the Chert-beds are mostly in a disintegrated condition. At Smallacombe Goyle, on Little Haldon, there is a bed (*Orbitolina*-chert) with *O. concava*, which forms a higher horizon, according to the Rev. W. Downes, than is met with at Blackdown. Many fossils have been obtained at Great and Little Haldon by Mr. W. Vicary; they include *Pectunculus umbonatus*, *Pecten quadricostatus*, also many Corals.[4]

Most of the deposits, at one time regarded as Upper Greensand, near Newton Abbot, are commingled with gravel-beds containing pebbles and blocks of flint and chert; traces of Greensand *in situ* may, however, occur on Haccombe Hill, and near Sandy Gate.[5] How far the Upper Greensand originally extended to the west is very doubtful, so much denudation having taken place since, but the occurrence of chert-gravel at Orleigh Court, near Bideford, suggests the former extension of the Greensand over a great part of Devonshire. It is probable that the formation owes its origin largely to the destruction of the older stratified and igneous rocks of Devonshire, some of which formed cliffs on the borders of the Greensand sea, and perhaps in great measure to the destruction of granitic rocks, the decay of which now gives rise to a quartzose sand not unlike some varieties of the Greensand.

The economic products of the Upper Greensand have been previously noted; it is usually a water-bearing formation.

[1] T. G. S. (2), iv. 236.
[2] See Midland Naturalist, vi. 98; and Rev. H. H. Winwood, Proc. Somerset Arch. and Nat Hist. Soc. xv.
[3] T. G. S. (2), vi. 449; P. G. S. iv. 197.
[4] See Downes, Q. J. xxxviii. 91; P. M. Duncan, Q. J. xxxv. 89; also De la Beche, Report, p. 247.
[5] Q. J. xxxii. 230.

CHALK.

The Chalk is one of the best known rocks; it forms some of the marked features in our island, it is developed over a large area, and from its nature is more easily identified than any other formation. The name was used geologically by Martin Lister in 1684.

The Chalk may be described as a white limestone, for it is almost wholly composed of carbonate of lime, but the lower beds usually are less pure than the upper, and sometimes become sandy and at others sufficiently argillaceous to form a marl, while here and there thin seams of laminated marl occur in higher beds of the Chalk. The layers of Chalk are generally much fissured and fractured, they sometimes attain a thickness of 3 or 4 feet, and are usually wedge-shaped masses, tapering in different directions. These divisional lines seem in some instances to be due to a kind of horizontal jointing rather than to any direct process of deposition.[1] Throughout the greater part of the Chalk there occur nodules of black and grey flint, usually in bands that coincide with the stratification of the rock. Thin tabular veins of flint are also met with in places, and these appear not only along the lines of bedding, but often obliquely, and even vertically in reference to it. The lowest beds of Chalk are usually destitute of flints; but an analysis of Chalk Marl from near Farnham showed over 21 per cent. of silica and alumina.[2]

The following analyses of Chalk were made by David Forbes:[3]—

	White Chalk, Shoreham, Sussex.	Grey Chalk, Folkestone.
Carbonate of lime	98·40	94·09
,, ,, magnesia	0·08	0·31
Insoluble rock débris (silica)	1·10	3·61
Phosphoric acid	—— }	trace
Alumina and loss	0·42 }	
Chloride of sodium	——	1·29
Water	——	0·70
	100·00	100·00

These analyses show the proportions of carbonate of lime in the upper and lower beds, but probably in selected specimens; were an extensive mass of Chalk analysed, the amount of silicate of alumina might prove to be larger.

Here and there erratic boulders have been met with in the Chalk, such as granite, greenstone, quartz, quartzite, sandstone, schist and coal;[4] but on the whole it is remarkably free from sand or pebbles, except at its western extremity near the junction with the Greensand below. It contains many nodules and sometimes crystals of iron-pyrites, locally called 'thunderbolts,' also manganese-ore in specks and dendritic markings.

[1] T. Webster, T. G. S. ii. 174; see also P. F. Kendall, G. Mag. 1884, p. 551.

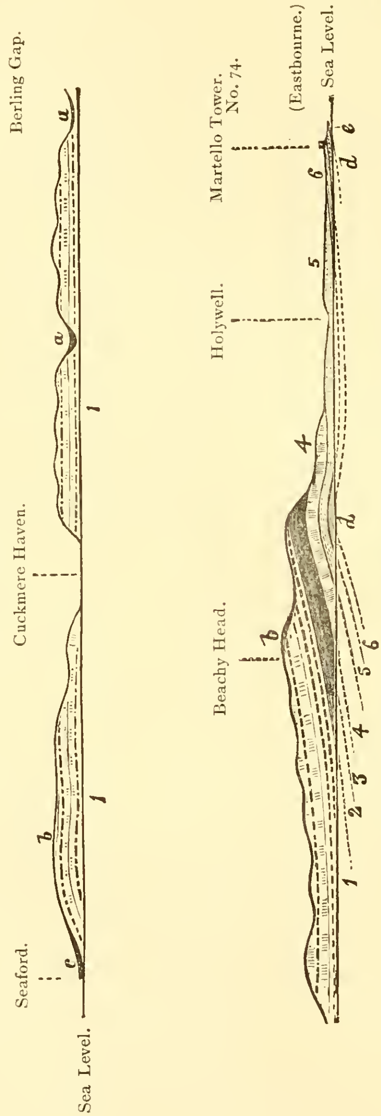
[2] J. T. Way and J. M. Paine, Journ. R. Agric. Soc. xii. 544.

[3] Q. J. xxvii. (p. xlix); Whitaker, Geol. London Basin, p. 15. See also Penning and Jukes-Browne, Geol. Cambridge. The chloride of sodium may perhaps be derived from sea-spray.

[4] Dixon's Geology of Sussex, new ed. by T. R. Jones, p. 129; Jones, Trans. Hertfordshire Nat. Hist. Soc. iii. 147.

Fig. 66.—Section along the Chalk Cliffs from Seaford to Eastbourne, in Sussex.

(W. Whitaker.)



Horizontal Scale an inch to a mile. Vertical Scale exaggerated.

a. Chalk- and flint-rubble.
b. Clay-with-flints.
c. Reading Beds.
d. Upper Greensand.
e. Gault.

Upper Chalk. { 1. Chalk with flints.
{ 2. Chalk with flints and nodular layers.
Middle Chalk. { 3. Chalk without flints, but with nodular layers.
{ 4. Massive thickly-bedded Chalk without flints.
Lower Chalk. { 5. Bedded Chalk without flints.
{ 6. Chalk Marl.

Certain striated or fibrous appearances in Chalk, which in some instances may be due to slickensides, have in other cases been attributed to chemical action inducing an incipient formation of aragonite.[1]

Chalk has been shown to consist to a large extent of fine amorphous particles of carbonate of lime, together with the shells of Foraminifera (*Globigerina*, etc.), valves of Ostracoda, fragments of Corals, Polyzoa and Sponges; and more rarely Radiolaria (*Polycistina*) and frustules of Diatomaceæ.

Some exceedingly minute bodies termed Morpholites, Coccoliths, and Rhabdoliths, also help to form the mass of the Chalk, and they have proved to be of organic origin, some belonging to protozoan structures and some to seaweeds. Other and more conspicuous organic remains help to form the Chalk, such as fragments of Mollusca (especially *Inoceramus*) and of Echinodermata; as well as calcareous matter voided by Fishes and other animals. Sometimes, however, about 90 per cent. of the Chalk is composed of shells and fragments of *Globigerinæ*. Its organic origin was pointed out by Lonsdale in 1835.[2]

The Chalk is considered to have been formed in a deep and open sea, and indeed the researches which have been carried on in the North Atlantic Ocean show that materials for a continuous bed of limestone, with flint-nodules, are now being deposited there, at depths of from 400 to 2000 fathoms, while many forms of life met with there are analogous to those of the Chalk.[3]

The Chalk itself, judging from its method of formation and general purity, probably extended at one time over the greater part of England and Wales. Chalk occurs at Antrim, which was no doubt connected with the Chalk of England; hence it may be that over about two-thirds of the country the Chalk has been entirely removed by denudation, and the extensive deposits of flint-gravel that occur, especially in the Thames Valley and the Eastern Counties, are but feeble records of the destruction. It is possible that some of the granitic peaks of Dartmoor (then a much loftier range than now) supplied the Chalk with the quartz grains in Devonshire; and this is about all one can say of the former existence of land in the area of England and Wales during the Chalk period. In Scotland there are certain estuarine beds, perhaps of late Cretaceous age, which point to the existence of land in the Hebrides at this epoch.[4]

Flints.—The flints are nodules of amorphous silica, which usually occur in approximately horizontal (though interrupted) layers from one to six feet apart, and these appear to correspond with the lines of bedding. Sometimes, however, they have no connection with the divisional lines present, and even the flint-layers themselves are often somewhat irregular when looked at in detail, isolated flints occurring above or below the general line.

That the flints are mineral aggregations is proved by their irregular and often fantastic shape, and the fact that they have been formed round various organisms

[1] See R. Mortimer and Dr. O. Ward, Q. J. xxxi. iii. 113; Judd, Q. J. xxix. 418.

[2] Lyell, Elements of Geology, 1841, vol. i. p. 56; see also H. C. Sorby, Address to Geol. Soc. 1879; Dixon's Geol. Sussex, edit. 2, by T. R. Jones, pp. 123, 283; Jones, Trans. Hertfordsh. Nat. Hist. Soc. iii. 152; Morris, Lecture on Geology of Croydon, and P. Geol. Assoc. viii. 212.

[3] Sir C. Wyville Thomson, Voyage of the "Challenger," The Atlantic, vol. ii. 1877, pp. 291–300; J. Prestwich, Address to Geol. Soc. 1871; W. H. Hudleston, P. Geol. Assoc. vii. 245.

[4] Judd, Q. J. xxxiv. 733, 738.

that have served as nuclei and to some extent moulded their outlines. Of these nuclei Sponges are most abundant, but they also include Mollusca, Echinoderms, Reptilian teeth, and other organic remains met with in the Chalk. That the flints have been formed subsequently to the deposition of the Chalk that immediately surrounds them, is indicated by their shape, which could not have been assumed unless the siliceous matter was enveloped and supported, and by the vertical lines of paramoudras which are sometimes connected. That some varieties of flint were formed subsequently to the consolidation of the beds, is suggested by the occasional occurrence of seams of "tabular flint," which may occupy horizontal planes, or fill vertical joints.[1] Thin seams of flint running in different directions have been noted in the Chalk at Wells in Norfolk, at Worthing, Rottingdean, and other places. In most cases the accumulations of flint have been formed before the disturbances to which Chalk has in many places been subjected. The reconstruction, however, of inorganic silica from mineral solutions, as suggested in 1852 by M. Gaudry, may account for some of the local veins of flint. The following is an analysis of Chalk-flint by Klaproth:[2]—

Silica	98·00
Lime	0·50
Alumina	0·25
Oxide of Iron	0·25
Water	1·00
	100·00

The silica itself was derived in the first instance from the sea-water (which contains a minute per-centage of it), partly by organisms which have to provide themselves with a siliceous framework, as certain Sponges, Polycistina, and Diatomaceæ. The decay of these, and especially of Sponges, would yield most of the material for the flints in the Chalk; and further, it is considered that the decomposition of certain organisms would produce chemical changes sufficient to eliminate silica from the sea-water, and to assist in its deposition.

From the fact that the majority of flints exhibit spongiform structure, it has been argued that their method of formation was essentially organic. It may, however, be said that the majority of flints enclose organisms, such as Foraminifera, that were once calcareous, and hence it seems clear that while sponges furnished a great part of the silica, they also acted as nuclei, around which siliceous matter was deposited. Sir C. Wyville Thomson observed that we often find the moulds and outlines of organisms considered to have been siliceous, from which the whole of the silica has been removed; and cases occur in which a portion of the delicate tracery of a siliceous sponge has been preserved entire in a flint, while the remainder of the vase which projected beyond the outline of the flint appeared in the Chalk as a trellis-work of spaces, vacant or loosely filled with peroxide or carbonate of iron. On the other hand, calcareous organisms have been perfectly replaced by silica in the white powder within some flints, as remarked by Prof. T. Rupert Jones and Mr. Joseph Wright.

The most puzzling point is the origin of the layers of flint. Their comparative regularity, looked at in a large way, points to some connection with the stratification of the rock. In this respect they are analogous to the septaria and clay-ironstone nodules of many formations, and to certain forms of alabaster met with in the Keuper Marl. The remarkable concentric rings of flint to be seen on the foreshore at Runton, near Cromer, are worthy of mention. There a platform of Chalk is exposed which exhibits rings, some made up of flints connected, others disconnected, and they often surround hard Chalk with isolated flints or a Paramoudra of gigantic dimensions; here they seem to be due to a kind of mineral

[1] Geology of Norwich (Geol. Survey), p. 20. See also G. J. Hinde, Fossil Sponge Spicules from the Upper Chalk (Horstead), 1880; W. J. Sollas, Ann. Nat. Hist. 1880, pp. 384, 437.

[2] Dixon, Geol. Sussex, edit. 2, p. 125.

segregation.[1] The formation of flints may in some instances have taken place during the consolidation of the Chalk, and have been induced or accelerated by the pressure of continual deposits, for it has been stated by Mr. Sorby that mechanical pressure increases the solubility of most substances. Dr. Wallich, who insists that flints in their method of origin may as truly be considered organic products as the Chalk itself, has given an explanation of the flint-layers which makes their regularity more intelligible than it has been hitherto.

The upper layer of Chalk-mud at the bottom of the abyssal ocean is the home of numerous vitreous or siliceous sponges; and it is filled with the delicate siliceous root-fibres of the sponges, which bind it together. Owing to its inferior specific gravity it floats, as it were, upon the calcareous mud beneath. Thus this superficial layer contains a large per-centage of silica, not merely from the sponges themselves, but from the continual subsidence of minute dead siliceous organisms, which become incorporated in its mass. Finally it becomes supersaturated with silica, and the first step towards the consolidation into flint is accomplished. Thus in time various bands of flint and layers of calcareous mud would be formed.[2]

Paramoudras.—In some places, as in Norfolk, the Chalk contains huge flints of a cylindrical or pear-shaped form, having a central cavity passing through their longer axis, which occupies a vertical position in the Chalk. These flints are known as "Pot-stones" or Paramoudras. The term Paramoudra has been a source of much perplexity. It was introduced from Ireland by Dr. Buckland, who first described these curious flints found on the coast of Antrim and at Moira, in county Down.[3] Mr. H. Norton suggests that the word is an anglicized form of the Gaelic and Erse words for "sea-pear," most likely used in the plural, *peura muireach.*[4]

The most celebrated exposure of Paramoudras was in a pit at Horstead, on the river Bure, of which a drawing made by the late Mrs. Gunn in 1838 has been published in Lyell's Elements of Geology. The pot-stones, many of them pear-shaped, were usually about three feet in height and one foot in their transverse diameter, placed in vertical rows, like pillars at irregular distances from each other, but usually from twenty to thirty feet apart, though sometimes nearer together, as in the above-mentioned sketch.[5]

The Horstead pit is now closed, but paramoudras occur occasionally in most of the pits around Norwich, at Trowse, Catton, and Whitlingham. On the whole, many more instances might be cited where the paramoudras occur in an isolated position, or irregularly, than where they occur vertically one above another. So variable too are the shapes assumed by large flints that a series might be obtained to show transitions from the most symmetrical paramoudra to a large irregular and tabular mass of flint having one or two openings or cavities in it. Mr. T. G. Bayfield, of Norwich, had in his collection a paramoudra having a double cavity, and there is a similar "double paramoudra" in the Ipswich Museum. Lyell remarked that some of these pear-shaped flints resemble in shape and size the large sponges called Neptune's Cups (*Spongia patera*), which grow in the seas of Sumatra. Ehrenberg, however, attributed their origin to the sinking of silica (deriving its origin from organic remains), by its own gravity, in a funnel shape, through a more solid but naturally still soft layer of chalk.[6] This explanation is not inconsistent with the account given by Dr. Wallich of the sheets of organic silica on the ocean-bed.

In many places we find flints which exhibit a white coating surrounding a nucleus of dark compact flint. This white coating often occurs as a thin film on flints directly taken out of the Chalk, but in specimens derived from Drift deposits, the coating has often eaten its way far into the interior of the flint, so that in many cases but a tiny nucleus remains to indicate the original character of the

[1] C. Reid, Geol. Cromer (Geol. Survey), p. 4; see also Penning and Jukes-Browne, Geol. Cambridge, p. 70.

[2] Q. J. xxxvi. 68; Ann. Nat. Hist. 1881, pp. 162, 261.

[3] T. G. S. iv. 413.

[4] Proc. Norwich Geol. Soc. i. 132.

[5] Lyell, Elements of Geology, 1865, p. 321; see also Geol. Norwich (Geol. Surv.), p. 24.

[6] Ann. Nat. Hist. 1839, ii. 162.

stone. Dr. Percy has detected no chemical difference between white and black flint; though some observers state that there is occasionally a little carbonate of lime in the white coating. Prof. Hughes is inclined to believe that in the flint in the Chalk this white exterior would, from its manner of occurrence, often appear to be due not to weathering but to the imperfect surface of the flint in process of formation, and hence the carbonate of lime has not been entirely replaced by silica.[1] In flints obtained from the Drift the white coating is, however, chiefly due to decay.

Another peculiar variety is the Banded flint so frequently to be seen among the stones of a gravel pit, or on the sea-shore where the shingle is largely composed of flint. This banding, as pointed out by Dr. S. P. Woodward, is due to infiltration, and is not in itself organic, but at the same time the banding may have sometimes been produced by the infilling with siliceous material of cavities which have resulted from the decomposition or decay of organic remains.[2]

The Chalk is rich in organic remains, although most specimens are usually procured rather from the quarrymen than by the geologist himself. Some Plant-remains have been recorded, but on the whole there are few remains of land-organisms. Of Foraminifera, about one hundred species and notable varieties occur. Sponges are also abundant, and many of the Ventriculites described by Mr. J. Toulmin Smith were obtained from Burham, near Chatham.[3] The more conspicuous fossils are the Echinoderms, *Ananchytes*, *Micraster*, *Cardiaster*, etc., and the Mollusca, *Ammonites*, *Turrilites*, *Scaphites*, *Baculites*, *Ostrea*, *Inoceramus*, *Pecten*, etc., *Hippurites* also occurs; while the Brachiopoda include species of *Rhynchonella*, *Terebratula*, etc. The more important species will be noticed subsequently. Polyzoa, Annelides, and Crustacea are met with; and among Crustacea the remarkable Cirripede, *Loricula pulchella*, first found in the Lower Chalk of Cuxton, near Rochester, has also been met with near Norwich; many Ostracoda also occur. The Corals include species of *Caryophyllia*, *Trochosmilia*, and *Parasmilia*. (See p. 353.) Remains of Fishes are not uncommon, they include *Notidanus microdon*, *Corax falcatus*, *Otodus appendiculatus*, *Lamna subulata*, *Beryx*, *Ptychodus mammillaris*, and *P. decurrens* (allied to the *Cestracion* or Port Jackson Shark). The Reptiles include *Mosasaurus*, *Pterodactylus*, *Acanthopholis*, *Chelone*, etc. Remains also of Birds have been found in the 'Cambridge Greensand,' and near Maidstone.[5]

The Chalk is generally divided as follows:—

Upper.—Chalk with flints.
Middle.—Chalk with few flints.
Lower.—Chalk without flints, Grey Chalk, Chalk Marl, Chloritic Marl, etc.

The division often made into Chalk with flints and Chalk without flints, is at best a very rough and general classification, derived from the character of the beds in the south-east of England; and it is now generally admitted that no

[1] Proc. Cambr. Phil. Soc. iii. 12; Geol. and Nat. Hist. Repertory, ii. 126.

[2] Geol. Mag. 1864, p. 145; also M. H. Johnson, Proc. Geol. Assoc. ii. 264; R. Mortimer, *Ibid.* v. 353; T. R. Jones, *Ibid.* iv. 453; Wetherell, Q. J. xv. 193.

[3] Ann. Nat. Hist. 1848.

[4] T. R. Jones, Geol. Mag. 1870, p. 74.

[5] For figures of Chalk fossils see Dixon's Geology of Sussex, ed. 2; also references, p. 353.

trustworthy divisions can be based on the abundance, rarity, or even absence of flint-nodules.

The researches of Prof. E. Hébert, Mr. Caleb Evans, and particularly of Dr. C. Barrois, have shown that the Chalk may be divided into certain palæontological zones, and these are indicated in the accompanying Table.[1] (See p. 402.)

The zones have been followed out in various parts of England by Mr. Meyer, Mr. Jukes-Browne, Mr. W. Hill, and others; but Mr. Whitaker has remarked that although they are very valuable when applied to particular sections, yet their application to great inland stretches of country without continuous sections, or when the structure of the deposits could be seen only in occasional pits, was by no means safe.[2] Lithological divisions, however, such as the Chalk Rock, the Melbourn Rock, and the Totternhoe Stone, appear to mark certain zones, and these rocks can be traced over considerable areas. As with other palæontological zones, the species taken as indices may range above or below the zones, and while these divisions mark the general succession of life-forms in different areas, they are not likely to be strictly contemporaneous: a few species, however, appear to be confined within narrow limits.

Lower Chalk.

Chloritic Marl. — The term Chloritic Marl, applied to beds between the Upper Greensand and Chalk Marl, was introduced in 1848 by Edward Forbes and Captain L. L. Boscawen Ibbetson.[3] The term *Craie Chloritée* was previously used by French geologists for the calcareous beds of the Upper Greensand.

The Chloritic Marl consists of white or pale-yellow marl, sometimes indurated, with dark green glauconitic grains, phosphatic nodules, and iron-pyrites. Among its fossils *Scaphites æqualis* is locally conspicuous; hence it has been termed the Scaphite-bed. Other species include *Ammonites Rothomagensis* (which takes its name from *Rothomagum*, Rouen), *A. Mantelli*, *A. Coupei*, *A. varians*, *Turrilites Wiestii*, *Nautilus expansus*, *N. lævigatus*, *Ostrea vesicularis*, *Terebratula biplicata*, *Rhynchonella Mantelliana*, *Holaster* (*Ananchytes*) *subglobosus*, *Stauronema Carteri*, etc.

In the Wealden district, according to Mr. Topley, the Chloritic Marl appears to be more closely allied to the Upper Greensand,[4] while in the west of England it constitutes the basement-bed of the Chalk. Such being the case, it may very naturally be considered as a passage-bed, but it is now usually regarded as the base of the Chalk, as Edward Forbes originally advocated. If, however, we regard it as ushering in the Chalk conditions, the Chloritic Marl may very well be of slightly different ages in different localities.

[1] The Upper Chalk is equivalent to the Senonian of D'Orbigny (so named from Sens, in the Department of Yonne), the Middle Chalk is equivalent to his Turonian (from Touraine), and the Lower Chalk and Upper Greensand together are equivalent to the Cenomanian (from Cænomanum or Mans in Sarthe). A. Geikie, Text-book of Geology, ed. 2, p. 825; see also Davidson, G. Mag. 1869, p. 200; and Barrois, Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande, 1876.

[2] Q. J. xxxiii. 446.

[3] Ibbetson, Notes on Geol. I. of Wight, 1849, p. 21; see also A. J. Jukes-Browne, G. Mag. 1877, p. 355.

[4] Geol. Weald, p. 153.

	Zones.	Yorkshire.	Norfolk.	Cambridgeshire.
Upper Chalk.	*Belemnitella mucronata.*		Chalk with flints and paramoudras, 500 feet. Norwich, Trimingham.	
Upper Chalk.	*Marsupites.*	Soft chalk without flints, 320 feet. Bridlington.	Chalk with tabular flints, etc., 200 feet. Wells, Walsingham, Diss.	
Upper Chalk.	*Micraster.*	Chalk with imperfect flints, 120 feet. Flamborough Head.	Chalk with flints, 100 feet. Swaffham, Creake, Stanhoe, Burnham.	White chalk with many layers of flint. *Micraster cor-bovis.*
Middle Chalk.	*Holaster planus.*	Chalk with many tabular flints, 50 feet. Breil Head. (Barren zone.)	Chalk with flints, 100 feet. Swaffham, Docking, Bircham Newton.	Chalk Rock, 6 to 10 feet. Soft white chalk with flints, 50 feet.
Middle Chalk.	*Terebratulina gracilis.*	Slaty chalk with thin flints. Hessle. Creamy chalk with nodular flints. Hard Speeton chalk. } *Inoceramus mytiloides* and *I. Cuvieri*, 200 feet.	Chalk, 100 feet. Sedgeford, Thetford.	Hard compact chalk and grey marl with few flints, 100 feet. Vandlebury beds.
Middle Chalk.	*Rhynchonella Cuvieri.*		Chalk, 100 feet. Shernborne. *Inoceramus mytiloides.*	Even-bedded white chalk with scattered flints, 60 to 70 feet. *I. mytiloides.* Melbourn Rock, 10 feet.
Lower Chalk.	*Belemnitella plena.*	(Not recognized.)	Hard Chalk, 50 feet. Hunstanton, Stoke Ferry.	Grey laminated and marly chalk, 5 feet.
Lower Chalk.	*Holaster subglobosus.*	Grey chalk with red bands and without flints, 100 feet. Burdale and Speeton.	Totternhoe Stone, Roydon.	Hard cream-coloured chalk, 80 feet. Totternhoe stone, 12 to 15 feet.
Lower Chalk.	*Rhynchonella Martini.*		"Sponge" Bed. Hunstanton.	Grey marl, 50 to 60 feet.
Lower Chalk.	*Scaphites æqualis. Plocoscyphia mæandrina*, etc.	Red chalk, 4 to 6 feet. *Belemnites minimus.*	Red chalk, 4 feet. Hunstanton.	Chloritic marl with phosphatic nodules, 10 inches or more. Cambridge Greensand.

BEDFORDSHIRE, BUCKINGHAMSHIRE, ETC.	SURREY.	KENT.	ISLE OF WIGHT.
		Chalk with flints. Gravesend ?	Chalk with flints, 265 feet.
		Chalk with few flints, 250 feet. Margate (100 feet).	
Chalk with flints, 300 feet.	Chalk with flints, 200 feet. 2. Charlton and Croydon Beds, *M. cor-anguinum*. 1. Riddlesdown Beds, *M. cor-testudinarium*.	Chalk with flint nodules and tabular flint, 81 feet. *M. cor-anguinum ? M. cor-testudinarium, M. breviporus.* Broadstairs, Ramsgate.	Chalk with flints. *M. cor-anguinum*, 325 feet. *M. cor-testudinarium*, 165 feet.
Chalk Rock, 4 feet.	Chalk with flints, 50 feet. Kenley Beds, *Micraster cor-bovis*.	Chalk Rock. Hard rocky chalk, with flints, 22 feet. Dover.	Chalk Rock, 8 to 10 in. Chalk with flints, 65 feet.
White Chalk with few flints, but with thin layers of marl, 350 feet.	Chalk with few flints, 75 feet. Whiteleaf Beds, *Inoceramus Brongniarti*.	Soft yellowish-white chalk with flints, 150 feet. *Inoceramus mytiloides, Echinoconus subrotundus.*	Chalk without flints, 65 feet.
Melbourn Rock, 10 feet.	Chalk without flints, 70 feet. Upper Marden Park Beds, *I. mytiloides*.	Hard nodular chalk, 38 feet. *Cardiaster pygmæus, I. mytiloides.* Melbourn Rock (grit bed), 32 feet.	Chalk without flints, 130 feet. *I. mytiloides.*
Soft grey marly chalk, 4 feet.	Yellowish concretionary chalk and hard white chalk, 60 feet. Lower Marden Park Beds.	Yellowish-white gritty chalk, 4 to 6 feet.	
Hard grey and white chalk, 60 feet. Totternhoe stone, 6 to 15 feet.	Chalk marl and grey chalk, 60 feet. Oxtead Beds, *Holaster trecensis* and *Ammonites varians*.	Grey chalk, 148 feet. Near Folkestone.	Chalk marl, 115 feet. *Turrilites costatus, T. Wiestii, Scaphites æqualis.*
Totternhoe marl, 80 feet.		Grey marly chalk, 21 feet. *Ammonites rothomagensis, A. varians.*	
Chloritic marl.		Coarse grey chalk with green grains, 10 feet. *Plocoscyphia mæandrina.*	Chloritic marl, 6 feet. *Ammonites laticlavius.*

Chalk conditions may have come on earlier in the east of England than in the west, for in Dorsetshire and Devonshire we have evidence of shallow-water conditions in the lowest beds of Chalk, while the Upper Chalk, as Mr. Whitaker has pointed out, overlaps the Lower. Moreover, the occurrence in the Chloritic Marl of the west of England of *Holaster subglobosus*, *Ammonites Rothomagensis*, *Scaphites æqualis*, and *Terebratula semiglobosa*, is noteworthy.[1] *S. æqualis* does not occur in the Chloritic Marl of the Isle of Wight.

The Red Chalk and the so-called 'Cambridge Greensand' will be described subsequently.

Chalk Marl.—The Lower Chalk includes the Chalk Marl (more or less argillaceous chalky beds with hard stony layers), and above it the Grey Chalk, divisions which are locally separated by the Totternhoe Stone, but are not always to be distinguished, especially in the west of England. Among the fossils of this formation we find *Turrilites costatus*, *T. tuberculatus*, *Hamites attenuatus*, *H. armatus*, *Baculites anceps*, *Belemnitella plena*, *Ammonites Rothomagensis*, *A. varians*, *A. Mantelli*, *A. Sussexiensis*, *Nautilus Deslongchampsianus*, *N. elegans*, *Pecten Beaveri*, *P. orbicularis*, *Spondylus striatus*, *Lima globosa*, *Inoceramus latus*, *Plicatula inflata*, *Rhynchonella Mantelliana*, *R. Cuvieri*, *R. Martini*, *Terebratula semiglobosa*, *T. biplicata*, *Terebratulina striata*, *Discoidea cylindrica*, *Holaster subglobosus*, *Ptychodus decurrens*, *Chelone Benstedi*, etc.

Totternhoe Stone.—This bed consists of hard grey and sandy chalk, containing about eight per cent. of silica, and charged in places with glauconitic grains. It takes its name from Totternhoe, about three miles west of Dunstable, in Bedfordshire. It contains *Ammonites Rothomagensis*, *A. varians*, *Nautilus elegans*, *Lima globosa*, *Ostrea vesicularis*, *Pecten fissicosta*, *P. orbicularis*, *P. Beaveri*, *Rhynchonella Mantelliana*, *Terebratula biplieata*, *T. semiglobosa*, etc.

Middle Chalk.

This division is locally marked by the occurrence of the Melbourn Rock at its base, and by the Chalk Rock at the top. It contains *Ammonites peramplus*, *Inoceramus mytiloides* (*labiatus*), *I. Brongniarti*, *I. Cuvieri*, *Terebratula semiglobosa*, *Terebratulina gracilis*, *Rhynchonella Cuvieri*, *Galerites subrotundus*, *Cardiaster pygmæa*, *Holaster planus*, *Discoidea minima*, etc.

Melbourn Rock.—This rock, named from Melbourn, between Cambridge and Royston, was described by Mr. Jukes-Browne in 1880.[2] It is a hard yellow and white nodular stone, locally known as 'rag,' and from eight to ten feet thick. It contains *Rhynchonella Cuvieri*, *Terebratulina striata*, etc.

Chalk Rock.—This bed was so named by Mr. Whitaker in 1859, originally as the topmost bed of the Lower Chalk in Wiltshire,

[1] Q. J. xxxiii. 446, 447.

[2] See Penning and Jukes-Browne, Geol. Cambridge, p. 55.

Berkshire, Buckinghamshire, Oxfordshire, and Hertfordshire.[1] It is now regarded as the upper limit of the Middle Chalk, and has been recognized in the Isle of Wight, in Dorsetshire, and Bedfordshire. The Chalk Rock consists of hard, blocky, cream-coloured chalk, jointed perpendicularly to the plane of bedding, with lines of irregularly-shaped, hard calcareo-phosphatic nodules, which are green outside, but cream-coloured within. It contains *Holaster planus*, *Ammonites Prosperianus*, *Scaphites Geinitzii*, *Lima* (*Spondylus*) *spinosa*, *Turbo gemmatus*, *Rhynchonella plicatilis*, *Terebratula carnea*, *T. semiglobosa*, etc.

Upper Chalk.

This division, which is generally marked by numerous flint-layers, contains however no flints in its upper part in Yorkshire, and very few in the upper beds of East Kent. It is characterized by *Ananchytes ovatus*[2] ('Fairy or Sugar Loaf,' now, alas! termed *Echinocorys vulgaris* by Dr. Wright, who has attempted to restore an obsolete name), *Galerites conicus* (*G. albogalerus* or *Echinoconus*, —'the Helmet'), *Cyphosoma Koenigi* ('the Shepherd's Crown'), *Micraster cor-anguinum* ('Fairy Heart'), *M. cor-bovis*, *M. cor-testudinarium*, *Marsupites ornatus* and *M. Milleri* ('Cluster stones' or 'Tortoise encrinites'), *Goniaster Parkinsoni*, *Bourgeticrinus ellipticus*, *Terebratula carnea*, *T. obesa*, *Rhynchonella plicatilis*, *Magas pumila*, *Crania Parisiensis*, *Pecten nitidus*, *Lima* (*Spondylus*) *spinosa*, *L. Hoperi*, *Pleurotomaria perspectiva*, *Belemnitella mucronata*, *B. quadrata*, *Baculites Faujasii*, *B. anceps*, *Siphonia* (*Choanites*) *Koenigi*, *Ventriculites radiatus*, etc. Ammonites are not common. Remains of *Mosasaurus* occur at Norwich and other localities.

The 'Upper Chalk' is a somewhat vague term; for, as Mr. Godwin-Austen has remarked, there is no portion of the formation in this country which has not been greatly denuded.[3]

YORKSHIRE.

The Chalk extends from Flamborough Head inland, forming the Yorkshire Wolds. On the coast it is difficult to study the various divisions (see p. 402), as the sea in several places washes the almost vertical cliffs, which at Flamborough Head rise to a height of about 400 feet. The base of the Chalk is well shown in Speeton Cliff, where there are alternations of red, grey, and white chalk above the bottom Red Chalk proper. Some beds of the grey chalk are very arenaceous, containing in one instance, according to Prof. J. F. Blake, as much as 25 per cent. of alumina, iron, and insoluble matter. The red colour does not coincide with the stratification,

[1] Q. J. xvii. 166; see also C. Barrois, Ann. Soc. Géol. du Nord, iii. 145; Penning and Jukes-Browne, Geol. Cambridge, p. 69.

[2] The generic name is derived from the Greek, ἀ, not, ἄγχω, to press tight, and signifies not pressed (Owen).

[3] Proc. G. S. iv. 168; G. Mag. 1865, p. 199.

but has an undulating boundary, cutting across the beds obliquely.[1] Red bands occur again in the hard chalk of Speeton (zone of *Holaster subglobosus*). The lowest bed of Red Chalk is the equivalent of the Hunstanton Limestone (see sequel), and it has been traced from Speeton along the western margin of the Yorkshire Wolds, by Market Weighton, west of Hull, and southwards on the western border of the Lincolnshire Wolds to Hunstanton.

The zone of *Belemnitella plena* has not been recognized; while that of *Belemnitella mucronata* is wanting, although this species and *B. quadrata* have been recorded from the highest beds at Bridlington. These beds are rich in Sponges. Large columns of flints like Paramoudras have been noticed at Flamborough.[2] The flints as a rule are greyish or white, and splintery. Much of the Chalk is excessively hard.[3] Layers of brown carbonaceous clays, one or two feet thick, have been noticed in the Chalk near Londesborough.

LINCOLNSHIRE.

The Wolds of Lincolnshire, which are formed of the Chalk, are, as Prof. Judd has pointed out, much covered with superficial deposits; hence the district does not present that uniformly bare and arid appearance so characteristic of the Chalk; in fact, nearly the whole of it has now been brought under the plough, and with the most satisfactory results.

The Chalk of this area is divided as follows:[4]—

Middle Chalk.	Chalk with flints and *Inoceramus Brongniarti*.
	Hard rocky Chalk.
Lower Chalk.	Chalk. Zone of *Holaster subglobosus*.
	Red Chalk.

No fossils indicating Upper Chalk have been determined, but possibly these beds are concealed beneath the Drift. The highest beds comprise Chalk with nodules and large tabular masses of flint, and sometimes Paramoudras; beneath comes a great thickness of hard chalk without flints, characterized here and there by bands of pink and red chalk, one well-marked bed at Louth being about six feet in thickness. The Louth red chalk can be traced over a considerable area: it contains *Holaster subglobosus*, *Discoidea cylindrica*, *Terebratula biplicata*, *T. obesa*, etc., species which occur also in the lowest bed of White Chalk. This is underlaid by the Red Chalk proper (Hunstanton Limestone), twelve feet in thickness, the upper part of which (called the 'Sponge-bed') contains the curious markings termed *Spongia paradoxica* (see p. 408), that also occur higher up in the White Chalk without flints. *Belemnites minimus* and other fossils occur in this Red Chalk.[5] (See p. 407.) The western entrance of Withcall Tunnel, east of Donnington, shows Lower Chalk resting on Red Chalk.[6]

[1] J. F. Blake, G. Mag. 1874, p. 364; P. Geol. Assoc. v. 240, 251, vi. 170; C. Barrois, *Ibid.* vi. 166; C. F. Strangways, Explan. Sheets 93 N.E., 95 S.W. and S.E. (Geol. Survey); Phillips, Geol. Yorkshire, Part I. edit. 3, pp. 54, 95; Rev. T. Wiltshire in Wright's Monog. Brit. Cretaceous Echinoderms (Palæontogr. Soc.), p. 8; Geologist, ii. 262.

[2] R. Mortimer, P. Geol. Assoc. v. 347.

[3] Dr. J. Mitchell, Proc. G. S. ii. 113.

[4] Jukes-Browne, Geol. E. Lincolnshire (Geol. Surv.), 1886.

[5] Judd, Q. J. xxiii. 235, xxiv. 223.

[6] A. Strahan, P. Geol. Assoc. viii. 386.

NORFOLK, ETC.

The Chalk of Norfolk was divided into Upper, Medial, and Lower Chalk in 1833 by Samuel Woodward,[1] while the palæontological divisions were marked out by Dr. C. Barrois in 1876.[2] The thicknesses given in the Table (p. 402) are approximate.

The greater part of the Chalk is concealed by Glacial Drift: the barer portions occur in West Norfolk, near Swaffham and Massingham, where there are extensive sheep-walks.

The thickness of the Chalk at Carrow, Norwich, was proved by a deep well to be as much as 1152 feet. To this at least thirty-five feet must be added to give the total thickness of the Chalk at Norwich, inasmuch as it rises to at least this height above the river-level near Mousehold. No trace of Red Chalk was found in this boring,

Red Chalk.—The Red Chalk, termed the Hunstanton Limestone and Hunstanton Red Rock by Prof. H. G. Seeley, forms a conspicuous band at the base of the White Chalk, and above the brown Carstone (Lower Greensand) in the cliff at Hunstanton, on the north-west coast of Norfolk. (See Frontispiece.) This band of Red Chalk has attracted much attention, and various opinions have been expressed concerning its age and origin since the days of William Smith: some geologists have grouped it as Gault, others as Upper Greensand, while more recently Mr. John Gunn suggested that it was the basement-bed of the Chalk, a view confirmed by the observations of Mr. Whitaker.[3] For our knowledge of the rock and its fossil contents we are chiefly indebted to Prof. Seeley and the Rev. Prof. Wiltshire.

The deposit is four feet in thickness, and according to Prof. Wiltshire it may be divided into three bands, the upper of which has a large quantity of fragments of *Inocerami*, the middle is rich in *Belemnites*, and the lower contains numerous *Terebratulæ*; these divisions, however, are extremely local. The bed contains rolled fragments of quartz and slate.

Amongst the more abundant fossils are *Bourgeticrinus rugosus*, *Pentacrinus Fittoni*, *Micrabacia*, *Holaster suborbicularis*, *Vermicularia umbonata*, *Terebratula biplicata*, *T. capillata*, *Inoceramus Crispii*, *Spondylus striatus*, *Avicula gryphæoides*, *Ostrea vesicularis*, *Ammonites auritus*, *A. lautus*, *Belemnites minimus*, etc. *Otodus appendiculatus* and *Ichthyosaurus campylodon* also occur. It is remarkable, as Mr. Whitaker points out, that while the commonest fossils are Gault species, some are Upper Greensand forms, and some are Chalk fossils. Among the Chalk fossils are *Cidaris sceptrifera*, *Rhyncho-*

[1] Outline of the Geology of Norfolk.

[2] Recherches sur le Terrain Crétacé, etc.

[3] Proc. Norwich Geol. Soc. i. 207 (this paper contains a full account of the labours of previous observers), P. Geol. Assoc. viii. 137; see also H. G. Seeley, Ann. Nat. Hist. 1861, Q. J. xx. 327; T. Wiltshire, P. Geol. Assoc. 1859, Q. J. xxv. 185; T. G. Bonney, Cambridgeshire Geology, pp. 33, 77.

nella Cuvieri, *Terebratula semiglobosa*, *T. sulcifera*, *Inoceramus tenuis*, etc. The Red Chalk was penetrated in a well-boring at Holkham, near Wells, in Norfolk.

Analysis of the Hunstanton Rock showed the following constituents :—

Carbonate of lime with a little alumina	82·3
Peroxide of iron	6·4
Silica	11·3
	100·0

Hence the deposit is rather an impure Chalk, or Chalk marl, coloured red by peroxide of iron. The amount of iron-oxide varies, as one analysis showed 9·60 per cent.[1] As remarked by Mr. David Forbes, it appears that the Red Chalk does not contain quite so much iron as does the Gault ; so that if the latter rock were subjected to any oxidizing influences, it would assume the red colour of the Hunstanton rock, as it does by burning. The term 'ferruginous,' therefore, as applied to rocks, is by no means a necessary indication that they contain any larger proportion of iron than do many rocks that have no ferruginous appearance.

In West Norfolk there is a deposit of marly clay 20 to 70 feet thick, which rests on the Lower Greensand, and contains at its base a Coprolite-bed (nine inches), which is largely made up of phosphatized Gault fossils. This Coprolite-bed has been worked at West Dereham ; but while it has been regarded as the base of the Chalk Marl, it is now included by Messrs. Jukes-Browne and Hill with the Gault.[2]

Near Lynn Mr. Whitaker identifies the Chalk Marl with a thickness of twenty feet, but it disappears near Sandringham ; in places it contains layers of a pale pink colour. The absence of this clayey division at Hunstanton, as well as the absence of the Gault clay, may in Mr. Whitaker's opinion have had something to do with the colouration of the Red Chalk, the peroxidation of the iron-ore being made more easy by freedom for the percolation of water.

Above the Red Chalk at Hunstanton is a layer about eighteen inches in thickness called the 'Sponge Bed,' in which the branching or ramose markings termed '*Spongia paradoxica*' are found. These markings have been shown by Prof. Hughes to be inorganic concretionary structures.[3] This 'Sponge Bed' has sometimes been included in the Hunstanton Series.

The Hard Chalk has been largely quarried at Stoke Ferry and Whittington ; it has yielded *Ichthyosaurus campylodon* ; also *Ammonites peramplus*, and *A. Austenii*, each about two feet in diameter. Many fossils have also been obtained at Marham and Shouldham. Mr. Jukes-Browne informs me that the 'Hard Chalk' includes representatives of both Lower and Middle Chalk. Totternhoe Stone occurs at Stoke Ferry, and near Roydon.[4] West of Harpley layers of tabular flint occur in the Middle Chalk, and these sometimes enclose lenticular masses of Chalk. Here also, and at Massingham and Wells, clayey seams occur in the Chalk ; while at Trimingham a sandy bed has been noticed by Mr. C. Reid. At Hillington curious concretionary structures affect the beds, presenting anticlinal and other appearances. 'Curved joints' have also been observed in the Chalk of Cherry Hinton, near Cambridge, which give an appearance of false-bedding to the rock.

[1] R. C. Clapham, Geologist, vi. 29 ; Bonney, Cambridgeshire Geology, p. 77.
[2] C. Reid and G. Sharman, G. Mag. 1886, p. 55.
[3] Q. J. xl. 273.
[4] Whitaker, Proc. Norwich Geol. Soc. i. 238.

The Middle Chalk of Swaffham is well known through the labours of C. B. Rose; it yields *Cardiaster* (*Infulaster*) *excentricus*, etc.[1] There are Chalk-pits at Litcham, and at Kenninghall and Bridgeham, near East Harling. *Belemnitella quadrata*, *Ostrea acutirostris*, etc., occur in the Upper Chalk near Walsingham, at Guist, near Fakenham, and at Banham.[2]

The uppermost beds of Chalk near Norwich are characterized by the presence of the gigantic flints termed paramoudras or pot-stones, often three feet in length and one foot in diameter, which are found at Horstead, Catton, Trowse, Thorpe, etc. (See p. 399.) The Chalk of Norwich contains *Belemnitella mucronata*, *B. lanceolata*, *Ostrea vesicularis*, *Pecten concentricus*, *Chama inæquirostrata*, *Terebratula carnea*, *Rhynchonella plicatilis*, var. *octoplicata*, *Ananchytes ovatus*, *Cardiaster granulosus*, etc.[3] Remains of *Mosasaurus* (*Leiodon anceps*) have been obtained by Mr. T. G. Bayfield at Lollard's Pit, near Bishops Bridge, Norwich.[4] The highest beds of Chalk known in Norfolk are those which occur at Trimingham; they contain *Trochosmilia cornucopiæ*, *Ostrea larva* (*canaliculata* or *lunata*), which occur in the newest zone (Danian) of European Chalk, and *Ostrea vesicularis* (*Gryphæa globosa*), etc.[5] Hence the highest Chalk of Norfolk has been sometimes compared with that at Maestricht, in Holland, and Faxoe, in Denmark, in which countries the Chalk exhibits gradations into the Tertiary strata.

The Upper Chalk is shown in the cliffs between Sherringham and Weybourn, beneath the Glacial Drift, and eastwards it occurs on the foreshore (see p. 398) as far as Cromer. The bluff at Trimingham, although *in situ*, has been disturbed and elevated by Glacial agency. (See sequel.)

The thick beds of flint-gravel, especially those on Mousehold, Poringland, and Strumpshaw Hills, testify to the great destruction of the Chalk; and they are of considerable interest from the many organic remains that have been found in the flints; these include many Sponges, etc., and some species not met with in the Chalk of the neighbourhood. *Echinoconus conicus* (*Galerites albogalerus*), met with in the gravel, has not been recorded from the Norwich Chalk. Flint casts of Cliona-borings are frequent in shells of *Belemnites* and *Inoceramus*. S. Woodward also mentions the occurrence of spherical flint-pebbles having a nucleus originating in a sponge; these are sometimes loose, the pebbles are then called Eagle-stones, or Ætites (a name given by Pliny). There is, however, no foundation for the notion that the sponges indicate a higher zone of Chalk than is developed at Norwich.[6]

In Suffolk the Chalk is exposed at Claydon, near Ipswich, Needham Market, Sudbury, Bury St. Edmunds, and Brandon. (See sequel.) At Combs, near Stowmarket, a deep well penetrated

[1] Proc. Geol. Assoc. i. 231.
[2] Geol. Fakenham, etc. (Geol. Survey), p. 7; and F. J. Bennett, Geol. Attleborough, etc. p. 4.
[3] Geol. Norwich (Geol. Survey), p. 8; Proc. Norwich Geol. Soc. i. 239.
[4] G. Mag. 1864, p. 296.
[5] C. Reid, Geology of Cromer (Geol. Survey), p. 5.
[6] Geol. Norwich (Geol. Survey), p. 26; see also remarks on flints of Surrey by Godwin-Austen, Proc. Geol. Soc. iv. 168.

843 feet of Chalk.[1] Near Mildenhall a bed of red marly chalk has been observed in the Lower Chalk.[2]

CAMBRIDGESHIRE.

The divisions of the Chalk have been previously noted. (See p. 402.) The so-called 'Cambridge Upper Greensand' consists of greenish chalky clay passing down into marl with glauconitic grains, from eight inches to one foot thick, and containing scattered phosphatic nodules (coprolites), and phosphatized fossils. The pits show sometimes twelve or fifteen feet of Chalk Marl above, while an eroded surface of the Gault is exposed beneath.

This phosphatic deposit is particularly rich in vertebrate remains, including a Bird discovered in 1858 by Lucas Barrett, and named *Enaliornis Barretti*, and another species, *E. Sedgwicki;* many Reptiles, *Ichthyosaurus campylodon*, *Plesiosaurus*, and the Dinosaurian *Acanthopholis* (also found in the Chalk Marl of Folkestone); likewise many Fish-remains, *Otodus appendiculatus*, *Lamna subulata*, *L. gracilis*, etc. Among Foraminifera a large form *Parkeria* is met with. Many Sponges occur. The Mollusca include *Ammonites*, *Scaphites Meriani*, *Inoceramus sulcatus*, etc.; and the Brachiopoda include *Terebratula biplicata*, *Rhynchonella sulcata*, etc. Many species are Chalk Marl fossils, a notable form being the Hippurite, *Radiolites Mortoni*.

The Rev. O. Fisher has observed that all the derived specimens (phosphates, etc.) have *Plicatulæ* attached to them, showing that, whatever they were originally, they were hard bodies when they lay at the bottom of the Chalk ocean. Many of them are broken; and the *Plicatulæ* may frequently be seen to be attached to the broken surfaces.[3] The species was named *Plicatula sigillina* by Dr. S. P. Woodward.[4] The coprolites are mostly black or deep brown in colour, while their surfaces are pitted, corrugated, or wrinkled: these black coprolites are distinct from the "red" coprolites of the Lower Greensand. Mr. Jukes-Browne observes that the 'coprolites,' fossils, and green grains which it contains have been mainly derived from the denudation of the Upper Gault; and he considers the bed to belong to the base of the Chalk Marl, the Upper Greensand being absent.[5] Hence it is probably homotaxial with the so-called Chloritic Marl of the southwest of England.

The origin of the phosphatic nodules, miscalled 'Coprolites' (see p. 104), is a subject that has been much discussed. Phosphate of lime, as pointed out by Prof. Bonney, is present in small quantities in the sea, in several rivers, and in numerous mineral springs; it is found in many plant and animal remains; and in the form of Apatite it is met with in many rocks. He considers that the phosphatic nodules are due to concretionary action, and have been formed by segregation out of mud saturated with phosphate of lime.[6] At the same time the deposition of the phosphatic matter has been determined by animal substances, for the bones and teeth, and

[1] Geol. Stowmarket, by W. Whitaker, F. J. Bennett, and J. H. Blake (Geol. Survey), p. 19.

[2] Jukes-Browne, Brit. Assoc. 1886.

[3] Q. J. xxix. 52.

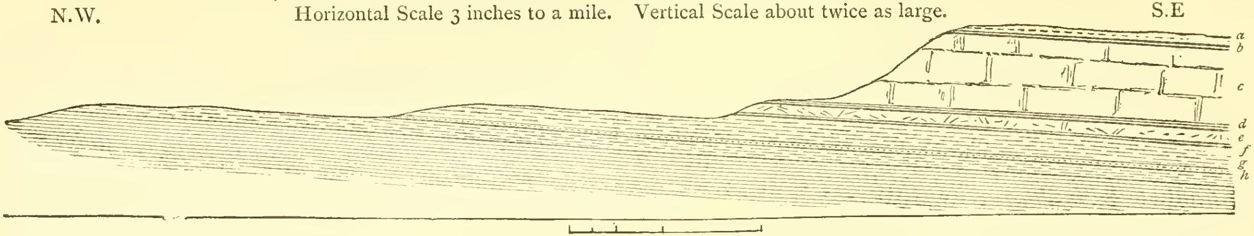
[4] G. Mag. 1864, p. 112.

[5] Q. J. xxxi. 256, 272; Seeley, Ann. Nat. Hist. 1861, 1865, Q. J. xxxii. 496; H. G. Fordham, P. Geol. Assoc. iv. 150.

[6] Cambridgeshire Geology, p. 30.

Fig. 67.—General Section near Prince's Risborough, Bucks. (W. Whitaker.)

Horizontal Scale 3 inches to a mile. Vertical Scale about twice as large.

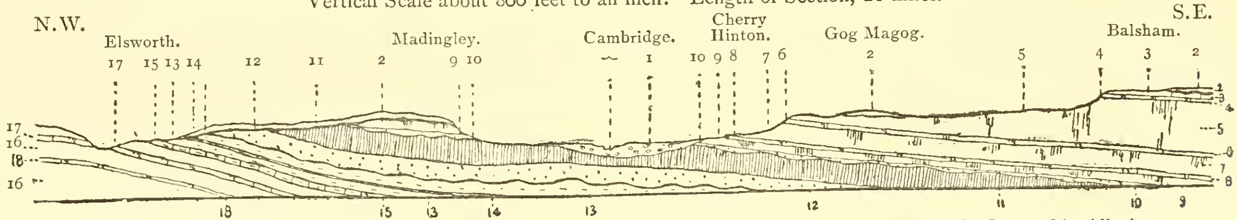


e. Chalk-without-flints, marly and blocky. } Lower Chalk.
f. Totternhoe Stone. } Lower Chalk.
g. Totternhoe Marl, with layers of stone. } Lower Chalk.
h. Clayey greensand. } Upper Greensand.
i. Light-grey calcareous sandstone. } Upper Greensand.
k. Gault.

a. Chalk-with-flints.—Upper Chalk.
b. Chalk Rock. } Middle Chalk.
c. Chalk-without-flints, or with a very few in the top part only. } Middle Chalk.
d. Chalk-without-flints, hard and bedded (= Melbourn Rock). } Middle Chalk.

Fig. 68.—Diagram Section from Elsworth to Balsham by Cambridge. (Prof. T. McK. Hughes.)

Vertical Scale about 800 feet to an inch. Length of Section, 21 miles.



13. Kimeridge Clay, with
14. Subordinate Limestones of Knapwell, Littleport, etc.
15. Corallian Beds, with Upware Rock and other Sandy Limestones.
16. Oxford Clay, with
17. } Elsworth Rock and other subordinate Sandstones.
18. }

7. Cherry Hinton Chalk. } Lower Chalk.
8. Totternhoe Stone. } Lower Chalk.
9. Chalk Marl. } Lower Chalk.
10. Cambridge Greensand. } Lower Chalk.
11. Gault.
12. Lower Greensand.

~ The Cam and its Alluvium.
1. Gravel.
2. Boulder Clay.
3. Upper Chalk.
4. Chalk Rock. } Middle Chalk.
5. White Chalk. } Middle Chalk.
6. Melbourn Rock. } Middle Chalk.

other organic remains may be partly encrusted, or wholly enveloped by phosphatic matter, while in some 'Coprolites' the original organic structure has been obliterated.[1] Between Hitchin and Cambridge the 'Coprolite' beds have been largely worked. There are coprolite-diggings at Horningsea, Guilden Morden in Cambridgeshire, Ashwell in Hertfordshire, and Shillington in Bedfordshire. The phosphatic nodules are extracted by washing. The average yield is about 300 tons per acre; and the nodules are worth about fifty shillings a ton. The diggers usually pay about £140 an acre for the privilege of digging, and return the land at the end of two years properly levelled and re-soiled.[2]

The Totternhoe Stone (see also p. 404) is well shown in the large Chalk quarries at Reach, and Burwell (Burwell Stone) in Cambridgeshire.[3] At Reach the Chalk Marl (clunch) has been most extensively worked, and the Totternhoe Stone is only exposed at the western end of the quarry. It appears as a very irregular dark-grey sandy limestone, about ten feet in thickness, containing towards its base hard, brown and green, calcareo-phosphatic nodules; the Chalk Marl below is a hard, white, flaggy chalk. The Totternhoe Stone weathers into numerous flaggy courses; but if got out in masses and dried carefully (the blocks being covered with matting to check the effects of the weather), the stone is useful for building. It is also used for hearthstone. The Cherry Hinton Chalk of Cherry Hinton, east of Cambridge, overlies the Totternhoe Stone, above which comes the Melbourn Rock. (See p. 404.) These beds and higher strata form the escarpment of Gog Magog and the Royston Downs. The beds above the Melbourn Rock are grouped as Vandlebury Beds by Mr. Jukes-Browne, from Vandlebury on the Gog Magog Hills, south-east of Cambridge.[4] (See Fig. 68.)

BUCKINGHAMSHIRE, ETC.

The Chalk forms the Chiltern Hills in Oxfordshire and Buckinghamshire, and the main divisions in this area (see p. 403) have been noted by Mr. Whitaker.[5] In Bedfordshire the Totternhoe Stone occurs at Totternhoe, Ivinghoe, Barton Hill, and Kensworth Hill; hills which form part of the Dunstable Downs, and which rise to a height of 810 feet at Kensworth Hill. The stone is largely quarried for building-purposes, and it constitutes a water-bearing stratum. (See p. 404.) At Luton the Chalk forms the Luton Downs, and in this neighbourhood many fossils have been obtained by Mr. J. Saunders.[6] The Melbourn Rock is shown at Leagrave, north-west of Luton, and near Ravensburgh Castle.

In Hertfordshire the Chalk occurs near Hitchin, Hertford and Ware, Northaw, Watford (see Fig. 72), and other places; the Chalk Rock is exposed at Boxmoor, near Hemel Hempstead,[7] and the Totternhoe Stone is shown at Arlesey.

In Essex we find the Chalk exposed at Great and Little Chester-

[1] O. Fisher, Q. J. xxviii. 396; see also W. J. Sollas, Q. J. xxviii. 397, xxix. 63, 76.

[2] Fisher, Q. J. xxix. 52.

[3] See Rev. J. Hailstone, T. G. S. ii. 248; Penning and Jukes-Browne, Geol. Cambridge, p. 43.

[4] G. Mag. 1880, p. 257; Q. J. xxxi. 272, and Geol. Cambridge, p. 24; see also W. Hill and A. J. Jukes-Browne, Q. J. xlii. 216.

[5] Q. J. xxi. 398; see also W. Hill and A. J. Jukes-Browne, Q. J. xlii. 216.

[6] G. Mag. 1867, pp. 157, 543.

[7] Whitaker, Geol. Middlesex (Geol. Survey), etc. p. 7.

ford, at Saffron Walden, near Bishop's Stortford,[1] and in the large pits at Grays Thurrock. At Grays the thickness is upwards of 660 feet, and in a deep well at Harwich it was proved to be 890 feet.

In Middlesex the Chalk is exposed at Harefield, north of Uxbridge; and it occurs at some depth beneath London; at Kentish Town its thickness was 645 feet, and at Meux's Brewery 655 feet.[2] (See Fig. 31, p. 202, and Fig. 70, p. 414.)

In the deep boring at Richmond the following beds of Chalk were passed through:[3]—

Upper Chalk, 300 feet.	Chalk with flints. Zone of *Micrasters* (the Chalk with *Belemnitellas* is not represented in the London area).
Middle Chalk, 150 feet.	Chalk Rock. Zone of *Holaster planus*, 5 feet.
	Chalk with few and scattered flints. Zones of *Terebratulina gracilis* and *Inoceramus labiatus*.
	Melbourn Rock, and Zone of *Belemnitella plena*. Nodular or conglomeratic chalk, about 15 feet.
Lower Chalk, 220 feet.	Grey marly Chalk without flints, and Chalk Marl.

In Berkshire the thickness of the Chalk is much the same as in Buckinghamshire and Oxfordshire; the Chalk-rock being from six to twelve feet thick. A fine section of Chalk Marl is exposed on the Great Western Railway at Wallingford Road Station. Here *Ammonites Rothomagensis*, *Turrilites tuberculatus*, *Pecten Beaveri*, *Inoceramus mytiloides*, etc., occur. The Upper Chalk is shown in the Railway-cutting at Pangbourn; and at a Chalk-pit near Hart's Old Lock, Upper Chalk, Chalk Rock, and Middle Chalk, were exposed.[4] Chalk is to be seen in the ice-house at Windsor Castle; while at Datchet it occurs at a depth of 117 feet from the surface. (See Fig. 64, p. 385.)

NORTH AND SOUTH DOWNS.

The Chalk forms the North and South Downs, bordering the Wealden district. It is well exposed in the cliffs at Gravesend, Westgate-on-Sea, Margate, Broadstairs, and Ramsgate, and in those extending from near Walmer Castle, south of Deal, by St. Margaret's, the South Foreland, and Dover, to Shakespere's Cliff and Abbot's Cliff, north of East Wear Bay, Folkestone; to the south it is exposed in the cliffs extending from Beachy Head and Seaford to Brighton and Littlehampton. (See Figs. 57, 60, and 66.)

The inclination of the Chalk along the North Downs from Dover to Guildford is from 10° to 15°; further west, at the Hog's Back, it increases to upwards of 45°, and hence its outcrop is very narrow in places.

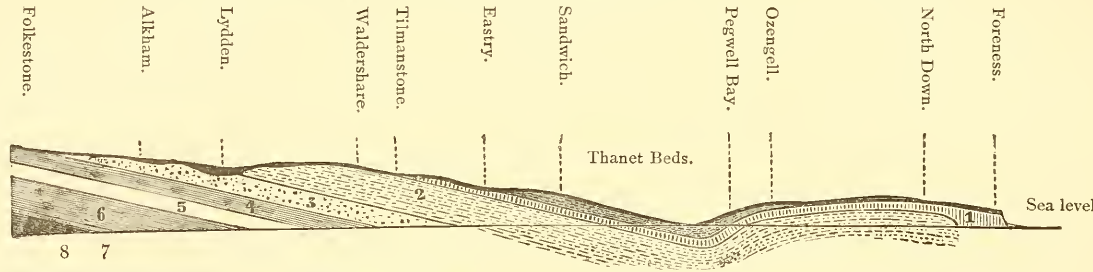
[1] See Geol. N. W. part of Essex, etc., by W. Whitaker, W. H. Penning, W. H. Dalton, and F. J. Bennett.

[2] Whitaker, Mem. Geol. Survey, iv. 21; Geol. London, ed. 4, p. 20. A revised edition of the Section Fig. 70, is published as a frontispiece to the last-named work.

[3] J. W. Judd, Q. J. xl. 731.

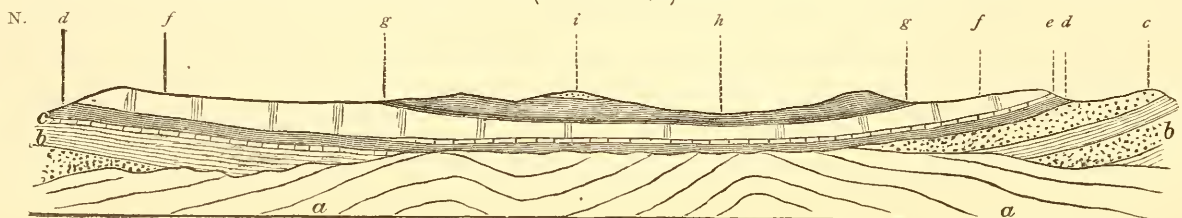
[4] W. Whitaker in Explan. Sheet 13 (Geol. Survey), p. 18.

Fig. 69.—Section from Folkestone to Foreness, Isle of Thanet. (G. Dowker.)



7. Upper Greensand. (See p. 388.) 5. Chalk without Flints. 3. St. Margaret's Chalk. 1. Margate Chalk.
8. Gault. 6. Grey Chalk. 4. Dover Chalk. 2. Ramsgate Chalk.

Fig. 70.—General Section of the London Basin, showing the probable Position of the Older Rocks. (W. Whitaker.)



i. Lower Bagshot Beds.
h. London Clay.
g. { Oldhaven Beds. Woolwich and Reading Beds. Thanet Beds.
f. Chalk.
e. Upper Greensand.
d. Gault.
c. Lower Greensand.
b. Wealden and Oolitic Beds.
a. Palæozoic Rocks.

In West Kent and East Surrey the divisions of the Chalk have been marked out by Mr. Caleb Evans; the names Riddlesdown, Purley, Kenley, Whiteleaf, and Marden belonging to places between Croydon and Oxtead.

The Riddlesdown Beds occur at Purley, and were formerly grouped as the Upper Chalk of Kenley, hence the Kenley Beds now include only the Lower Chalk of Kenley as originally described. The thicknesses of the divisions of the Lower Chalk are given approximately in the Table (p. 403). *Galerites conicus* is characteristic of the zone of *Micraster cor-anguinum*. Mr. Evans observes that *Holaster subglobosus* has not yet been obtained from Oxtead. The Chalk of Gravesend is, he thinks, slightly higher in the series than that of Charlton and Croydon, as it contains *Belemnitella mucronata*.[1]

One of the most interesting discoveries in the Chalk with flints was that of a granitic boulder which was found in a pit opposite the 'Royal Oak' at Purley, near Croydon. It was a rounded and waterworn block originally about three feet long, and was accompanied by some decomposing fragments of 'greenstone' and with a mass of siliceous sand. Mr. Godwin-Austen considered that an ice-floe was the agent by which alone such a block could have been lifted from the coast and conveyed far out to sea. It probably came from Scandinavia. Coal has been found in the Chalk near Dover.[2] (See p. 395.)

There are many pits where the Chalk may be studied and from which fossils may be collected, at Lewisham (Loam-pit hill), Charlton, Dartford, Camden Park (between Bromley and Chiselhurst), Greenhithe, Northfleet, and Gravesend.

In East Kent the total thickness of the Chalk has been estimated at from 700 to 800 feet; its thickness at the boring at Chatham was proved to be 682 feet. The Chalk of the Isle of Thanet has been described by Mr. Whitaker and Mr. G. Dowker, while an excellent description of the Chalk of Dover was published many years ago by William Phillips.[3] The following table shows the chief lithological divisions which have been made (see Fig. 69):—

Upper Chalk, 330 feet, or more.	Chalk with few flints. Margate Chalk.[4]	
	Chalk with numerous flints, both tabular and nodular. Broadstairs[4] or Ramsgate Chalk.[5]	
	Chalk with many flints. St. Margaret's Chalk.[5]	
Middle Chalk, 240 feet.	Chalk with few flints. Dover Chalk.[5]	
	Chalk without flints. Shakespere's Cliff, Dover.	
Lower Chalk, 180 feet.	Grey Chalk and Chalk Marl.	Near Folkestone.
	Chloritic Marl. (See p. 388.)	

Between Broadstairs and Ramsgate the beds are affected by a number of faults. At Cliff End, Birchington, and Kingsgate Bay, many Ammonites are to be seen *in situ* in the chalk, and in 1874 Mr. F. A. Bedwell recorded as many as eighty-nine

[1] On some Sections of Chalk between Croydon and Oxtead, Geol. Assoc. 1870; P. Geol. Assoc. v. 149.
[2] Q. J. xiv. 252, xvi. 326.
[3] T. G. S. v. 16.
[4] These names were applied by Mr. Whitaker, Q. J. xxi. 395.
[5] These names were given by Mr. Dowker, from St. Margaret-at-Cliffe by the South Foreland, north-east of Dover, etc. G. Mag. 1870, p. 466.

specimens, one of which was at least four feet in diameter. In the Margate Chalk *Ammonites leptophyllus* occurs, nearly three feet in diameter.[1] The Margate Chalk does not belong to so high a zone as the Norwich Chalk; indeed, as Mr. Whitaker has remarked, there is probably no representative of the uppermost English Chalk in East Kent.[2]

The palæontological zones first indicated by Prof. E. Hébert have been worked out in detail by Mr. F. G. H. Price[3] and Mr. W. Hill.[4] (See p. 403.)

At the base of the Chalk Marl near Folkestone there is a dark sandy marl, fourteen feet thick, which is noted by Mr. Price as the zone of the Sponge *Stauronema Carteri*: this bed has usually been regarded as Upper Greensand, but sometimes it has been termed Chloritic Marl. It is barely recognizable between Folkestone and Guildford, but has a thickness of thirty feet at Eastbourne. (See p. 388.) Coprolites have been observed at the base of the Chalk at Aylesford. The Channel Tunnel was commenced in the Chalk at Shakespere's Cliff.[5]

Eastbourne is situated on the lower part of the Chalk. In this neighbourhood it has been divided as follows by Mr. F. G. H. Price:[6]—

	Top beds not measured. (See Fig. 66.)	Feet.
Middle Chalk.	Soft yellowish bed with *Inoceramus mytiloides*, *Terebratulina gracilis*	120
	Hard gritty chalk, with comminuted fragments of *Inoceramus*, etc., *Cardiaster pygmæus*. [Melbourn Rock.]	8
Lower Chalk.	Belemnite-zone	8
	Lower or grey chalk. Zone of *Holaster subglobosus*	170
	Hard coarse grey marl, with *Plocoscyphia mæandrina*	30

The neighbourhood of Lewes is, through the labours of Dr. G. A. Mantell, a well-known locality for Chalk-fossils. Here, in 1832, he discovered the Hippurite *Radiolites Mortoni*. There are pits at Hamsey, Offham, Southeram; and further west at Steyning, Burpham, Arundel and Brighton.[7] Chalk is seen on the coast at Worthing and Littlehampton, and at these localities and at Brighton, flint-pebbles containing chalcedonic sponges, mostly *Siphonia* (*Choanites*) *Koenigi*, are picked up on the beach and polished as Brighton pebbles.

West of Littlehampton, Chalk has been exposed on the shore opposite Felpham, while at Middleton Chalk has been dug at low-water.[8]

HAMPSHIRE, ETC.

The Chloritic Marl occurs in the neighbourhood of Alton and Selborne, where it is from a few inches to fifteen feet thick. It contains a good deal of phosphatic matter, and the beds have been largely worked at Froyle. The celebrated 'coprolite' beds found near Farnham in Surrey, and worked at Dippen Hall, vary in thick-

[1] G. Mag. 1874, p. 16; P. Geol. Assoc. iii. 217.
[2] Q. J. xxi. 396. See also Geol. Norwich (Geol. Survey), p. 20.
[3] Q. J. xxxiii. 433.
[4] Q. J. xlii. 232.
[5] De Rance, P. Geol. Assoc. vii. 339; see also Prestwich, Proc. Inst. Civ. Eng. xxxvii., and Topley, Quart. Journ. Science, 1872.
[6] Dixon, Geol Sussex, ed. 2, p. 137.
[7] Mantell, Day's Ramble in Lewes, 1846; see also J. Howell, P. Geol. Assoc. ii. 168, v. 80.
[8] Woodbine Parish, Proc. G. S. ii. 114.

ness from two to fifteen feet. This neighbourhood is celebrated for its hop-gardens.[1]

Much of the Chalk around Basingstoke, Mitcheldever, and Andover has but little soil and forms bare and open ground. Northwards the anticlinal structure of the beds at Kingsclere and Highclere tilts the Chalk to a high angle, as at Guildford, and brings the Upper Greensand to the surface in a so-called "Valley of Elevation." (See Fig. 63, p. 382.) The Chalk too in this neighbourhood attains, at Inkpen Hill, its highest elevation in England (nearly 1000 feet). A fine section of Upper Chalk is exposed at Paul's Grove Pit, Portsdown Hill, near Portsmouth.

In the Isle of Wight the chief palæontological divisions of the Chalk have been determined by Dr. Barrois.[2] (See p. 403.) In the fine cliffs at Culver, on the east side of the island, the Chalk dips at a very high angle, and on the opposite side, at Alum Bay, it is nearly vertical. (See Fig. 73.) The main features in the geology were noted many years ago by Sir Henry C. Englefield and Mr. T. Webster.[3]

Mr. C. Parkinson regards the Chloritic or Glauconitic Marl as a distinct bed in the Isle of Wight. It may be traced immediately over the Upper Greensand, along the Undercliff, from Blackgang chine to Luccombe chine, and again near Culver cliff. He observes that it varies in thickness from 6 to 7 feet, and may be divided into two beds separated by a layer of phosphatic nodules. The best sections are at Ventnor Station quarries and below Old Park, St. Lawrence. He proposes to call it the "zone of *Turrilites Morrisii*," rather than the zone of *Scaphites æqualis*.[4]

SOUTH-WEST OF ENGLAND.

In Wiltshire and Dorsetshire the total thickness of the Chalk is about 800 feet. It forms the Marlborough Downs and Salisbury Plain, extending westwards to the hills near Mere. The Chalk Marl (rich in Ammonites) varies in thickness from twenty to fifty feet. *Ammonites Wiltonensis* was obtained by Mr. W. Cunnington from the hard chalk of Devizes; the Pewsey cup-corals, *Parasmilia cultrata*, are also met with in that neighbourhood. The Chloritic Marl is sometimes six feet thick; at Wroughton, near Swindon, this phosphatic bed is eighteen inches thick. The Chalk Rock has been observed near Marlborough.

From Salisbury the Chalk extends by Cranborne Chase to Blandford, Bere Regis, Piddletown, and around Dorchester and

[1] Godwin-Austen, Q. J. iv. 257; H. W. Bristow and W. Whitaker, Geol. of parts of Berks and Hants (Geol. Survey), p. 12.

[2] Recherches, etc. (see p. 401), and Ann. Soc. Géol. du Nord, vi. 10; see also H. W. Bristow, Geol. Isle of Wight (Geol. Survey), and W. Whitaker, Q. J. xxi. 400.

[3] Englefield, Trans. Linn. Soc. 1802; see also his Description of the picturesque beauties, etc., of the Isle of Wight, 1816, with notes and sketches by T. Webster; also T. G. S. ii. 161; and Mantell, Geol. Excursions round the Isle of Wight, edit. 3, 1854.

[4] Q. J. xxxvii. 372.

Maiden Castle. It occurs also in outliers between Beaminster and Crewkerne.

The Chalk of Ballard Down and Handfast, north of Swanage, is a natural continuation of the Isle of Wight Chalk, the Needles of the Isle of Wight being repeated in Pinnacles called 'Old Harry and his wife.' The Lower Chalk strata by Ballard Hole are nearly vertical, further north a fault is met with and the beds occur at a gentle angle. (See Fig. 56, p. 351.) The high inclination is continued along the ridge of Purbeck Hill by Corfe Castle, where the very hard nature of the Chalk may be examined. At Worbarrow Bay and Lulworth Cove, the Chalk is also seen; and further west it again appears on the coast at White Nore and West Swyre Cliff, on the margin of Ringstead Bay, near Weymouth. Here in places the Chalk is very much disturbed, the bedding being sometimes vertical or even reversed.[1] The Chalk Marl (about twenty feet) is worked at Knowl Hill, west of Corfe; it is excavated along the dip in deep trenches.

Along the coast near Lyme Regis and west of Seaton in Devonshire, the following general divisions have been made in the Chalk (see Fig. 40, p. 252):—

Upper and Middle Chalk.	Chalk with flints, and hard nodules	100 to 150 feet.
Lower Chalk.	White (or Grey) Chalk, with sometimes hard brown or cream-coloured nodules	40 to 50 feet.
	Beer Stone (local).	
	Chalk with quartz grains (Chalk Marl)	3 to 10 feet.
	Chloritic Marl, (impersistent) nodular chalky bed with green grains and phosphatic nodules	1 to 3 feet

These divisions are not always to be detected, for De la Beche has remarked that the Chalk with quartz grains, though so conspicuous at Pinhay and Dowlands, thins out near Beer, and is no longer visible at Branscombe.[2] At the mouth of the Axe it is about three feet thick, and contains fossils.

Westward of Seaton the famous Beer Stone is met with. It contains *Inoceramus mytiloides*; and consists of beds of hard sandy chalk, from 6 to 10 feet in thickness, which may represent the Totternhoe Stone. Its occurrence is local, but this fact is significant as showing the variable nature of the Chalk. The bed has been worked, or rather mined, since Norman times; portions of Exeter Cathedral were built of it. It is much used now for building-purposes, and is also burnt for lime. Similar stone was formerly dug at Ware, near Lyme Regis.

There is no hard line of division in the Chalk series: and, as Mr. Whitaker has remarked, it is often difficult to mark the junction of Chalk and Greensand. He has noticed the overlap of the Upper Chalk-with-flints on to the Greensand at Beer Head, and has also identified the Chalk Rock in places in Dorsetshire and Devonshire.

In Dorsetshire, Devonshire, and Somersetshire the Chloritic Marl is usually very fossiliferous. It is well seen in places on the coast, and also in the neighbourhood of Chard and Chardstock. (See Fig. 65.) Among the specimens obtained at Chard by Mr. C. Reid and myself, were *Terebratula biplicata*, *T. semiglobosa*, *Myoconcha cretacea*, *Corimya carinifera*, *Nautilus expansus*, *Ammonites Coupei*, *A. navicularis*, *A. varians*, *A. Mantelli*, *A. Rothomagensis*,

[1] Damon, Geol. Weymouth, 1884, fig. 54, p. 135, etc.
[2] T. G. S. (2), ii. 117; W. Whitaker, Q. J. xxvii. 97; W. Linford, Tr. Edin. G. S. ii. 181.

Turrilites Wiestii, *Scaphites æqualis*, *Holaster subglobosus*, and *Echinoconus castaneus*.[1] (See pp. 321, 401.)

From the Chalk at Beer Head, near Seaton, Mr. C. J. A. Meyer records, Chalk Marl with *Rhynchonella Mantelliana*, *Ammonites Mantelli*, *Discoidea cylindrica*, *D. subuculus*; Lower and Middle Chalk, *Terebratula carnea*, *T. semiglobosa*, *Rhynchonella Cuvieri*, *Inoceramus mytiloides*, *I. Brongniarti*, *I. Cuvieri*, *Holaster planus*, *Micraster corbovis*; Upper Chalk, *Micraster coranguinum*.[2]

In this district the Chalk becomes of additional interest, from the fact that the outlier at Dunscomb Hill, east of Sidmouth, is the most westerly portion of the formation in England; the extensive beds of flint and chert gravel that cap the Greensand heights of Blackdown and the Haldon Hills, and that descend into the Bovey Valley, however, furnish some records of the former extent of the Upper Cretaceous strata in that direction.

Economic products, etc., of the Chalk.

The Chalk is extensively burnt for lime, by which process it loses about half its weight in carbonic acid. The lime is employed for manuring land, and mixed with sand it forms mortar. Chalk is also manufactured into whiting at Grays, Northfleet, Kintbury (between Hungerford and Newbury), Hartford Bridges, near Norwich, Hessle, and other places. The whiting is prepared by grinding the Chalk to a fine pulp with water, and allowing the whole to flow into a series of tanks; the sediment is then formed into cakes and dried. By the addition of linseed oil a form of putty is also made from this sediment. Chalk, mixed with clay (such as Gault or Boulder Clay) or with river-mud, is burnt and manufactured into Portland or Roman cement at Northfleet, Rochester, Dovercourt, Arlesey near Hitchin, Burgh Castle near Yarmouth, etc. Mixed with gum arabic and a little glycerine, it forms a good cement for mending fossils.

Hard beds of Chalk, as previously mentioned, have been employed for building-stone, notably the Beer Stone of Devonshire. In Lincolnshire hard chalk was used in the construction of Louth Abbey, and in Norfolk beds have been similarly employed, although chiefly for inside work. The important Coprolite-beds found in many places at the base of the Chalk have been already described. (See pp. 410, 416.)

Many Chalk or 'Marl' pits, known as *Cealc-seathas*, were opened in Saxon times. (See p. 242.) At the present day pits are occasionally opened to a depth of upwards of 100 feet; and the men work at the top with levers and throw down the Chalk in great masses. Blasting is occasionally resorted to; and a remarkable blowing up of Chalk took place many years ago at the Round Down Cliff, Dover, when hundreds of tons were thrown into the sea to make an opening for the railway beneath the cliff. The Chalk is sometimes worked by means of tunnels or galleries driven into the hill-slopes, a plan less frequently adopted now than formerly, although the object was to avoid the removal of superincumbent beds of gravel, etc., known in Norfolk as 'Uncallow.' Near Norwich many of these subterranean workings remain, and, as at Stone Hills, on the Dereham road, they extend a considerable distance, branching in various directions; the passages are not less than six feet in height and six feet in width, and sometimes more lofty. There are similar Chalk caves at Camden Park, near Chiselhurst.

Not only has Chalk itself been worked for various purposes, but extensive

[1] Geol. E. Somerset (Geol. Survey), p. 141. See also J. Wiest in Davidson's Brit. Cretaceous Brachiopoda, p. 114.

[2] Q. J. xxx. 371, 393.

excavations have been made in it to obtain the flints, while other openings have been made simply to afford places of security and refuge, and these latter are known as Deneholes (meaning *Den* holes, although pronounced and sometimes spelt *Dane* holes). The Deneholes of Kent and South Essex consist of narrow vertical shafts leading to artificial chambers excavated in the Chalk : their depth varying with the distance of that rock beneath the surface. They are found singly, in groups of twos and threes, or in larger collections of perhaps fifty or sixty pits. In South Essex they abound at East Tilbury, at Hangman's Wood near Grays, and along the course of the Mardyke, near Purfleet ; and in Kent they have been met with at Bexley, south of Dartford, and on Blackheath.[1]

Flint has been used since Palæolithic and Neolithic times for the manufacture of implements and weapons. In the earlier times flints were more often obtained from Gravel-beds, but in Neolithic times shafts were sunk into the Chalk to depths of 20 to 40 feet to obtain Flint, and this was extracted by the aid of picks made of Red Deer's antlers. Pits of this description, which often communicate one with another by underground passages, have been discovered at Grime's Graves near Brandon, in the parish of Weeting, Norfolk,[2] and also at Cissbury near Worthing, in Sussex.[3] A cave in the chalk at Royston, discovered in 1742, which is reached by a shaft, is considered to be of early British or Romano-British age, and has been occupied as a Temple or Chapel.

Gun-flints in former times were largely manufactured from the chalk-flints, and are still made at Brandon, and, until recently, at Catton and Whitlingham, near Norwich, for export to Africa. Before the invention of percussion-caps, when the demand for gun-flints was much greater, they were made at Lewisham, Maidstone, Purfleet, Greenhithe, and Northfleet,[4] and also at Beer Head, in Devonshire.

The flints derived from the Chalk are largely used for road-mending, and when burnt and ground to powder the material is employed in the manufacture of china, porcelain, and flint-glass. Flints have also been used for building-purposes. Inlaid flint-work in church towers and porches is not uncommon in Norfolk and Suffolk ; and specimens of mosaic work are sometimes to be seen. The Old Bridewell by St. Andrew's Church, Norwich, erected about 1400, is a fine specimen of flint work, according to Blomefield "being esteemed the most curious wall of black flints in all England for its neat work and look, the stones being broken so smooth and joined so well." The faces of these flints are covered with "mastoid" pittings, evidently due to the fact that in the original setting of the flints the workmen gave each one numerous taps with probably a wooden mallet, in order to fix it in position, and the blows induced incipient conchoidal fractures which were afterwards perfected by the action of the weather.[5] The term Conchoidal, meaning shell-like, is applied to the fracture of flints, and some other rocks, which often exhibit smooth or ribbed convex fractures resembling a *Mactra* or some other bivalve Mollusc. Conical fractures are not uncommon with flints : they are spoken of as the 'bulb of percussion.'

Over large areas of the Wiltshire Chalk there is no durable stone except the scattered 'Sarsens,' consequently the Druidical Temples of Avebury and Stonehenge have suffered pillage. (See sequel.)

The Chalk is one of the most important sources of water-supply, on account of its wide extent, thickness and absorbent nature, a Chalk country as a rule rapidly drying after rain, as the waters sink away quickly.[6] Springs are thrown out at the

[1] T. V. Holmes, Trans. Essex Field Club, iii. 54, iv. part 9; Report Lewisham and Blackheath Assoc. 1881 ; F. C. J. Spurrell and T. V. Holmes, P. Geol. Assoc. vii. 400 ; Buckland, T. G. S. iv. 290.

[2] Canon W. Greenwell, Journ. Ethnol. Soc. 1871.

[3] J. Park Harrison, Journ. Anthrop. Inst. 1878 ; Dixon's Geol. Sussex, ed. 2, p. 96.

[4] Dr. J. Mitchell, Edin. New Phil. Journ. 1837, xxii. 36 ; Skertchly, Manufacture of Gun-flints (Geol. Survey), 1879.

[5] Geol. Norwich (Geol. Survey), p. 30 ; C. B. Rose, P. Geol. Assoc. i. 60.

[6] See Whitaker, Proc. Norwich Geol. Soc. i. 277.

lower portion of the Chalk, the clayey Chalk Marl being, as a rule, impervious; at Lydden Spout, Folkestone Hill, there is a copious perennial spring. (See Fig. 69.) The Totternhoe Stone yields many springs. Inland the streams come to the surface at different levels in a valley according to the season and the amount of rainfall; hence in Wiltshire we find the names Winterbourne Basset, Winterbourne Monckton, etc., applied to villages in the district. (See sequel.) Prof. Prestwich has stated that it is only under certain conditions that he considers the Chalk a source of good water supply. "Those conditions are that there should be a large receiving surface, and that the spring or well should be in a low situation relatively to the mass of exposed chalk. A spring shows itself; but in the case of a well, as the water does not permeate freely through the mass of the chalk, it is further necessary to hit upon a fissure below the level of the water-line. The depth or size of the fissure determines the supply."[1] Suggestions have been made to increase the supply of water in wells from the Chalk by means of galleries;[2] and this system has been adopted in many places with success.

Chalk water is hard; that at Grays contains about 15 grains of carbonate of lime in the imperial gallon.

Over parts of the dry Chalk Downs of Berkshire, etc., shallow excavations known as Dew Ponds have been made to supply water for cattle. These, I am informed by Mr. F. J. Bennett, are filled with water, preferably with snow, in the first instance, and that they rarely dry up, the supply being maintained by mists, as well as by rain, etc. The ponds on the Chalk generally require to be clayed.

Fuller's Earth has been recorded from the Chalk at Bepton, near Midhurst, in Surrey.[3]

Sulphuretted hydrogen, produced by the decomposition of iron-pyrites by water, is sometimes rather troublesome to well-sinkers, and carbonic acid gas (choke-damp) is apt to accumulate in tunnels and borings in Chalk.[4]

The Chalk Downs are in many places celebrated for the extent of their prospect, while the boldness of the escarpment and the whiteness of the substance have given the idea of forming figures in various parts by cutting away the turf. The White Horse, south of Uffington in Berkshire, occupies about an acre of ground, and may be seen from some points of view at the distance of twelve miles. There is also a land-mark of the same kind at Cherhill, near Calne, cut about the year 1780, by Dr. Alsop, a physician of that town; and another White Horse at Bratton, near Westbury, in Wiltshire. On the chalk hill that faces Weymouth there is a representation of George III. on horseback; and near Cerne Abbas there is a figure of a giant (180 feet in height) holding a club in one hand and extending the other. Near Prince's Risborough a large cross has been cut in the Chalk. One of the largest artificial mounds in Europe, that of Silbury Hill, near Avebury, was formed of Chalk rubble. Its height is 170 feet and the circumference at the base 2027 feet.

The Chalk Downs produce a short herbage, adapted for sheep, of which the South Down and Hampshire Down breeds are noted. In some parts good crops of turnips and wheat are produced; and much fine barley is grown on Chalk soils, near Devizes, Warminster and Salisbury. The Lower Chalk and Chalk Marl are, as a rule, more fertile than the Upper Chalk. The Chalk Downs are considered to retain their ancient character more than any other tracts of country. Beech trees grow exceedingly well on the Chalk (especially where it is covered with clay-with-flints or brickearth), and in Buckinghamshire the wood is largely used for chair-making; as a rule, however, the Downs are bare and open.

The fissured and sometimes rubbly surface of the Chalk is to a large extent caused by rain and frost, but occasionally in the Eastern Counties the Chalk has undergone disturbance by some more powerful agent, so that the mass of the rock

[1] Report on the Water-springs at Grays, 1860; Water-bearing Strata around London, 1851, p. 57.

[2] J. Lucas, Horizontal Wells, 1874.

[3] F. Sargent, T. G. S. (2), i. 168.

[4] Dr. J. Mitchell, Proc. G. S. iii. 151.

is broken up, and in part re-arranged, the flint layers are disrupted, and all symptoms of stratification destroyed. Thus in a pit at Costessey, near Norwich, the flints were disturbed to a depth of 20 feet. The Chalk when in this condition is known as "Glaciated Chalk," and to this reference will subsequently be made. The surface of the Chalk frequently exhibits great hollows or channels filled with material from the superincumbent deposit. These hollows, called "pipes" or "sand-galls," are caused by the dissolving away of the Chalk, and are filled by the overlying sand or gravel; sometimes these hollows give way suddenly, causing subsidence of the ground. (See also notes on reconstructed Chalk, p. 429.)

Part iii.

CÆNOZOIC.

TERTIARY AND QUATERNARY.

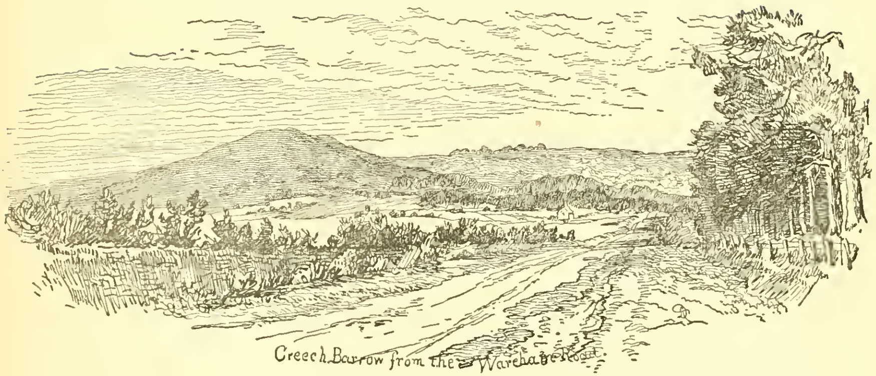


FIG. 71.—VIEW NEAR CORFE CASTLE, IN DORSETSHIRE.

THE strata overlying the Chalk in this country comprise a series of clays and marls, sands, gravels, and pebble-beds, with but few layers of limestone, or, indeed, with few hard bands that exhibit prominent layers of bedding. Hence they appear in marked contrast to the Secondary and older formations, for the beds have been less consolidated by the pressure of overlying deposits, and thus they form a transition between those harder rocks and the deposits now in course of accumulation.

The term Tertiary introduced by Cuvier and Brongniart, has been applied to the strata newer than the Chalk.[1] The term

[1] The terms Superior or Newest Flœtz Order were used by Conybeare and Phillips (1822), and Supercretaceous by De la Beche (1830). See G. Cuvier and Alex. Brongniart, Desc. Géol. des Environs de Paris, ed. 2, 1822, p. 9; Buckland, Ann. Phil. xvii. (N.S. i.) 451.

Cænozoic proposed by John Phillips (spelt also Kainozoic), signifying *recent life*, has been employed as a synonym; but from the introduction of the term Quaternary (or Post-Tertiary), it seems desirable to group the strata as follows:—

Cænozoic { Quaternary.
Tertiary.

TERTIARY.

The Tertiary era is characterized by the occurrence of numerous genera of large Mammalia, hence it has been termed the Age of Mammals. Remains of Birds are found, also those of Reptiles in some abundance; and it is remarkable that fossil remains of Gavials, true Crocodiles, and Alligators are represented in our Lower Tertiary strata, although "at the present day these forms are all geographically restricted in their range, and are never associated together."[1] Turtles and Serpents are likewise represented: the latter appearing for the first time. Among Fishes the Teleosteans abounded, as did also the Selachian Fishes represented by the Rays and Sharks. Among Mollusca, *Ammonites* and *Belemnites* are no longer known in this country; the *Nautilus*, however, survives, and is still living in other seas. Gasteropods and Lamellibranchs are found in great numbers and variety: they include *Voluta*, *Cypræa*, *Pleurotoma*, *Cyrena*, *Cardita*, *Cytherea*, *Mactra*, *Mya*, etc. Brachiopoda are poorly represented. Few Insects are preserved.[2] Crustacea (especially *Brachyura*), Echinodermata, and Corals are met with. Among Foraminifera, the genus *Nummulina* (*Nummulites*) is a characteristic fossil, but is met with only at certain horizons (Bracklesham and Barton Beds).

The Flora and Fauna of the Lower Tertiary strata are rich in tropical and subtropical forms; while the highest strata contain Plants and other organic remains belonging to a temperate climate, and even indicating the approach of the Glacial period. There were, however, considerable fluctuations in climate during the Tertiary era. All kinds of Plants are represented in the strata, from Fungi, Lichens, Mosses, and Hepaticæ, upwards.[3]

The organic remains now begin to approach more closely to

[1] H. A. Nicholson, Manual of Palæontology, ed. 2, vol. ii. p. 210; A. S. Woodward, P. Geol. Assoc. ix. 327.

[2] H. Goss, P. Geol. Assoc. v. 282.

[3] Flora of Eocene Formation, by J. S. Gardner and Baron C. von Ettingshausen (Palæontogr. Soc.); P. De la Harpe, Bull. Soc. Vaudoise des Sc. Nat. 1856.

existing types; every stage brings us into contact with forms nearer to those now living. It was for this reason that Lyell in 1830, in conjunction with G. P. Deshayes, proposed the terms Eocene, Miocene, and Pliocene for the three great divisions into which European Tertiary deposits had been divided. These terms were based upon the percentage of recent Mollusca found in the strata to which they were applied.[1] Thus the Eocene strata (dawn of recent) contain a very small proportion of living species; the Miocene strata (less recent), although containing more recent species, yet contain a minor proportion compared with the Pliocene strata (more recent), which contain a plurality of recent species. These names are now used simply as stratigraphical terms, for Lyell himself subsequently admitted that the Eocene, Miocene and Pliocene periods have been made to comprehend certain sets of strata, of which the fossils do not always conform strictly, in the proportion of recent to extinct species, with the definitions first given by him, or which are implied in the etymology of those terms. The name Oligocene (signifying little recent, or few forms of life recent) was proposed in 1854 by Prof. H. E. Beyrich, for the strata known as Upper Eocene, because in their fauna and development he considered the beds entitled to distinct recognition. The term has been very largely adopted.

From astronomical calculations based on the considerations of climate, it has been calculated that the Eocene period occurred from 2,620,000 to 2,460,000 years ago.[2]

The Tertiary strata exhibit marine, estuarine, freshwater and terrestrial conditions, repeatedly changing; some of the divisions, and especially the Middle Eocene (termed Nummulitic by D'Archiac in 1842), were spread more or less continuously over a wide area of the earth's surface.[3]

The Tertiary group is subdivided as follows:—

Pliocene.
Miocene (wanting in England and Wales[4]).
Eocene[5] { Upper (Oligocene). / Middle. / Lower. }

The Eocene strata now occupy two distinct tracts, termed respectively the London and Hampshire (or Isle of Wight) Basins. The synclinal or basin-like arrangement of the Chalk strata upon which these newer deposits lie is, perhaps, more conspicuous

[1] Principles of Geology, edit. i.; see also Elements Geol. ed. vi. p. 187; and Students' Elements, 1871, p. 121. The names are sometimes spelt Meiocene and Pleiocene.

[2] Croll, Climate and Time, 1875.

[3] See J. S. Gardner, P. Geol. Assoc. vi. 90.

[4] The Bovey Beds were formerly grouped as Miocene, and the Hempstead Beds have also been classed with that system.

[5] The term Hantonian was proposed by Mr. Jukes-Browne for the Eocene and Oligocene strata, G. Mag. 1885, p. 293.

in the Hampshire district, which includes the Tertiary beds of Dorset, Hants, the Isle of Wight, and Sussex. In the London Basin the seaward extension of the strata on the east is unknown, but wherever observed the beds rest upon a foundation of Chalk. The formation of these so-called Basins is due to disturbance and denudation subsequent to the Eocene period, whereby the former continuity of the strata has been destroyed. The chief anticlinals affecting the area are that of Weymouth, the Isle of Purbeck and Isle of Wight; that of Portsdown and Highdown, near Chichester; that of the Vale of Wardour and Winchester; the Wealden anticlinal, and that of Pewsey and Kingsclere. These disturbances were produced at an epoch during which the north-western parts of the British area were subject to great volcanic activity.[1]

Although there is nowhere any marked unconformity in stratification between the Chalk and overlying Eocene strata, yet the change from deep-sea conditions to those of comparatively shallow-water is abrupt; and when we consider that in Denmark and Holland there are passage-beds between the Cretaceous and Tertiary formations which are not represented in England, the natural conclusion is that in our country these two great groups of rocks are unconformable. The level surface of the Chalk beneath the Tertiary beds may, as Dr. John Evans has suggested, be a plain of marine denudation;[2] and no doubt the Chalk was gradually upheaved in places above the sea-level, so as to form cliffs, for the earlier Tertiary shingles are almost entirely made up of flint. At the same time in certain areas the Eocene sediments were laid down on an undisturbed foundation; and thus, as Mr. Whitaker has remarked, in the Isle of Thanet the Tertiary beds appear to be conformable to the Chalk.[3]

The irregular hollows or "pipes," due to the dissolution of the Chalk by subaërial agents, are features that have in many instances been produced on the surface of the Chalk, after the deposition of the newer strata. These "pipes" occur where the surface of the Chalk is easily reached by water, and they are absent or rare where the Chalk is covered by impervious strata; hence "pipes" beneath a clayey stratum of considerable thickness indicate unconformity.

The former extent of the Eocene strata is not known; the lowest member (Thanet Sands) is overlapped towards the west by the Woolwich and Reading Beds, and although there is no evidence that the London Clay ever was deposited immediately on the Chalk, yet Mr. John Gunn thinks it highly probable that the London Clay did overlap the older Eocene strata in Norfolk, and Mr. J. S. Gardner has suggested a similar overlap in Dorsetshire.

The Tertiary strata were mapped for the Geological Survey in the southern counties chiefly by H. W. Bristow, Joshua Trimmer, W. Whitaker, and T. R. Polwhele; and in the eastern counties by W. Whitaker, W. H. Penning, F. J. Bennett, W. H. Dalton, C. Reid, and the writer.

[1] See J. S. Gardner, Proc. Royal Soc. xxxviii. 14; and Prestwich, Q.J. ii. 252.
[2] P. Geol. Assoc. v. 499.
[3] Q. J. xxi. 397, 405.

EOCENE.

The Eocene strata have been divided as follows:—

Eocene.	Upper (Oligocene).	Fluvio-Marine Series of the Isle of Wight and Hampshire.		
	Middle.	Upper Bagshot Beds.		
		Middle Bagshot Beds.	Barton Clay.	Bartonian.
			Bracklesham Beds.	
		Lower Bagshot Beds.		
	Lower.	London Clay and Bognor Beds (Upper London Tertiaries).		
		Oldhaven and Blackheath Beds.		Lower London Tertiaries.
		Woolwich and Reading Beds.		
		Thanet Beds.		

The strata are on the whole conformable, but there are evidences here and there of local, and, probably, contemporaneous erosion. Our knowledge of these divisions is chiefly due to the researches of Prof. Prestwich.

The Eocene strata are characterized by living families and orders of Mammalia; among living genera is that of the Opossum (*Didelphys*). From the occurrence of *Palæotherium* the term Palæotherian was used by John Phillips for this series.[1]

LOWER EOCENE.

THANET BEDS.

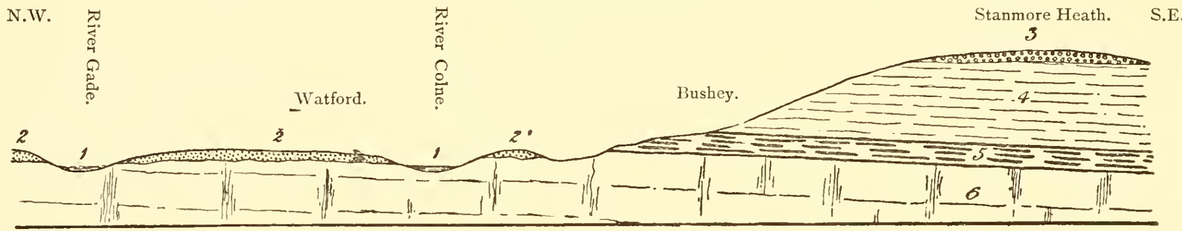
The name Thanet Sands was given by Prof. Prestwich in 1852, from the fact that the beds are best exhibited in part of the Isle of Thanet and adjacent country.[2]

The series consists of pale-yellow quartzose sand and loam, with sometimes greenish particles; so that in places it becomes an impure argillaceous greyish greensand. A marked feature is the occurrence of green-coated flints at the base of the deposit, resting on the Chalk. The thickness of the beds is variable; under London it is about 20 feet, in West Kent upwards of 60 feet.

[1] For figures of fossils see Monographs of the Palæontograph. Soc.; Eocene Mollusca, by F. E. Edwards and S. V. Wood; Crustacea, by T. Bell; Reptilia, by R. Owen and T. Bell, etc.; Plants, by J. S. Gardner and Baron C. von Ettingshausen; see also Lowry, Chart of British Tertiary Fossils.

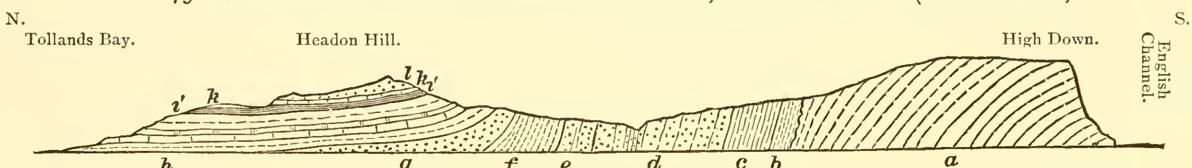
[2] Q. J. viii. 235.

Fig. 72.—Diagram-Section through Watford and Bushey. Length about 6 miles. (W. Whitaker.)



1. Alluvium.
2'. Brickearth. } Glacial Drift.
2. Gravel. } Glacial Drift.
3. Pebble Gravel.
4. London Clay.
5. Woolwich and Reading Beds.
6. Chalk with Flints.

Fig. 73.—Section across Headon Hill and High Down, Isle of Wight. (H. W. Bristow.)



l. Gravel and Sand.
k. Bembridge Beds.
i. Osborne Beds.
h. Headon Beds.
g. Upper Bagshot Beds.
f. Barton Clay.
e. Bracklesham Beds.
d. Lower Bagshot Beds.
c. London Clay (Bognor Beds).
b. Woolwich and Reading Beds.
a. Chalk.

The following subdivisions in the Thanet Beds have been noted by Mr. Whitaker:[1]—

(*e*) Fine sharp light-grey sand, slightly greenish, often iron-shot, with layers of calcareous sandstone here and there; the fossils sometimes silicified; thins eastwards, and is almost confined to East Kent, where it attains about 40 feet in thickness, and passes down into—

(*d*) Bluish-grey sandy marl, weathering to a pale yellowish-grey, often rather hard, with green grains and fossils, more sandy at top; thins westward, and is almost confined to East Kent, where it is the thickest member of the series near and beyond Canterbury.

(*c*) Fine light-buff sand, mostly soft, with few fossils (only some very obscure remains have been found); it is thickest in West Kent (up to 60 feet or more), where for the most part it forms nearly the whole of the Thanet Beds, thinning out westward in Surrey, and eastwards in Kent.

(*b*) Alternations of brown clay and loam, without fossils, thin and local (in part of East Kent).

(*a*) The 'base-bed,' clayey greensand, with unworn green-coated flints, resting on the Chalk, thin (rarely over 5 feet) but constant. This is called the 'Bull's Head bed' by workmen.

In every large section the junction between the Chalk and Thanet Beds is even; where, however, there is but a thin capping of the latter it often fills 'pipes,' irregular-shaped hollows, that have been formed since the deposition of the beds, by the infiltration of water holding carbonic acid in solution. The layer of green-coated flints at the base is considered to have been formed after the deposition of the Thanet Sand by the decomposition of the top of the Chalk.[2]

In the neighbourhood of the Bedwins (in Wiltshire), near Savernake Forest, and also in Berkshire, Mr. Whitaker has noticed in many places, close by the junction of the Reading Beds and the Chalk, a bed of reconstructed Chalk.[3] This bed, which in places may be 20 feet in thickness, contains blocks of chalk, scattered lines of flint, and much rubbly chalk; and it may possibly have been formed at the period when the Thanet Sands were elsewhere deposited. A similar bed occurs in a pit north-east of Northaw, in Hertfordshire.

The Thanet Beds are a marine deposit, formed probably in a shallow sea open to the north.[4] They yield remains of Mollusca, Polyzoa, Crustacea, Entomostraca, Echinodermata, Sponges, Foraminifera, and Plants. Among the more prominent species are the Mollusca *Cyprina Morrisii*, *Pholadomya cuneata*, *P. Koninckii*, *Cytherea orbicularis*, *Astarte tenera*, *Nucula Bowerbankii*, *Panopæa granulata*, *Thracia oblata*, *Ostrea bellovacina*, *Corbula Regulbiensis* (of which a band occurs near the junction with the Woolwich Beds at Herne Bay), *Scalaria Bowerbankii*, *Dentalium nitens*, *Natica subdepressa*, and *Aporrhais Sowerbyi*. The fern *Osmunda* (*Osmundites*) *Dowkeri* has been obtained at Herne Bay.

The beds are well exposed in the cliffs of Pegwell Bay, and those east of Herne Bay,[5] also in pits near Upnor and Erith, at Charlton near Woolwich, by the S.E. Railway near Westcombe Park, Greenwich (see Fig. 74), at Loam Pit Hill, Lewisham

[1] Geol. London Basin, Mem. Geol. Survey, iv. 56.

[2] Whitaker, Q. J. xxii. 404; T. McK. Hughes, *Ibid.* 402; see also G. Dowker, G. Mag. 1866, p. 210.

[3] Q. J. xvii. 527.

[4] Prestwich, "The Ground Beneath Us," 1857, p, 71; see also J. S. Gardner, Q. J. xxxix. 203.

[5] Prestwich, Q. J. viii. Plate xv.

(40 feet—see p. 432), and at Purfleet; and they were exposed at Park Hill, Croydon.[1]

The Thanet Beds are met with in deep wells under London, but they do not extend further west than Windsor, nor do they occur in the Hampshire Basin. Eastwards they occur near Grays Thurrock and West Tilbury. Their occurrence near Sudbury and near Ipswich on the northern side of the London Basin has been noticed by Mr. Whitaker.[2]

Allophane (hydrous silicate of alumina) occurs at the junction of the Thanet Beds and Chalk at Charlton, near Woolwich, it also occurs at Purley Downs, near Charlton. Silicified wood is met with in the Thanet Beds in East Kent. The beds furnish a good foundry-sand at Charlton.

WOOLWICH AND READING BEDS.

This series was named by Prof. Prestwich in 1853, from the localities in Kent and Berkshire, at which it is characteristically developed. It consists of alternations of mottled plastic clay, loam, and sands variegated in colour, together with pebble-beds of rolled flint, which are sometimes hardened into pudding-stone.[3] The term Plastic Clay, originally applied to the series, was adopted by T. Webster from the term *Argile plastique* of Cuvier and Brongniart,[4] and was given on account of the nature of the clay.

The thickness of the beds varies from 15 to 90 feet in the London Basin; and in the Isle of Wight from 84 feet in Alum Bay to 163 feet in Whitecliff Bay. The strata sometimes rest on a slightly eroded surface of the Thanet Beds.

It has been shown, and mainly through the researches of Prof. Prestwich, that three distinct conditions of the Woolwich and Reading series are developed; these may be noted as follows:[5]—

A. In the Hampshire Basin, and in the London Basin all along the northern outcrop, and on the western part of the southern outcrop from Berkshire through North Hampshire and the greater part of Surrey, this series is generally unfossiliferous. It consists of irregular alternations of clay and sands; the former of many and bright colours, mostly mottled and plastic; the latter also of many colours, sometimes with flint pebbles, and now and then hardened into sandstone or conglomerate; loam also occurs.

B. In the eastern border of Surrey, in West Kent, the border of East Kent, and partly in South Essex, we find, with the light-coloured sands, finely-bedded grey clay, mostly crowded with estuarine shells, and often with oyster-shells compacted into rock. Above this there is often (on the south-east of London) a fairly thick bed consisting of alternations of sand and clay, or loam with impressions of leaves;

[1] H. M. Klaassen, P. Geol. Assoc. viii. 227.
[2] Q. J. xxx. 401; Explan. Sheet 47 (Geol. Surv.), p. 12; Geol. Ipswich, p. 6.
[3] Q. J. x. 75. The name Woolwich Loam and Sand was used by John Farey in Sowerby's Mineral Conchology, vol. i. 1812.
[4] Description Géol. des Env. de Paris.
[5] See Whitaker, Mem. Geol. Survey, iv. 98, 576.

at the base of the shelly clays there is generally a bed of imperfect lignite, and lower down sometimes a pebble-bed.

C. In East Kent we find the simplest state of this formation, which there consists throughout of sharp light-coloured and false-bedded sand with marine fossils, differing alike from the estuarine Woolwich Beds and the changeful Reading Beds. One part of the formation is fairly constant. Where it rests on the Thanet Beds, this lowest member of the Woolwich and Reading Series is a greensand, more or less clayey, with flint-pebbles and here and there oyster-shells. Where, however, it rests on the Chalk, it is usually of a more clayey character; the flints at its base are angular and green-coated, instead of being in the state of perfectly rolled pebbles; as before, there are sometimes oyster-shells in the greensand, and besides there are (somewhat rarely) casts and impressions of other shells in the accompanying roughly laminated grey clays (with green grains). The difference in the condition of the flints in the two cases is just what one would expect: in the latter they have been derived directly from the underlying Chalk, whilst in the former they must have been carried some distance, and therefore worn. The estuarine Woolwich Beds also occur at Newhaven in Sussex.[1]

The beds are poorly represented near Hertford, where they rest directly on the Chalk. Thence they occur at Bishop's Stortford, by Elsenham, near Shalford, Castle Hedingham to Middleton near Sudbury, and Bramford (18 feet); and, according to Mr. W. H. Dalton, they may be traced in well-borings at Woodbridge, Saxmundham, and possibly at Hoxne.[2] Prof. Prestwich determined their presence in a well at Yarmouth, and there 46 feet of these beds and 310 feet of London Clay were found beneath 170 feet of newer deposits.[3] Eocene beds therefore are probably present above the Chalk to the east of Surlingham and Wroxham, in Norfolk.

The Hertfordshire pudding-stone is composed of flint pebbles of various colours, black, yellow and brown, embedded in a siliceous matrix, and so firmly cemented that the pebbles are fractured equally with the matrix, along joint-planes. This bed, which occurs near the base of the Woolwich and Reading series, has been exposed in pits near New Organ Hall, Radlett, also at North Mims churchyard and in ploughed fields to the north-east of that village.[4] Many specimens have been procured from the Drift deposits of the eastern counties.

The 'Bottom-bed' of the Woolwich and Reading Series is described by Mr. Whitaker as a roughly laminated dark grey clay and clayey sand, generally with green grains; it is often termed the Oyster-bed from the abundance in it of *Ostrea Bellovacina*.[5] It sometimes includes an overlying and underlying shell-bed with *Cyrena*, making the total thickness from 6 to 8 feet. This bed may be seen resting on the Chalk, at Castle Hill, Coley Hill pits, and Katesgrove pit, near Reading, also near Newbury, Pebble Hill near Kintbury, Hungerford, at Bromley, and Charlton.

The fossils of the Woolwich and Reading Beds comprise Mammals, Birds, Reptiles, Fishes, Mollusca, Polyzoa, Crustacea (including Ostracoda), Sponges, Foraminifera, and Plants. They indicate marine, estuarine, and freshwater conditions.

The Tapir-like *Coryphodon* has been met with in these strata, also Turtles among the Reptiles. *Gastornis Klaasseni* was obtained by

[1] Prestwich, Q. J. x. 83; Whitaker, *ibid.* xxvii. 265.
[2] Geol. Mag. 1880, p. 518; Whitaker, Geol. Ipswich, p. 14.
[3] Q. J. xvi. 449.
[4] Whitaker, Mem. Geol. Survey, iv. 224; J. Hopkinson, P. Geol. Assoc. viii. 452; see also Buckland, T. G. S. iv. 301.
[5] Geologist, iii. 390.

Mr. H. M. Klaassen from the railway-cutting at Park Hill, Croydon:[1] this bird was as large as the Dinornis of New Zealand. The Mollusca include *Ostrea Bellovacina*, *Pectunculus terebratularis*, *Corbula Regulbiensis*, *Cyrena cuneiformis*, *C. Dulwichiensis*, *Unio subparallela*, *Paludina*, *Pitharella*, *Melania inquinata*, etc.

Among Plants, *Pinites* and '*Carpolithes*' have been recorded. The Flora indicates a climate whose temperature was gradually increasing towards the tropical conditions that prevailed during the deposition of at least a part of the London Clay.[2] Plants have been obtained near Reading, Croydon, Dulwich, and Newhaven; and more recently Mr. Whitaker has discovered Plant-remains (derived from Woolwich and Reading Beds) in the Basement-bed of the London Clay at Colden Common, between Bishopstoke and Winchester.

The large pits by the Medway at Upnor, near Rochester, show the following strata:[3]—

London Clay.
Oldhaven Beds.—Buff sand, shells and flint pebbles, 4 to 8 feet.
Woolwich Beds.—Sands and shelly clay, with bed containing small flint-pebbles at base, 50 feet.
Thanet Beds.—Light buff and grey sand with shells, 23 feet.
Chalk.

At Loam Pit Hill, near Lewisham, the Woolwich Beds have been well exposed; indeed the succession shown is as follows:[4]—

London Clay.	Brown clay	15 feet.
	Basement-bed	1 ,,
Woolwich Beds		50 ,,
Thanet Beds		40 ,,
Chalk.		

The Woolwich Beds here comprise light-coloured sand, laminated clay, a shell-bed with *Ostrea* and *Cyrena*, and a pebble-bed 12 feet in thickness. At Peckham a Paludina- or Cockle-bed, a thin layer of grey clayey limestone, occurs near the top of the Woolwich Beds; it contains *Paludina lenta* in abundance. Mr. C. Rickman obtained a number of fossils during sewer-excavations, under the Five-fields at Dulwich; these included *Pitharella Rickmani*, *Cyrena Dulwichiensis*, etc.[5] The Woolwich Beds are also exposed at Charlton, near Woolwich, and at Sundridge Park, near Bromley. In the Isle of Wight the beds consist of mottled clays and sands. (See Fig. 73, p. 428.) Mr. T. Codrington has shown that while the subdivisions of the Lower Eocene beds in the island vary much in

[1] E. T. Newton, G. Mag. 1885, p. 362; and Trans. Zool. Soc.; see also P. Geol. Assoc. viii. 226, 250.
[2] J. S. Gardner, P. Geol. Assoc. viii. 305.
[3] Whitaker, Mem. Geol. Surv. iv. 144.
[4] Whitaker, Mem. Geol. Surv. iv. 127; H. J. Johnston-Lavis, P. Geol. Assoc. iv. 528; Buckland, T.G.S. iv. 290, Plate 13.
[5] Q. J. xvii. 6; P. Geol. Assoc. i. 106, 336.

thickness on the east and west coasts, yet the total thickness of the series is much the same.[1]

In Dorsetshire the Woolwich and Reading Beds are exposed on the south of Studland Bay; and there are beds of plastic clay near Corfe Castle, East Lulworth and Dorchester, which have been referred to the Series, as have also the pebble-beds and sands of Bincombe Heath and Black Down, between Abbotsbury and Dorchester. Mr. J. S. Gardner is, however, disposed to refer the latter beds to the London Clay.[2] Bride Bottom, west of Black Down, a comb which forms the source of the River Bredy, contains a number of blocks of puddingstone, breccia, and Greywether sandstone, and is known also as the "Valley of Stones."[3] (See p. 449.)

Economic products, etc.

The clays near Reading and many other places are largely used for brickmaking, also for coarse pottery; and sometimes pipe-clay is found in the beds. Fire-bricks have been made at Nonesuch Park, Ewell. Fuller's Earth is said to have been found in the Reading Beds at Katesgrove Kiln, Reading, a pit which has been worked for more than a century.[4]

Websterite (hydrous sulphate of alumina) occurs at the junction of the Tertiary beds and Chalk at Newhaven in Sussex; it was named after the discoverer, Mr. T. Webster.[5]

Prof. T. R. Jones and Major C. Cooper King have noted the occurrence at Coley Hill, Reading, of clay-galls (rolled pieces of clay) in buff and grey sands. Many of these are stated to be "ferruginous and hard from change, and somewhat septarian," while some nodules consist only of limonite crusts and ochreous cores.[6]

The pebble-beds are worked in places for road-metal, as at Bolter End, south-west of West Wycombe. Eocene pebbles from Chittern Down, near Heytesbury have been used to form pavements for grottoes, etc.[7] Beds of sand are sometimes employed for making mortar, and the purer kinds have been used in glass works.

OLDHAVEN AND BLACKHEATH BEDS.

The name Oldhaven Beds was given by Mr. Whitaker in 1866 to the sands and pebble-beds that come between the London Clay and Woolwich Beds in Kent; these beds had previously been classed by Prof. Prestwich with the basement-bed of the London Clay, and to a small extent with the Woolwich Beds. The true basement-bed of the London Clay may sometimes be seen over-

[1] Q. J. xxiv. 520.
[2] Q. J. xxxix. 208.
[3] Damon, Geol. Weymouth, 1884, p. 139; Buckland and De la Beche, T.G.S. (2), iv. 4.
[4] J. Rofe, T. G. S. (2), v. 127; see also Buckland, T. G. S. iv. 277. Loam-pits (lam-pyttes) were known in places in Saxon times.
[5] See T. G. S. ii. 191.
[6] Q. J. xxxi. 453; see also P. Geol. Assoc. iv. 522, v. 514.
[7] Benett, Cat. Org. Rem. Wilts.

lying the Oldhaven Beds. The name Oldhaven Beds is taken from Oldhaven Gap, on the coast of Kent, west of Reculvers, where the beds are well displayed. The term Blackheath Beds is also employed from Blackheath in the same county.[1]

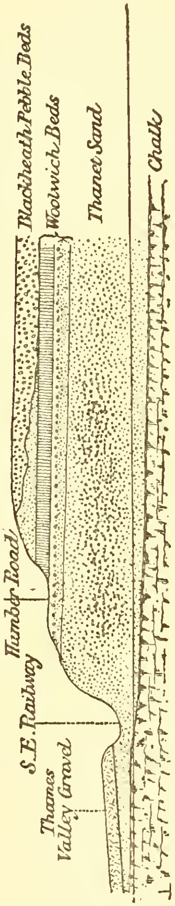


Fig. 74.—Section in Westcombe Park, Greenwich. (T. V. Holmes.)

The formation consists largely of flint-pebbles in a fine sandy base, or of fine sharp light-coloured quartzose sand, and it occasionally contains limonite. Current-bedding is displayed in places. Sometimes the pebble-beds are cemented into a hard rock, or pudding-stone; and in East Kent the sand is occasionally indurated. The total thickness of the beds varies from a few feet to 60 feet.

In the neighbourhood of Canterbury, at Shottenden Hill, near Sittingbourne and Rochester, at Plumstead Common, Abbey Wood, Blackheath, Greenwich (30 to 40 feet), and Woolwich, the beds are well displayed. They thin out in the neighbourhood of Lewisham, and are not met with under London, nor in the western part of the London Basin; but they have been met with in South Essex and at Ipswich.[2]

The Oldhaven Beds are sometimes fossiliferous. The fossils are partly fluviatile and estuarine and partly marine, being sometimes of the same species as those of the Woolwich Beds below, and sometimes more nearly approaching those of the London Clay above, seeming therefore to prove oscillations of surface or changes of current and nearness to land, conditions which might also be expected from the masses of pebbles. There are no distinctive organic remains. The Bromley leaf-beds (Widmore pit) are regarded by Mr. Whitaker as belonging to an Oldhaven freshwater series; Mr. J. S. Gardner, however, places them with the Woolwich Beds. It would seem that the pebble-beds were not formed as a beach along a chalk-shore, as in that case they should contain many flints but partly worn, and Mr. Whitaker therefore infers that they must have been deposited some way off the shore, as a bank to which no flints could get until after having been long exposed to wearing action. In some places the strata rest

[1] W. Whitaker, Q. J. xxii. 412, xxxix. 210; Mem. Geol. Surv. iv. 239; see also J. S. Gardner, Q. J. xxxix. 205. The term Blackheath Sand was used by William Smith.

[2] Whitaker, Geol. Ipswich, p. 15.

unconformably on the Woolwich Beds, Thanet Beds, or on Chalk. (See Fig. 74.)[1]

Near Higham, in the Hundred of Hoo, east of Gravesend, a railway-cutting showed London Clay, resting on 12 feet of Oldhaven Beds, which there yielded *Cardium*, *Pectunculus*, *Natica*, and *Corbula*; beneath, the Woolwich Beds and Thanet Beds were exposed.[2] Fossils have also been obtained at Grove Ferry, a few miles inland, near Oldhaven Gap; these include *Cytherea*, *Aporrhais*, etc.

The pebble-beds are dug for ballast, etc., and near Canterbury beds of ironstone have been worked for iron-ore and used for road-metal.

LONDON CLAY.

This formation, so named by William Smith in 1812, from its development around London, consists of stiff brown and bluish or slate-coloured clay, containing layers of septaria or cement-stones. The clay as a rule is of so homogeneous a nature that it affords no indications of stratification;[3] then the only guides are the layers of septaria. At its base it displays green and yellow sandy and loamy beds containing flint pebbles, sometimes 'cemented by carbonate of lime into semi-concretionary tabular masses;' this division was termed the 'Basement-bed' of the London Clay by Prof. Prestwich.[4] The top strata are also sandy, passing, in places, by alternations of sand and clay into the Lower Bagshot Beds above.

The London Clay contains much iron-pyrites and selenite; and it is believed that the formation of the selenite may be largely due to the decomposition of iron-pyrites and the destruction of organic remains, the sulphuric acid resulting from the decomposition of the pyrites uniting with the carbonate of lime of the fossils. Almost all the London Clay fossils found at Sheppey are impregnated with iron-pyrites; and Dr. Duncan has observed that sulphuric acid itself may result from the decomposition of organisms. Hence the formation of iron-pyrites and selenite may represent the former organisms; and as the selenite in process of time may disappear, he argues that there is no reason why the purest clay-slate may not have been formed from a fossiliferous clay.[5]

In thickness the London Clay varies from a few feet in Wiltshire, and from 50 to 60 feet in Berkshire, to nearly 500 feet in the south of Essex. The London Clay yields a very extensive series of fossils, and, although specimens are abundant, it is not always easy to find them, as they occur in groups or colonies conspicuous at

[1] T. V. Holmes, P. Geol. Assoc. viii. 59; and Report Lewisham and Blackheath Assoc. 1881.

[2] W. Whitaker, P. Geol. Assoc. vii. 190.

[3] See Godwin-Austen, Q. J. vi. 81.

[4] Q. J. iii. 354, vi. 255, x. 401, 435.

[5] Q. J. xxii. 19; see also O. Fisher, Q. J. xviii. 82; Dixon, Geol. Sussex, ed. 2, 58; Bauerman, Metallurgy of Iron, ed. 5, p. 37.

one locality and not seen at the same horizon in another. Specimens have been obtained at Pebble Hill, not far from Kintbury, near Hungerford, at Newnham and Cuffell (near Basingstoke), Bognor, Clarendon Hill near Salisbury, Highgate, Finchley, Islington, Herne Bay, Whitstable, Sheppey, Harwich, etc.

At Sheppey there were found in great abundance the fossil fruits described by Dr. Bowerbank; amongst these the Palm, *Nipadites ellipticus*, is conspicuous. Many of the Palms are apparently identical with living species.[1] Mr. Carruthers has stated that here also have been found no less than 40 species of *Leguminaceæ* allied to the *Mimosæ* and *Acaciæ*; also *Euphorbias*.[2] Mr. J. S. Gardner records the Alder from the London Clay of Swale Cliff, near Whitstable.

The fossils include also many Foraminifera[3] and Diatomaceæ; and the Coral *Paracyathus brevis*, etc. Among the Mollusca we find *Pectunculus brevirostris*, *P. decussatus*, *Cryptodon angulatum*, *Cytherea obliqua*, *Leda amygdaloides*, *Nucula Bowerbankii*, *Panopæa intermedia*, *Corbula globosa*, *Murex subcoronatus*, *Fusus tuberosus*, *Pleurotoma* (many species), *Rostellaria ampla*, *R. Sowerbyi*, *Phorus extensus*, *Voluta nodosa*, *Pyrula tricostata*, *Turritella imbricataria*, *Natica glaucinoides*, *N. Hantoniensis*, *Nautilus centralis*, *N.* (*Aturia*) *ziczac*, *N. regalis*, *N. imperialis*, etc. *Camptoceras*, a genus of fresh-water Mollusca, now living only in India, was found near Sheerness.[4] The Annelide *Ditrupa plana* is common, and sometimes fossil wood with *Teredo*-borings is met with.[5] Among Echinodermata we find *Astropecten crispatus*, *Ophiura Wetherelli*, and *Pentacrinus sub-basaltiformis*; the Crustacea include *Xanthopsis Leachii*, *Hoploparia Belli*, and *Ostracoda*.

Amongst the Reptiles were the Sea-snake *Palæophis toliapicus*, (probably about thirteen feet in length), and *Crocodilus toliapicus*; many Turtles also occur, including *Chelone planimentum* (or *Harvicensis*), *C. breviceps*, etc., and several species of *Emys*. Of the Fishes there were *Otodus obliquus*, *Lamna elegans*, *Myliobatis*, *Carcharodon*, etc.

Most remarkable perhaps are the Birds found at Sheppey and described by Sir Richard Owen. They include the *Odontopteryx*, a web-footed bird having jaws provided with tooth-like forms; *Lithornis*, allied to the Vultures; the *Dasornis*, a terrestrial bird belonging to the Struthionidæ; and a bird allied to the Albatross, the *Argillornis* found by Mr. W. H. Shrubsole.

Among Mammals the *Hyracotherium leporinum* (which received its name from its supposed affinities with the living Hyrax), the

[1] J. S. Gardner, Rep. Brit. Assoc. 1886.

[2] P. Geol. Assoc. iv. 319; Bowerbank. Fossil Fruits of the London Clay, 1840. Mr. Gardner states that Dr. Bowerbank determined only a few of the Fruits correctly; owing to their pyritic condition they rapidly decay, but may be preserved by being boiled in paraffine-wax. P. Geol. Assoc. viii. 305. See also Baron C. von Ettingshausen, G. Mag. 1880, p. 37.

[3] See C. D. Sherborn and F. Chapman, Journ. Roy. Micros. Soc. (2), vi. 737.

[4] H. H. Godwin-Austen, Q. J. xxxviii. 220.

[5] See J. S. Gardner, G. Mag. 1886, p. 161.

tapir-like *Lophiodon*, and the *Coryphodon*, have been found in the London Clay of Sheppey, etc. A deposit of yellow and white sand belonging to the basement-bed of the London Clay at Kyson (Kingston) near Woodbridge, has yielded remains of *Hyracotherium cuniculus* (the teeth of which were originally considered to belong to a Monkey, *Macacus Eocænus*); and also *Didelphys Colchesteri*, obtained by Mr. W. Colchester in 1839 and 1840.[1]

The London Clay is a marine formation, and Prof. Prestwich considers that its fauna indicates a moderate rather than a tropical climate, although the flora is tropical in its affinities. The lithological characters denote a tranquil and uniform deposit, of considerable duration, accompanied by a quiet and gradual subsidence of the bed of the sea; the sediment was for the most part brought down by a large river. Prof. T. Rupert Jones remarks that the indication of sea-depth for the London Clay, afforded by the Foraminifera, is that the water was about 100 fathoms deep. The proximity of land is indicated by the remains of Plants, Mammals, and Reptiles.

The London Clay has been divided into four stages by Prof. Prestwich, which contain assemblages of fossils, the species of which, although not restricted, are more abundant at certain horizons. These divisions are but roughly marked out according to localities from which collections have been made, and they have no distinctive lithological characters: they are, in descending order, as follows:[2]—

4. Beds at Sheppey, Brentwood, Southend, Egham Hill, etc.	70 to 150 feet.
3. Beds at Highgate Archway, Newnham, etc.	80 to 100 feet.
2. Beds at Chalk Farm (Primrose Hill), Islington (Copenhagen Fields, etc.), Kew, Brentford, etc.	100 to 140 feet.
1. Beds at Harwich, Erith, Bognor, etc.	50 to 90 feet.

Certain species of *Nautilus* occur more abundantly at some horizons, but their range does not appear to be restricted to any particular zones.

The chief development of Plant-remains, of Fishes, and Reptiles, is in the upper beds, while the lower stages indicate deeper-sea conditions. These conditions, however, varied, as in the western parts of the area the London Clay (which is there reduced in thickness) yields a fauna exhibiting conditions of shallower water than on the east.

The London Clay extends over the northern parts of Kent and Surrey, over a considerable part of Berkshire, Middlesex, Hertfordshire, and Essex, and it occurs along the borders of Suffolk to Yarmouth in Norfolk. (See p. 431.)

Bognor Beds.—On the shore near Bognor in Sussex are exposed beds of clay and calcareous sandstone (Barnes and Bognor Rocks), which form part of a series of sands and clays with occasional layers of pebbles. These beds are developed at Portsmouth, and they are generally placed on the horizon of the London Clay. Mr. C. Evans has pointed out the difficulty of paralleling the organic remains in the deposits of Hants and the London Basin, while at the same time the variation in mineral character would seem to

[1] Prestwich, Q. J. vi. 272; Whitaker, Geol. Ipswich (Geol. Survey), p. 26; Owen, Brit. Foss. Mammals, pp. 3, 424.

[2] Q. J. x. 408; see also N. T. Wetherell, Phil. Mag. 1836, ix. 465.

render it desirable to retain the distinctive term of Bognor Beds, a name which was employed by Prof. Prestwich.[1] Casts of fossils are met with, which are sometimes converted into crystallized carbonate of lime. The species include *Dentalium*, *Solarium bistriatum*, *Cyprina planata*, *Pectunculus brevirostris*, *Pinna affinis*, *Modiola elegans*, *Ostrea gigantica*, *Lingula tenuis*, *Vermetus Bognoriensis*, etc. The total thickness of the Bognor Beds is estimated at 290 feet.

Chichester is situated on the London Clay, and this formation occurs near Southampton, Romsey, Wimborne Minster, and south-westwards towards Dorchester. (See p. 433.)

In the Isle of Wight the junction with the Woolwich and Reading Beds is sharp and well defined, and both in Alum and Whitecliff Bays the division is indicated by a band of flint-pebbles —the basement-bed of Mr. Prestwich. At about thirty-five feet above this bed there is a zone of *Panopæa intermedia*, and *Pholadomya margaritacea*; at fifty feet a band of *Ditrupa plana*; and at about eighty feet a band of *Cardita* occurs. (See Fig. 73, p. 428.)[2] The total thickness of the London Clay is about 300 feet at Whitecliff Bay, and 220 feet at Alum Bay. At the former locality the beds are vertical and in places slightly reversed.[3]

Economic products, etc., of the London Clay.

Fossil copal (Copaline) or Highgate resin was discovered during the excavations for the Highgate Archway. Pyrites has been procured on the Sussex coast, also at Sheppey, for the manufacture of sulphuric acid, etc.[4]

Septaria or Cement-stones have been largely used in the manufacture of Roman, Portland, or Parker's cement. For this purpose they have been dredged in Chichester Harbour, and off the coast of Hampshire: they have also been collected at Sheppey, near Southend, and at Harwich.[5] Medina cement is made in the Isle of Wight. Stucco is also manufactured: a material extensively employed to obscure inferior bricks.

An analysis of Cement-stone from Sheppey showed the following composition :—

Carbonate of lime	64·00
Silica	17·75
Alumina	6·75
Magnesia	0·50
Oxide of iron	6·00
Oxide of manganese	1·00
Water	3·00
Loss	1·00
	100·00

[1] P. Geol. Assoc. ii. 76. See also Prestwich, Q. J. iii. 362, x. 418; Dixon, Geol. Sussex, ed. 2; C. J. A. Meyer, Q. J. xxvii. 74; and J. W. Elwes, G. Mag. 1884, p. 548 (Southampton).

[2] Prestwich, Q. J. ii. 223, x. 409; Bristow, Geol. I. of Wight, p. 35; J. S. Bowerbank, T. G. S. (2), vi. 169.

[3] Whitaker, G. Mag. 1864, p. 69.

[4] P. Geol. Assoc. iv. 321.

[5] Webster, T. G. S. ii. 190.

The London Clay is extensively used for making bricks,[1] tiles, and pottery. It is also burnt for ballast. The brown colour at and near the surface of the London Clay is merely a colour of decomposition; the protosalt of iron that gives the bluish tint peroxidating by exposure to atmospheric action.[2] It has been discoloured brown to a greater depth, as a rule, than the Kimeridge or Oxford Clays. Chalybeate springs are sometimes met with in the London Clay. Sulphuretted hydrogen is often developed in tunnels and wells excavated in the formation.[3]

The London Clay forms a stiff, tenacious, and sometimes loamy soil, making good pasture-land, and yielding, by the application of marl, good crops of corn. Teazles are cultivated in Essex, and elm, oak, and ash timber in different places. The London Clay is impervious, and yields no water save in the basement beds, or in sandy layers that sometimes occur.

MIDDLE EOCENE.[4]

BAGSHOT BEDS.

The structure of the Bagshot Beds, so named from Bagshot Heath in Surrey, was first elucidated by Prof. Prestwich.[5] The strata are divided as follows:—

Upper Bagshot Beds.		Bartonian.
Middle Bagshot Beds	Barton Clay.	Bartonian.
	Bracklesham Beds.	
Lower Bagshot Beds	Bournemouth Freshwater Beds and Bovey Tracey Beds.	
	Alum Bay Beds.	

The divisions are conformable, and it is often difficult to draw hard lines between them: thus some authorities would link the Barton Clay with the Upper Bagshot Beds, and the Bournemouth Freshwater Beds with the Bracklesham Beds. It seems, however, undesirable to introduce changes that are not absolutely necessary. The Bagshot Beds include freshwater and marine beds, and they belong to the shallow-water and western equivalents of the great Nummulitic formation.[6]

[1] In London, buildings erected from limestone are liable to rapid decay, which arises mainly from the effects of the combustion of coal and the amount of sulphurous acid, and even sulphuric acid, which is brought down from the atmosphere by rain.

[2] Whitaker, Mem. Geol. Surv. iv. 273; see also Parkinson, T. G. S. i. 336. Referring to the odour of clay when a shower of rain first begins to wet a dry clayey soil, Mr. C. Tomlinson has remarked that it is commonly attributed to alumina, and yet pure alumina gives off no odour when breathed on or wetted. The fact is, the peculiar odour referred to belongs only to impure clays, and chiefly to those that contain oxide of iron.—P. Geol. Assoc. i. 242.

[3] Dr. J. Mitchell, Proc. G. S. iii. 151.

[4] This division is now termed Upper Eocene, by those geologists who regard the Oligocene as distinct from the Eocene.

[5] Q. J. iii. 378, x. 401. The name Bagshot Heath Sand was given by John Farey, in Sowerby's Mineral Conchology, vol. i. 1812. See also H. Warburton, T. G. S. (2), i. 48. The beds belong to the 'Lower Marine' of Webster.

[6] T. R. Jones, P. Geol. Assoc. vi. 437.

Lower Bagshot Beds.

This deposit consists of pale yellow or buff false-bedded sand and loam, with layers of pipe-clay, and occasional beds of flint-pebbles. Ironstone veins and nodules are sometimes met with. The thickness varies from 100 feet or less to 150 feet.

In the London Basin the beds locally show no marked inclination; in the Isle of Wight they are highly inclined. (See Fig. 73, p. 429.)

Organic remains of animals are exceedingly rare, only a few casts of Mollusca having been found. The Leaf-beds (pipe-clay) of Alum Bay and Bournemouth have yielded many land-plants of subtropical genera, such as palms, maples, etc.

Prof. Prestwich considers that the Bagshot Beds were derived by denudation from the older crystalline and granitic rocks, but Mr. G. Maw has suggested that some of the fine white clays may have been due to the destruction of the Chalk.[1]

In sections near Brentwood the London Clay is seen to pass upwards into the Lower Bagshot Beds: there the passage-beds consist of alternations of clays, sands, and loams, furnishing excellent brickearths. The pebble-beds in the Lower Bagshot series, which are composed almost entirely of flint pebbles, were first noticed by Mr. S. V. Wood, jun., although he has suggested that they may be Pliocene.[2] They occur at Brentwood, Stock, Billericay, and other localities in Essex. Their thickness is 15 feet at Brentwood, where the following divisions are exposed:[3]—

		Feet.
Lower Bagshot Beds.	8. Pebble-beds	15
	7. Brickearth or loam	25
	6. Sand	
London Clay.	5. Brickearth or loam	50
	4. Clay	
	3. Sand, 2 or 3 feet	
	2. Brickearth or loam	
	1. Clay, with Septaria.	

From the Bagshot Beds themselves varying so much in section, and from the passage upwards of the London Clay into them, it is impossible to be certain of the horizon taken as the junction of the two formations in the many outliers in Essex: where a purely sandy condition prevailed at one spot a loam may have been formed at another, and a clay at a third. Hence around Rayleigh a larger area of Bagshot Beds has been shown on the Geological Survey Maps than near Brentwood, because the junction there has been taken at a lower level.

Outliers of Lower Bagshot Beds occur at Langdon Hill, High Beech, Highgate (426 feet above sea-level), Hampstead (440 ft.),[4] and Harrow, forming some of the highest hills near London, and commanding extensive views.

[1] Q. J. xxiii. 387; see also Godwin-Austen, Q. J. vi. 86.
[2] Q. J. xxiv. 465; xxxvi. 473.
[3] See Whitaker and H. B. W., Mem. Geol. Surv. iv. 320, 321, 328.
[4] C. Evans, P. Geol. Assoc. iii. 21.

The Lower Bagshot beds of Surrey (100 to 150 feet in thickness) may be studied near Wokingham and Virginia Water, between Woking and Weybridge, at Ash, Aldershot, and other places, where they rest on the London Clay. Irregular lines of pebbles occur at different horizons.[1] Mr. W. H. Herries mentions that at St. Anne's Hill, near Chertsey, the beds contain Sarsen stones, and some of the pebble-beds are solidified.[2] Mr. W. H. Hudleston has drawn attention to a railway-cutting through Walton Common which exhibits symptoms of slight local unconformity between the London Clay and Lower Bagshot Beds.

At Ramsdell, north-west of Basingstoke in Hampshire, a bed of brown clay, nearly 30 feet thick, occurs in the lower part of the Bagshot Beds. This clay, termed the Ramsdell Clay by Mr. Bristow, is separated from the London Clay, which it much resembles, by beds of sand; and the structure, which favours the conformity of the formations, is similar to that at Brentwood.[3]

The Lower Bagshot beds are exposed in Alum and Whitecliff Bays in the Isle of Wight; at the former locality they attain a thickness of upwards of 660 feet, and at the latter 140 feet. They are described by Mr. Bristow as a series of variously-coloured (white, yellow and crimson) unfossiliferous sands and clays, with seams of lignite and iron-sandstone. The clays at Alum Bay have yielded many land-plants of subtropical genera, which were described by Dr. P. De la Harpe;[4] but the plant-bearing beds are no longer well exposed.

Mr. Bristow observes that the flora of Alum Bay (Alum Bay leaf-bed) is more especially distinguished by the number and variety of its Leguminaceæ (*Cæsalpina*, etc.). Fig-trees of lofty proportions with long thick leaves, fig-sycamores with more delicate heart-shaped leaves, an *Aralia* with palmated leaves, must from their abundance have imparted a singularly majestic aspect to the vegetation of the period. Ferns, Parasitic Fungi, Reeds and Rushes have also been found.

A still richer series of plant-remains has been found at Bournemouth, and Poole. (See p. 439.) The Bournemouth leaf beds immediately underlie the Bracklesham series; and they have yielded about 20,000 specimens to the labours of Mr. Gardner. They include *Polypodium*, *Acrostichum*, *Osmunda*, *Nipadites*, *Sequoia*, *Eucalyptus*, *Araucaria*, *Alnus*, *Populus*, *Ulmus*, *Platanus*, etc.; trees and hard-wooded shrubs are most prevalent. The occurrence of Insect-remains and also of a Bird's feather has been noticed.[5] The beds consist of variously-coloured sands and clays, the latter

[1] H. W. Monckton and R. S. Herries, Q. J. xlii. 402.

[2] Geol. Mag. 1881, p. 174; see also Rev. A. Irving, P. Geol. Assoc. viii. 143; Q. J. xli. 492; G. Mag. 1886, p. 402.

[3] Geol. parts of Berks and Hants, by H. W. Bristow and W. Whitaker, p. 39; Mem. Geol. Surv. iv. 312; see also J. S. Gardner, G. Mag. 1882, p. 469; and W. H. Hudleston, Q. J. xlii. 162.

[4] Prestwich, Q. J. ii. 223; Bristow, Geol. I. of Wight, p. 38.

[5] Rev. P. B. Brodie, G. Mag. 1885, p. 384.

yielding the plant-remains; and they are exposed in the cliffs from Poole Harbour to beyond Bournemouth.

Mr. J. S. Gardner places the Bournemouth freshwater series in the Middle Bagshot group, drawing the line between these and the Lower Bagshot Beds above the pipe-clays of Corfe, Studland and Alum Bay, on account of the dissimilarity of the floras; none of the prevailing types, familiar at Alum Bay, being found at Bournemouth. The Bournemouth flora passes upwards into the Oligocene flora;[1] and it is considered by Mr. Gardner to be on the same horizon as that of the Bovey Tracey Beds. The Lower Bagshot Sands of Studland are brighter than the sands at a higher level in the Bournemouth freshwater series; they resemble the Alum Bay sands, and contain similar plant-remains in the pipe-clays. Sections of variously-coloured sands and pottery-clays with much ironstone have been exposed in the railway-cuttings between Wareham and Corfe Castle. (See also Fig. 1, p. 1, Section on the Frome, Stoborough, South of Wareham; and Fig. 54, p. 347.)

Bovey Tracey Beds.—The celebrated clays and lignite-beds of Bovey Tracey, near Newton Abbot, in Devonshire, have been long known, for the 'Bovey Coal' has been worked since 1714.[2]

The Bovey Beds comprise two divisions, the lignite-beds which are developed at Bovey Tracey, and the clay-beds which are so largely worked near Kingsteignton and Newton Abbot. Sands are found at various horizons in the series, and pea-like grains of quartz sometimes occur in the clay.

The exact relations between these two divisions cannot readily be ascertained, for the lignite-beds are cut off by a fault (determined by Mr. John Divett), where the vertical displacement is estimated at 100 feet; but probably the lignites form the upper series above the clays. The former are developed over a small area south-east of Bovey Tracey; and they have been exposed at Aller, near Newton Abbot.[3] The beds opened up at Bovey (according to Mr. Pengelly) are as follows:—

	Feet.	Ins.
'Head,' superficial drift (7 ft. 6 in.)		
Plastic clay	2	6
Quartzose sand	6	3
Clays and lignites	5	11
Sand	2	0
Clay	2	0
Sand and fine conglomerate	0	8
Clays and lignites	33	10
Quartzose sand with lenticular patches of clay	11	1
Clay and lignites	53	4
	117	7

A boring made east of the fault showed upwards of 80 feet of

[1] J. S. Gardner, P. Geol. Assoc. v. 51, viii. 305; Q. J. xxxviii. 3; G. Mag. 1882, p. 470; see also G. Maw, G. Mag. 1868, p. 74.

[2] Rev. Jeremiah Milles, Phil. Trans. (1745), li. 534, 941.

[3] J. H. Key, Q. J. xviii. 9.

sands and clays, with some coaly beds in the lower portion; and these appear to be the lowest of the Bovey Beds that have been exposed. The clay of Kingsteignton is about 40 feet thick, it rests on sand, and contains occasional sandy beds. The total thickness of the Bovey deposit can only be conjectured as between 200 and 300 feet.[1]

The beds extend over a considerable tract of low-lying heath-land bounded by ranges of hills. The physical and palæontological evidence points to the deposit having been formed in a fresh-water lake, which probably extended from Bovey Tracey to Kingskerswell, without being open towards Teignmouth. The purely sedimentary matter was evidently derived from the waste of the Greensand and of the granitic rocks of Dartmoor; the clays being due to the decomposition of the felspars, and the quartzose sands being the relics of the harder material.[2] (See Fig. 30, p. 194.)

Numerous plant-remains have been found in the lignites, and rarely in the clays. Attention was directed to these in 1857 and subsequent years, by Dr. Oswald Heer and Mr. Pengelly. From Dr. Heer's investigations it seems that the woods covering the slopes which surrounded the old lake, consisted mainly of a huge coniferous tree (*Sequoia Coutssiæ*), a form resembling the *Sequoia* (*Wellingtonia*) *gigantea* of California. The leafy trees of most frequent occurrence were the Cinnamoms and an Evergreen Oak like those which now are seen in Mexico. Species of Evergreen Fig were rarer. The trees of the ancient forest were evidently festooned with Vines, and among other forms there were the prickly Rotang-palm, the Laurel and numerous Ferns; one species of *Pecopteris* seems to have formed trees of imposing grandeur, while on the surface of the lake were expanded leaves of the Water-lily.[3] Sir J. D. Hooker has observed that the lignite is mainly composed of coniferous wood, and he noticed the occurrence of small pieces of resin similar to the Highgate resin, which was probably secreted by the coniferous trees.[4] Excepting an Insect, *Buprestis*, no remains of animals have been obtained from the Bovey Tracey Beds.

In 1879 Mr. J. Starkie Gardner expressed the opinion that the Bovey Beds were not Miocene, but correspond in age with the Bournemouth Leaf-beds, and his subsequent observations tend to confirm this view.[5]

[1] De la Beche, Report Geol. Cornwall, etc., p. 248; see also Geol. Manual, 1831, p. 191.

[2] See Prestwich, Geologist, i. 113.

[3] W. Pengelly and Rev. O. Heer, On the Lignite Formation of Bovey Tracey, Phil. Trans. Part II. 1862 (reprint 1863).

[4] Q. J. xi. 566; see also Dr. J. G. Croker, *Ibid.* xxii. 354.

[5] Q. J. xxxv. 227, xxxviii. 3; G. Mag. 1879, p. 152; P. Geol. Assoc. vi. 100.

Economic products, etc., of the Lower Bagshot Beds.

The lignite or brown-coal of Bovey Tracey, which has been used extensively for fuel, is very little employed now, as it gives off a sulphurous smell when burning. It has been employed in the pottery at Bovey Tracey. Iron-pyrites is abundant in the lignite-beds, and from its presence spontaneous combustion sometimes takes place after heavy rain in the refuse-heaps.

The Bovey Beds yield excellent pipe and potter's-clay. The best clay is shipped at Teignmouth, whence it is sometimes termed 'Teignmouth Clay.' According to Mr. Hunt's Statistics above 42,000 tons were sent from the port of Teignmouth in 1865. The mode of raising the clay is extremely simple—the gravel 'head' is removed, and a large rectangular pit is sunk, which is supported by wood. The workmen cut out the clay in cubical lumps weighing about 30 lbs. each, and fling them from stage to stage by means of a pointed staff; it is then carried to the clay cellars, and when properly dried sent to the potters. The clays are employed for whitening stones, etc.; they have also been used in the manufacture of alum.

An analysis of the clay, recorded by Mr. C. D. Blake, showed the following composition:—

Silica	47·0
Alumina	48·0
Oxide of iron	1·5
Magnesia	2·0
Water and Waste	1·5
	100·0

Although the clays maintain their purity, the proportions of silica and alumina are subject to great variation.[1]

Stiff unctuous white clay, about 80 feet thick, has been worked at Petrockstow, between Torrington and Hatherleigh, in Devonshire, and this deposit, which contains seams of lignite, may, in Mr. Ussher's opinion, be of the age of the Bovey Tracey Beds.[2] The deposits of China clay in Cornwall will be described in the sequel.

White clays, etc. (of uncertain age, but possibly Eocene or Pliocene), have been noticed in pockets of the Carboniferous Limestone, etc., near Mold, Oswestry, Llandudno, in Staffordshire,[3] and also at Stacpole Court, in Pembrokeshire.[4]

The Poole Clay, so called from its being shipped at Poole, comprises beds of pipe- and potter's-clay, which were worked by the Romans. It is now dug between Wareham and Corfe, at Creech Grange, Nordon, Matcham and Rempstone;[5] also at Branksea Island and Parkstone near Poole; and it is manufactured into ornamental tiles, tesselated pavements, tobacco pipes, etc. (See Fig. 75.) In the Isle of Wight this pipe-clay is almost entirely replaced by sands. Alum was formerly manufactured in the Island from the clays of Alum Bay, and as early as 1579 at works in Parkhurst Forest.[6] Lignite from Nordon, near Corfe Castle, has locally been used as fuel.

The Agglestone (or Haggerstone), near Studland, is an irregular weathered remnant of Bagshot Sands about 18 feet high, which stands on the summit of a

[1] G. Maw, Q. J. xxiii. 391; T. Reeks and F. W. Rudler, Cat. British Pottery and Porcelain, Mus. Pract. Geol., ed. 3, p. 281.

[2] Trans. Devon Assoc. 1879.

[3] G. Maw, G. Mag. 1865, p. 200, 1867, p. 250; D. C. Davies, P. Geol. Assoc. iv. 423; D. Mackintosh, G. Mag. 1874, p. 67; see also P. B. Brodie, *Ibid.* 1866, p. 432.

[4] Murchison, Silurian System, p. 529.

[5] W. H. Hudleston, P. Geol. Assoc. vii. 378.

[6] Bristow, Geol. I. of Wight, p. 107.

hill, and it owes its preservation to the induration of the sands.[1] (See Fig. 54, p. 347, and Fig. 101.) A smaller rock known as the Puckstone occurs on a neighbouring hill. The red and crimson sands of Alum Bay, etc., are coloured by peroxide of iron ; there are coloured sands in the Lower Bagshot Beds, and also higher up in the Bracklesham Beds. Creech Barrow (see Fig. 71) is a conical hill of Lower Bagshot Beds, rising to an elevation of over 600 feet, and situated to the west of Corfe Castle.

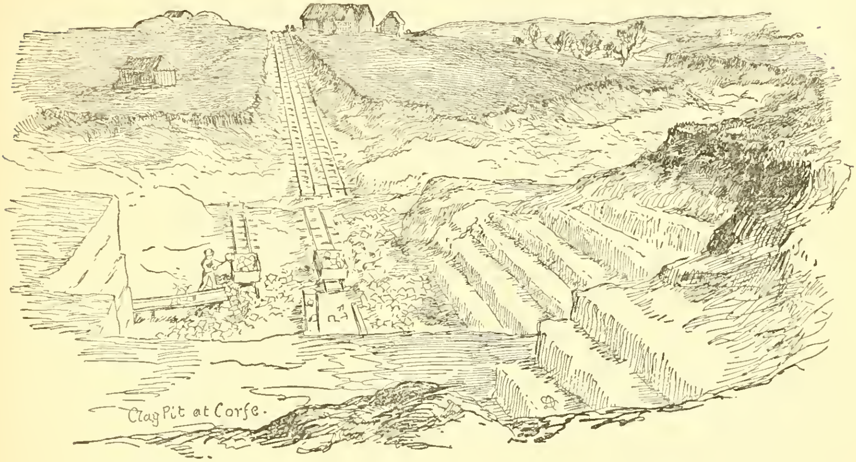


FIG. 75.—CLAY PIT, NEAR CORFE CASTLE, DORSETSHIRE.

Middle Bagshot Beds.

In the Hampshire Basin these beds have been found to admit of two divisions :—

2. Barton Clay.
1. Bracklesham Beds.

The series is represented by the lower division (Bracklesham Beds) in the London Basin. Its thickness has been estimated at 410 feet in Alum Bay, and 710 feet in Whitecliff Bay.

Bracklesham Beds.—The Bracklesham Beds were so named because the strata are displayed at Bracklesham Bay in Sussex, where their position was defined in 1847 by Prof. Prestwich.[2] According to the Rev. O. Fisher, they consist of alternations of sand and sandy clay, the clays being more prevalent in the upper part,

[1] Prestwich, Geologist, i. 113.
[2] Q. J. iii. 354, x. 435 ; Fisher, Q. J. xviii. 69 ; C. Evans, P. Geol. Assoc. ii. 153 ; Etheridge, Address Geol. Sec. Brit. Assoc. 1882.

and the sands in the lower: green grains abound in many of the beds. They appear to have been formed in a quiet estuary, by the sediment brought down by a great river, the changes to the coarser detritus being caused by the state of flood. The climate of this period must have been almost tropical.

The fossils include Plant-remains, *Nipadites*, etc.; the Mollusca, *Cardita* (*Venericardia*) *planicosta*, *Corbula gallica*, *C. pisum*, *Cypræa Bowerbankii*, *Solen obliquus*, *Psammobia æstuarina* (*Sanguinolaria Hollowaysii*), *Ostrea flabellula*, *Pecten corneus*, *Cytherea suberycinoides*, *Cerithium giganteum* (which attains a length of 2 feet in the Paris Basin), *C. cornucopiæ*, *Pleurotoma attenuata*, *Voluta Selseiensis*, *V. cithara*, *Conus deperditus*, *Turritella multisulcata*, *T. sulcifera*, *T. imbricataria*, etc.; the Coral, *Litharæa Websteri*; the Foraminifera, *Nummulina lævigata*, *N. variolaria*, and *Alveolina fusiformis*; the Fishes, *Myliobatis toliapicus*, *Ætobatis*, *Otodus obliquus*, *Lamna elegans*, and *Carcharodon heterodon*; Reptiles, *Palæophis typhæus*, *Chelone*; and Mammals, *Lophiodon*, etc.

Fossils have been obtained south-east of Bracklesham, at the Houngate Rocks in Bracklesham Bay, and north-east of Selsea; at Stubbington, north-west of Gosport; at Whitecliff and Alum Bays in the Isle of Wight. Our knowledge of the fossils is largely due to collections made by Mr. F. E. Edwards, Mr. F. Dixon, Dr. Bowerbank and others. It has been remarked that although Bracklesham Bay affords at some tides and seasons the most abundant harvest to the palæontologist, yet it may happen, owing either to the wind covering the beds with sand, sometimes to two or three feet in thickness, or to the tide not leaving the shore sufficiently exposed, that no fossils can be procured. The best time for collecting is the first two days before, and the last three days after, the full and new moon; the lowest tides are generally in March and October. When the beds are visited under favourable circumstances, there is an exposure, at one view, of an immense horizontal surface of fossils, among which *Cardita planicosta* and *Turritella imbricataria* are prominent forms.[1]

South of Selsea Bill, the Clibs and Mixen rocks consist of arenaceous limestone, made up of *Alveolina* and other Foraminifera (Alveolina limestone). These rocks and also the Houngate Rocks have yielded building-stone for houses at Selsea.

In Alum Bay the Bracklesham Beds consist of clays and marls, overlaid by white, yellow, and crimson sands. The lower beds are remarkable for the lignite they contain, which is found in solid beds from fifteen inches to over two feet in thickness. Like true coal, each bed is based upon a stratum of clay, containing apparently the rootlets of plants. The deposit is a little more than 100 feet in thickness. In Whitecliff Bay the series is thicker, and the lower beds, consisting of green clayey sands, yield *Cardita planicosta* and *Turritella imbricataria*: the former species giving name to the Cardita bed. A bed of conglomerate, formed of flint-pebbles, constitutes a strongly-defined division between the Bracklesham Beds and the Barton Clay.[2]

[1] Dixon, Geol. Sussex, ed. 2, p. 58; Fisher, Q. J. xviii. 82. Many of the fossils are extremely delicate; and owing to their perishable condition, in order to preserve them Mr. Fisher recommends their being steeped in isinglass dissolved in gin, while Mr. Dixon used a mixture of diamond-cement and water.

[2] H. W. Bristow, Geol. I. of Wight, p. 43.

On the Dorsetshire coast the beds at Hengistbury Head have been thus divided by Mr. J. S. Gardner:[1]—

Barton Beds.			
Bracklesham Beds.	Upper Bracklesham and Highcliff Sands (white sands).....		25 feet.
	Hengistbury Head Beds.	2. Sands and clays, with ironstone	45 ,,
		1. Clay with green grains.....	12 ,,
	Boscombe Sands (sands and shingle-beds)		140 ,,
	Bournemouth Marine Series (sands and dark clays)		40 ,,
Bournemouth Freshwater Series. (See p. 439.)			

The Highcliff Sands take their name from a cliff in Christchurch Bay, and the Boscombe Sands are so termed from Boscombe Chine, east of Bournemouth. Mr. Gardner includes the Bournemouth Freshwater Series with the overlying strata. The Bournemouth Marine Series contains numerous fossils, but there are few organic remains in the higher beds beneath the Barton Clay.

In Berkshire and Surrey the Bracklesham Beds have a thickness of from 20 to 50 feet, and consist of grey clays, white pipe-clays, greenish loamy sands, and white and yellow sands with pebbles. *Cardita planicosta* has been met with in the beds, which contain lignite, pyrites, etc. The beds are visible at Bagshot and near Sandhurst, and they were exposed in a cutting at Goldsworthy Hill, near Woking.[2]

The green sands of the Bagshot Beds owe their colour sometimes to silicate of iron, and in other instances, according to the Rev. A. Irving, the green is due to vegetable matter.[3]

Barton Clay.—The Barton Clay, so well exposed in the cliffs of Barton and Hordwell (Hordle) in Hampshire, consists of grey and bluish-green clay and sands with septaria, altogether attaining a thickness of 300 feet. The beds are shown also in Alum Bay.[4]

The Clays are very fossiliferous, and contain *Rostellaria rimosa*, *Voluta luctatrix*, *Fusus* (*Clavella*) *longævus*, *F. pyrus* (*Leiostoma bulbiformis*), *Typhis pungens*, *Murex asper*, *Conus dormitor*, *Phorus agglutinans*, *Calyptræa tuberculata*, *Sanguinolaria compressa*, *Crassatella sulcata*, *Pecten reconditus*, *Nummulina*, *Trionyx*, *Zeuglodon*, etc.

Clay-ironstone nodules from Hengistbury have been worked as iron-ore.[5] The clay is used for making bricks.

[1] Q. J. xxxv. 209; G. Mag. 1879, p. 148; see also Lyell, T. G. S. (2), ii. 279.

[2] Prestwich, Q. J. iii. 382; Bristow and Whitaker, Geol. parts of Berks and Hants, p. 41; T. R. Jones, P. Geol. Assoc. vi. 433; W. H. Herries, G. Mag. 1881, p. 173; H. W. Monckton, Q. J. xxxix. 349; Rev. A. Irving, Q. J. xli. 492.

[3] G. Mag. 1883, p. 404; P. Geol. Assoc. viii. 152; see also Prestwich, Q. J. iii. 397.

[4] Gustavus Brander, Fossilia Hantoniensia, 1766; see also T. Webster, T. G. S. (2), i. 90; Prestwich, Q. J. iii. 354, v. 43; Bristow, Geol. I. of Wight, p. 49.

[5] T. Codrington, G. Mag. 1870, p. 23.

Upper Bagshot Beds.

This division consists of white and pale-yellow, and sometimes mottled sands, showing no distinct lines of bedding, and rarely any false-bedding.

In the Isle of Wight the beds are exposed at Alum and Whitecliff Bays, having a thickness of from 140 to 200 feet.[1] Casts of bivalves, *Tellina*, etc., are occasionally found in ironstone, but on the whole organic remains are rare. Being developed at Headon Hill, the term Headon Hill Sands has been used, but the name is inconvenient on account of the Headon Beds which occur above; the name Barton Sands has been suggested by Mr. H. Keeping, because the fossils connect the beds with the Barton Clay below, and indeed the term Bartonian has been used to include both Barton Clay and Upper Bagshot Beds. Between Long Mead End and Paddy's Gap Ravine, near Milford, on the Hampshire coast, a bed was discovered by Mr. S. V. Wood, which yields *Neritina concava*, *Cerithium concavum*, *C. pleurotomoides*, *Cyrena cycladiformis*, etc. This occurs above the Barton Clay, and furnishes evidence of an estuarine transition into the Lower Headon Beds.[2]

The age of the so-called Upper Bagshot Beds in the London Basin has been questioned; Mr. J. S. Gardner indeed doubts whether Upper Bagshot Beds are represented in this area, owing to the absence of the Barton Clay and the similarity between the sands in Surrey, etc., and those of Highcliff, Hengistbury, and Boscombe in Hampshire, which are grouped with the Bracklesham Beds.[3] (See p. 447.) These Upper Bagshot Beds are developed on Frimley and Chobham Ridges, and in the heaths of Bagshot, Hartford and Sandhurst, where their thickness varies from 120 to 300 feet. They contain few pebbles, and few, if any, clay bands, but they have an abundance of ferruginous concretions, which sometimes contain casts of marine shells. The fossils collected by Mr. H. W. Monckton and others, from Frimley and Pirbright, show that the beds, like the Headon Hill Sands, are intimately connected with the Barton Beds. Among the species are *Lucina mitis*, *Pecten reconditus*, *Cardita sulcata*, *Tellina scalaroides*, *Ostrea flabellula*, *Natica ambulacrum*, *Turritella imbricataria*, etc.[4]

In the Isle of Wight the Headon Hill Sands have been extensively worked for making glass.

Greywethers.—Scattered here and there over the southern and south-eastern parts of England, we find large blocks of hard

[1] Bristow, Geol. I. of Wight, p. 51.

[2] London Geol. Journal, No. 1, 1846, p. 1; S. V. Wood, jun. G. Mag. 1883, p. 493, 1884, p. 65; H. Keeping, *Ibid.* p. 95; H. W. Monckton, Q. J. xxxix. 353.

[3] G. Mag. 1879, p. 151; Q. J. xxxv. 210.

[4] See Prestwich, Q. J. iii. 393; Whitaker, Mem. Geol. Surv. iv. 333; W. H. Herries, G. Mag. 1881, p. 172; H. W. Monckton, Q. J. xxxix. 352; H. W. Monckton and R. S. Herries, Q. J. xlii. 415; T. R. Jones, P. Geol. Assoc. vi. 433.

sandstone, which from their occasional resemblance in the landscape to sheep have been popularly termed "Greywethers." They are also known as Sarsen or Sarsden Stones, and Druid Sandstone: the name Sarsden may be derived from the village of that name near Andover.

In size these stones attain dimensions of 10 or 15 feet across, and from 2 to 4 feet in thickness; they are roughly oblong. Their texture varies, but they are usually formed of hard saccharoid sandstone, pale-grey, white, or reddish-brown in colour. Fossil roots of Palms (?) have been observed in the stone.[1]

These Greywethers are concretionary masses of sandstone that were hardened by siliceous cement in a sandy formation, and the majority of the blocks have been derived from Eocene strata. They are in fact relics of beds which formerly extended over the Chalk Downs of the south and west of England; in some cases they rest not far from their parent source, in others they have been transported to some distances by the agents of denudation. The strata which may have yielded these blocks are the Reading Beds, the basement-bed of the London Clay, and the Bagshot Sands: and from the last-named formation most of the Greywethers have undoubtedly been derived.[2] Flint-pebbles and stones, only slightly rolled, sometimes occur in the Greywethers, but large blocks of conglomerate (Hertfordshire puddingstone) are also found. (See p. 431.)

The occurrence of Greywethers is most conspicuous on the Chalk downs west of Marlborough, in Wiltshire, and in Berkshire, but many occur also in the Vale of White Horse, near Wantage.[3]

In Surrey, many Greywethers are obtained from the surface of the Frimley Ridges and other places, where they lie not far apart one from another, sometimes in the Upper Bagshot Sands, and sometimes in the superficial gravels. In the latter instances they occur sometimes in a more or less worn condition.[4] They are found by sounding the sands and gravel with iron rods. The sandstone is friable when first excavated, but it hardens by exposure. It is broken up into small cuboidal stones for paving or building, and for road-metal. In some places the greywethers are used for gate-posts, stepping-stones, etc. Much of Windsor Castle is built of greywether sandstone.

At Hampden, and other places, to the north and north-west of High Wycombe there are beds of Drift brick-earth containing masses of greywether sandstone (known as Hampden Stone), which are worked for road-metal, paving, and building.[5] Greywethers have also been found in superficial deposits on the Chalk hills near Maidstone, near Southampton, and other places.

Near Sidmouth large blocks of a siliceous breccia are met with, and pebbles of the same rock, called the Sidmouth pebbles, are picked up on the beach and polished; similar blocks occur at Portisham, near Abbotsbury.[6] (See p. 433.)

[1] W. Carruthers, G. Mag. 1885, p. 361.

[2] Prestwich, Q. J. x. 123; Whitaker, Explan. Sheet 13 (Geol. Survey), p. 47, Q. J. xviii. 258; Ramsay, Explan. Sheet 34 (Geol. Surv.), p. 41; Lieut.-Col. W. T. Nicolls, G. Mag. 1866, p. 296; Rev. J. Adams, *Ibid.* 1873, p. 198; T. Codrington, Mag. Wilts Arch. Soc. 1885.

[3] Godwin-Austen, Q. J. vi. 461.

[4] T. R. Jones, P. Geol. Assoc. vi. 436; Rev. A. Irving, *Ibid.* viii. 153.

[5] Whitaker, Geol. Middlesex, etc. (Geol. Surv.), 1864, p. 66; Morris, G. Mag. 1867, p. 457.

[6] Buckland, T. G. S. (2), i. 101, ii. 126; Reliquiæ Diluvianæ, p. 248.

At Stonehenge the outer ring is formed of huge Greywethers; the Altar-stone is a grey micaceous sandstone, possibly Old Red Sandstone from the neighbourhood of Frome; while most of the stones forming the inner circle are Diabase, and others are Felsites, Hornstones and Schists, whose source is not known.[1] Sir A. C. Ramsay has stated that these are certainly not drifted boulders, and without asserting that they came from Wales or Shropshire, he observes that they are of the same nature as the Igneous rocks of part of North Pembrokeshire, of Caernarvonshire, and of the Llandeilo flag district of Montgomeryshire, etc., west of the Stiper Stones.[2]

Avebury or Abury, between Marlborough and Calne; Kits Coty House,[3] near Aylesford; and Wayland Smith's Cave or Forge, near Ashbury, south of Shrivenham, are formed of Greywethers.

OLIGOCENE.

UPPER EOCENE OR FLUVIO-MARINE SERIES.

The term Fluvio-Marine Series has been applied to this division because the strata are partly of freshwater and partly of estuarine and marine origin.[4] They are exposed on the Hampshire coast, but most completely developed in the northern part of the Isle of Wight, where their relations and palæontological contents were systematically worked out by Edward Forbes.[5] The Series is divided as follows:—

Hempstead Beds.
Bembridge Beds.
Osborne Beds.
Headon Beds.

The Fluvio-marine Beds consist of marls, clays, and sands, with occasional beds of limestone, and there is no evidence of any break in the series.

No members of the Fluvio-marine series have been met with in the London Basin, but attention has been drawn by Mr. Clement Reid to the occurrence of Amber in the Pliocene Beds on the Norfolk coast. It is associated with Jet, and both are probably present as worn fragments washed out of an older and under-

[1] N. S. Maskelyne, P. Geol. Assoc. vii. 138; Wilts Mag. xvii. 159; W. Cunnington, *Ibid.* xxi. 141, with notes by T. Davies; G. B. Greenough, in Conybeare and Phillips, Geol. Eng. and Wales, p. 14.

[2] Explan. Sheet 34 (Geol. Surv.), p. 43.

[3] P. Geol. Assoc. i. 64; see also Mantell, Fossils S. Downs, p. 253.

[4] The term Vectian was suggested by Prof. Phillips (see p. 365).

[5] Q. J. ix. 259, and Tertiary Fluvio-marine Formations of the Isle of Wight, 1856; H. W. Bristow, Geol. Isle of Wight, 1862; Prestwich, Q. J. ii. 223; T. Wright, Proc. Cotteswold Club, i. 87; Mantell, Geol. Excursions round the I. of Wight, edit. 3, 1854; E. Hébert, Bull. Soc. Géol. France (2), ix. 191; C. Evans, P. Geol. Assoc. ii. 162. Some of the earliest observations on the strata were made by Webster (see Englefield's Isle of Wight); and also by G. B. Sowerby and Sedgwick, Ann. Phil. 1821 and 1822.

lying deposit. True Amber is a fossil resin which is the product of the extinct Conifer *Pinites succinifer.* Remains of a Spider and several Flies have been obtained from the Norfolk Amber, and Mr. Reid suggests that the specimens have been derived from Upper Eocene or Oligocene deposits, which form an extension, beneath the German Ocean, of the well-known Amber-bearing beds of the Baltic shores of Prussia.[1]

HEADON BEDS.[2]

These beds, named by Prof. E. Forbes from their occurrence at Headon Hill, on the west of the Isle of Wight, consist of green shelly sands, clays, marls, and limestones, which have been subdivided as follows:—

Upper Headon Beds.	
Middle Headon Beds	Colwell Bay Marine Bed. Brockenhurst Beds.
Lower Headon Beds.	Hordwell Beds, etc.

The total thickness of the Headon Beds varies from 133 feet at Headon Hill to 175 feet at Whitecliff Bay.

Lower Headon Beds.

These beds consist of sands and clays with lignite in places, and are exposed at Headon Hill (67 feet) between Weston Chine and Warden Cliff, and in Whitecliff Bay (40 feet). They contain a Unio-bed with *U. Solandri*, and a bed of Limnæa limestone at the top (How Ledge Limestone)[3] with *L. longiscata* and *L. fusiformis.* *Cyrena cycladiformis* is a marked shell in this division, which exhibits fresh- and brackish-water conditions: among other species we find *Planorbis euomphalus*, *Paludina lenta*, *Potamomya plana*, and *Potamides cinctus.*

Hordwell Beds.—At Hordwell remains of *Spalacodon* (an insectivorous Mammal), also the Mammals *Anthracotherium*, *Palæotherium* (*Paloplotherium*), *Didelphys*, *Theridomys*, *Hyænodon* and *Viverra Hastingsiæ* have been recorded from the Lower Headon Beds, together with a Bird, *Macrornis*, and remains of *Crocodilus*

[1] Trans. Norfolk Nat. Soc. iii. 601, iv. 247; see also P. B. Brodie, Rep. Warwicksh. Nat. Hist. Soc. 1871, and S. V. Wood, Supp. to Crag Mollusca.

[2] The Upper, Middle, and Lower Headon Beds correspond respectively with the Upper Freshwater, Upper Marine, and Lower Freshwater formations of Webster, terms adopted from Cuvier and Brongniart, Desc. Géol. des Env. de Paris. See also Lyell, T. G. S. (2), ii. 287; and Bowerbank, *Ibid.* vi. 169.

[3] Keeping and Tawney, Q. J. xxxvii. 98; see also H. W. Bristow, Geol. I. of Wight, p. 62.

Hastingsiæ, *Trionyx* (several species) and *Emys crassus*.[1] The thickness of the Lower Headon Beds between Long Mead End and Paddy's Gap is about 80 feet, according to measurements by Messrs. E. B. Tawney and H. Keeping. The beds consist of greenish marly clay and sands.

The Lower Headon marls have been used for marling lands in Hampshire. The Lower Headon Beds of the Isle of White furnish white glass-house sand of fine quality.

Middle Headon Beds.

Colwell Bay Marine Bed, etc.—The Middle Headon Beds consist of sand and sandstone with clays attaining a thickness of about 100 feet. At Headon Hill they contain a brackish-water fauna, yielding *Potamides cinctus*, *P. ventricosus*, *P. concavus*, *Neritina concava*, *Cerithium concavum* (taken sometimes to indicate a zone), *Cytherea incrassata*, etc. Further north in Colwell Bay the upper and lower portions of the series are marked by the presence of brackish-water Mollusca, but the central part assumes a distinctly marine character (Colwell Bay Marine Bed), consisting of clays with *Cytherea incrassata* (Venus bed), and containing also Oyster-beds with *Ostrea flabellula*. *Planorbis euomphalus*, *Limnæa longiscata*, and *Paludina lenta* abound in the freshwater beds, and *Chara Wrightii* is abundant in the Neritina bed (with *N. concava*) at the base of the series. *Trigonocœlia deltoidea* occurs in a layer above the Neritina bed.

Brockenhurst Beds.—In 1858 Mr. H. Keeping collected a series of fossils from Cutwalk Hill, near Lyndhurst, but attention was not particularly directed to the fauna until 1864, when Baron Adolf von Koenen observed that the railway-cuttings at Whitley Ridge in the New Forest (Brockenhurst, etc.) had exposed certain marine beds overlying the Lower Headon (freshwater) series, and containing fossils which he believed to constitute the marine equivalent of the Middle Headon strata.[2] The Brockenhurst Beds occur at the base of the marine Headon Beds at Brockenhurst and Lyndhurst, and also at Whitecliff Bay (14 feet), but they have not been recognized at Colwell Bay and Headon Hill.

The Brockenhurst Beds yield *Voluta spinosa*, *Pisania (Fusus) labiata*, *Typhis pungens*, *Pleurotoma transversaria*, *P. Hantoniensis*, *Ostrea ventilabrum*, *Cytherea Solandri*, *Psammobia æstuarina*, *Corbula pisum*, etc. The fossils obtained at Whitley Ridge railway-cutting differ a little from those obtained from a brickyard at Roydon in the same neighbourhood, and this has led Messrs. Keeping and Tawney to divide the beds into two zones, both of which are on a

[1] S. V. Wood, London Geol. Journal, No. 1, p. 1; Dr. T. Wright, Proc. Cotteswold Club, i. 120; Marchioness of Hastings, Bull. Soc. Géol. France (2), ix. 141 (the collection made by this lady is in the British Museum); Tawney and Keeping, Q. J. xxxix. 566; W. Davies, G. Mag. 1884, p. 433; R. Lydekker, *Ibid.* 443, 547.

[2] Q. J. xx. 97; G. Mag. 1867, p. 507.

lower horizon than the Venus-bed of Headon Hill (Headon Hill zone). They group the beds as follows:[1]—

Brockenhurst Beds.	Roydon zone. Clays with *Voluta geminata* ....about	14 feet.
	Brockenhurst zone. Sandy clays with *Voluta suturalis*	1 to 2 ,,

Prof. Judd came to the conclusion that the Colwell Bay Marine Bed and the Brockenhurst Beds were of the same age, but on a higher horizon than the Middle Headon Beds of Headon Hill, etc. His views, however, have not been accepted.[2]

Upper Headon Beds.

The Upper Headon Beds consist principally of clays and sands, yielding freshwater and brackish-water Mollusca. These include *Paludina lenta*, *Potamides margaritaceus*, *Melania muricata*, *Potamomya gregaria*, *Cyrena Wrightii*, *Corbicula obovata*, and many species found also in the Lower Headon Beds. These beds are seen at Headon Hill, Colwell Bay, etc. At the former locality there are thick and conspicuous beds of limestone with *Limnæa fusiformis*, which thin out towards the north, and are represented by sands and marls in Whitecliff Bay. The thickness of the series is about 50 feet.

OSBORNE BEDS.

These Beds, formerly termed the St. Helen's Beds, were named by Prof. Forbes after the Royal demesne of Osborne, near Cowes.[3] The series consists of red and greenish mottled clays and marls, pale greenish-white limestones, and sandy beds. The beds are from 70 to 100 feet thick, and they are very variable in character. They are well seen east and west of Ryde, in Whitecliff Bay, and at Cliff End, Colwell Bay. They yield *Chara Lyellii*, *Limnæa longiscata*, *Paludina lenta*, *Melania excavata*, *Planorbis* (several species), *Melanopsis carinata*, *Corbicula obovata*, etc.

Locally the beds were divided as follows by Prof. Forbes:—

2. The *St. Helen's Sands* (named from a place south-east of Ryde), which comprise pale green, yellow, and white sands, hardening into sandstone, with white and yellow marls and clays, having a total thickness of about 80 feet.
1. The *Nettlestone Grits* (named from Nettlestone Point east of Ryde), which include beds of grit, soft sandstone, clay and limestone, having a thickness of about 20 feet.

[1] Q. J. xxxvii. 113; Tawney, G. Mag. 1883, p. 157.

[2] Judd, Q. J. xxxvi. 137; xxxviii. 461; H. Keeping and E. B. Tawney, Q. J. xxxvii. 85; H. Keeping, G. Mag. 1883, p. 428; see also R. Etheridge, Address Geol. Section, Brit. Assoc. 1882; A. S. Lucas, G. Mag. 1882, p. 97; O. Fisher, *Ibid.* p. 138; J. W. Elwes, *Ibid.* 1883, p. 527; W. Topley, P. Geol. Assoc. vii. 187.

[3] The beds were grouped by Prof. Judd, together with the Upper Headon Beds, as Lower Bembridge Marls. Q. J. xxxvi. 170; see also Keeping and Tawney, Q. J. xxxvii. 92.

BEMBRIDGE BEDS.

This series, named by Prof. Forbes from Bembridge, south-east of Ryde, has been subdivided as follows:—

Bembridge Marls.	*Upper Bembridge Marl*, consisting of marls and laminated grey clays, yielding in great abundance *Melania turritissima*.
	Lower Bembridge Marl, comprising unfossiliferous mottled clays alternating with fossiliferous laminated clays and marls, with *Cerithium mutabile*, *Cyrena pulchra*, etc.
	Bembridge Oyster Bed, a band containing *Ostrea Vectensis*.
	Bembridge Limestone, comprising the uppermost shell-limestones (25 feet) of Headon Hill, Sconce, Hempstead Ledge, Gurnet Bay, near Cowes, Binsted, Bembridge, etc. This limestone is sometimes hard and compact, at others soft and tufaceous; it is cream-coloured, and occurs in layers from 1 to 6 feet thick, with clays and marls, attaining a total thickness of 25 feet. The beds contain *Clausilia*, *Bulimus ellipticus* (Bulimus limestone), *Helix globosa*, *Planorbis discus*, and *Limnæa longiscata* (Limnæan limestone).

The Bembridge Marls attain a thickness of about 90 feet, and are well seen below St. Helen's, by Brading Harbour, at Whitecliff Bay, and at Hempstead; and they occur at Osborne. The Oyster-bed, consisting of green sand and shelly marl, about 18 inches thick, is shown in Whitecliff Bay, and near St. Helen's by the entrance to Brading Harbour. In addition to the fossils already mentioned, the Bembridge Beds have yielded remains of *Trionyx*; also the Mammalia *Anoplotherium*, *Chœropotamus*, *Pterodon*, *Dichobune* and *Palæotherium*;[1] the Phyllopod *Branchipodites Vectensis*;[2] and some Plant- and Insect-remains obtained by Mr. J. A'Court Smith from the Bembridge Beds of Gurnet Bay.[3]

The Bembridge limestone has been largely quarried at Binsted (near Ryde), East Cowes, etc.; Quar Abbey, Yarmouth Castle, and portions of the interior of Winchester Cathedral were constructed from it, but the beds are now seldom worked.

HEMPSTEAD BEDS.

These beds, named by Prof. Forbes from their occurrence at Hempstead between Yarmouth and Cowes, have been divided as follows:—

		Ft.	ins.
Corbula Beds.	Brown and greenish clay with shelly bands, *Corbula pisum*, *C. Vectensis*, etc.	15	0
Freshwater and Estuarine Marls.	Upper, containing *Cerithium plicatum*, *C. elegans*, *Corbula*, *Rissoa*, *Hydrobia*, *Melania*, *Paludina*, etc.	40	0
	Middle, with *Cyrena semistriata*, *Cerithium*, *Rissoa*, *Panopæa minor*, etc.	50	0
	Lower, with *Melania muricata*, *M. fasciata*, *Melanopsis carinata*, *Cyclas Bristovii*, *Unio Gibbsii*, etc.	65	0

[1] S. P. Pratt, T. G. S. (2), iii. 451. [2] Dr. H. Woodward, Q. J. xxxv. 346.
[3] J. S. Gardner, P. Geol. Assoc. vi. 91, viii. 312; Rep. Brit. Assoc. 1886.

These beds were classed as Lower Miocene by Sir Charles Lyell, as Prof. Heer had recognized from them some species of Plant-remains found also in the lignite of Bovey Tracey: that deposit, however, is now regarded as Eocene.[1] The plants include *Chara*, *Sequoia*, *Nymphæa*, *Carpolithes*, etc.

A Bird, *Ptenornis*, has also been found in the strata. The beds consist chiefly of red and green mottled clays, marls, and shales. The base of the lower Hempstead beds is marked by a "Black Band" of carbonaceous clay, nearly two feet thick; and that of the middle Hempstead beds by a "White Band" of broken and entire shells, 9 inches to 4 feet thick, which forms a conspicuous feature in the cliffs. *Panopæa Gibbsii* occurs at the base of this White Band, and this middle division has yielded remains of *Hyopotamus*, besides Turtles, Fishes, etc.[2]

PLIOCENE.

The Pliocene deposits of this country occur chiefly in Norfolk and Suffolk, and they consist of shelly sand, gravel, and laminated clay.

The term Icenian was proposed for these strata by Dr. S. P. Woodward, because their order of succession was first determined in the Eastern Counties, the country of the Iceni.[3]

The beds are subdivided as follows:—

Newer Pliocene. { Cromer Forest Bed Series. / Norwich Crag Series.[4] / Red Crag.
Older Pliocene.—Coralline Crag.

Mr. S. V. Wood, jun., maintained that the Pliocene period properly included the Glacial deposits, because in Norfolk we find a continuous succession of deposits from the Crag and Forest Bed Series upwards into the newer accumulations.[5] The term Pliocene is, however, generally confined to deposits newer than the Miocene and older than the Glacial period, and in this sense it is here used.

[1] Q. J. xviii. 371; Lyell, Student's Elements, 1871, p. 219; see also J. S. Gardner, Q. J. xxxviii. 12.

[2] Bristow, Geol. I. of Wight, p. 90.

[3] Manual of the Mollusca, p. 410. The term Subapennine was given by the Italian geologist, G. B. Brocchi, to those Tertiary strata which lie on the lower part of the Apennines on the sides both of the Adriatic and the Mediterranean, and constitute the older Pliocene strata of Italy. Beds, however, of Miocene as well as Pliocene age have been included under this term. The term Neogene was used by Moriz Hörnes for the Miocene and Pliocene deposits. See Lyell, Elements of Geol. ed. 6, 1865, p. 207.

[4] The term Upper Crag has been used as a synonym for this series; the term Middle Crag was applied to the Red Crag by A. and R. Bell in 1871; while the Coralline Crag is sometimes known as the Lower Crag.

[5] Q. J. xxxvi. 457; xxxviii. 667.

Under this grouping also may be included the 'Forest Bed' of Norfolk (familiarly known as "Pre-Glacial," but sometimes grouped as Pleistocene), because that deposit clearly underlies the oldest Boulder Clay in the country, and is more intimately connected with the later deposits of the Crag than with the overlying Glacial accumulations.

It would, however, be wrong to group all so-called Pre-Glacial deposits as Pliocene, as the former ambiguous term (introduced by John Phillips in 1853) is sometimes conveniently used for deposits that underlie Boulder Clay, and that can be definitely referred neither to the Pliocene nor to the Glacial period.

Some of the pebbly gravels which cap the Tertiary hills in Hertfordshire, Surrey, Berkshire, and elsewhere, may possibly be of Pliocene age, but this view depends, to some extent, upon the position of the boundary-line taken between Pliocene and Glacial deposits.[1] In some localities also there are deposits of white clay, sand, and chert, the age of which is exceedingly doubtful. (See p. 444.)

The occurrence of Crag deposits at Lenham in Kent (600 feet above sea-level), and at St. Erth in Cornwall, suggests that a great part of the east and south of England was submerged during Pliocene times.[2]

The Pliocene strata contain a large number of living species of Mollusca, and they yield some species, such as *Voluta Lamberti*, *Panopæa Faujasii*, *Pectunculus glycimeris*, etc., which are found also in Miocene deposits.

The Mammalia include the *Machærodus*, *Trogontherium*, *Elephas meridionalis* (and other species), *Hippopotamus*, *Mastodon*, and many other forms, some of which are Recent species. No evidence of Man's existence during the Pliocene period has been obtained in this country.[3]

The climate of the Pliocene period appears to have undergone a gradual refrigeration. The warmer Miocene period was succeeded by a milder climate during the deposition of the Coralline Crag, whose Molluscan fauna is like that of the Mediterranean; while in the Red and Norwich Crags the southern forms diminish in numbers, and we find an increase of northern and arctic Mollusca. The higher stages of the Cromer Forest Bed Series indicate more markedly the approach of the still colder climate, which culminated in our Glacial period.[4]

CRAG.

The deposits of shelly sand and gravel known as 'Crag,' which occur on the eastern borders of Norfolk, Suffolk, and Essex, have

[1] Bristow, Geol. parts Berks and Hants (Geol. Surv.), p. 43; T. McK. Hughes, Q. J. xxiv. 285; Whitaker, Guide to Geol. London, ed. 4, p. 58; Prestwich, G. Mag. 1881, p. 466; Ussher, Post-Tertiary Geol. Cornwall, p. 10, G. Mag. 1879, p. 102.

[2] C. Reid, Nature, Aug. 12, 1886, p. 342; see also P. F. Kendall and R. G. Bell, Q. J. xlii. 207.

[3] See A. Bell, G. Mag. 1886, p. 71.

[4] See E. Forbes, Mem. Geol. Survey, i. 336.

long attracted the attention of collectors, on account of the abundance of fossils at certain localities, and the readiness with which they may be obtained. 'Crag' is a Suffolk term for gravel, the shelly portions of which have been in former years largely dug as 'marl' for agricultural purposes.[1]

In 1835 Mr. Edward Charlesworth gave the first good account of the Crags in Suffolk, and he then proposed the terms 'Red Crag' and 'Coralline Crag' to distinguish them from one another, and from the Norfolk or Norwich Crag, to which in 1836 he applied the term 'Mammaliferous Crag.'[2] Since this date the labours of Mr. S. V. Wood, jun., Mr. F. W. Harmer, Prof. Prestwich, Mr. Clement Reid, and others, have added greatly to our knowledge of the structure of the deposits; while for the minute description of their Molluscan remains we are indebted to Mr. Searles Wood, sen.[3]

CORALLINE CRAG.

The Coralline Crag consists of yellow calcareous shelly sands, having a thickness estimated at from 40 to 80 feet. The beds are often 'piped' like the Chalk.

The following general divisions are abbreviated from those given by Prof. Prestwich:[4]—

Upper or Polyzoan (Bryozoan) Zone. 36 feet.	7. Sand and comminuted shells, with remains of Polyzoa, sometimes forming a soft building-stone, showing much false-bedding.
Lower or Shell zone. 47 feet.	6. Sand with small shells and seams of comminuted shells.
	5. Sands with numerous Polyzoa, often in the original position of growth, and containing also small shells and Echini.
	4. Comminuted shells, large entire or double shells, and thin bands of limestone.
	3. Marly beds with well-preserved shells.
	2. Comminuted shell-beds with Cetacean remains and Polyzoa.
Suffolk Bone-bed.	1. Bed with Phosphatic nodules ('Coprolites,') and Mammalian remains.

It has been questioned whether so thick a series of strata is developed at any one locality;[5] but Mr. P. F. Kendall is of opinion that the thicknesses of both Coralline and Red Crags have been underestimated.

[1] The term Crag Marl was used by Sowerby in 1812, Min. Conch. vol. i. Supp. Index.

[2] Phil. Mag. (3), vii. 81, 465; Rep. Brit. Assoc. for 1836; Proc. G. S. ii. 195.

[3] S. V. Wood, Crag Mollusca (Palæontogr. Soc.), 1848-61, Supplements 1872, 1874, and 1879; see also Crag Polyzoa, by G. Busk, 1859, etc.; A. and R. Bell, P. Geol. Assoc. ii. 185, 270.

[4] Q. J. xxvii. 121.

[5] Lyell, Student's Elements, 1871, p. 173.

The term Bryozoan or Polyzoan Crag was used by Mr. Godwin-Austen because there are few Corals in this Crag, the forms which led to the proposal of the term Coralline Crag being Bryozoa or Polyzoa. The terms Suffolk Crag and White Crag have also been employed.[1]

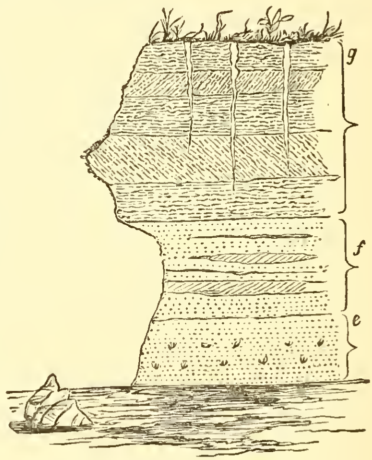
The Coralline Crag has been well shown in the neighbourhood of Woodbridge, Aldborough, and Orford, at Sutton (see Fig. 76), Ramsholt, Tattingstone, Iken, Sudbourne, Broom Hill, Gedgrave, Gomer (a small temporary excavation in a field between Low Gedgrave and Broom Hill), etc.

FIG. 76.—SECTION OF CORALLINE CRAG AT SUTTON, NEAR WOODBRIDGE. (Prof. J. Prestwich.)

Polyzoan zone. *g.* Dark ferruginous beds of Polyzoa, mostly in fragments, with soft white calcareous veins. 11 feet.

Shell zone. *f.* Fine sand and sandstone, comminuted shells, small perfect shells and Polyzoa. 6 feet.

e. Fine compact sand, with small shells and Polyzoa in the position of growth. 4 feet.



Amongst the fossils are the Mollusca *Cypræa Europæa*, *Voluta Lamberti*, *Turritella incrassata*, *Fusus consocialis*, *Trophon gracilis*, *Scalaria clathratula*, *Natica multipunctata*, *Calyptræa Chinensis*, *Pyrula reticulata*, *Trochus zizyphinus*, *Fissurella Græca*, *Anomia ephippium*, *Ostrea edulis*, *Pecten opercularis*, *P. maximus*, *P. Gerardii*, *Pinna pectinata*, *Pectunculus glycimeris*, *Nucula nucleus*, *Lucina borealis*, *Diplodonta rotundata*, *Cardita senilis*, *C. scalaris*, *Astarte Omalii*, *A. gracilis*, *Cyprina Islandica*, *C. rustica*, *Venus casina*, *Panopæa Faujasii;* Brachiopoda, *Terebratula grandis;* Cirripedia, *Balanus crenatus;* Polyzoa, *Idmonea*, *Retepora*, *Cupularia*, *Eschara*, *Fascicularia aurantium*, *Hornera infundibulata*, *Cellepora edax*, *C. cæspitosa*; Echinodermata, *Echinus Woodwardi*, *Temnechinus excavatus*, etc. Crustacea and Corals also occur.

Altogether there are about 316 species of Mollusca, of which, according to Dr. J. Gwyn Jeffreys, 52 are extinct and 264 living species. *Isocardia cor*, which is taken to indicate a zone in the

[1] T. R. Jones and W. K. Parker, Ann. Nat. Hist. (3), xiii. 65.

Belgian Crag, is not abundant in this country. Among the Fish-remains (Otoliths, etc.) are *Morrhua* (Cod), *Merlangus*, together with remains of *Platax Woodwardi*, *Raia antiqua*, and *Zygobatis Woodwardi*. Mr. Wood considers that the Coralline Crag was deposited in the sea at no depth greater than 300 feet.

Suffolk Bone-bed.—In 1843 the Rev. J. S. Henslow called attention to the occurrence of phosphate of lime in 'pebbly beds' (nodules) of the Red Crag at Felixstow; and from the fact that some of the nodules yielded upon analysis 56 per cent. of the phosphate, he was led to suggest their employment in the preparation of manure for agricultural purposes. These observations led to further important discoveries of phosphatic nodules (see p. 410), for Mr. Henslow also observed their occurrence in the 'Cambridge Greensand.'[1] These phosphatic nodules of the Crag have been extensively worked, and being associated with many vertebrate remains, in a highly mineralized condition, the layer has been termed the Suffolk Bone-bed.

This Bone-bed or 'Coprolite bed,' has been described by Prof. E. Ray Lankester as being from half a foot to three feet in thickness, and lying upon the London Clay in Suffolk wherever the Red Crag and the Coralline Crag are found. It is composed of rounded phosphatic nodules called 'coprolites,' and water-worn teeth and bones of *Mastodon Arvernensis*, *Rhinoceros incisivus*, *R. Schleiermacheri*, *Cervus dicranoceros*, *Sus*, *Tapirus*, *Ursus Arvernensis*, *Canis vulpes*, *Hyænarctos*, *Felis pardoides*, *Hipparion*, *Hyæna striata*, *Halitherium Canhami*, *Belemnoziphius*, *Choneziphius*, *Trichechus*, *Delphinus*, Cetotolites or ear-bones of Whales (*Balæna*, etc.); bones of the Bird *Diomedea*; teeth of Sharks (*Carcharodon megalodon*), etc. Prof. Lankester considers that the Cetacean remains were derived from the lowest Crag-deposits known in Belgium as the Diestian or Black-crag. Most of the ziphioid bones bear the marks of Pholas-borings.[2] Prof. Prestwich, however, believes that the Mastodon and Rhinoceros may have lived during the period of the Coralline Crag; the Whale certainly existed at that time.[3]

Among the coprolites and bones we occasionally find fragments of septaria, teeth of Fishes, and Crustacea derived from the London Clay, also Chalk flints (often encrusted with Barnacles), Greensand chert, quartz, porphyry, etc.

The 'coprolites' yield from 45 to 60 per cent. of phosphate of lime; they have been worked near Sutton, Boyton, Butley, Trimley, Bawdsey, Shottisham, etc. The beds are however becoming exhausted. According to Prof. Prestwich seams of phosphatic nodules, or dispersed nodules, may be found through the whole of the Red Crag; and all of them were probably derived from the bed at the base of the Coralline Crag.

[1] Memoir of the Rev. J. S. Henslow, by the Rev. L. Jenyns (Blomefield), 1862, p. 201; Q. J. i. 36; see also Buckland, T. G. S. (2), iii. 234.
[2] Geol. Mag. 1868, p. 256; Q. J. xxi. 224 and xxvi. 501; see also Owen, Q. J. xii. 217; Wood, Q J. xv. 32; J. E. Taylor, Geol. Suffolk (reprinted from White's History), 1884; R. Lydekker, G. Mag. 1884, p. 443, Q. J. xlii. 364. xliii.
[3] Q. J. xxvii. 117, 133, 326.

In the Suffolk Bone-bed are found rounded masses and nodules of sandstone termed Box stones, which sometimes contain fossils, mostly in the form of casts. They are probably of the age of the Black Crag (Diestian) of Antwerp. The name Box stone was given by the workmen because when struck by a hammer they break open and reveal the enclosed fossil. Fossils have been thus found at Foxhall, Waldringfield, Falkenham, and on Felixstow beach. Many were obtained by the Rev. H. Canham. They include casts of *Isocardia*, *Cardita*, *Pectunculus*, *Conus*, *Cassidaria*, *Pyrula*, *Turritella*, *Voluta*, etc.; also teeth of *Mastodon*, etc.

Lenham Beds.—In certain localities on the Chalk in Kent and Surrey there have been found traces of sand and clay and iron-sandstone with casts of Mollusca, mostly bivalves; these deposits sometimes fill pipes in the Chalk, and have been met with at Headley east of Guildford, Chipsted south of Croydon, Paddlesworth north-west of Folkestone, Lenham near Maidstone, etc. The examination of the beds in 1857 by Prof. Prestwich,[1] and a study by Mr. Wood of the fossils which had been found in the iron sandstone at Lenham, led to the beds being doubtfully referred to the Crag; but both Mr. Bristow[2] and Mr. Whitaker[3] have inclined to refer the materials filling most of the pipes to the Eocene period, regarding them as representatives of Woolwich or Oldhaven Beds, although it is quite possible that the deposits are not all of the same age, for fossils have only been met with at Lenham and Paddlesworth. In 1886 Mr. Clement Reid obtained a number of blocks of ironstone from Lenham, and took impressions of the moulds of fossils which occurred in the rock. The species determined include *Pyrula reticulata*, *Ringicula ventricosa*, *Turritella incrassata*, *Pectunculus glycimeris*, *Diplodonta rotundata*, *Terebratula grandis*, etc.[4] As remarked by Mr. Reid, the species are southern forms, and indicate that the deposit is of the age of the Coralline Crag, and equivalent, as Prof. Prestwich considered, to the lower part of this Crag, known as Diestian (named after Diest in Belgium).

St. Erth Beds.—Pliocene deposits were in 1883 discovered at St. Erth, near the Land's End, by Mr. Thomas Cornish and Mr. F. W. Harmer[5] The evidence was furnished by the occurrence of Mollusca in a bed of blue clay, resting on sand, and overlaid by clayey loam. The species include *Cypræa avellana*, *Nassa serrata* (*reticosa*), *N. solida*, *Melampus* (*Conovulus*) *pyramidalis*, *Columbella sulcata*, *Turritella incrassata*, *Natica multipunctata* (*millepunctata*), *Nucula nucleus*, *Pectunculus glycimeris*, *Lucina borealis*, etc. Polyzoa, Ostracoda, and Foraminifera likewise occur.

Our knowledge of the deposit is chiefly due to the labours of Mr. Percy F. Kendall and Mr. R. G. Bell,[6] who have largely

[1] Q. J. xiv. 322.
[2] Q. J. xxii. 553.
[3] Q. J. xxii. 430; Mem. Geol. Survey, iv. 336, 601. See also A. von. Koenen (who maintained the Crag age of the deposits), G. Mag. 1867, p. 502.
[4] Nature, Aug. 12, 1886, p. 342.
[5] S. V. Wood, jun., Q. J. xli. 65.
[6] Q. J. xlii. 201.

increased the list of fossils, and have discovered remains of Tunicata (*Leptoclinum tenue*), and spicules of Calcisponges. They conclude that the deposit was accumulated during the earlier portion of the Red Crag period, but Mr. Clement Reid is disposed to group it with the Lenham Beds, which are of the age of the lower part of the Coralline Crag.[1] Possibly the St. Erth beds may represent passage-beds between these strata.

Messrs. Kendall and Bell are of opinion that during the accumulation of the St. Erth Beds no channel of direct communication existed between the North Sea and the Atlantic Ocean, the Straits of Dover being closed, while on the north-west the Tertiary volcanic chain threw a barrier across from the north of Scotland to Greenland by way of the Shetland and Faroë Islands and Iceland. Such a barrier may have had considerable influence on the climate of later Pliocene and Glacial times in North Britain. Deposits of sand and clay, apparently similar to those of St. Erth, occur at St. Agnes Beacon, but they have yielded no organic remains.[2]

RED CRAG.

This deposit consists generally of dark red shelly sand, exhibiting false-bedding, and having a thickness of from 25 to 40 feet. Sometimes the colour is yellow, brown or grey. Seams of laminated clay are occasionally met with.

Mr. S. V. Wood, jun., expressed the opinion that the lower stages of the formation were not, as a rule, deposited under water; but from their being regularly inclined at angles varying between 25° and 35°, he regarded them as due to a process of 'beaching up,' by which was formed a reef extending from the river Alde on the north to the southern extremity of the deposit in Essex. At Walton-on-Naze, however, the lowest bed of grey Crag contains evidence of being a subaqueous deposit, and is remarkably free from derivative fossils; but it is covered by two reef stages, and these again by horizontal beds. The uppermost beds are generally horizontal, and contain evidence of having been formed under water. Owing, however, to the probable reconstruction or re-accumulation of different stages, Mr. Wood considered it impossible to separate the Red Crag in general into more than three divisions, as follows:[3]—

3. Scrobicularia Crag. { Largely made up of *Tellina prætenuis*, and *T. obliqua*, with also *Scrobicularia plana* (*piperata*).
2. Deben, Orwell, and Butley Red Crag, with northern forms of mollusca predominating.
1. Walton Grey and Red Crag, containing many species characteristic of the Coralline Crag.

[1] Nature, Aug. 12, 1886, p. 342.

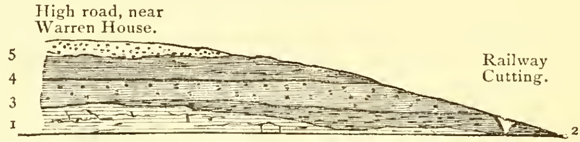
[2] W. A. E. Ussher, Post-Tertiary Geology of Cornwall, 1879, p. 12; G. Mag. 1879, p. 103: De la Beche, Report on Geol. of Cornwall, etc. p. 258.

[3] Q. J. G. S. xx. 121, Ann. Nat. Hist. (3), xiii. 185. See also Prestwich, Q. J. xxvii. 324, 352; T. G. Ringler-Thomson, Q. J. v. 353; W. Whitaker, Geology of Ipswich, etc. (Geol. Surv.), p. 29.

The Red Crag is well shown at Walton-on-the Naze, Felixstow, Waldringfield, Sutton, Ramsholt, Trimley, Bawdsey Cliff, Butley, Hollesley, etc. Its presence at Sudbury has been noticed by Mr. Whitaker.[1] Near Aldborough, at Sudbourne, and at Park Farm, Tattingstone, near Ipswich, the Red Crag was to be seen in section superimposed upon the Coralline Crag; the beds are unconformable. (See Fig. 77.) Over the greater part of the area the Red Crag rests on the London Clay.

FIG. 77.—SECTION NORTH OF ALDBOROUGH, IN SUFFOLK.

(Prof. J. Prestwich.)



5. White sand and gravel (Glacial Drift).
4. Chillesford Clay.
3. Chillesford Sand.
2. Red Crag.
1. Coralline Crag.
Height about 25 feet.

In 1839 Lyell[2] described an old cliff of Coralline Crag at Sutton, against which the Red Crag rested, and from which it derived much material, and Prof. Prestwich speaks of the Red Crag as occupying "an excavated area in the Coralline Crag, wrapping round the isolated reefs of the latter, filling up the hollows between them, and lying nearly on a level with the conterminous Coralline Crag."[3] Many organic remains found in the Red Crag have been derived from the London Clay and the Coralline Crag; about 25 species of the Mollusca have, it is thought, been derived from the latter formation.

The fossils of the Red Crag include the *Trophon* (*Fusus*) *antiquus*, of which the sinistral or left-sided form (var. *contrarius*), is found in the Walton Crag, while the dextral form abounds in the rest of the Red Crag. Other Mollusca are *Pecten opercularis*, *Pectunculus glycimeris*, *Mactra arcuata*, *M. ovalis (solida)*, *Tellina obliqua*, *T. crassa*, *T. prætenuis*, *Lucina borealis*, *Cardium edule*, *C. angustatum*, *Mytilus edulis*, *Nassa granulata*, *N. reticosa*, *Buccinum undatum*, and var. *tenerum*, *Natica catena*, *N. multipunctata*, *Purpura tetragona*, *P. lapillus*, *Littorina littorea*, *Turritella incrassata*, etc. The Echinodermata include *Echinocyamus pusillus*, etc., the Crustacea, *Balanus crenatus*, and claws of Crab; vertebræ of Fishes also occur.

The total number of species of Mollusca from the Red Crag is about 273; of these 240 are living, and 33 extinct species. Some land-shells of living British and Continental species have been recorded.[4]

It has been noticed by Prof. Prestwich that, as we recede from the centre of the district, the beds become almost devoid of shells, or they occur only in patches. This is due in some cases to original absence, in others to dissolution. The subject

[1] Q. J. xxx. 403; Explan. Sheet 47 (Geol. Surv.), p. 30.
[2] Proc. G. S. iii. 127.
[3] Q. J. xxvii. 325, 350.
[4] R. G. Bell, G. Mag. 1884, p. 262.

of dissolution has been discussed by Mr. W. Whitaker, who has shown how certain apparently eroded surfaces in the Red Crag are due to the dissolving action of carbonated water in permeable beds, appearances formed after the deposition of the upper beds by the dissolving away of the shells that they once contained.[1]

The introduction of the iron-oxide which colours the Crag appears for the most part to be subsequent to the formation of the beds. In some places, Mr. Prestwich observes, the iron-oxide has given rise to large tabular beds of sandstone, and concretionary masses of limonite. Crag at some distance beneath the surface, as proved in well-borings, is usually blue or grey.

In the section at Chillesford the Scrobicularia Crag rests upon the Red Crag (of Butley) and is directly overlaid by the Chillesford Beds. It was this section, first noticed by Prof. Prestwich, which led to the relations of the Norwich (Fluvio-marine) Crag and Red Crag being determined—the former being the equivalent of the higher portion of the latter. (See sequel.) The accompanying section (Fig. 77) shows the general relations of the beds in the neighbourhood of Aldborough.[2]

NORWICH CRAG SERIES.

The term Norwich Crag was introduced by Lyell in 1839.

The beds consist of a variable group of sands, pebbly gravels, and laminated clays, with occasional seams or patches of shells. In Norfolk the beds rest on the Chalk and are exposed on the borders of the valleys of the Bure, Yare, and Waveney, and their tributaries. Near Norwich and in the Bure Valley the thickness is about 30 feet; but at Beccles as much as 128 feet, and at Saxmundham 105 feet of Newer Pliocene strata have been determined.[3]

The following is a general summary of the divisions that may locally be made:—

4. Buff and red false-bedded sand and gravel, formed chiefly of flint-pebbles, with also pebbles of quartz and ironstone nodules. Veins and seams of laminated clay occur, and the gravel is occasionally cemented into a conglomerate or "Iron-pan."[4] [This division has been called the Pebbly Sands and Pebble Beds, and the Bure Valley Beds.]
3. Laminated clay, with seams of sand and gravel; or clay and sand in thin layers rapidly alternating. [This division has been called the Chillesford Clay.]
2. White and brown sand with pebbly gravel and ironstone nodules. [This division, including also No. 1, has been separated into an Upper or Chillesford Crag, and a Lower or Fluvio-marine Crag.]
1. Bed of unworn and rolled flints, called the "Mammaliferous Stone-bed."

In by far the larger number of sections shells are absent; but they most frequently occur in beds 1 and 2, to which the term Norwich Crag has usually

[1] Q. J. xxxiii. 122.
[2] Prestwich, Q. J. xxvii. 339, 342.
[3] Geol. Norwich (Geol. Surv.), pp. 89, 156.
[4] The term Iron-pan is applied to any bed of gravel or sand cemented by iron-oxide.

been restricted. As, however, the beds above noted are all intimately connected, the term Norwich Crag Series may conveniently be applied. The bands of clay (3) have no doubt served in some instances to protect the shells from destruction by percolating waters, for when these occur in the pebbly gravel (4) they are generally in the form of casts.

Mammaliferous Stone-bed.—At the base of the Fluvio-marine Crag there is usually found a bed of unworn and partially rolled flints, termed by Mr. John Gunn the 'Stone bed.' It rests on the Chalk, the surface of which is occasionally bored by *Pholas* and Annelides. This bed yields numerous Mammalian remains, including *Mastodon Arvernensis*,[1] *Elephas meridionalis*, *E. antiquus*, *Hippopotamus major*, *Gazella anglica* (Antelope),[2] *Cervus Suttonensis*, *C. Falconeri*, *Trogontherium Cuvieri*, *Arvicola intermedius*, *Equus caballus fossilis*, *Felis pardoides*, *Hyæna antiqua*, etc. On first thoughts it might strike one that this bed was of the same character as the Suffolk Bone-bed previously described (see p. 459). This is not the case; the bones are not phosphatized, and, although Mr. Whitaker has found one or two coprolites in the base of the Crag at Thorpe near Norwich, these phosphatic nodules are rare. Moreover, the state of preservation of the bones is in favour of their belonging to the period, and not being derived from any earlier deposit. The bones are frequently found on, as well as in, the Stone-bed, and occasionally in the overlying strata. Crag shells, especially *Pecten opercularis*, *Tellina crassa*, *Mytilus edulis*, *Trophon antiquus*, etc., are interspersed with the flints, and occur even in crevices of the Chalk. Hence we are justified in regarding the Stone-bed as the marine basement-bed of the Crag.[3] The bones, like the land and freshwater shells in the Crag, may have been carried into the sea by rivers.

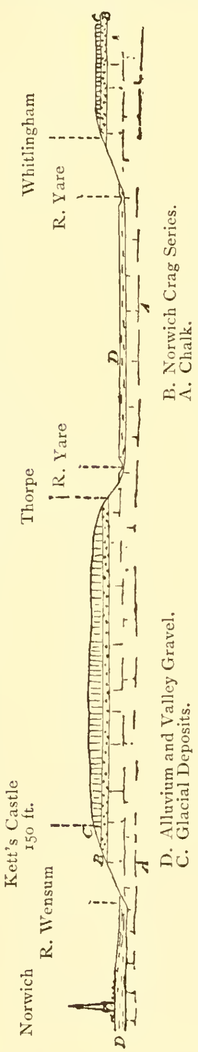


Fig. 78.—Section near Norwich. Distance about three miles.

Fluvio-marine Crag.—The Fluvio-marine Crag, so termed by Lyell, consists of buff shelly sands and shingle, often false-bedded, having a thickness of 5 or 10 feet, and containing an admixture of marine and freshwater Mollusca. The influence of freshets

[1] See Dr. H. Falconer, Q. J. xiii. 307.
[2] E. T. Newton, Q. J. xl. 280; Geol. Norwich, p. 55.
[3] See O. Fisher, G. Mag. 1868, p. 546; F. W. Harmer, Q. J. xxxiii. 139.

is also indicated by the varieties and monstrosities of the specimens of *Littorina* and *Purpura*. The deposit is probably of the same age as the upper part of the Red Crag.

The term Fluvio-marine Crag is by no means a good name, because the higher stages of the Crag are in places fluvio-marine. As Mr. Godwin-Austen remarked, the fluvio-marine portions of the Crag are simply the indications of places where rivers discharged into the sea. Prof. Prestwich speaks of the Norwich Crag as formed in sandy bays, and mentions in support of the inflowing of streams from the north and west, the occurrence in the Crag at Norwich of Lias Ammonites, Carboniferous Limestone Corals, besides many fossils derived from the Chalk.

Among the common fossils are the Mollusca, *Tellina obliqua*, *T. lata* (*calcarea* or *proxima*), *T. prætenuis*, *Cardium edule*, *Mytilus edulis*, *Mactra ovalis*, *M. subtruncata*, *Scrobicularia plana*, *Mya arenaria*, *Littorina littorea*, *Melampus* (*Conovulus*) *pyramidalis*, *Purpura lapillus*, *Trophon scalariformis*, *T. antiquus*, *Turritella terebra* (*communis*), *Cerithium tricinctum* (*punctatum*), *Scalaria Grœnlandica*, *Natica catena*, *N. clausa*, *Paludina media*, *Hydrobia subumbilicata*, etc. A Brachiopod, *Rhynchonella psittacea*, has been occasionally met with. Cirripedes, *Balanus crenatus*, *B. porcatus*, etc., are abundant. Fish-remains also are plentiful; they include *Platax Woodwardi*, *Raia antiqua*, etc. Bones of Birds have also been found, as well as the Mammals previously noted.[1] Jet and Beekite are occasionally met with in the Fluvio-marine Crag.

Dr. J. E. Taylor in 1865 drew attention to the fact that at Bramerton, near Norwich, where two layers of Crag are to be seen, the upper division contains a larger number of shells of a northern or arctic character than the lower one, which contains a larger number of littoral shells; and this Upper Crag (or 'Taylor's Bed') was identified by Messrs. Wood with the Chillesford shell-bed above the Red Crag at Chillesford.[2] The divisions, however, are of very local value, for even at Bramerton they are only separated by a few feet of false-bedded sand, which contains shells sparingly; and there the so-called Chillesford Clay is a very insignificant deposit. In the pit at Bramerton the following beds are seen resting upon the Chalk:—

			Feet
Norwich Crag Series.	Bure Valley Beds.	Sand and gravel	4
	Chillesford Beds.	Chillesford Clay	1
		Chillesford Sand with Shell-bed	5
	Fluvio-marine Crag.	Sand with few shells	12
		Fluvio-marine Crag	5
		Stone-bed.	1

The Fluvio-marine Crag yields the species previously enumerated; the 'Chillesford' shell-bed yields more abundantly *Astarte borealis*, *A. compressa*, *Corbula striata*, *Cyprina Islandica*, *Leda oblongoides*, *Lucina*

[1] Geol. Norwich (Geol. Survey), p. 41; S. Woodward, Outline of the Geology of Norfolk, 1833; Lyell, Proc. G. S. iii. 127.

[2] Taylor, G. Mag. 1871, p. 314; Geol. Norwich, p. 82; see also R. C. Taylor, T. G. S. (2) i. 372, plate 47.

borealis, *Buccinum undatum*, var. *tenerum*, etc., all of which are found in the lower bed.

The upper bed at Bramerton has been correlated by Messrs. Wood and Harmer with the seam of shells at Brundall, and with the Crag at Aldeby, Horstead, and Burgh near Aylsham.

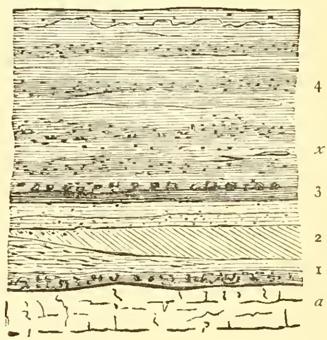
Bramerton has always been the chief collecting ground in the Norwich Crag. Sowerby's specimens were nearly all obtained from this locality ; so also were those enumerated by Mr. S. V. Wood in his "Crag Mollusca." *Tellina Balthica* therein recorded by him has been subsequently regarded as erroneous : it has never been met with by Mr. James Reeve during his exhaustive examination of the beds. To Mr. Reeve indeed we are mainly indebted for our present knowledge of the Bramerton Crag fauna.[1]

An excellent section of the Norwich Crag Series is exposed at Thorpe, near Norwich, and here, although some divisions can be indicated, there is no conspicuous bed of Chillesford Clay, and no distinction between Fluvio-marine Crag and 'Chillesford shell-bed.'

FIG. 79.—CRAG-PIT AT THORPE, NEAR NORWICH.
(Prof. J. Prestwich.)

4. Ochreous flint-shingle and sand, with a layer of iron-sandstone at *x* containing casts of Mollusca. Deer's horn. 20 feet.
3. Grey clay. 1 to 1½ feet.
2. White and buff sands with seams of gravel and patches of shells largely comminuted. 5 to 12 feet.
1. Stone-bed made up of unrolled and little-worn flints, with Mammalian remains, etc. 1 foot.

a. Chalk with flints.



The top bed (4) has yielded *Nucula Cobboldiæ*, *Tellina obliqua*, etc.[2] The beds are numbered according to the series of strata noted previously (p. 463).

The Fluvio-marine Crag beds are shown also at Whitlingham, Arminghall, and at Postwick near Norwich, at Bulchamp, Wangford (10 feet), Yarn Hill, near Potters Bridge, Southwold, Dunwich, and Thorpe near Aldborough in Suffolk ; they have also been exposed at Ditchingham near Bungay. At Whitlingham three distinct layers of shells have at times been exposed, and there it is impossible to distinguish the local divisions that are indicated in the section at Bramerton. (See Fig. 80.)

Chillesford Beds.—The Chillesford Beds were so named from Chillesford near Orford, in Suffolk, where the beds were described

[1] Proc. Norwich Geol. Soc. i. 69, 110.
[2] Geol. Norwich, p. 75 ; Prestwich, G. Mag. 1870, p. 539, Q. J. xxvii. 469.

by Prof. Prestwich in 1849.[1] They have been subdivided by Mr. Wood, jun., as follows:—

2. Chillesford Clay.
1. Chillesford Sand with Shell-bed.

The Chillesford Sand consists of micaceous sand with a shelly bed (not constant); this passes upwards into a bed of laminated micaceous clay, the Chillesford Clay. The entire thickness is from 20 to 25 feet.

At Chillesford the sands have yielded *Cardium Grœnlandicum*, *Cyprina Islandica*, *Leda oblongoides*, *Nucula tenuis*, and *Tellina lata*. From other localities the strata correlated with the Chillesford Beds have yielded also *Astarte borealis*, *Tellina obliqua*, *T. prætenuis*, *Cardium edule*, *Cyprina Islandica*, *Lucina borealis*, *Nucula Cobboldiæ*, *Mactra ovalis*, *Mya truncata* (= Mya bed of the Rev. O. Fisher), *Purpura crispata*, *Littorina littorea*, etc.

Mr. Wood observes that the Chillesford Clay varies from a dark blue tenacious laminated clay to a loamy micaceous sand, more or less interbedded with seams of laminated clay. At Chillesford the clay contains impressions of shells, and it has yielded remains of a Whale; at Easton Bavent a number of Mollusca, and one impression of a Leaf, have been obtained by Prof. Prestwich from the clay.

The section at Chillesford is as follows:—

		Feet
Chillesford Beds	Chillesford Clay............	8
	Chillesford Sand with Shell-bed ...	8
Red Crag	Scrobicularia Crag	10
	Red Crag	10

The upper shell-bed at Bramerton and the Chillesford Beds, according to Mr. Wood, are marine; while at Easton Bavent, Burgh Kiln (near Aylsham), Coltishall, Horstead, Aldeby (Toft Monks), the portions of the Norwich Crag Series which he correlates with the Chillesford Beds are fluvio-marine in character. The fossiliferous bed at Aldeby (Aldeby Beds) was first brought into notice by Mr. C. B. Rose in 1865, who identified it as Norwich Crag. It is, however, almost entirely owing to the labours of Messrs. W. M. Crowfoot and E. T. Dowson that its fauna is known to us.[2]

Beds of Clay, regarded as equivalent to the Chillesford Clay, occur at Mells Wood, near Halesworth, and at Withersdale Cross, near Harleston. At Aldeby, Surlingham, Hartford Bridges, near Norwich, South Walsham, Hoveton (near Wroxham Railway Station), Coltishall, and Ludham, there are good "jambs" of laminated clay,[3] from 3 to 18 feet in thickness; and any one who visited these

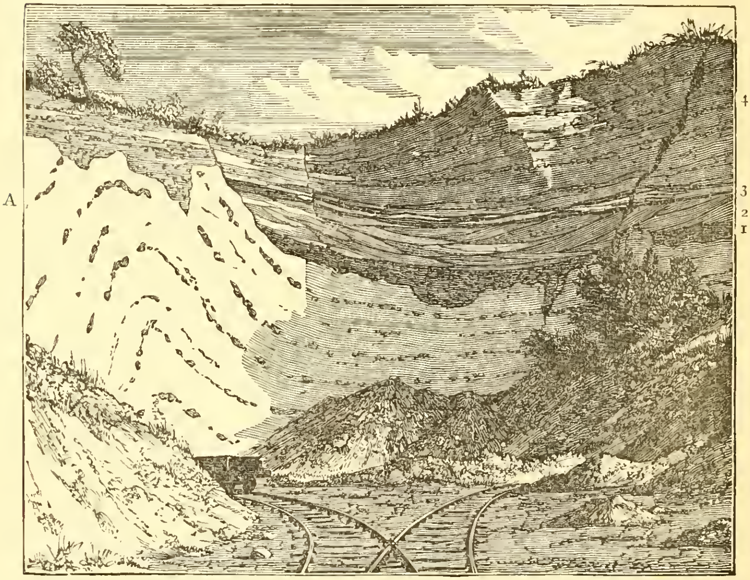
[1] Prestwich, Q. J. v. 345, Q. J. xxvii. 337. See also O. Fisher, Q. J. xxii. 19; Wood and Harmer, Introd. to Supp. to Crag Mollusca, 1872, p. viii. See also Rev. W. B. Clarke, T. G. S. (2), v. 359.

[2] Proc. Norwich Geol. Soc. i. 24, 81.

[3] The term "jam" or "jamb" is applied to any impersistent, and generally lenticular mass of clay, marl, or brickearth—it is a bed "jammed between other strata."

localities in succession would be convinced that the Chillesford Clay was a well-marked horizon in Norfolk. But if he endeavoured to trace out these clays on the ground, noticing the intermediate sections, and the behaviour of the clays themselves, he would become convinced that, while such laminated clays are *characteristic* of the Pliocene beds of Norfolk, they are not confined to one horizon, they were not all deposited at one particular time, and their absence is not necessarily the result of denudation. The sections at Coltishall and Hartford Bridges demonstrate that these clays are intimately connected by false-bedding with the pebbly gravels (Bure Valley Beds) that often overlie them, and that they pass occasionally by interbedding in their horizontal extension into sand and gravel. In some sections we find two or more bands of clay, any one of

FIG. 80.—CHALK-PIT AT WHITLINGHAM, NEAR NORWICH.



4. Pebbly gravel and sand, with seam of shells.
3. Laminated clay (impersistent), and shelly seam.
2. False-bedded sand and gravel, with shells.
1. Stone bed.
} Norwich Crag Series. 15 to 20 feet.

A. Chalk with flints.

which might on lithological grounds be termed the Chillesford Clay. Hence but little dependence can be placed on the particular correlation of beds by means of laminated clay-bands, for similar beds occur also in the Cromer Forest Bed Series: indeed, the name Laminated Series has been applied by Mr. Gunn to the Pliocene strata of Norfolk.

When we come to study the shells in the several beds of Crag, even those acknowledged to be on the same horizon, we find that they vary not only in the abundance of particular forms, but also in the number of different species, indicating perhaps slightly varying depths of water or diversities in the sea-bed, that influenced their distribution. At Brundall Station *Nucula Cobboldiæ* is very abundant. At Brundall Church, a bed distinctly on the same horizon, this shell is rare, and *Cyprina Islandica* is met with in profusion in entire shells. At

Blake's pit, Bramerton, *Scrobicularia plana* is abundant, while it is exceedingly rare in the adjoining pit on the Common. *Calyptræa Chinensis* and *Loripes divaricatus* are abundant in a lane-cutting close by, in Kirby Bedon parish, and not nearly so common in either of the pits at Bramerton. At Arminghall *Mactra ovalis* is so abundant that Mr. J. E. Taylor well observed that the deposit might be called the *Mactra*-bed. In one pit at Wroxham *Astarte borealis* is particularly common, *Tellina Balthica* is very rare; while at Belaugh the reverse is the case. The fact is, that not only sands, gravels, and clays, but also shell-beds were forming at one and the same time in different areas throughout the history of the Norwich Crag; and that there was an uninterrupted succession of life and shell-deposits, however locally they may be preserved. Hence it is not possible to correlate local and minor subdivisions in different places.

Bure Valley Beds.—These Beds, so named by Mr. Wood in 1866, comprise most of the pebbly sands and gravels that overlie the Chalk and underlie the Lower Glacial Brickearth (Contorted Drift, etc.), in the valley of the river Bure, in Norfolk. They are characterized by *Tellina Balthica* (*solidula*), and, chiefly on account of the presence of this shell, the Bure Valley Beds were separated from the Norwich Crag by Messrs. Wood and Harmer, and grouped by them as Lower Glacial.[1] The typical Bure Valley Beds were described by them at Belaugh, Wroxham, Crostwick, etc.; and only at Horstead, Coltishall, and Burgh-next-Aylsham were fossiliferous sections of any lower portion of the Norwich Crag Series (Chillesford Beds) recognized, by these authorities, in the Bure Valley. There is, however, rarely any satisfactory separating line between the so-called Bure Valley Beds and the Norwich Crag, and they are best united under the more comprehensive name of the Norwich Crag Series.

The term Mundesley and Westleton Beds has been applied by Prof. Prestwich to beds of the age of the Bure Valley Beds, but the Mundesley Beds occur on top of the Cromer Forest Bed Series, and the Westleton Beds (of Westleton) belong to the Glacial Series.[2] (See sequel.)

When Messrs. Wood and Harmer separated the pebbly gravels in which *Tellina Balthica* occurs from the Norwich Crag, it was believed that this shell was confined to Glacial and Recent deposits. In 1876, however, Mr. John Gunn and Mr. A. C. Savin obtained many specimens in the estuarine part of the Cromer Forest Bed Series, and Mr. Clement Reid subsequently traced the Weybourn Crag (also grouped as Lower Glacial by Messrs. Wood and Harmer) beneath that series.[3] *Tellina Balthica* may thus be said to characterize the upper zone of the Norwich Crag Series, and its introduction may have followed the gradual encroachment of the Crag sea further and further northward, and be due to submergence which opened up connexion with a previously distinct marine area.

The Bure Valley Beds contain *Astarte borealis*, *A. compressa*, *Cardium edule*, *Mya arenaria*, *Tellina obliqua*, *Littorina littorea*, *Purpura lapillus*, etc.; and with the exception of *Tellina Balthica*, all the marine Mollusca found in it occur in the lower stages of the Norwich Crag.

Weybourn Crag.—At Weybourn the Crag beds (Weybourn Sands

[1] Q. J. xxii. 547; G. Mag. 1869, p 232, 1870, p. 20.

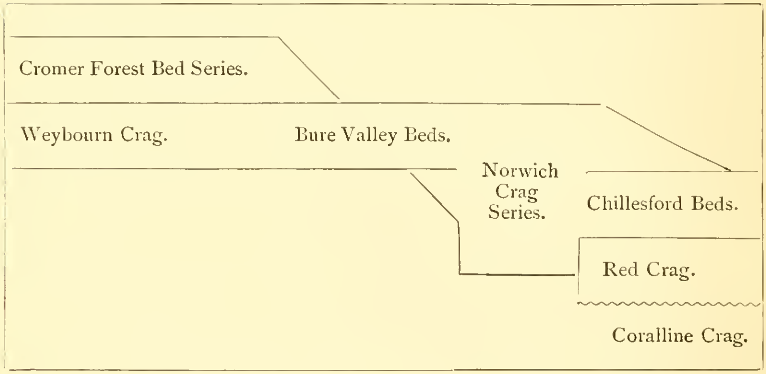
[2] G. Mag. 1882, p. 452; Prestwich, Q. J. xxvii. 461, G. Mag. 1881, p. 466, 1882, p. 29.

[3] Proc. Norwich Geol. Soc. i. 50; J. H. Blake, *Ibid.* 141; C. Reid, G. Mag. 1877, p. 301.

of Lyell) consist of sand and laminated clay, with Stone-bed at the base, altogether about 10 feet thick. They rest on the Chalk, and have been traced to Lower Sherringham and Runton, eastwards of which they occur for some distance at or beneath the sea-level. The beds reappear at Trimingham, and they have been observed inland at Honing, besides at the localities previously mentioned.[1] (See Fig. 81.)

Ironstone nodules, consisting of a hard shell of iron-sandstone with a nucleus of clay iron-ore or ochre, abound in the Norwich Crag Series. They may have originated from the segregation of iron-oxide around clay balls or clay "pebbles," which are often present in the series, and from which to the ironstone nodules gradations in structure may be traced.[2] (See p. 433.)

The accompanying diagram is intended to show the general relations of the Norwich Crag Series to the Red Crag and to the Cromer Forest Bed Series:—



CROMER FOREST BED SERIES.

This Series, so noted for the Mammalian remains which it has yielded, occurs along the base of the cliffs and fore-shore between Weybourn in Norfolk and Kessingland in Suffolk, although it is not persistently exposed for the entire distance, and is indeed usually much obscured by recent accumulations. It occurs below the Glacial Drift and above the Weybourn Crag; but no sections of the beds have been observed inland. It comprises beds of sand and gravel, laminated clays and peaty beds, attaining a thickness of from 20 to 30 feet.

[1] C. Reid, Geol. Cromer (Geol. Survey), p. 11; see also Geol. Fakenham, p. 11; and Lyell, Phil. Mag. (3), xvi. 361.
[2] P. Geol. Assoc. v. 514.

To the indefatigable researches of Mr. John Gunn (whose collection is placed in the Norwich Museum), and to collections made by the Rev. James Layton, the Rev. S. W. King (in the Museum at Jermyn Street), Mr. Randall Johnson, Mr. James Backhouse, and others, we chiefly owe our knowledge of the larger Mammalia; while to the detailed observations of Mr. Clement Reid,[1] on the coast section between Weybourn and Eccles, and to those of Mr. J. H. Blake,[2] southwards to Kessingland, we most largely owe our present knowledge of the strata. Previous labourers, like R. C. Taylor,[3] the Rev. C. Green,[4] Lyell,[5] Prof. Prestwich[6] and others, have all furnished many important facts; while Mr. Reid and Mr. A. C. Savin have collected with great care the smaller fossils in which these strata are remarkably rich. The vertebrate remains have been described by Mr. E. T. Newton, Prof. W. Boyd Dawkins, and Dr. A. Leith Adams.[7]

The following divisions of the Cromer Forest-bed Series on the Norfolk coast have been determined by Mr. Clement Reid:—

Arctic Freshwater Bed (Glacial).
Leda-myalis Bed.
Upper Freshwater Bed. }
Forest-bed (Estuarine). } Forest-bed Series.
Lower Freshwater Bed. }
Weybourn Crag. (See p. 469.)

The estuarine deposits of the Forest-bed were accumulated when the physical conditions allowed an extension of what is now the Rhine over the area of the German Ocean, and parts of east Norfolk.[8]

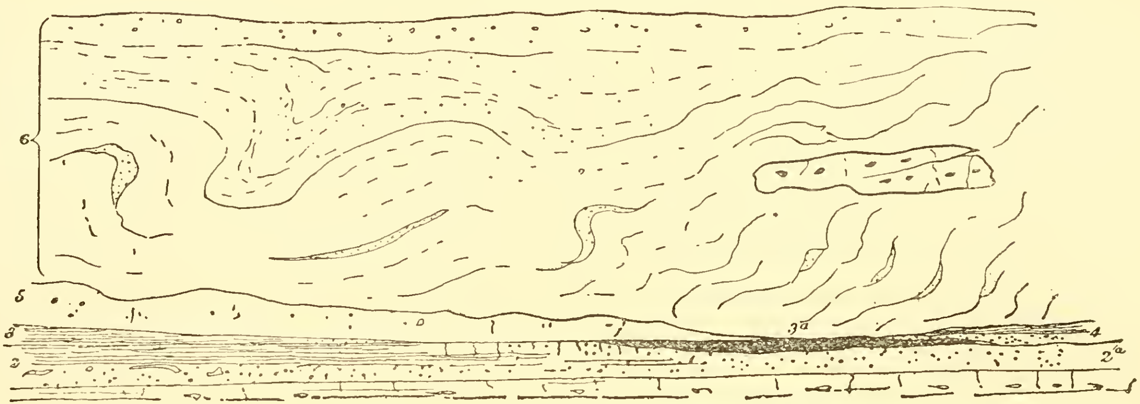
Lower Freshwater Bed.—This bed consists of green carbonaceous silt and loam with lignite, about 2 feet thick; it has been observed resting on the Weybourn Crag (Bure Valley Beds) near Trimingham; it is seldom preserved, though its Flora is known from derivative masses of peat and clay-ironstone found in the Estuarine Beds. It contains *Chara*, *Trapa natans*, *Menyanthes trifoliata*, etc.

Forest-bed (*Estuarine*).—This division consists of sand and gravel, sometimes cemented into an Iron-pan (Elephant-bed of Mr. Gunn), and lenticular beds of laminated clay with seams of gravel and sand (Laminated Beds of Mr. Gunn);[9] the beds are frequently false-bedded. The gravel is composed of flints, worn and unworn, together with pebbles of quartz, quartzite, etc., clay-ironstone, and rolled lumps of clay. It attains in places a thickness of 15 feet, but is usually much less.

Considerable discussion has taken place on the subject of the stumps of trees embedded in the Forest Bed. Attention was first

[1] Geol. Cromer (Geol. Survey), p. 10; and Horizontal Section, Sheet 127.
[2] Horizontal Section, Sheet 128 (Geol. Survey), with Explanation, 1884.
[3] Phil. Mag. lx. 132, lxiii. 81.
[4] History, etc., of Bacton, 1842.
[5] Phil. Mag. (3), xvi. 345.
[6] Q. J. xxvii. 452. See also S. V. Wood, jun., and F. W. Harmer, Introd. to Supp. Crag Mollusca, 1872; O. Fisher, G. Mag. 1868, p. 544.
[7] Newton, Vertebrata of the Forest Bed Series (Geol. Surv.), 1882; Dawkins, Q. J. xxviii. 405; Adams, Fossil Elephants, Palæontogr. Soc.
[8] J. Gunn, G. Mag. 1867, p. 158; C. Reid, Geol. Cromer, p. 57.
[9] Geol. Norfolk (White's History, etc.), 1883.

FIG. 81.—DIAGRAM-SECTION NEAR CROMER.[1]



6. Gravel and Sand (Middle Glacial) resting on Contorted Drift (loam, sand, and marl, with large included boulders of Chalk).
5. Cromer Till.
} Glacial Drift.

4. Laminated Clay and Sands (*Leda-myalis* Bed).
3. Freshwater Loams and Sands; 3*a*. Black Freshwater Bed of Runton. (Upper Freshwater Bed.)
2. Forest Bed—Laminated Clays and Sands, with Roots and débris of Wood, Bones of Mammalia, Estuarine Mollusca, etc.: the upper part in places penetrated by rootlets (Rootlet-bed).
} Newer Pliocene Series.

2*a*. Weybourn Crag.
1. Chalk with Flints.

[1] See also Lyell, Antiq. of Man, ed. 4, p. 255.

directed by Mr. Henry Norton [1] to the uncertainty of the evidence brought forward by R. C. Taylor, Lyell, and others. Mr. Reid has since pointed out that where these tree-stumps are embedded in clay the clay is well laminated, and unweathered, which would not be the case had it formed an old soil; the stumps do not exhibit the smaller fibres of the roots, but are broken off and rounded or frayed; moreover, they occur in various positions, being sometimes upside down. It therefore appears that the stumps have probably been derived from the wasting of river banks on which the trees grew, and that, although they belong to the period of the Forest Bed, they are not rooted on the spots where they lived. The beds in which they occur contain occasional Mammalian remains, also *Mya truncata*, *Tellina Balthica*, *Cardium edule*, Fish-remains, etc. The Mammalian remains include *Elephas antiquus*, *E. meridionalis*, *E. primigenius* var.[2] (rare), *Hippopotamus amphibius*, *Rhinoceros Etruscus*, *Trogontherium Cuvieri*, *Equus caballus fossilis*, *Cervus Sedgwickii*, *C. bovides*, *C. verticornis*, *Hyæna crocuta* var. *spelæa*, *Machærodus*, *Ursus ferox* (*spelæus*), *Gulo luscus* (Glutton), *Physeter macrocephalus* (Sperm Whale),[3] etc. Specimens are not readily to be found except after certain tides have cleared away the recent accumulations on the foreshore, near Runton, Overstrand, Sidestrand, and other places.

Upper Freshwater Bed.—The upper surface of the Estuarine beds is in places weathered into a soil and penetrated by small roots; hence the name Rootlet Bed has been applied to it.[4] (See sequel.) Laminated loamy and peaty sands and carbonaceous clay occur in places, and attain a thickness of about 5 feet. The beds yield *Anodonta cygnæa*, *Unio pictorum*, *Pisidium amnicum*, *P. astartoides*, *Corbicula fluminalis*, species of Slugs (*Limax*), also *Helix*, *Planorbis*, *Valvata*, etc. A number of (*Limax*), Fishes have been obtained; likewise the Newt *Triton cristatus*, the Frog *Rana*, the Viper *Pelias berus*, and the common Snake *Tropidonotus natrix*. The Mammals include *Myogale moschata*, *Arvicola intermedius*, *Trogontherium Cuvieri*, *Castor Europæus*, *Ursus ferox*, *Rhinoceros Etruscus*, etc. Many Plant-remains have been obtained by Mr. Reid, including *Nuphar lutea*, *Ceratophyllum demersum*, *Rumex maritimus*, *Alnus glutinosa*, *Potamogeton*, *Scirpus*, *Pinus sylvestris*, *P. abies*, Elm, Beech, Oak, etc.[5] Of these and other Plants at present determined from the Forest Bed Series, only one species (*Trapa natans*) has disappeared from the British Islands. (See Fig. 81.)

Leda-myalis Bed.—This bed appears to have been recognized by

[1] Paper read before Norwich Geol. Soc. and reprinted from Norwich Mercury, May 5, 1877; C. Reid, Geol. Cromer, p. 22; T. M. Reade, G. Mag. 1883, p. 221.
[2] Gunn, G. Mag. 1883, p. 456.
[3] E. T. Newton, G. Mag. 1883, p. 433; Q. J. xlii. 316.
[4] Prestwich, Q. J. xxvii. 463; Gunn, Q. J. xxxii. 124; J. H. Blake, Proc. Norwich Geol. Soc. i. 146.
[5] Trans. Norf. Nat. Soc. iv. 189. See also W. Carruthers, Address Biological Sec. Brit. Assoc. 1866, and Q. J. xxvi. 349.

Prof. W. King in 1863, and he applied the term *Leda-myalis* Clay.[1] As described by Mr. Reid, the bed is a fine false-bedded loamy sand, with grains of chalk, thin seams of loam or clay, and a little gravel: together from 10 to 15 feet thick. Fossils are not as a rule abundant, but about a quarter of a mile west of Lower Sherringham an Oyster-bed with *O. edulis* has been noticed, while at West Runton a Mya-bed with *M. truncata*, was described by Joshua Trimmer in 1845.[2] The term Mya-bed is inappropriate as a general designation, for the same species occurs in the position of life, at a lower horizon on this coast, in the Estuarine beds (Forest-bed). At West Runton, *Leda myalis*, *Astarte borealis*, *Tellina Balthica*, and other species occur; but the bed is rarely exposed owing to débris from the cliffs.

This fossiliferous bed was at one time grouped with the Weybourn Crag (Bure Valley Beds), and it has even been termed Norwich Crag, a mistake which led to the Forest Bed being regarded by some observers as beneath that formation.[3] The Mundesley Beds of Prof. Prestwich belong in part to this horizon, and in part to the estuarine 'Forest-bed,' divisions which, Mr. Reid observes, are not always to be clearly distinguished at Mundesley. (See p. 469.)

Arctic Freshwater Bed.—Above the *Leda-myalis* bed there has been traced in places, below the Glacial Drift, a stiff blue clay and loam, with sand and gravel, 1 to 4 feet thick, in which, at Mundesley, Dr. A. Nathorst in 1872 discovered remains of *Hypnum turgescens* and *Salix polaris*. Mr. Reid has since traced the bed at Beeston, and at Ostend, near Bacton, and has obtained other Plant-remains, *Betula nana*, and *Hippuris vulgaris*; also elytra of Beetles, Land Mollusca, and remains of *Spermophilus*. He terms this the Arctic Freshwater Bed, and observes that the fauna and flora show the first incoming of arctic *land* species. The bed is properly included with the Glacial Deposits.[4]

On the Kessingland and Corton coast the beds beneath the Glacial Drift are thus divided by Mr. J. H. Blake:[5]—

	Pebbly sand, etc.
Forest Bed and Chillesford Series.	Rootlet-bed.
	Laminated clay and sand.
	Gravel and sand, with Mammalian remains.

The lowest beds of gravel and sand contain Mammalian remains which link the beds with the estuarine 'Forest Bed' of the Cromer coast, but Mr. Blake is disposed to group them with the Norwich Crag. The overlying laminated beds he classes with the Chillesford Clay; they are intimately associated with the underlying strata, and merge upwards and horizontally into the Rootlet-bed. The Rootlet-bed is simply a root-indented stratum, although it presents evidence, as Mr. Blake remarks, of an old terrestrial surface: and he would regard it as the true Forest Bed; it consists chiefly of greenish-grey unstratified clay, and contains

[1] Geologist, vi. 160.
[2] Proc. G. S. iv. 435; Q. J. xiv. 171.
[3] G. Mag. 1882, p. 454; Reid, Geol. Cromer, p. 46.
[4] Geol. Cromer, p. 83.
[5] Explanation of Horizontal Section, Sheet 128 (Geol. Survey); G. Mag. 1877, p. 298; Proc. Norwich Geol. Soc. i. 137.

many Mammalian remains. Associated with this Rootlet-bed is a *Unio*-bed, with *U. pictorum*, etc., which serves to link the strata with the Upper Freshwater Bed of Runton near Cromer. Much black peat overlies the Rootlet-bed at Corton and also at Kessingland. The rootlets were first noticed at Corton by Mr. S. R. Pattison,[1] and they have subsequently attracted much attention; they possibly belong to Fir trees. The age of the Pebbly Sand is doubtful: it may represent the *Leda-myalis* bed of Runton, or it may possibly belong to the Glacial Series. The precise correlation of the other divisions is a subject on which considerable difference of opinion exists, especially in reference to the identification of the Chillesford Clay. It would probably be safer, as well as simpler, to use the term Forest Bed Series alone for the divisions above noted.

QUATERNARY.

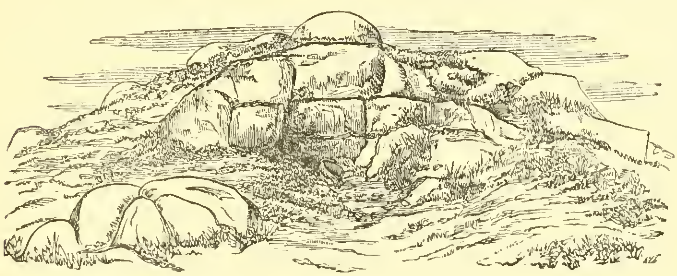


FIG. 82.—ROCHES MOUTONNÉES [Millstone Grit], GWERN-CEFN-Y-GARREG, NEAR YSTRAD-FELLTE, IN BRECKNOCKSHIRE.
(J. W. E. David.)

The accumulations of Post-Tertiary or Post-Pliocene age in England and Wales have a wide range, possess varied characters, and occupy irregular positions; whereas the earlier strata present comparatively uniform characters, and occur in more definite positions. We have to consider many deposits due to diverse agents, not only Marine and Estuarine and Freshwater; but we have accumulations formed on land at various levels, on mountain and in vale, some due to Glacial action, others to Chemical erosion, while some again are purely Organic, and a few have been drifted by Wind. Broadly speaking, the deposits may be grouped together as belonging to one epoch, still in progress; the difficulty is to correlate in point of time the minor and local divisions, which, although the product of many distinct agents, may yet have been in course of formation at the same time. We have, in short, to discuss all the records of one period of geological time; whereas in dealing with previous formations, we find for the most

[1] S. R. Pattison, Geologist, vi. 207; Prestwich, Q. J. xxvii. 463; J. Gunn, Q. J. xxxii. 123; Harmer, Q. J. xxxiii. 134.

part records only of particular physical conditions, chiefly Marine or Estuarine, the Freshwater, and the more purely Terrestrial deposits being less frequently preserved. Hence the study of these newer deposits is in many respects more complex than that of the earlier formations.

In seeking a divisional line between Tertiary and Quaternary, we enter, it is true, debateable ground; for in the Eastern counties there is a sequence of deposits from the Newer Pliocene (Forest Bed Series) to the earliest Quaternary strata (Glacial Beds); and many geologists object to the use of the term Quaternary as unnecessary, for it suggests a great division among strata, which neither in thickness nor in life-history can compare with the divisions of Primary and Secondary. Nevertheless, the term Quaternary (introduced by A. Morlot in 1854)[1] is largely adopted in Europe and America; it is convenient to distinguish deposits that on the whole were formed under different physical conditions from the Tertiary strata, and that as a rule lie scattered with marked unconformity over the denuded surfaces of the Tertiary and older formations, from one end of the country to the other. Moreover, the term Quaternary is convenient in marking the period during which Man existed in this country, from that in which no traces of his presence have been found.[2] The occurrence of Man, indeed, renders this epoch of Geological history of especial interest.

In the early days of Geology the Quaternary deposits were broadly divided into Diluvium and Alluvium. The former term is now but little used, from the fact of its implying that the deposits were mainly produced by extensive floods, and from the tendency to associate them with the notion of a Universal Deluge.[3] The term Drift, used by Lyell in 1840 as a substitute for Diluvium, is now applied generally to the Quaternary deposits, which consist for the most part of gravel and sand, loam or brickearth, and clay: it naturally refers to strata laid down at some distance from the rocks, to whose destruction they are largely due; but although applied to River deposits, the word Drift is more appropriately used in reference to the accumulations of the Glacial period.

The occurrence of stones and boulders far removed from their parent source early attracted the attention of geologists, but for a long period the phenomena, now known as of Glacial origin, were unexplained, and the Drifts were looked upon as little more than "extraneous rubbish," the product of geological agents quite distinct from those which helped to form the more 'solid' rocks that underlie them. Inasmuch as, in certain places, they rival in thickness some earlier geological formations, and as taken collectively, they have a more direct influence on Agriculture than any other strata, their importance may readily be conceded. The interest now taken in these superficial deposits was mainly aroused

[1] Bull. Soc. Vaudoise des Sc. Nat. iv. 41.
[2] See Prestwich, G. Mag. 1870, p. 131.
[3] See Buckland, Reliquiæ Diluvianæ; H. H. Howorth, G. Mag. 1882, p. 266.

by Joshua Trimmer,[1] who commenced to map the Drifts on the One-inch Ordnance Map; and he was followed by Mr. S. V. Wood, jun., to whose enthusiastic labours we are most largely indebted for the foundation of our knowledge on this subject. It is, however, impossible to indicate with accuracy the distribution of the Drifts, on a map smaller than the One-inch Geological Survey Map; and with the exception of the Alluvial marshes, they occupy a comparatively insignificant part in the scenery of our country, for the main features were marked out before the Drifts were accumulated.

That the Pliocene period was followed by one of intense cold has been previously indicated (see p. 456). This Glacial period was itself characterized by considerable physical changes and fluctuations in climate, and during the milder intervals certain large Mammalia inhabited this country, including many forms that do not belong to our present fauna or to that which survived to Modern times. Thus the Quaternary era has been divided as follows:—

Recent.
Pleistocene.

The PLEISTOCENE period, so named by Lyell in 1830, includes Terrestrial, Alluvial, Estuarine, Marine, and Glacial accumulations; and the organic remains found in certain Caverns and River-deposits, being associated with relics of Palæolithic Man, these deposits are sometimes regarded as of Palæolithic age.

The Pleistocene Beds are characterized by remains of the Musk Sheep (*Ovibos moschatus*), Bison (*B. priscus*), *Hippopotamus* (*H. major* or *amphibius*), the straight-tusked or early Elephant (*Elephas antiquus*), and the Mammoth (*E. primigenius*), the Woolly Rhinoceros (*R. tichorhinus*), and the small-nosed species (*R. leptorhinus*), the Grisly Bear (*Ursus ferox*), Glutton (*Gulo luscus*), Lynx (*Felis lynx*), Cave Lion (*Felis leo* var. *spelæa*), Leopard (*Felis pardus*), Cave Hyæna (*H. crocuta* var. *spelæa*), sabre-toothed Lion (*Machærodus latidens*), pouched Marmot (*Spermophilus citillus*), and Norwegian Lemming (*Myodes lemmus*). None of these species lived on to Recent times in this country; but the Pleistocene deposits contain also some forms which, if they were driven out of this country, returned in the Recent period, and many of which still exist in England. These include the Horse (*Equus caballus*), the Urus (*Bos primigenius*), Roe Deer (*Cervus capreolus*), Red Deer (*C. elaphus*), Reindeer (*C. tarandus*), Irish Elk (*C. megaceros* or *Megaceros Hibernicus*), Wild Boar (*Sus scrofa*), Brown Bear (*Ursus arctos*), Fox (*Canis vulpes*), Wolf (*C. lupus*), Wild Cat (*Felis catus*), Otter (*Lutra vulgaris*), Badger (*Meles taxus*), Stoat (*Mustela erminea*), Marten (*Mustela martes*), Weasel (*M. putorius*), Hare (*Lepus timidus*), Rabbit (*L. cuniculus*), Beaver (*Castor fiber*), and the Mole (*Talpa Europæa*).[2] These Mammalia include forms whose modern representatives

[1] Q. J. vii. 37.
[2] Fossil bones usually adhere to the tongue owing to their loss of animal gluten; for the preservation of such remains glue is recommended for larger bones, and gelatine for smaller ones. W. Davies, G. Mag. 1865, p. 239.

exist under diverse climatal conditions: but while the Hippopotamus and the Musk Sheep, for instance, are found in the same deposits, their remains may have been entombed at different times and reassorted by river-action, or on the other hand the rivers may have commingled the remains of animals that occupied distinct areas. (See sequel.)[1] The Mollusca are all of existing species, although the *Corbicula* (*Cyrena*) *fluminalis* is now extinct in Europe (Sicily excepted), and *Unio littoralis* is no longer living in Britain.

The RECENT period, so named by Lyell in 1839, includes Terrestrial, Alluvial, Estuarine, and Marine deposits of Modern Age, that contain relics of Neolithic Man, as well as relics of subsequent periods up to the present day.[2]

The Recent deposits are characterized by the presence of domestic as well as wild animals, including the Celtic short-horn *Bos longifrons*, the Goat (*Capra hircus*), the Sheep (*Ovis aries*), Dog (*Canis familiaris*), etc.; and they contain also the Moose (*Cervus alces*), Shrew (*Sorex vulgaris*), Vole (*Arvicola amphibius*), and other species previously mentioned as survivors from Pleistocene times.[3] The Mollusca are all living British species.[4]

From the occurrence of works of Man in Pleistocene deposits, the investigations of the Geologist are now merged with those of the Archæologist, and it becomes necessary to indicate the divisions of time marked out by the researches into the Antiquity of Man.

In speaking of the Stone Age, the Bronze Age, and the Iron Age, Archæologists indicate phases in the civilization of Western Europe. Thus the implements and weapons of Stone have been shown to have preceded those of Bronze, which again are types of an earlier stage than those of Iron.

The Stone age is characterized by works made chiefly of flint, but also of chert, quartzite, felstone, etc., and these indicate two periods termed the Neolithic or Newer Stone, and the Palæolithic or Older Stone period. The implements of the newer type are generally well-shaped and finely-chipped or polished; those of the Palæolithic type are more rudely chipped; the latter are sometimes formed from flint obtained directly from the Chalk, at others from gravel-flints, pebbles of quartzite, etc. There is in this country no transition or connecting link between the Palæolithic and Neolithic

[1] See J. Geikie, Great Ice Age, ed. 2. p. 508.

[2] The term Post-Glacial (used by John Phillips in 1853) is sometimes employed for deposits posterior in age to the principal Glacial beds, and anterior to the Modern Alluvium, etc. In that respect it is a vague and ill-defined term, for strictly speaking it is synonymous with Recent; but it is sometimes used more or less locally for beds newer than the Glacial Drift of the district. The term Modern was used by De la Beche for deposits now in progress.

[3] W. B. Dawkins, Q. J. xxv. 194, xxviii. 410, xxxvi. 398, 401, and Early Man in Britain, 1880; Dawkins and W. A. Sanford, Pleistocene Mammalia (Palæontograph. Soc.); A. L. Adams, Fossil Elephants (*Ibid.*).

[4] See Edward Forbes on the Connexion between the Distribution of the existing Fauna and Flora of the British Isles, and the Geological Changes, etc., Mem. Geol. Survey, i. 336; Rev. J. Crombie, Alpine flora of Great Britain, Geol. Assoc. (separately printed).

types, but the latter is intimately connected with the Bronze and Iron periods; the gap between the two is indicated by great physical changes, and by differences in the associated animals.[1] These changes drove away the Pleistocene fauna associated with Palæolithic Man; and when he returned again to this country, he had attained a higher stage of culture, and was associated with the Recent fauna. It must, however, be borne in mind that the term Neolithic is used to represent a phase of culture which different races reach and pass, and to which a different relative position in time must be assigned in various parts of the world.[2]

The word Palæolithic (or Archæolithic) was first introduced by Sir John Lubbock in 1865: and the stone implements (hatchets, adzes, or chisels) of this type, as well as many of the polished forms of later age are termed Celts—from the Latin, *celtis*, a chisel. The remains of Palæolithic man being strictly speaking Prehistoric, this term, which has been confined to remains of Neolithic and Bronze ages in Britain, cannot be so restricted; and in order to have some terms to express the difference the following arrangement has been suggested:[3]—

Recent.	Historic.	*Cænanthropic.*	
	Iron.	*Mesanthropic.*	Pre-historic.
	Bronze.		
	Neolithic,		
Pleistocene.	Palæolithic.	*Palæanthropic.*	

Concerning the antiquity of Palæolithic Man, little more can be said, than that he lived in this country and throughout Western Europe with the Lion and Mammoth, the Hyæna and Woolly Rhinoceros. Prof. Dawkins remarks that he was probably more or less nomadic, following the Urus and the Elk, and shifting from place to place as they migrated with the seasons. In his weapons of warfare and of the chase he resembled the dwellers on the shores of Arctic seas, and judging from the associated animals he probably lived in an age when continental conditions and higher mountains produced much greater extremes of climate than are found in the same countries now. In many places he probably followed hard on the receding glaciers, before the advance of which, perhaps, his ancestors retreated. Whether or not he appeared in Pre-Glacial times, has not been proved, for no remains have been found in deposits definitely Pre-Glacial, such as the Cromer Forest-bed Series. Thus, although we cannot assign a date to his first appearance, we must refer him to a period so remote that wide valleys have been scooped out and many animals have been exterminated since his time, but how long it took to bring this about we cannot yet tell. Nevertheless the earliest inhabitant comes before us, endowed with all human attributes, and without any signs of a closer alliance with the lower animals than is presented by the savages of to-day.[4] (See also p. 23.) The human remains of Neolithic times, as remarked

[1] Some caverns in the south of France may contain records of the interval between Palæolithic and Neolithic periods, and this intermediate age was (in 1863) termed the 'Reindeer period' by M. L. Lartet, because the caverns contain in great abundance remains of this animal. Associated with these are the famous sculptured bones, containing pictorial representations of the Mammoth, etc. Lyell, Student's Elements of Geology, 1871, p. 126.

[2] See Lubbock, Pre-historic Times, 1865; Lyell, Antiquity of Man, ed. 4, 1873; Prestwich, Phil. Trans. 1860, 1864; John Evans, Archæologia, 1860, 1862; Address to Geol. Soc. 1875; Ancient Stone Implements, etc., of Gt. Britain, 1872; E. T. Stevens, Flint Chips, 1870; Pengelly, G. Mag. 1877, p. 431; T. R. Jones, Lecture on Antiquity of Man (Croydon Microsc. Soc.), 1877.

[3] Reports of Sub-committees, Internat. Geol. Congress, Cambridge, 1885, p. 18.

[4] W. Boyd Dawkins, Cave Hunting, 1874; and Early Man in Britain, 1880; Dr. H. Woodward, G. Mag. 1869, p. 58; J. Geikie, Pre-historic Europe; Hughes, Present state of the Evidence bearing upon Antiq. Man (Victoria Institute), 1879.

by Prof. Dawkins, are chiefly of Iberic types, those of the Bronze age belong to Celtic types.

According to Dr. John Evans, the Iron Age in Western Europe lasted until about the Christian era; and in Britain the Bronze Age may have extended from about 1400 or 1200 B.C. to 500 or 400 B.C., and the Neolithic period for about 2000 or more years previously. But in this country it is not possible to fix precise limits for these (to us Pre-historic) periods.[1] In Neolithic times the only metal known was Gold. Later on, the prevalence of implements and weapons of Bronze before those of Iron in this country, as in other parts of Western Europe, is remarkable. Bronze (or Gun-metal) is an alloy in the proportion of nine parts of copper to one of tin; and Copper was the first metal which became of real importance to man. Tin also early attracted notice, probably on account of the great heaviness of its ores; and when metals were very scarce, it would naturally sometimes happen that, in order to make up the necessary quantity, some tin would be added to copper, or *vice versâ*. In this way Sir John Lubbock accounts for the early use of Bronze.[2]

In these later Pre-historic times we had dwellings like those of the Swiss Lake population, as at Barton Mere in Suffolk, and at Ulrome in Holderness.[3] We have also the Pit-dwellings such as those of Standlake, west of Oxford, of which pits a model is preserved in the Ashmolean Museum;[4] but many of the so-called Pit-dwellings are in reality excavations made for stone or gravel.[5] (See p. 394.) The Deneholes (see p. 420), and the Beehive pits or granaries on Portland, are not without geological interest, although their precise age is uncertain.[6] We have the Druidical remains of Avebury, and those of Stonehenge, which are referred to the later part of the Bronze age. The domestic and wild animals have been previously mentioned, and it will be readily acknowledged how comparatively few remains are handed down for the edification of geologists, as the bones are seldom preserved unless covered up in river-deposits and in peat-beds, or stored up in caverns and fissures of rocks.

Dr. Croll on astronomical data would place the Glacial deposits at a period beginning about 240,000 years ago, and extending down to about 80,000 years ago.[7] Although there is evidence that in Pleistocene times the greater part of the northern hemisphere, at any rate, was subject to a considerable decrease of temperature;[8] yet whether the entire globe was affected at one time, or whether there was an alternate glaciation of the northern and southern hemispheres, may be questioned. The cold, according to Mr. S. V. Wood, jun., was brought about, not by changes in the excentricity of the earth's orbit, nor by changes in its axis, nor so much by alterations in the distribution of land and water, but was due primarily to a diminution of the heat-emitting power of the sun.[9] On this subject, however, there is considerable diversity of opinion.[10] (See p. 21.)

[1] Ancient Bronze Implements, etc. 1881; Nature, Sept. 28, 1882; see also T. Wright, The Celt, the Roman, and the Saxon.

[2] Pre-historic Times, p. 4.

[3] Evans, Ancient Bronze Implements, pp. 486, 487; Dawkins, Early Man in Britain, p. 352; Rev. Harry Jones, Q. J. Suffolk Inst. 1869, p. 31; F. J. Bennett, Geol. Diss, etc. (Geol. Surv.), p. 19; C. Reid, Geol. Holderness, p. 112; Dr. R. Munro, Brit. Assoc. 1885, Nature, Oct. 15, 1885.

[4] Proc. Roy. Soc. Antiq. iv. 213.

[5] Midland Naturalist, vi. 98; F. C. J. Spurrell, Arch. Journ. xl. 281.

[6] T. V. Holmes, P. Geol. Assoc. viii. 404; Trans. Essex Field Club, iv. part 9; Damon, Geol. Weymouth, 1884, p. 164; Fitton, T. G. S. (2), iv. 220.

[7] Climate and Time in their Geological Relations, 1875.

[8] Ramsay, Phys. Geol. and Geogr. Gt. Britain, ed. 5, p. 375.

[9] G. Mag. 1883, p. 293; Q. J. xxxvi. 457, xxxviii. 667.

[10] See Address to Brit. Assoc. 1886, by Sir J. W. Dawson, pp. 22–25; G. H. Darwin, Address Math. and Phys. Sec. Brit. Assoc. 1886; and Sir R. S. Ball, Nature, Oct. 21, 1886, p. 607.

Thus the chief divisions of the Quaternary era are partly based on physical considerations, and partly on the evidence of the organic remains. It may therefore be useful to give the following summary of the principal changes that appear to have occurred in our country during this era:[1]—

Recent.	The Present. Depression bringing about final insulation of Britain. Climate humid. Decay of Forests and growth of Peat-mosses.	Alluvium. Submerged Forests. Modern Beaches and Marine deposits (Burtle Beds, etc.), Blown Sand, etc.	Neolithic and later evidences of Man's presence.
	Britain again becomes continental. Summer and winter temperatures more excessive than now; age of great Forests. Incoming of Recent Fauna.	Raised Beaches (in part), River-gravels, and some Cavern-deposits.	
Pleistocene.	Retreat of the ice, and period of small local glaciers on the higher mountain-regions, when Britain was probably isolated, and land of less extent than now.	Eskers, Perched Blocks, etc. 'Head' (subaërial detritus) of south of England (of all ages subsequent to Pliocene period?)	
	Severe glacial conditions, with glaciers and coast-ice, affecting more particularly Scotland, Wales, and the northern districts of England.	Hessle and Purple Clays of Lincolnshire, Newer Pennine Boulder Clay, and newest Boulder Clay of N. Wales, etc.? Erratic beds of Selsea.	
	Britain continental with climate changing from intense cold to temperate and genial. Arctic and southern Mammalia visit Britain, according as climatal conditions become suited to their needs.	Plateau gravels (in part); Raised Beaches (in part). Old River- and Cavern-deposits, with Palæolithic Implements, remains of Mammoth, Rhinoceros, Hyæna, etc. *Corbicula fluminalis*. Marine deposits of March, Kelsea Hill, Nar Valley, etc., with Mammalian remains, etc. Hessle mammaliferous gravel.	
	Elevation of land, accompanied by intense glacial conditions, with great ice-sheets formed by confluent glaciers, extending over large tracts of country.	Chalky Boulder Clay. Basement-clay of Lincolnshire (with Bridlington shell-bed). Upper Boulder Clay (in part) of Lancashire, Cheshire, and Midland Counties.	
	Submergence of considerable areas and deposition of marine sands and gravels, etc.	Middle Glacial Sands of East Anglia. Shelly sands and gravels of Moel Tryfaen, Macclesfield, Blackpool, etc.	
	Elevation of land and severe glacial conditions.	Cromer Till, and earliest Boulder Clays of other parts.	
Pliocene.	Indications of approaching cold.	Cromer Forest Bed and Norwich Crag Series.	

[1] This Table is partly based on that given by Prof. James Geikie, Great Ice Age, ed. 2, p. 570. The earliest attempt at a Table showing changes during Post-Pliocene times was made in 1853 by J. Trimmer, Q. J. ix. 295; see also Ramsay, Phys. Geol. and Geog. Gt. Britain, ed. 5, p. 380; Researches in Newer Pliocene and Post-Tertiary Geology, by James Smith of Jordan Hill, 1862; and Ussher, Post-Tertiary Geol. Cornwall, 1879, p. 50.

It is obvious that we cannot precisely mark off all the records of the Quaternary era into the two divisions previously noted. Many Caverns contain Pleistocene as well as Recent deposits, and there may be marine deposits of both ages, which it would be inconvenient to describe separately. Hence the descriptions of the Quaternary phenomena will be arranged mainly according to method of formation, as follows:—

MARINE.	*Recent*, etc.	Raised Beaches, Shingle Beaches, and other Marine deposits.
TERRESTRIAL.	*Recent* and *Pleistocene.*	Soils and Rainwash. Blown Sand. Caverns and Cavern-deposits. Springs and Tufa.
ALLUVIAL (FLUVIATILE, LACUSTRINE and ESTUARINE).	*Recent* and *Pleistocene.*	Alluvium, including Peat, Submerged Forests and River-deposits (Valley gravel, brickearth, etc.), *Scrobicularia*-clays, etc.
GLACIAL.	*Pleistocene.*	Boulder Clay, Gravel, etc.

PLEISTOCENE.

GLACIAL BEDS.

The Glacial Period may be regarded as including the records of all deposits from the close of the Pliocene period to the commencement of Recent times, but strictly speaking the Glacial deposits are those more immediately connected with the agency of ice. These deposits include wide-spread accumulations of Boulder Clay, Loam, Gravel and Sand. The Boulder Clay is more especially due to the direct influence of ice, but associated with it are deposits which may be due to the melting of ice-sheets, or which may have been formed in areas subject to the influence of coast-ice, and ice-bergs. Thus the term Glacial Beds refers to age rather than to particular methods of formation. The Cavern- and River-deposits and the Raised Beaches, which may have been accumulated during the Glacial period, will be noticed separately.

It must be borne in mind that this Glacial Period, or 'Great Ice Age,' was not necessarily the most important Glacial period that has occurred during geological times. Dr. Croll has stated his opinion that these periods of intense cold were periodical: we have indications of transport by ice agency in the Chalk period; and in Permian times there are some (doubtful) evidences of Glacial deposits. (See also p. 36.) The accumulations, however, that evidence the Post-Pliocene Glacial period are the most extensive of the kind that have been preserved, for subsequent changes have not been of sufficient magnitude to obliterate them.

Attention was drawn in 1840 by Agassiz and Buckland to the evidence of the former existence of glaciers in the British Islands.

Dr. Buckland's attention was first directed by Prof. Agassiz, in 1838, to the phenomena of polished, striated, and furrowed surfaces, and also to the transport of the erratic boulders on the Jura, as the effects of ice; but it was not until he had devoted some days to the examination of actual glaciers in the Alps, that he acquiesced in the correctness of Prof. Agassiz's theory relative to Switzerland. On his return to Neuchâtel from the glaciers of Rosenlaui and Grindelwald, he informed M. Agassiz that he had noticed in Scotland and England phenomena similar to those he had just examined, but which he had attributed to diluvial action; thus in 1811 he had observed on the head rocks on the left side of the gorge of the Tay, near Dunkeld, rounded and polished surfaces; and in 1824, in company with Lyell, he had seen grooves and striæ on granite rocks near the east base of Ben Nevis. About the same time Sir George Mackenzie pointed out (in a valley near the base of Ben Wyvis) a high ridge of gravel, laid obliquely across, in a manner inexplicable by any action of water, but in which, after his examination of the effects of glaciers in Switzerland, Dr. Buckland recognized the form and condition of a moraine. Eventually Agassiz and Buckland together visited some of the scenes of former Glacial action in Britain, and announced the conclusions at which they arrived.[1] That ice might have had some influence in the transport of many masses of rock belonging to the "Erratic Block Group," had been suggested by several observers,[2] but not until clear evidence was obtained of the former presence of glaciers, was the great influence of ice realized and admitted.

The more striking evidences of Ice-action to which attention was first called consist of Ice-scratched boulders or stones, that had been embedded in the Glacier-ice, and been scored by friction against the rocky channel, or against loose fragments of rock occurring in it; Rock-surfaces and rounded eminences, smoothed, polished, and striated (*Roches moutonnées* of Saussure); Perched Blocks (*Blocs perchés*), boulders often of immense size, left at some distance from their parent source in hazardous positions, such as they could not have occupied if they had been 'tumblers' falling from a higher level, so that they must have been transported by Glaciers or Ice-bergs, and have been left when the ice melted.[3]

The term 'Boulder Clay' is applied to beds of a clayey or loamy nature that contain angular and subangular fragments of rock, and boulders, many of which are striated, and have been brought from a distance. Boulder Clay may at times contain very few stones or boulders, and at others be almost entirely made up of them: in many parts of the Eastern Counties it is to a large extent composed of Chalk. It is generally unstratified, but it contains seams of sand and gravel. The term 'Till' was first applied in Scotland to the stiff unstratified clays containing angular, subangular, and rounded blocks of rock mostly polished and striated; and it is now generally used as synonymous with Boulder Clay, the accumulations being usually of a tumultuous and variable nature. The term 'erratic' is applied to boulders that have travelled long distances from the parent rocks.

Boulder Clay is directly due to the action of ice, whether in the

[1] Proc. G. S. iii. 327, 332, 345, 579; Buckland, Reliquiæ Diluvianæ, pp. 202-206; Address to Geol. Soc. 1841, p. 65; Louis Agassiz, His Life and Correspondence, by E. C. Agassiz, 2 vols. 1885, p. 263; Agassiz, Edin. New Phil. Journ. Oct. 1842; see also Midland Naturalist, 1883, p. 225.

[2] De la Beche, Geol. Manual, pp. 155, 164; Lyell, Phil. Mag. (3), xvi. 348. The term "Erratic Tertiaries" was used by Trimmer; and that of "Great Northern Drift" has also been applied.

[3] See Hughes, Q. J. xlii. 527.

form of Glaciers, Ice-sheets, or Coast-ice. It often exhibits obscure horizontal streaks of different materials, which at first sight might be taken for lines of bedding, but this "fluxion-structure,"[1] as it has been termed, is usually formed of crushed material, and is probably due to the pressure of moving ice.[2] Here and there, as on the Norfolk coast, beds of laminated and even ripple-marked clay and marl occur between beds of Boulder Clay; and deposits of this nature, as remarked by Mr. Reid, may be in reality glacier-mud, such as would flow from beneath the ice, and be deposited during its temporary retreat.

The Glaciers which accumulated on the higher grounds of Britain merged in some instances to form Ice-sheets (*mer de glace*) ; and the thickness of these has been reckoned at hundreds and even several thousands of feet : but probably an estimate of from 400 to 2000 feet would be sufficient.[3] Be this as it may, there can be no doubt that considerable areas of ice were formed by the amalgamation of Glaciers, and these were forced over the land, aud sometimes pushed out to sea. In the latter case they would break off in the form of ice-bergs, and eventually melt and deposit the mud and boulders stored up in the ice and in crevices of it. Much material so laid down would be more or less sorted and arranged in layers, but in some instances where the ice-bergs grounded, the deposits would be disturbed. The direction of the ice-sheets which, as a rule, radiated from the dominant high grounds, was often modified by local causes, and perhaps also by the incoming of ice-flows from Scandinavia. While the detritus or stony material brought down by glaciers and deposited by the melting ice is known as Moraines, that which was formed under the land-ice is known as the Ground-moraine, Bottom-moraine or *Moraine profonde*, and this varies to a considerable extent according to the nature of the rocks over which the ice-sheets travelled. Over hard rocks the ice leaves its marks in the form of grooves and striæ ; over softer strata the beds are much crumpled and disturbed. The striæ and the transported boulders indicate the directions from which the ice came.

Unfortunately, we have very little information concerning what kinds of accumulations are being formed by land-ice in the arctic regions. There the icy agents can be studied ; but the effects are not, as a rule, so conspicuous. In this country we see the results, and have to infer what were the agents.

In the formation of our Chalky Boulder Clay, for instance, icebergs are generally admitted to have had little or no influence, for the ice from which the floating masses would be severed must have passed over considerable tracts of Chalk, and the Chalk would have been submerged if the icebergs were to have fair play. Mr. Wood advocated the view that the Chalky Boulder Clay was extruded at the foot of an ice-sheet that enveloped the Yorkshire and Lincolnshire Wolds ; but the general absence of stratification in it goes against the view of this clay having been for the most part deposited under water. He remarked that if we consider the soluble nature of Chalk, it must be evident that none of this material can have been detached from the parent mass either by water-action, or by any other atmospheric agency than moving ice.[4] We require, too, an agent capable of exerting a comparatively uniform influence over wide tracts, of abrading and pushing on material in a manner more extensive than could be attributed to coast-ice. Moreover, the Clay has been much compressed, and is so tough and hard in

[1] Hugh Miller, jun., R. Phys. Soc. Edin. viii. 157.

[2] C. Reid, Geol. Cromer, p. 90.

[3] The thickness of the Arctic and Antarctic ice-sheets must in places be several thousand feet, judging from the size of some of the ice-bergs, especially in the latter region. The Alpine glacier-ice is from 100 to 600 feet thick. J. Geikie, Outlines of Geology, 1886, pp. 53, etc. ; C. Reid, G. Mag. 1881, p. 234 ; see also the Duke of Argyll, Address to Geol. Soc. 1873 ; Sir J. W. Dawson, Address to Brit. Assoc. 1886, p. 27 ; and H. Carvill Lewis, Natnre, Nov. 25, 1886, p. 89.

[4] Q. J. xxvi. 100 ; Wood and Rome, Q. J. xxiv. 167.

places that navvies engaged in making railway-cuttings have remarked that they never had a more troublesome material to deal with.

The occurrence of the chalk lumps in the clay may perhaps be accounted for in the following way. The surface of the Chalk in Norfolk, along the sea-margin, and in places inland, is seen to have weathered in a very rubbly form, to a depth sometimes of six or eight feet. Frost and rains have no doubt been the chief influences in producing this; and this weathered Chalk would furnish "ready made" the very material for the Chalky Boulder Clay, which consists so largely of lumps of Chalk which have not necessarily been rounded by rolling.

It has indeed been considered that most of the material forming Boulder Clay was obtained ready made, from the disintegrated surfaces of the strata. During later Tertiary times, a great part of the country was dry land, and then no doubt much "head" or subaërial detritus was formed; for, as observed by Prof. J. Geikie, in all the glaciated countries of Europe there is a general absence of those thick sheets of "weathered rock" which are so conspicuous a feature in regions which have not been subjected to glacial action.[1]

The term Esker is used in Ireland, and Kame in Scotland, to denote certain peculiar ridges and mounds of drift which rest sometimes on the Boulder Clay and other Glacial Beds, and regarding whose origin there has been much diversity of opinion. Some geologists maintain that they have been formed by marine agency; some again consider that they are due to the action of sub-glacial waters (waters flowing underneath land-ice), or that they are morainic accumulations deposited either on land, or beneath the sea; while yet others have attributed them to torrential or fluviatile action. They occur often in long winding ridges, and rise boldly and sharply with steep slopes, to heights of 100 feet or even more. As remarked by Prof. A. H. Green, the gravel is very distinctly though irregularly bedded, and the beds arch over, so that in a general way the direction and amount of the dip is about the same as the slopes of the surface of the ridge. No one explanation will account for all Eskers, but the majority were probably formed where a river with fall enough to enable it to carry down gravel entered a tidal sea.[2]

During the Glacial period many of the old river-courses were completely choked up with clay, stones, and gravel, so that when the ice melted away, the rivers did not always, and in the north of England not often, regain their old channels. Much Boulder Clay thus is found overlying old river-gravels, and it is sometimes arranged in ridges, "drums" or "drumlins" (drum lines). These clayey mounds are usually formed of boulder clay interstratified with undisturbed beds of sand and finely laminated clay, and occasionally they pass into Eskers in the lower parts of valleys. Some river-gravels, when traced to their sources in the mountains, merge into moraine-débris.

There are certain phenomena known as 'Crag and Tail'; these terms are applied to a bare scarp or boss of rock (Crag) which has superficial deposits banked up against it on the other side, forming a long sloping "tail." These appearances are due to the ice being obstructed in its passage by the abrupt hill of hard rock, which permitted the accumulation of rock-fragments on the unexposed side.

The effects of Coast-ice must not be neglected in any attempt to elucidate Glacial phenomena. In high latitudes an "ice-foot" or belt of ice is formed along the shores, and sometimes reaches a height of 30 or 40 feet. Many fragments of rock are frozen into the bottom of the ice, and it is also liable to receive accumulations of detritus due to landslips and the weathering of cliffs. Eventually this coast-ice is broken up, and large masses of it may be driven on shore, crushing and grinding the rocks over which they are pushed, and striating them as well as many of the loose stones.[3] The Hessle Clay of Yorkshire and Lincolnshire may have

[1] Outlines of Geology, 1886, p. 373; A. Geikie, Text-Book of Geology, pp. 325, 894; see also P. Geol. Assoc. ix. 123; F. J. Bennett, Proc. Norwich Geol. Soc. i. 256.

[2] Physical Geology, 1882, p. 632.

[3] See Prof. John Milne, G. Mag. 1876, pp. 304, 403; Q. J. xxxiii. 929; and A. J. Jukes-Browne, Physical Geology, 1884, p. 131; Geol. East Lincolnshire (Geol. Surv.); Penning and Jukes-Browne, Geol. Cambridge, pp. 115, 117.

been formed by Coast-ice, as well as other Boulder Clays, in North Wales, Lancashire, etc.

The subject of milder Interglacial periods is not yet one on which definite views can be expressed ; the evidence of the shell-fauna of the Middle Glacial sands of East Anglia is open to question (see sequel) ; and Sir J. W. Dawson has shown, on the evidence found in Canada, that the occurrence of marine shells, land plants, and insects in the Glacial deposits of that country, indicates not so much the effect of general Interglacial periods, as the local existence of conditions (favourable to animal- and plant-life) like those of Grinnel-land and Greenland, in proximity to each other at one and the same period, and depending on the relative levels of land and the distribution of ocean currents and ice-drift.[1]

The Glacial deposits scattered over the country have been examined in detail in many areas, and the general sequence of events has been marked out. At the same time the deposits themselves are so changeable, that the attempts made to correlate divisions in different parts of the country are very far from satisfactory, and it will be better to describe the principal local deposits, without attempting to indicate to which particular portions of the Glacial period each subdivision may belong; and without trying to explain its precise method of formation. It is considered that at the climax of cold (during the accumulation of the Chalky Boulder Clay and its equivalents), the northern parts of England and Wales were smothered up in ice, which filled also the shallow seas adjoining, while the south of England was never subjected to such glaciation, and the scattered Drifts and occasional boulders there met with are due to marine currents and occasional ice-bergs. The great accumulations of 'Head' and other subaërial detritus in the southern counties are no doubt memorials of the 'Great Ice Age.' But it is difficult to frame a scheme that will fairly exhibit all the changes that have taken place even in Glacial times. In certain areas in the north we find evidence of three or even more beds of Boulder Clay, in other areas we find but one or two beds. It is probable that in many cases earlier Boulder Clays were re-constructed in later times, and the sequence is obliterated; thus creating great difficulties in the correlation of the beds. Where, as is too often the case with Glacial deposits, there is room for much diversity of opinion, geologists fully avail themselves of it. Hence it is best to picture the Glacial period in a general way, and to admit that Glaciers and Ice-sheets, Ice-bergs and Coast-ice, have all had their share in the production of the phenomena, although we cannot always localize their action.

NORTHERN AND WESTERN COUNTIES OF ENGLAND AND WALES.

Glacial Drift occurs over a great part of Northumberland ; and in that county and in Durham the Boulder Clay largely conceals the Coal-measures. There are also great accumulations of gravel and sand, with occasional bands of unctuous clay that fill up a number of old Pre-glacial valleys. Thus, according to Sir A. C. Ramsay, the miners, while mining a bed of coal, sometimes find the seam crop

[1] Address to Brit. Assoc. 1886 ; Major H. W. Feilden, Address to Norfolk Nat. Soc. 1886.

out deep underground, against a mass of Drift that fills an ancient rocky valley of which the plain above gives no indication. Over the moors of western and central Northumberland there are considerable accumulations of pebbly gravel, termed by Prof. G. A. Lebour the Moor gravels. The most recent Glacial accumulations are Eskers, of which the 'Bradford Kaims,' seen on the road from Lucker to Bamburgh, furnish an example.[1] The Cheviot Hills, according to Prof. J. Geikie, appear at one time to have been smothered in ice, for he found Boulder Clay on the very watershed.

In Cumberland, west of Carlisle, there is a great accumulation of "earthy gravel," which attains a thickness of nearly 200 feet at Abbey Town; and many Eskers occur in this neighbourhood.[2]

The Glacial phenomena of the Lake District, according to the Rev. J. Clifton Ward, comprise Till (*moraine profonde*), mainly the product of a confluent glacier-sheet; Drift gravel, and stratified sand and gravel, often occurring in the form of Eskers, due principally to marine action, though some of the beds may be moraine matter; and Boulders carried far from the parent-rock by glacier-ice at one time, and floating-ice at another. During the formation of the Till the principal valleys were occupied by ice: then came submergence and the drifts were re-assorted: and afterwards on re-elevation a second and lesser land-glaciation took place.[3]

Prof. T. G. Bonney has pointed out some of the striking instances of glaciation in Borrowdale, Buttermere, and other places. He mentions a boss of ice-worn rock on the north side of St. Mary's Churchyard, Ambleside; *Roches moutonnées* near Great Langdale; a rounded rock on the left bank of the stream opposite to the inn at Wythburn; marks of glaciation on each side of Thirlmere, etc. He observes that the Glen of the Lodore Falls appears to have been once occupied by a glacier, though the main outlet was not by the chasm of the fall.[4]

A study of the distribution of the granitic boulders from Criffel, in Kirkcudbrightshire, from Eskdale, and from Shap Fell or Wastdale Crag three miles south of Shap in Westmoreland, furnishes many striking proofs of glacial action.[5] The transport of Shap granite into the plains of Yorkshire attracted attention as early as 1825, for blocks have travelled down the slope of their native mountains, over the limestone ridge of Orton (1000 feet), across the Vale of Eden, over the limestone ridge of Stainmoor (1400 feet at the pass, over 2000 feet in other places), down the Vale of York, over the Oolitic ridge (300 to 1485 feet), and over the Chalk hills (500 to 800 feet) to Flamborough Head.[6]

Wastdale Crag itself is 1600 feet high, and the rock is a remarkable porphyritic granite, with large crystals of felspar. The Crag itself is much smoothed and polished, and in some places scored by glacial striations. The erratic blocks have probably been transported by land-ice.[7]

Boulders of Criffel granite occur in the Drift of the plain of Cumberland, and further south, while near St. Bees there are many boulders of syenite from Ennerdale, etc. The cliff-sections near St. Bees show Drift with huge boulders of rock and masses of red and purple shale (Permian and Carboniferous).

The Glacial phenomena of the Eden Valley and the western part of the Yorkshire Dale-district have been described by Mr. J. G. Goodchild. Many fine sections have been exposed in cuttings of the Settle and Carlisle Railway. The lowest drift consists of stiff clay full of well-glaciated stones, and this is overlaid by

1 Geol. Northumberland. p. 14; see also Howse, G. Mag. 1864, p. 268; and Bryce, Rep. Brit. Assoc. 1855.

2 Holmes, Trans. Cumberland Assoc. Part vi., G. Mag. 1883, p. 438.

3 Geol. Mag. 1879, p. 111; Q. J. xxix. 439, xxxi. 152.

4 G. Mag. 1866, p. 291. See also Miss E. Hodgson, G. Mag. 1870, p. 328.

5 Mackintosh, G. Mag. 1870, pp. 349, 564; Q. J. xxix. 351; xxx. 711; Harkness, Q. J. xxvi. 517; J. R. Dakyns, Yorks Geol. and Polyt. Soc. 1879; Dr. H. A. Nicholson, Geol. Cumberland, etc. p. 45.

6 Phillips, Rivers, etc., of Yorkshire, p. 18; Guide to Geology, ed. 6, p. 208; Buckland, Proc. G. S. iii. 348; Rev. W. Thorp, Proc. Geol. and Polyt. Soc. W. Riding, iii. 244; J. G. Goodchild, G. Mag. 1875, Q. J. xxxi. 55.

7 Croll, G. Mag. 1871, p. 15; see also *Ibid.* 1864, p. 228.

angular drift with fewer glaciated stones: many sections show an alternation of contorted beds and undisturbed strata. Mr. Goodchild concludes that while the whole district, to a height of about 2400 feet, was enveloped in a portion of a great ice-sheet, formed of ice partly from Scotland and partly from the Lake District, and adjoining uplands, yet the drifts were mainly accumulated afterwards by the melting of this covering, and the consequent liberation, as a sediment, of the stones, sand, and mud that had been dispersed throughout the ice. Much of the surface-configuration of the Dale-district was due to the modification of pre-existing features by Glacial erosion.[1]

In North Lancashire and adjacent parts of Yorkshire and Westmoreland evidences also of widespread and almost universal glaciation were previously recorded by Mr. R. H. Tiddeman. There the general movement of the ice was to the south across deep valleys and over hills of considerable elevation, its direction being modified by ice from the Lake-district. Striæ were not observed at heights over 1500 feet. Regarding the Till in this area as the product of an ice-sheet, Mr. Tiddeman has observed that there is abundant evidence that it is not coloured by the rocks on which it lies, but by the rocks over which it has been pushed; and that it is quite possible, nay certain, that in some areas there may be beds of Till of totally different appearance, colour, and material, deposited side by side, by the same agents, and under the same conditions, at the same time.[2]

In West Cumberland, Lancashire, parts of North Wales, and Cheshire, the Drift deposits have been divided as follows:—

Upper Boulder Clay	20 to 100 feet.
Middle Drift (sand and gravel)	10 to 200 ,,
Lower Boulder Clay	20 to 120 ,,

The total thickness is rarely more than 150 to 200 feet. The beds were first divided in the neighbourhood of Manchester by Prof. E. Hull. The Upper Boulder Clay consists of reddish-brown clay, with grey and blue partings, and glaciated stones and boulders. It sometimes contains bands of sand and finely-laminated clay. It may be seen at Ormskirk, Wigan, Lancaster, etc. There are many old marl pits over the area occupied by this Clay, and it has been worked for brick-marking at Blackpool, Preston, Blackburn, Croston, and other places.

The Middle Drift consists of fine sands and gravel with subordinate beds of clay and loam, the whole in general distinctly stratified, but frequently contorted. The maximum thickness in Cumberland is about 120 feet; at Gresford, near Wrexham, 150 feet; at Kersal Moor, Lancashire, 200 feet. In many places it contains fragments of marine shells in abundance. (See sequel.)

The Lower Boulder Clay consists of stiff reddish-brown clay, with subordinate beds of laminated loam, seams and pockets of sand, stones and many large boulders. This, according to Mr. Mackintosh, graduates into a harder and more stony clay "with a tendency to arched stratification in the neighbourhood of the hills"; it is known as "Pinnel" in Furness. Its thickness at Lindal, Furness, is about 120 feet. The lowest portion of the accumulation is a blue or bluish-grey stony clay, with many scratched boulders. This Boulder Clay is also largely used for brick-making.

All the divisions, according to Mr. Mackintosh, are locally shelly, excepting the 'Pinnel,' and the lowest blue Boulder Clay.[3] The most abundant shells are fragments of *Tellina Balthica*, *Cardium edule*, *Astarte borealis*, and *Turritella terebra*. The Boulder Clay contains blocks of granite, and various eruptive rocks, grits, slate, Carboniferous Limestone, etc. Chalk-flints have been found in the Drift

[1] Q. J. xxxi. 55. See also J. W. Davis, G. Mag. 1879, p. 313; W. Gunn, *Ibid.* p. 384.

[2] Q. J. xxviii. 471, 485.

[3] See Daniel Mackintosh, G. Mag. 1870, p. 445, 1871, pp. 250, 303, 1872, pp. 190, 399; Q. J. xxv. 407, xxviii. 391, xxx. 174, xxxiii. 730, xxxvii. 351; G. H. Morton, Geol. Liverpool, 1863.

of Cheshire and Lancashire: but most of the rocks have come from the Lake District, the south of Scotland, and the Pennine hills. Faint indications of stratification may be occasionally observed in the Boulder Clays, but, as a rule, the pebbles and boulders are embedded pell-mell and at all angles in the mass. Ripple-marks have been observed in places in the Drift.[1] A peat-bed has been noticed in the Boulder Clay at Oldham, and similar beds have been observed in the Drifts at Lindal, Crossgates, Walney Island, Drigg, St. Bees, and Maryport.[2] Curious weathered boulders have been obtained by Dr. C. Ricketts from the Boulder Clay, and these, in his opinion, may indicate variations in the severity of the seasons during the Glacial period.[3] Portions of consolidated sand and shingle belonging to the Middle Drift stand out between tide-marks off the Norbreck coast, near Bispham, north of Blackpool.[4]

The divisions of the Drifts are well exposed in the Valley of the Ribble at Red Scar, east of Preston, in the railway-cuttings between Chorley and Blackburn, in the cliffs from Blackpool to Norbreck, etc., on the banks of the Mersey at Egremont, near Eastham in Wirral, on the banks of the Dee near Parkgate, and at Colwyn Bay.

The value of the tripartite classification of the Drifts in the north-west of England has been questioned by several observers, for seldom can the three divisions be clearly seen in sequence. The case is similar to that in the Eastern counties, where the triple division is locally maintained, but in many places the Upper and Lower Boulder Clays come together, and it is difficult to distinguish between them. This must always be the case where a newer rests directly on an older Boulder Clay.

Mr. De Rance has observed that in the Furness district Upper Boulder Clay rests on sands and gravels at Ulverston, and a Lower Boulder Clay can be seen resting on the rock, but in following any of the streams reaching the sea in this district into the deep valleys of the Lake District from which they flow, the sequence is lost, and the character of the Drift becomes more and more confused as the mountains are approached. Well-preserved moraine mounds occur in numerous valleys, far above the level of glaciated rocks lower down in the valleys, and there is clear evidence of an early excessive glaciation, during which era those lakes which lie in the rock-basins probably came into existence, and of later glaciers, which shrunk gradually as the period of glacial cold passed away.[5]

Mr. Mellard Reade observes that the section at Blackpool has long been considered a typical one by those who divide the Drift into three important beds. His section (Fig. 83) shows the lower part of the Boulder Clay generally harder, and with a larger number of striated boulders than the higher Boulder Clay, from which it is separated by sands and gravels. Northwards, however, these sands and gravels taper away into the upper Clay. And if we could see a section further inland, Mr. Reade thinks it highly probable that these two clays would coalesce and shade into each other, as indeed, was shown to be the case in a section drawn by Mr. E. W. Binney in 1852.[6] The main mass of the higher Boulder Clay, which usually occupies the lower grounds (Low-level Boulder Clay), is, in Mr. Reade's opinion, a marine deposit; and the period of greatest cold preceded the deposition of this Boulder Clay. He, however, notes evidence of land-glaciation of the Keuper Beds beneath it, at the Moor Hey brickyard, Great Crosby. Mr. Strahan has also noticed terminal curvature in the Keuper Marls of Cheshire: there the Upper Boulder Clay occupies a large area, and is thickest on the lower grounds.

In addition to waterworn fragments of Mollusca, many specimens of Foraminifera and Ostracoda have been obtained from the Boulder Clay by Mr. W. Shone.[7]

[1] T. M. Reade, Q. J. xl. 267; see also Q. J. xxxi. 34.
[2] J. D. Kendall, Q. J. xxxvii. 29; G. H. Hollingworth, *Ibid.* 713.
[3] Q. J. xli. 598; Proc. Liverpool Geol. Soc. 1879, 1881.
[4] C. E. De Rance, Superficial Geol. S. W. Lancashire (Geol. Suurv.), p. 52; Q. J. xxvi. 641, 648, G. Mag. 1869, p. 489, 1871, p. 107.
[5] P. Geol. Assoc. iv. 223; G. Mag. 1883, p. 505.
[6] Reade, Q. J. xxxix. 106, 110, xli. 102, 456. See also G. Mag. 1877, p. 39.
[7] A. Strahan, Geol. Chester, p. 26.

Fig. 83.—Section in Blackpool Cliffs, Lancashire. (T. Mellard Reade.)
Horizontal scale 1120 feet to an inch. Vertical scale 112 feet to an inch.

A. Red Boulder Clay, with two thin bands of stratified sand, B joining the beds of sand C. D. Boulder Clay becoming very stony at E. F. Sand overlaid by sand and gravel G. H. Boulder Clay. I. Boulder Clay, less stony than the Clay below. The greatest height of the cliff is about 60 feet.

The sands also contain shells (see p. 492). Mr. Mackintosh has observed that in the western part of the plain of east Denbighshire and Shropshire the Upper Boulder Clay degenerates into a loamy gravel, which in many places covers the Middle Drift sand and gravel, as around Whittington, Oswestry, etc. The Upper Boulder Clay is well represented between Shrewsbury and Wellington. The Lower Boulder Clay also degenerates south of Chester, passing into gravelly and loamy deposits.

In the Isle of Man Mr. J. Horne has described the following beds :—

> Boulder Clay, containing some scratched stones and angular boulders, 6 to 8 feet.
> Sands and Gravels, finely stratified with many foreign rocks, also Chalk-flint, evidently a marine deposit, 8 to 10 feet.
> Bluish clay, very tough, containing scratched stones, but no large boulders, about 12 feet in thickness; this is the representative of the Scotch Till, and a product of land-ice.

The beds are well exposed about half a mile south of Ramsey, and they are overlaid by a series of well-stratified sands and gravels, which appear to rest on an eroded surface of the boulder clay, and pass upwards into that great series of sands, gravels, and shelly clays which form the cliff from Ramsey to the Point of Ayre. The shelly clays contain marine Mollusca. Some of the gravels belong to the Esker series.[1] Drift gravel with many granitic and other boulders occurs on the Calf of Man. North of Ramsey the sands are here and there cemented into hard concretionary masses.

Esker Drift occurs on the western slopes of the Lancashire moorlands, from 200 to 400 feet above the sea-level; the constituents are more local than those of the Middle Drift, and are not scratched. Gravel knolls of an esker-like character have been observed between Minera and Llangollen Vale; and also in Cheshire, at Delamere Forest, Newchurch Common, and Ellesmere.[2] The Meres of Delamere, etc., occur in the Glacial sands. (See p. 241.)

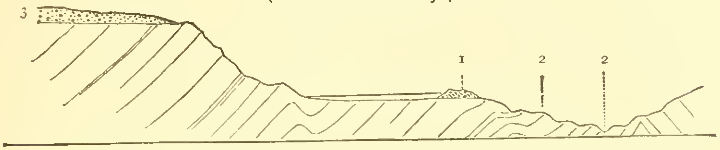
In North Wales there are many scattered Drifts, and as remarked by Sir A. C. Ramsay these deposits often rest on and sometimes conceal the rounded, polished, grooved, and scratched surfaces (*roches moutonnées*), due to the operation of glaciers, the effects of which are so clearly traceable in the Pass

[1] Trans. Edin. Geol. Soc. ii. (1874); G. Mag. 1875, p. 329; J. A. Birds, *Ibid.* pp. 80, 226, 428; J. C. Ward, G. Mag. 1880, p. 6; J. G. Cumming, Q. J. ii. 317, x. 211; H. E. Strickland, Proc. G. S. iv. 9; H. H. Howorth, G. Mag. 1877, pp. 410, 456.

[2] Mackintosh, Q. J. xxxviii. 184; G. Mag. 1877, p. 94; A. Strahan, Geol. Cheshire, Iron and Steel Inst.; Geol. Chester (Geol. Surv.), p. 17.

of Llanberis, in Nant Francon, and other valleys of Caernarvonshire. Llyn Llydaw and Llyn Idwal are clearly dammed up by moraines of Glaciers.[1] (See Fig. 84.)

FIG. 84.—SECTION THROUGH LLYN IDWAL, NORTH WALES.
(Sir A. C. Ramsay.)



1. Moraine.
2. Grooved and polished surfaces formed by more ancient glaciers.
3. Drift at an elevation of 2300 feet.

Prof. Hughes describes the Drifts of the western part of North Wales under two heads, as follows :[2]—

2. The Newer or Clwydian Drift, or that due to the destruction of the older glacial deposits by marine action, during which boulders were carried on floating-ice from the north, and flints travelled in the shingle round the coast. All the shells found in it are of species still living on the adjoining coast ; but some of the shells found in what he considers part of the same series of deposits in neighbouring districts, are of a more arctic type, and may belong to an earlier part of the same epoch. This is also termed the St. Asaph Drift.

1. The Older or Arenig Drift, or that in which boulders were transported from Arenig into the Vale of Clwyd.

It is not always possible to separate these Drifts ; but in the main the older Boulder Clay is made up of local detritus, and the newer of material from the north-west of England, etc. Boulder Clay is well shown at Llandudno, Colwyn Bay, and other places. The newer Drift skirts the margin of Flintshire and Denbighshire, extending into the Vale of Clwyd, and over much of Cheshire.

The striated surfaces of the rocks in this area are connected with the Boulder Clays, and in Mr. Strahan's opinion the striæ below the Drift which came from the north, were produced by floating-ice, driven by tidal or oceanic currents, during a period of submergence. He considers that the marine origin of these newer and erratic drifts is indicated by their well-marked stratification as a whole, by the alternations of sands and gravels with the Boulder-clays and by the occurrence through all the beds of marine shells.[3]

In 1831 Joshua Trimmer discovered marine shells, for the most part broken, in sand and gravel on Moel Tryfaen, about five miles south-east of Caernarvon. Their occurrence suggested a great submergence in Post-Pliocene times. Fossils have since been obtained at heights of 1330 to 1360 feet. The Drift as described by Mr. Mackintosh consists of 35 feet of irregularly stratified gravel and sand, which rise from the floor of the highest excavation of the Alexandra Slate Quarry on the north side of the hill, to within a few yards of its summit.[4] The following section was noted by Mr. Darbishire :—

	Feet	ins.
Peaty soil	0	9
Irregular sandy and stony clay	1	9
Gravel and sand with shells	26	0
Slate, much broken and disturbed beneath the Gravel.		

[1] Q. J. viii. 373, and The Old Glaciers of Switzerland and N. Wales, 1860.

[2] Brit. Assoc. 1886, Q. J. xliii.

[3] A. Strahan, Q. J. xlii. 369. See also D. Mackintosh, G. Mag. 1872, p. 15 ; T. G. Bonney, G. Mag. 1867, p. 289 ; Miss Eyton, G. Mag. 1868, p. 349 ; H. F. Hall, G. Mag. 1870, p. 509.

[4] J. Trimmer, Proc. G. S. i. 331 ; Journ. Dublin Geol. Soc. i. 286, 335 ; Practical Geology, pp. 396, 406, 491 ; C. Darwin, Phil. Mag. (3), xxi. 180 ; D. Mackintosh, Q. J. xxxvii. 352 ; R. D. Darbishire, Mem. Lit. Phil. Soc. Manchester, 1863, iii. 177.

The following Mollusca are most abundant: *Tellina Balthica*, *Cyprina Islandica*, *Cardium edule*, *Astarte borealis*, *A. compressa*, *Turritella terebra*, *Trophon antiquus*, etc. Over 60 species have been obtained at Moel Tryfaen, and of these 11 species are arctic or northern forms, most of them are littoral, and the rest indicate depths of from 10 to 20 fathoms.[1] It has been suggested that the beds were not originally deposited where they are now found, but were thrust uphill by an advancing ice-sheet.[2] It has been argued on the one hand that the forms of Mollusca would not have lived together, and on the other, that ice would have crushed the delicate shells; but nearly all the organisms are more or less fragmentary, although perfect specimens of *Tellina Balthica* have been obtained. Moreover, as Trimmer observed, beneath these Drift deposits the surface of the slate-rock is "covered with scratches, furrows, and dressings."

Sands and gravels containing marine shells, were discovered by Prof. Prestwich at the height of 1200 feet east of Macclesfield in Cheshire. The beds are about 35 feet thick, and the shells include *Cytherea chione*, *Arca lactea*, *Tellina Balthica*, *Cyprina Islandica*, *Cardium rusticum*, *C. edule*, *Astarte arctica*, *Turritella terebra*, etc.[3] The first two species are southern forms, and the other species indicate temperate conditions. North of Macclesfield, shells have been found in sand and gravel at the new cemetery, at heights of 500 feet and upwards. The thickness of the beds is in places 100 feet, and at Congleton they are overlaid by Boulder Clay.

Shells have been found at Upton and near Tarporley in Cheshire,[4] at Preston (350 feet high),[5] Leylands (Worden Hall Pits), and Blackpool in Lancashire. The sands at Blackpool Cliff, etc., have yielded *Nassa reticulata*, *Buccinum undatum*, *Aporrhais pes-pelicani*, *Purpura lapillus*, *Littorina littorea*, *Astarte borealis*, *Cardium edule*, *Tellina Balthica*, *Ostrea edulis*, *Mytilus edulis*, etc. Shells have also been found in the Drift at Petton in Shropshire, near Crewe, at Lilleshall Abbey, north of Shiffnall, and at Strethill, near Buildwas station, and other places in the Severn Valley between Bridgnorth and Shrewsbury.[6] In Shropshire these shell-bearing sands and gravels are about 30 feet thick, and rest on blue (Boulder) clay. At Ironbridge the thickness of the Drift is upwards of 200 feet.

From the occurrence of marine shells in the sands and gravels of Shropshire, Staffordshire, and Worcestershire, Murchison and Prof. Buckman were led to infer an 'Ancient Strait of Malvern,' and that the sea had covered the Valley of the Severn from Bridgnorth to the Bristol Channel. It is quite likely that this was the case, but a large area of the midland and eastern counties was at the same time submerged.[7]

The "Weaver Clays" of the Weaver Hills, north-east of Cheadle, in Staffordshire, described by Mr. Edwin Brown, consist of white clays and sands roughly bedded, 30 feet thick at Ribden. The former beds furnish fire-clay, and the sands are used for glass-making.[8] The beds are overlaid in places by Boulder Clay, and they are occasionally much disturbed: their age is, however, extremely doubtful. (See p. 444.)

[1] J. Gwyn Jeffreys, Q. J. xxxvi. 353.

[2] T. Belt, Nature, May 14, 1874; C. Reid, G. Mag. 1881, p. 235. See also H. H. Howorth, G. Mag. 1883, pp. 9, 71, 113; and J. G. Goodchild, G. Mag. 1874, p. 496.

[3] R. D. Darbishire, G. Mag. 1865, p. 293; Mem. Lit. and Phil. Soc. Manchester (1864), iv. 41; Q. J. xxx. 38; W. Shone, Q. J. xxxiv. 383; E. Hull and A. H. Green, Geol. Stockport, etc. pp. 77, 95; T. M. Reade, Q. J. xxx. 27, xxxix. 83, 95.

[4] Egerton, Proc. G. S. ii. 189; De Rance, P. Geol. Assoc. iv. 229.

[5] J. Rofe, P. Geol. Assoc. i. 321.

[6] Miss C. Eyton, G. Mag. 1870, pp. 106, 545; J. E. Taylor, *Ibid.* p. 162; E. W. Binney, *Ibid.* 1867, p. 231; G. Maw, Q. J. xx. 130, G. Mag. 1867, p. 279; C. J. Woodward, G. Mag. 1865, p. 567; Geol. and Nat. Hist. Repertory, i. 157; Trimmer, Proc. G. S. ii. 200.

[7] Murchison, Proc. G. S. ii. 231, 334; The Ancient Straits of Malvern, by J. Buckman, [N.D.].

[8] G. Mag. 1867, pp. 248, 335, 382.

In Cardiganshire, near Aberystwith, etc., and over much of Central Wales, there are accumulations of Glacial Drift, consisting of Boulder Clay overlaid by loam, sand, and gravel. The materials are of local derivation. Perched blocks, and Eskers have been noticed.[1]

In South Wales, near Cardiff, Cowbridge and Bridgend, there are extensive deposits of Drift gravel and clay with boulders, which are connected with the Glacial period. West of Llantrissant, Gwaun Ynysplwm might be taken for an old moraine-dammed pool, for it is almost hemmed in on the south by a bank of Drift gravel, exposed in the railway-cutting.[2] In describing the evidences of Glacial action in South Brecknockshire and East Glamorganshire, Mr. J. W. E. David has pointed out grooves and striæ on the surfaces of the Pennant sandstones and Millstone Grit, and *Roches moutonnées* were observed by him in Brecknockshire. (See Fig. 82, p. 475.) The Boulders in the Drifts appear to be almost entirely of local derivation, but Chalk-flints are met with in places.[3]

SOUTH-WESTERN COUNTIES.

There is very little Drift on the Cotteswold Hills, but in the neighbouring vales there is much gravel; this has been divided by Mr. W. C. Lucy[4] and Mr. E. Witchell[5] into the Angular Gravel of the slopes, the rolled Oolitic Gravel of the river valleys, and the Northern Drift. The older or 'Northern Drift' gravel occurs at various elevations and contains fragments of Greensand, Chalk and Chalk-flint, in addition to the more abundant fragments of older rocks. Thus an isolated hill, at Limbury near Hartpury, in the Vale of Gloucester, showed 8 feet of gravel, composed for the most part of pebbles of quartzite, with fragments of Silurian and other strata, besides eruptive rocks. Mr. Lucy has noticed the occurrence of rocks from the North of England; these might have been derived from the Boulder Clay of Cheshire and Shropshire, for the gravel is not of Glacial formation, though it may be connected with the Glacial period. The Oolitic gravel is for the most part modern river gravel, and the Angular gravel is due to the subaërial waste of the hills and escarpments. Quartz pebbles have, however, been found here and there on the higher parts of the Cotteswold Hills, from the neighbourhood of Cheltenham to Bathampton and Farley Downs near Bath.

The Mendip Hills are remarkably free from Drift, but there are deposits of loam and clay, with here and there a boulder of some local rock, whether Old Red Sandstone or Millstone Grit, whose position cannot well be accounted for by the action of rain, rivers, or sea.[6] Near Watchet and at Minehead possible evidences of Glacial action have been described.[7]

In Devonshire and Dorsetshire, on the summits of the hills and high lands formed of the Chalk and Upper Greensand there is generally found an accumulation of materials derived chiefly from those formations. The Chalk itself, as is well known, is frequently capped by a bed called Clay-with-flints, due in part to the dissolution by carbonated water of the Chalk, whereby the insoluble portions and the flints remain (see sequel); and in part to the former presence of Eocene clays. This Clay-with-flints is found in many places near Seaton and Axminster, but it is associated frequently with deposits of Chert detritus, the fragments being sometimes rolled, and transported to a distance (though not necessarily a great one)

[1] W. Keeping, G. Mag. 1878, p. 532, 1882, p. 251.

[2] Science Gossip, Sept. 1880; G. Mag. 1872, p. 574.

[3] Q. J. xxxix. 39. See also Lyell, Address to Geol. Soc. 1836; Murchison, Proc. G. S. ii. 230, and Silurian System; Trimmer, Q. J. ix. 282; W. S. Symonds, Geol. and Nat. Hist. Repertory, i. 148, Records of the Rocks, 1872.

[4] Proc. Cotteswold Club, 1870, and vii. 50; see also Murchison, Proc. G. S. ii. 231.

[5] Proc. Cottesw. Club, vi. 146; see also Hull, Q. J. xi. 487.

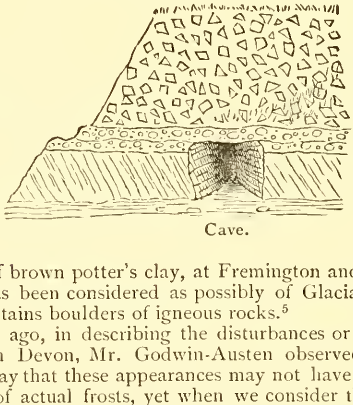
[6] Geol. E. Somerset (Geol. Survey), p. 162.

[7] W. C. Lucy, G. Mag. 1874, p. 256; *Ibid.* p. 573; T. M. Reade, Proc. Liverpool Geol. Soc. 1881.

from the spots where they originally were formed. The flints from the Chalk also are sometimes rolled and transported to positions where they could not have been worked out *in situ*. Mingled with these accumulations we find near Yarcombe and other places between Honiton and Chard many quartz pebbles, and pebbles of hard quartzose grit and quartzite which are evidently foreign to the immediate neighbourhood. Looking at these deposits in a large way, it seems that they may be partly due to the subaërial denudation of the Chalk and Greensand; and if the foreign pebbles be not relics of Tertiary deposits, they may have been introduced during the Glacial period.[1] Near Tiverton also there are considerable accumulations of gravel which may be of Glacial age.[2]

The Gravels and Sands bordering the Bovey Basin near Newton Abbot seem to be connected with the Drifts which cap the Haldon and Blackdown Hills. They appear to have been deposited in this Basin, and perhaps to have filled it, when many of the neighbouring valleys had not been excavated.[3] (See Fig. 30, p. 194.) The deposits consist of coarse gravel and sand with seams of clay; and the stones include large blocks and pebbles of grit, quartz, flint and chert. They have been well exposed at Woolborough and Milber Down. The occurrence of *Betula nana* and *Salix cinerea*, in a superficial deposit at Bovey Heathfield, has been noted by Mr. Pengelly.[4] The same geologist has also described some scratched stones found at Englebourne, and some boulders of hard micaceous sandstone met with at Waddeton near Dartmouth in South Devon, which are suggestive of Glacial action, although the boulders are of local origin. The same is the case in North Devon, at Saunton and other places where boulders have been observed.

FIG. 85.—SECTION OF CLIFFS AT GODREVY, CORNWALL. (W. A. E. Ussher.)
Vertical scale 1 inch to 24 feet.



A deposit of brown potter's clay, at Fremington and Roundswell, south-west of Barnstaple, has been considered as possibly of Glacial age; it is in places 40 feet thick, and contains boulders of igneous rocks.[5]

Many years ago, in describing the disturbances or 'Terminal curvature' of the slate in South Devon, Mr. Godwin-Austen observed that though it would be hazardous to say that these appearances may not have resulted from the long-continued action of actual frosts, yet when we consider the great extent to which this separation of the leaves of the slate has been carried, and the very inconsiderable depth to which frost at present penetrates in this part of England, we seem to require a period with a lower temperature and the action of deeper searching cold.[6]

[1] G. Mag. 1874, p. 335; W. A. E. Ussher, Q. J. xxxiv. 51; Buckland, T. G. S. (2). i. 101, ii. 127; Buckland and De la Beche, T. G. S. (2), iv. 7; Godwin-Austen, Q. J. vi. 91, xiii. 45.

[2] G. Mag. 1872, p. 574.

[3] Q. J. xxxii. 230; see also De la Beche, Geol. Manual, 1831, pp. 157, 190; J. A. Birds, G. Mag. 1878, p. 113; T. Belt, Q. J. xxxii. 80.

[4] Trans. Devon Assoc. xv. 368, vii. 154, ix. 177, xii. 304; see also G. W. Ormerod, G. Mag. 1869, p. 40; G. Maw, Q. J. xx. 451.

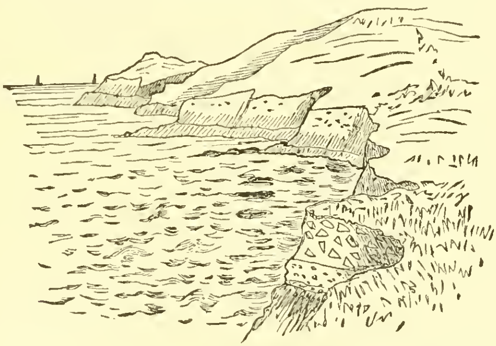
[5] G. Maw, Q. J. xx. 445; G. Mag. 1865, p. 526; Ussher, Q. J. xxxiv. 450.

[6] T. G. S. (2), vi. 433; see also De la Beche, Geol. Manual, p. 41.

The phenomena have been described more particularly by Mr. D. Mackintosh[1] and Mr. W. A. E. Ussher.[2] Good instances are noted at Gupworthy, near Wiveliscombe, Slapton, and other places in Devon, and also south of the Carclaze mine in Cornwall ; and while some appearances are due to contortions, and some to the intrusion of roots of trees and the action of frosts, etc., the more extensive bending-back of the slates has been attributed to land-ice or to the grazing force of grounding ice-bergs. (See p. 13, and Fig. 18, p. 132.)

Certain accumulations of angular detritus and stony loam termed "Head," seen along the coasts of Cornwall and parts of Devon, are probably the equivalents of Glacial deposits elsewhere.[3] They are the result of great subaërial waste, and suggest a more rigid climate. The Head, as pointed out by Mr. Ussher, is newer than the Raised Beaches, as it frequently rests upon them. (See Figs. 85, 86.)

Fig. 86.—The Coast towards Rosemullion Head, near Falmouth. (W. A. E. Ussher.)



Rock-platforms, and Cliffs composed of Head resting upon Raised Beach.

In his opinion, the oldest Drifts in Cornwall are probably the quartz gravels of Crousa Down, in the Lizard district. Some of the features of the country have, it is thought, been produced by Glacial action.[4]

Pebbles and boulders of quartz, granite, and porphyry have been found on the high grounds near Poole in Dorsetshire, and also in the Isle of Wight. (See Fig. 73, p. 428.) Flint-gravel occurs on Headon Hill, Brading and Bembridge Downs, and in the New Forest.[5]

On the south coast of England, at Brighton, and westwards, between the Chalk-hills and the sea, the surface of the country is formed by a raised terrace of beds locally known as the 'red gravels,' and the 'white gravels,' the former, as Mr. Reid informs me, being simply due to the dissolution of Chalk fragments from the latter. The gravels are, in places, overlaid by brickearth, which is somewhat variable in its characters ; and they are underlaid by a marine 'Mud-deposit.' (See sequel.)

At Selsea and Siddlesham the gravels are about 25 feet in thickness, they become clayey, and contain a variety of pebbles and boulders of granite, syenite,

[1] Q. J. xxiii. 323 ; G. Mag. 1878, p. 190.

[2] Q. J. xxxiv. 52 ; see also O. Fisher, G. Mag. 1873, p. 164.

[3] Godwin-Austen, Q. J. vii. 118, xxii. 1 ; Ussher, Post-Tertiary Geology of Cornwall, 1879, pp. 10, 42 ; G. Mag. 1879, pp. 102, 109, 168, 205, 208.

[4] H. C. Salmon, Q. J. xvii. 517 ; G. H. Kinahan, G. Mag. 1870, p. 310 ; N. Whitley, Glacial Action in Cornwall and Devon (Penzance), 1881. See also Dr. J. F. Berger, T. G. S. i. 99.

[5] Trimmer, Q. J. x. 15 ; Godwin-Austen, Q. J. xi. 116 ; C. Evans, P. Geol. Assoc. ii. 170 ; T. Codrington, Q. J. xxvi. 538.

diorite, mica-schist, slaty, and old fossiliferous rocks. One boulder measured 27 feet in circumference. These beds have been described by Mr. Godwin-Austen as Glacial deposits.[1] The transported fragments may have come from the coast of Normandy and Brittany, or from old rocks (now destroyed) that may have been nearer; and many of the boulders are so large that they must have been drifted into their present positions by coast-ice. The gravel contains a few littoral shells of living species, indicating an ancient coast-line. The superficial deposits of the south-east of England exhibit no positive evidence of Glacial action.[2]

MIDLAND COUNTIES.

In the Midland Counties there are extensive deposits of Drift formed of rocks from many different formations. The area between Wolverhampton and Stafford may, in the opinion of Mr. Mackintosh, be regarded as the meeting-ground of erratics from the N.N.W., and of erratics from the E.N.E., the former chiefly granite and felstone, the latter chiefly Cretaceous and Jurassic débris. These deposits he regards as a southerly continuation of the Lower Boulder-clay of Lancashire, Cheshire, etc., and as passing into the Chalky Clay of the Eastern counties. The true Chalky Clay, both in his opinion and in that of Mr. W. J. Harrison, does not extend much further west than Charnwood Forest.[3] It has, however, been observed in a railway-cutting between Kenilworth and Berkeswell, west of Coventry.[4] There is no evidence of Upper and Lower Boulder Clays in the area around Wolverhampton and Stafford; but these divisions, with intervening Middle Drift, have been found by Dr. Crosskey at 'California,' Harborne, near Birmingham.[5]

The Drift of Warwickshire contains pebbles similar to those in the Trias of Budleigh Salterton in Devonshire, and derived from the Bunter Pebble-beds of Cannock Chase, etc. (See p. 225.) Much of the country north-west of Rugby, also around High Cross, near Wibtoft (known as 'the centre of England'), is covered with stony clay, sand, and gravel. At New Bilton, near Rugby, the Lias clay beneath the Drifts is contorted.[6] Erratics from Mount Sorrel occur at Leicester and Coventry, indicating in that neighbourhood a south-westerly dispersion of rocks from the Charnwood district.[7]

At Tickhill, west of Bawtry, the Drift clay is used for brick-making; and at Annesley, in Nottinghamshire, Mr. Aveline describes the gravel as sometimes cemented together into a breccia, and at Blidworth this forms isolated masses popularly known as Druidical remains.

Quartzose gravel occurs in places on Wychwood Forest, north-west of Oxford, aud there is much Drift clay and gravel around Buckingham.

The older geologists were much puzzled to account for the occurrence of fragments and masses of Chalk far away from the formation where it occurs *in situ*: thus such masses were noticed at Sywell in Northamptonshire, at Ridlington in Rutlandshire, and at Stukeley in Huntingdonshire.[8] They are now known to form part of the Glacial Drift, and similar transported beds occur in Norfolk and elsewhere. (See sequel.)

[1] Godwin-Austen, Q. J. xiii. 46, 59, xii. 4.

[2] See Murchison, Q. J. vii. 349.

[3] Q. J. xxxv. 451, xxxvi. 178. See also Jukes, S. Staff. Coal-field, ed. 2, p. 207; and Memoirs of H. E. Strickland, by Sir W. Jardine, 1858, pp. 90, 105.

[4] W. Andrews, Proc. Warwick Field Club, 1884, p. 32. See also P. B. Brodie, Q. J. xxiii. 208, 209; Rev. A. H. W. Ingram, Q. J. xxxv. 678.

[5] H. W. Crosskey, Proc. Birmingham Phil. Soc. iii. iv.; Crosskey and C. J. Woodward, *Ibid.* 1873, p. 43; see also Brodie, Q. J. xxxvii. 434.

[6] J. M. Wilson, Q. J. xxvi. 192.

[7] Rev. W. Tuckwell, Brit. Assoc. 1886.

[8] Conybeare and Phillips, Geol. Eng. and Wales, p. 63; Buckland, T. G. S. v. 539; Fitton, T. G. S. (2), iv. 308.

The Drift deposits of the Trent Basin have been divided as follows, by Mr. R. M. Deeley :—

Newer Pleistocene	Later Pennine Boulder Clay. Interglacial River Alluvium.
Middle Pleistocene	Chalky Sand and Gravel. Great Chalky Boulder Clay. Melton Sand.
Older Pleistocene	Middle Pennine Boulder Clay. Quartzose Sand. Early Pennine Boulder Clay.

The Early and Middle Pennine Boulder-clays, which closely resemble each other, are composed of materials derived almost entirely from the Derbyshire hills, but with a slight admixture (to the westward) of erratics derived from Scotland and Cumberland. The latter were probably brought from those districts by an ice-stream, the main materials of the deposits having been transported from the Pennine chain by glaciers, and deposited in the partially submerged valley of the Trent. The intermediate quartzose sand was deposited in the sea during a milder interval attended by considerable submergence. The Middle Pleistocene deposits, distinguished from the earlier beds by containing large quantities of chalk and flints derived from the north-east, were apparently formed at a time when the level of the Trent valley was lower than that of the Cretaceous tracts in Lincolnshire and Yorkshire. The Chalky Boulder-clay was chiefly a ground-moraine formed beneath an ice-sheet on land, but in places it presents signs of aqueous origin. The Melton sand (of Melton Mowbray, etc.), in which Cretaceous detritus first appears in abundance, consists of sands with occasional beds of gravel or loam, and indicates a less extreme temperature. In West Staffordshire the gravels and sands probably represent the entire Middle Pleistocene deposits, no Chalky Boulder-clay being found, and in this area fragments of marine Mollusca are of frequent occurrence. The Chalky Gravel was also a marine deposit, and, like the Melton Sand, was probably formed when the temperature was rather milder than it was during the deposition of the Chalky Boulder-clay. In the newer Pleistocene epoch re-elevation of the Trent valley and of the Pennine chain appears to have again produced a change in the direction from which the materials of the deposits were derived. The Interglacial Alluvium was of fresh-water origin, but the admixture of Scotch and Cumbrian detritus with that derived from the Pennine range indicates that glaciers from the north again reached the Trent area. A colder age succeeded, during which the Later Pennine Boulder-clay was formed, partly of local materials, partly of erratics from the Pennine range, mixed with a few from Cumberland and even from Wales. This deposit is almost entirely unstratified, and consists largely of moraine detritus, the ice-sheets having disturbed and rearranged the earlier deposits and mixed them with rock-detritus from the neighbourhood. To this later ice-sheet may be attributed the contortions so frequently observed in the older and middle Pleistocene deposits, disturbances which could not be accounted for by soil-cap motions.[1] While Drift occurs in the plains east and west of the Pennine chain, the higher grounds are comparatively free from it.[2]

NORTH-EASTERN AND EASTERN COUNTIES.

In the north-east of Yorkshire, the table-land of the Oolites is remarkably free from Glacial Drift ; thus Boulder Clay extends to a height of about 800 feet in some of the valleys, but the uplands appear to have formed an insular space round which the ice-sheets swept, but which was not itself buried up. This is in

[1] R. M. Deeley, Q. J. xlii. 437.

[2] Geol. N. Derbyshire, by A. H. Green, C. Le N. Foster, and J. R. Dakyns, p. 127 ; see also J. Aitken, Q. J. xxxii. 184.

striking contrast with the dales of the West Riding, where the hill-tops, 2300 feet high, are distinctly glaciated.[1]

Near Middlesborough a laminated brickearth of Glacial age has been employed at the Linthorpe pottery.

In the neighbourhood of York the Boulder Clay rests on the Trias, and is capped by Glacial gravels and brickearth. In the Boulder Clay itself there are contorted bands of sand and laminated clay, as in the Contorted Drift of Norfolk.[2] A considerable amount of Boulder Clay extends along the Yorkshire coast, from Flamborough northwards. The beds are in places capable of division into Upper and Lower Boulder Clay and Middle Sands. The Lower Boulder Clay contains many large boulders of Shap Granite, Carboniferous Limestone, etc. The Middle Sands are shown in the cliffs of Robin Hood's Bay. Eskers have been observed in some of the Yorkshire valleys.[3]

In the cliffs of Holderness the Glacial Beds are grouped as follows :—

Hessle Clay.
    Hessle Gravel (of Mr. Wood), unfossiliferous.
Upper Purple Clay.
Lower Purple Clay.
    Kelsea Hill Gravel.
    Hessle Mammaliferous Gravel?
Basement Clay,
    With Bridlington Shell-bed.

Our knowledge of these beds is mainly due to the observations of Mr. S. V. Wood, jun., the Rev. J. L. Rome, Mr. G. W. Lamplugh, and Mr. C. Reid.

Bridlington Shell-bed.—The Basement Clay, originally described by Mr. S. V. Wood, jun., is a dark green or bluish Boulder Clay, containing numerous erratic Boulders and much Chalk. Its most marked characteristic, and one that distinguishes it from other Boulder Clays in the East of England, is the common occurrence in it of transported masses of olive-grey sand and clay containing Mollusca, often quite uninjured and with the valves united. These fossiliferous beds have been considered to be in place, and they have been designated the Bridlington Crag.[4] The shells were originally noticed by Sedgwick, and later on by William Bean, John Phillips, and others ; their occurrence in the Glacial Drift was first pointed out by Mr. Wood.[5] Still more recently Mr. G. W. Lamplugh has had opportunities of studying exposures of the shelly beds at Bridlington (or Burlington) Quay, and he has proved that they are included in the Basement Clay, and not in the Purple Clay, as stated by Mr. Wood.[6] The beds, however, are only visible, in places, at low-tide.

Similar shelly layers occur in the Basement Clay at Dimlington, where a seam with perfect specimens of *Nucula Cobboldiæ* was found by Sir Charles Lyell and Prof. Hughes ; and broken shells are also found in the Clay itself. In the former case, as with the Bridlington shell-bed, the shelly layers occur as Boulders ; and Mr. Lamplugh has given his reasons for concluding that the shells lived on an old sandy sea-bottom, which was afterwards covered by a thick deposit of glacial

[1] Geol. of Eskdale, etc. (Geol. Survey), notes by C. Reid, and G. Barrow, p. 51.

[2] J. E. Clark, Proc. Yorks Geol. and Polyt. Soc. 1881, vii. 421 ; Rev. W. Thorp, *Ibid.* iii. 244 ; C. F. Strangways, Geol. N.E. of York, etc. p. 29 ; Strangways and G. Barrow, Geol. Whitby and Scarborough, p. 52 ; J. R. Mortimer, P. Geol. Assoc. viii. 287.

[3] J. R. Dakyns, Q. J xxviii. 382 ; G. Mag. 1879, p. 382.

[4] C. Reid, Geol. Holderness, p. 8.

[5] Ann. Phil. (2), xi. 339 ; Bean, Mag. Nat. Hist. viii. 355 ; Lyell, *Ibid.* (2), iii. 313 ; Phillips, Geol. Yorkshire, Part 1, ed. 3, p. 87 ; Sorby, Proc. Geol. and Polyt. Soc. W. Riding, iii. 559 ; Wood, G. Mag. 1864, p. 246.

[6] G. Mag. 1878, p. 509, 1879, p. 393, 1881, pp. 537, 543, 1882, p. 383 ; Proc. Geol. and Polyt. Soc. W. Riding (2), vii. 383, viii. 27, 240 ; Q. J. xl. 312.

mud; and then the whole was subjected to some disturbing force—ice in some form—which removed it piecemeal, perhaps in frozen masses.[1]

The Molluscan fauna of the Bridlington Crag is essentially Arctic in character. The species include *Saxicava rugosa*, *Pecten Islandicus*, *Pectunculus glycimeris*, *Cardium Islandicum*, *C. Grœnlandicum*, *Nucula Cobboldiæ*, *Cyprina Islandica*, *Astarte borealis*, *A. depressa*, *Tellina Balthica*, *Scalaria Grœnlandica*, *Buccinum undatum*, *Trophon scalariformis* (*clathratus*), etc.; also *Rhynchonella psittacea*.[2] Foraminifera and Ostracoda have been determined, as well as a few Cirripedes. Some Vertebrata occur, which have been derived from Crag, Eocene, and older strata.

Beds of laminated clay, bedded loam and sand from 4 to 20 feet thick, occasionally intervene between the Basement Clay and overlying Purple Clay; and the latter appears in some places to be stratified.[3]

Overlying this Basement Clay, there are in Yorkshire beds of a purplish-brown colour termed the 'Purple clay' by Mr. S. V. Wood, jun., and the Rev. J. L. Rome.[4] This clay has the most extensive development of any bed superior to the Chalk in this county, not only overlapping the Basement clay in all directions, but extending far beyond the north scarp of the Wolds in an irregular belt along the coast northwards. In its lower portion it abounds with boulders of older Secondary, Palæozoic, and Metamorphic rocks, and in Holderness it contains considerable quantities of Chalk.

The Lower Purple Clay is described by Mr. Reid as a tough lead-coloured or purplish-blue Boulder Clay, generally very chalky near the base, but less so in the upper part. It contains shell-fragments and many scratched boulders.

The Upper Purple Clay is very similar to the Lower, but contains few shell-fragments. It includes the 'Purple Boulder Clay without Chalk' of Mr. Wood. The two Clays are sometimes separated by a few feet of gravel, or by a "red band" of reconstructed Boulder Clay. Above the Upper Purple Clay there occurs, in places, stratified sub-angular gravel, which is thicker and more persistent than the lower beds of gravel; it was termed the Hessle Gravel by Messrs. Wood and Rome, from Hessle, west of Hull, and is probably distinct from the mammaliferous gravel of Hessle, and the marine gravel of Kelsey Hill. Upon this gravel rests the Hessle Clay of Mr. Wood. This Clay, sometimes known as the 'Brown Clay,'[5] is not distinguishable, when unweathered, from the Purple Clays, though the boulders are generally smaller and less abundant, and shell-fragments, rare in the Upper Purple Clay, have not yet been found in the Hessle Clay. Indeed, Mr. Reid states that the three Boulder Clays are so much alike, that, without continuous sections, it is impossible to say to which division an isolated exposure belongs.[6] The beds of Boulder Clay vary from 10 to 40 feet in thickness, and the total thickness of the Drifts is upwards of 100 feet.

Hessle and Kelsey Hill Beds.—Inland at Hessle remains of *Elephas primigenius*, *Rhinoceros*, etc., have been found in gravel and sand beneath Boulder Clay. The precise age of the deposit is not fixed; it rests on Chalk, and is overlaid by Boulder Clay, but that Drift cannot be correlated with any particular division of the Boulder Clay exhibited on the Holderness coast, though undoubtedly it belongs to the series. According to Mr. Reid this mammaliferous deposit is probably older than the so-called Hessle gravel of Messrs. Wood and Rome, seen on the coast between the Upper Purple Clay and the Hessle Clay. At Kelsey Hill near Hedon, and other places near Hull, there is a deposit of gravel containing fragments of marine shells, *Purpura lapillus*, *Buccinum undatum*, *Ostrea edulis*, *Cardium edule*, *Cyprina Islandica*, *Tellina Balthica*, etc.; and also *Corbicula fluminalis*, *Elephas primigenius*, and *Rhinoceros*. The gravel is upwards of 60 feet thick at Kelsey Hill, and it is underlaid and overlaid by Boulder Clay. The land

[1] Q. J. xxxvi. 515.
[2] S. P. Woodward, G. Mag. 1864, p. 49; C. Reid, Geol. Holderness, p. 22.
[3] See also J. R. Dakyns, G. Mag. 1879, p. 528.
[4] Q. J. xxiv. 184.
[5] See also Whewell, Proc. G. S. ii. 638, iii. 83.
[6] Geol. Holderness, p. 27.

and freshwater remains were no doubt brought down by a river. Similar beds were seen at High Paull Cliff. South of the Humber the gravel is shown near Ulceby, at Great Coates and other places.[1]

These marine gravels can be traced round the ancient bay of Holderness, which was bounded by Chalk cliffs. They are probably of the same age as the March gravels, but possibly older than the Basement Clay, or intermediate between it and the Purple Clays; but these fossiliferous beds are not shown in the coast-section. At Speeton there is a sandy shell-bed beneath the Lower Purple Clay which corresponds with the Marine gravels of Kelsey Hill;[2] and at Aby near Claythorpe in Lincolnshire, similar shelly gravels occur.[3] At the former locality the following beds are exposed:[4]—

Upper Purple Clay	30 feet.
Sand and Gravel	5 ,,
Lower Purple Clay	10 ,,
Sandy Shell-bed	16 ,,

The cliff at Cleethorpes, about 40 feet high, is the only cliff in Lincolnshire, and it exhibits a purple stony Boulder Clay which seems to correspond with the higher divisions of the Holderness coast—the Hessle Clay and the Upper Purple Clay.

Inland in Lincolnshire the Hessle Clay is usually a reddish-brown mottled clay, while the Purple Clays are blue and grey. They occupy low levels on the western edge of the Fenland, and to the east of the Lincolnshire Wolds.[5] The Chalky Boulder Clay occupies a tract between the Chalk Wolds and the Cliff range (Oolites); it is seen around Corby, Ponton, Horncastle, Tattershall, etc. There are no clear sections showing the junction of Chalky Boulder Clay with the newer Boulder Clays. The Hessle Clay is shown in brickyards near Alford. Coarse flint-gravel, with boulders of Chalk, occurs in places as at Wrawby; similar gravel occurs at Wells, in Norfolk.

In the Stoke cutting, south-west of Great Ponton, on the Great Northern Railway, and south of Grantham, in Lincolnshire, a section was exposed, showing Boulder Clay that contained an enormous irregular mass of Oolitic rock (Lincolnshire Limestone), 430 feet long, and, at its deepest part, 30 feet thick. It was much broken and disturbed, but the parts retained to some extent their relative position, and although distinctly isolated, the mass had not been far removed from its original site.[6] Other re-deposited masses of Oolitic rock and Marlstone have been noticed in the district, sometimes of sufficient bulk to be quarried.

At Roslyn Hole or Roswell Hill, near Ely, a large transported mass of Chalk rests in places on the Kimeridge Clay.[7] This mass forms part of the Boulder Clay, which is probably the same as the Chalky Boulder Clay of Norfolk and Suffolk, although the large re-deposited masses of Chalk met with in the Norfolk cliffs occur in the Contorted Drift. (See sequel.) The Boulder Clay covers much of the country west of Cambridge, it skirts the Chalk escarpment, and occurs in isolated patches at various levels, as at Gog Magog and Balsham.[8] (See Fig. 68, p. 411.)

[1] Prestwich, Q. J. xvii. 446; Reid, Geol. Holderness, p. 51.

[2] Reid, *op. cit.* p. 69.

[3] Jukes-Browne, Geol. East Lincolnshire (Geol. Surv.).

[4] Lamplugh, G. Mag. 1881, p. 177.

[5] Reid, Geol. Holderness, pp. 35, 43; Jukes-Browne, Q. J. xxxv. 399, xli. 124, 131; Geol. S. W. Lincolnshire, p. 85.

[6] J. Morris, Q. J. ix. 318; Judd, Geol. Rutland, etc., p. 246; Jukes-Browne, Geol. S. W. Lincolnshire, p. 81.

[7] O. Fisher, G. Mag. 1868, p. 407; T. G. Bonney, *Ibid.* 1872, p. 403; Skertchly, Geol. Fenland (Geol. Surv.), p. 238.

[8] Jukes-Browne, Post-Tertiary Deposits of Cambridgeshire, 1878; Penning and Jukes-Browne, Geol. Cambridge, p. 73; Penning, Q. J. xxxii. 191.

The Glacial Drifts of the Eastern Counties have been divided as follows :—

Upper Glacial	Plateau Gravel. Coarse "cannon-shot" gravel and sand.	
	Chalky or Upper Boulder Clay.	
Lower Glacial	"Middle Glacial" Sand and Gravel.	
	Contorted Drift. Stony loam or brickearth.	Lower Boulder Clay.
	Cromer Till.	

Our knowledge of these beds is largely due to the observations of Mr. S. V. Wood, jun., and Mr. F. W. Harmer;[1] while the occurrence of an Upper and Lower Boulder Clay at Corton in Suffolk was first pointed out by Mr. John Gunn.[2]

The Lower Glacial Beds of Norfolk have a maximum thickness of about 200 feet; they are well shown in the 'Mud cliffs' between Weybourn and Eccles, that in places rise to a height of upwards of 200 feet, but the thickness of the beds is often exaggerated by contortion.[3] As a rule, the Lower Glacial Drifts rest on a very even surface of the Forest Bed Series, which consists of sands, gravels, and laminated clays. Mr. Reid mentions, however, that in places where the Till rests on laminated clays, the beds have been slightly crumpled.

Cromer Till.—This is a tough bluish-grey unstratified Boulder Clay, containing fragments of *Tellina Balthica*, *Mya arenaria*, *Cardium edule*, and *Cyprina Islandica*. It contains also many glaciated fragments of Chalk and flint, of septaria (probably from the Kimeridge Clay), fragments of Lias, and Carboniferous Limestone; as well as many Igneous and Metamorphic rocks, such as mica-schist, granite, felstone, basalt, etc. In this Till fine examples of glaciated stones are more abundant than in any other Drift in Norfolk, and Mr. Reid has observed that the fragments of septaria and Chalk have sometimes been bored by Annelides, and subsequently striated. The Till rests in places on an Arctic Freshwater Bed (see p. 474), below which are the Pliocene strata (Forest Bed Series, etc.); it is best exhibited in the neighbourhood of Happisburgh (Hasboro) and Mundesley, but is impersistent in the coast-section, for Mr. Reid has not traced it so far west as Cromer. It forms a band that can generally be recognized, but it is sometimes separated into an upper and lower Till, by intervening laminated and ripple-marked clays and marls.[4] (See p. 484.) Inland it is not to be distinguished from the Contorted Drift.

Contorted Drift.—This deposit consists largely of brown stony loam, sometimes well stratified and containing seams of gravel and sand, at others containing seams of chalky loam or boulder clay, and exhibiting most violent and remarkable contortions. Hence the name Contorted Drift, applied by Lyell. It can be studied in the cliffs between Eccles and Mundesley, where the main portion of the cliffs is made up of this brown loamy deposit, which rests on the blue Cromer Till; here the beds are but little disturbed. The contortions become conspicuous west of Mundesley, and thence near to Cromer, and between Cromer and Weybourn seams of very chalky loam, marl, or boulder clay occur here and there in isolated irregular and lenticular masses; the Drift becomes, in fact, a conglomeration of all kinds of sediments, containing masses or nests of sand with marine shells, and sometimes coarse gravel, although loam and marl predominate. In many places the beds are disturbed and twisted into **S**-shaped contortions.

Among the remarkable features of this Contorted Drift are the large boulders which it contains, not merely those of quartzite, grit, schists, gneiss, granite, and

[1] G. Mag. 1870, p. 18; see also Supplement to Crag Mollusca (Palæontograph. Soc.), with geological map of the Crag district; and Wood, Q. J. xxxvi. 457, xxxviii. 667. For list of works on the Geology of Norfolk, see Geol. Norwich (Geol. Survey); and for list of works on Suffolk, see Geol. Ipswich, by W. Whitaker.

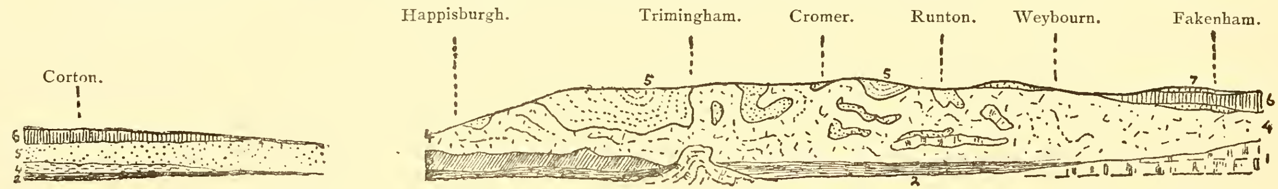
[2] Trimmer, Q. J. xiv. 171.

[3] See diagrams of Coast-sections by S. Woodward, Geol. Norfolk, 1833; Wood, jun., Remarks in Explan. of Map, 1865 (privately printed); C. Reid, Horizontal Section (Geol. Survey), Sheet 127.

[4] Reid, Geol. Cromer, p. 86.

Fig. 87.—Diagrammatic Section to illustrate the mode of Occurrence of the Glacial Drifts in Norfolk and part of Suffolk.

The length of the cliff-section from Happisburgh to Weybourn is about 20 miles, and the distance inland from Weybourn to Fakenham is about 14 miles. Between Corton and Happisburgh there is a gap of about 20 miles; the portion of the cliff shown at Corton represents about 5 miles. The vertical scale is exaggerated, and the geological details are generalized.



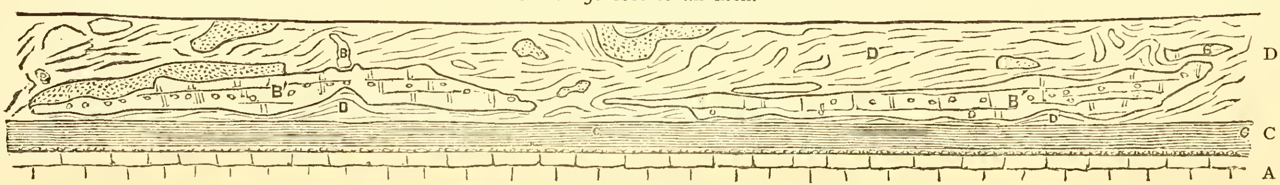
7. Cannon-shot Gravel.
6. Chalky or Upper Boulder Clay. } Upper Glacial.

5. Middle Glacial Sand and Gravel.
4. Contorted Drift. } Lower
3. Cromer Till. } Boulder Clay. } Lower Glacial.

2. Weybourn Crag and Forest Bed Series. } Pliocene.
1. Chalk.

Fig. 88.—Cliff-section West of Wood Hill, Runton, near Cromer. (C. Reid.)

Scale 150 feet to an inch.



B. Boulders of Chalk.
A. Chalk.

D. Contorted Drift (Boulder Clay, with masses of sand).
C. Forest Bed Series (undisturbed).

basalt, of which blocks measuring over 6 feet in length have sometimes been found ; but huge boulders of Chalk-with-flints, one re-deposited mass or rather strip of which was upwards of 180 yards in length. These masses are well seen between East Runton and Sherringham.[1] (See Fig. 88.)

Messrs. Wood and Harmer attribute the formation of the marly portion of the Contorted Drift to a discharge of ground-up Chalk from the *débouchure* of a Glacier that occupied the Chalk country to the west ; the brickearth or stony loam which forms the easterly development of the Contorted Drift being due to a river discharge in that part ; the two sediments intermingling in the intermediate area, and producing the alternations of marl and brickearth there presented by this formation. The detached masses of the marl were, they consider, introduced into the brickearth portion of the deposit by the agency of bergs, which, breaking from the Glacier and grounding, picked up masses of the marl forming over the sea-bottom in that part of the area. These masses the bergs carried out into the area where the brickearth was accumulating, and grounding again, embedded them in the brickearth, and even in the subjacent Till, contorting the beds in the process. From detached portions of this marl, which they have found as far south as Claydon, near Ipswich, and Stanstead, near Lavenham, in Suffolk, they infer that this deposit covered the west of Suffolk and Norfolk, but underwent denudation in the former area during 'Middle Glacial' times, the sands of that age, west and south of Diss, being banked up to bosses of it in some parts, and overlying it in others. In fact, it was the opinion of Messrs. Wood and Harmer that during the interval between these deposits, the valley system of East Anglia was marked out.[2] The contortions have also been attributed partly to the thawing of masses of ice which had been fixed among the beds during their deposition.

Although the term Contorted Drift is usually confined to the Lower Glacial Beds, yet similar contortions also affect the Chalk and sometimes the Norwich Crag ; and there are strong reasons for believing that the disturbances were produced by the agent which formed the Chalky Boulder Clay, a view first suggested by Mr. S. B. J. Skertchly. (See sequel.)

The Cromer Till may be regarded as the product of an ice-sheet, deriving its shell-fragments from the bed of the sea or from Pre-glacial deposits over which the material was pushed. Submergence following, the succeeding Contorted Drift, which exhibits evidence of stratification and sometimes of ripple-marks, was probably deposited in the sea ; while some of the large blocks of igneous and metamorphic rocks may have been brought by ice-bergs, perhaps from the Scandinavian area. The Middle Glacial sands and gravels succeeded the more muddy sediments, and all these deposits were subsequently acted upon by a force sufficient to produce the violent contortions before mentioned ; but before attempting to explain them, it is desirable to describe these sands and gravels and other overlying Glacial Drifts.

Inland many large boulders have been taken out of the Lower Boulder Clay, or have been turned up during the ploughing of land in tracts where this formation is uppermost. These have, in numerous instances, been removed to the adjacent village or homestead to serve some useful purpose.

The Contorted Drift is extensively worked for bricks around Norwich, North Walsham, Aylsham, and many other parts of Norfolk ; it is sometimes called the Norwich Brickearth. In Suffolk it has been observed at Somerleyton, Beccles, Harleston, Woolpit, Boxted, Sudbury, Kesgrave, Hasketon, etc.[3] At Woolpit there is a laminated clay which has been celebrated for the manufacture of white bricks since the time of Queen Elizabeth.[4] At Diss, and also near Surlingham and Rockland, there are beds of laminated brickearth which have been employed for brickmaking. (See p. 467.)

The marl beds are worked for lime at Weybourn, Holt, Heydon (hydraulic cement), and other places.

[1] Wood, G. Mag. 1868, p. 454 ; Reid, G. Mag. 1880, p. 62.
[2] G. Mag. 1868, p. 454 ; Q. J. xxxiii. 78 ; Q. J. xxxvi. 471.
[3] G. Mag. 1868, p. 454.
[4] J. H. Blake, Geol. Stowmarket (Geol. Surv.), p. 13.

Middle Glacial Beds.—The Middle Glacial beds (or Middle Drift of Mr. Wood) consist of gravel and sand, with occasional beds or seams of chalky Boulder Clay, near Hertford. The gravel is largely composed of Chalk flints both subangular and rolled, and pebbles of quartz and quartzite. Its thickness varies from 10 to upwards of 70 feet. In some localities sand predominates, in others gravel, and occasionally a good deal of brickearth is associated with the beds. The sand sometimes contains pebbles or grains of Chalk. The term Boulder Sands and Gravels was used by Prof. Prestwich. The gravel in some places contains a great many rolled fossils derived chiefly from Jurassic rocks. The pits at Muswell Hill and Finchley, owing to the labours of Mr. N. T. Wetherell, have yielded a large number of specimens (see p. 506); and these fossils occur in many other places, at St. Ives, Somersham, etc.

On the Norfolk coast large basins or pockets in the Contorted Drift are filled with Middle Glacial sand and gravel, and these features are for the most part due to contortion. (See Figs. 81, 87, 88, pp. 472, 502.) The sands and gravels form portions of the higher grounds near Cromer, and they are well exhibited in the cliffs near Yarmouth and Lowestoft. The sands in places contain shoals of broken shells, and these, more conspicuous in the cliffs at Gorleston, Hopton, and Corton, between Yarmouth and Lowestoft, were noticed by the earlier geologists as re-deposited Crag shells. Thus shells were found at Caistor, near Yarmouth, in 1836, by Mr. John Cunn; and they have been found also at Billockby, in the same neighbourhood.[1] Messrs. Wood and Harmer have procured upwards of 100 species of Mollusca from these sands, and the assemblage is a very curious one.[2] With the exception of one *Venus*, a *Loripes*, and some new species, all the shells are found in our Crag deposits; but while including a number of species which might have come out of the Coralline, Red, and Norwich Crags, yet "not a trace or fragment of most of the common strong shells of the Coralline and Red Crags has occurred." Nearly all the specimens found are more or less rolled, but fragile shells like *Anomia ephippium* are occasionally preserved. Messrs. Wood and Harmer conclude that the fauna was contemporaneous, although the shells bear evidence of having been shifted and rolled by currents which brought them from some other part of the sea-bottom; while in their opinion some of the delicate shells may have been transported by floating masses such as seaweed.

Mr. Clement Reid, who has carefully examined the shells found in the Glacial sands of the Cromer Cliffs, remarks: "It is not improbable that a large proportion of the fragments of the common shells may be derivative; but near Cromer, as at Yarmouth, the peculiar and characteristic types are the most perfect. Though the commonest forms are *Tellina Balthica*, *Cardium edule*, *Cyprina Islandica*, and *Mya arenaria*, of the last three nothing but small fragments were seen, and of *Tellina Balthica* only a few nearly perfect valves; but the single specimens of *Nassa reticosa*, *Anomia*, and *Dentalium* were nearly perfect, as were two or three of *Scalaria Grœnlandica* and *Natica Grœnlandica?* The re-appearance of Crag forms may be explained by the submergence of the land to a greater extent than had occurred since the time of the Coralline Crag, thus re-opening the connection with the southern seas, and allowing species long exterminated in this area to again migrate into it."[3] There is nevertheless room for great doubt about the shell fauna being contemporaneous. Traced southwards, these so-called Middle Glacial Sands pass mostly into gravels, which underlie the Chalky Boulder Clay over a considerable part of Essex, and only in two or three places in Suffolk, south of Corton, have fragments of Crag shells been found in the Drift of this portion of the eastern counties. Moreover, near Hertford and other places, seams of Boulder Clay have been met with in gravel beneath the main mass of Chalky Boulder Clay—which gravel has been grouped as Middle Glacial by Mr. Wood,[4] and this does not support the view of a much milder climate; while the Ostracoda

[1] See also Rose, P. Geol. Assoc. i. 193.
[2] See Supplements to Crag Mollusca (Palæontograph. Soc.).
[3] Geol. Cromer, pp. 93, 94.
[4] See Whitaker, Guide to Geol. London, ed. 4, p. 62.

from the Sands at Hopton Cliff, near Yarmouth, present "a general Arctic character."[1]

Mr. T. F. Jamieson has described beds of Drift sand and gravel on the eastern border of Aberdeenshire, which contain fragments of shells, comprising forms found in the Coralline, Red, and Norwich Crags, as well as in more recent deposits, although all of the species, excepting *Tellina Balthica*, occur in the Red Crag.[2] The Bridlington shell-bed also contains fossils derived from the Crag. Hence all difficulty is removed in seeking a northern derivation for the shell accumulations in the so-called "Middle Glacial" Sands of East Anglia. Moreover, local geographical distribution of the Mollusca in the Crag period may account for the peculiarities in the fauna. At any rate we are justified in making the suggestion that the Middle Glacial shells may have been largely derived from old Crag accumulations, now entirely destroyed or buried up beneath the waters of the North Sea.[3]

The Westleton beds, which Prof. Prestwich described in 1870, from the village of Westleton, between Yoxford and Dunwich in Suffolk, attain at this typical locality "a thickness of from 30 to 40 feet, and consist of a series of stratified beds of well-rounded flint-pebbles imbedded in white sand, and with two or three subordinate beds of light-coloured clay," looking as Prof. Prestwich remarked, "more like the pebble-beds of Blackheath than any other beds in the Eastern counties."[4] Continuations of these Westleton Beds have been traced to Southwold, Dunwich (top of cliff), Henham Park, Halesworth, Haddiscoe, Thorpe-next-Haddiscoe, and Chedgrave, near Loddon—localities which are rarely fossiliferous, and yield no distinctive species. In Norfolk, however, the Westleton Beds have been correlated with the Bure Valley Beds, and with the Mundesley Beds; but the pebble-beds at Dunwich, which are clearly the same as those at Westleton, occur in the 'Middle Glacial' Beds of Mr. S. V. Wood, jun. Hence, the Westleton Beds are in reality distinct from the Bure Valley Beds (Norwich Crag Series), and they cannot be definitely correlated with the Mundesley Beds which underlie the Lower Glacial Drift on the Norfolk coast.[5] (See p. 469.)

The Middle Glacial Sands are frequently cemented into a hard rock, more especially at or near the junction with the Chalky Boulder Clay above: this induration is caused by infiltration of water holding carbonate of lime. An example of this rock is seen in a pit, formerly known as Mackie's Nursery, near Norwich. In West Norfolk and Suffolk the sands form extensive areas of 'waste land,' and there the light soil is liable to be drifted by the wind. (See remarks on Blown Sand.)

In some places in Essex the Middle Glacial gravel is very pebbly in nature, which in Mr. Wood's opinion was probably due to the proximity of Tertiary pebble-beds. In the neighbourhood of Hertford the Tertiary beds are capped by pebbly gravel composed chiefly of flint and quartz pebbles. This is very distinct from the more mixed gravel on the Chalk, and has been termed by Prof. Hughes the 'gravel of the higher plain' (or Hatfield Beds), to distinguish it from that in the lower grounds.[6] He suggested that it might be Pre-Glacial. It occurs also at Barnet, Totteridge, etc., where it has been mapped by the Geological Survey under the name of 'Pebble Gravel';[7] but it is not always possible to separate it from the Middle Glacial gravel. Some of this pebbly gravel has been described by Professor Prestwich as equivalent to the Mundesley and Westleton Beds.[8] (See p. 456.)

[1] Monograph Post-Tertiary Entomostraca, by G. S. Brady, Rev. H. W. Crosskey, and D. Robertson, 1874, p. 103.

[2] Q. J. xxxviii. 145.

[3] P. Geol. Assoc. ix. 111.

[4] Q. J. xxvii. 461; see also Brit. Assoc. for 1881, G. Mag. 1881, p. 466, 1882, p. 29; and Wood and Harmer, Supp. to Crag Mollusca, p. xv.

[5] G. Mag. 1882, p. 452.

[6] Q. J. xxiv. 283; Journ. Anthrop. Inst. vii. 162; S. V. Wood, jun. Q. J. xxiv. 464; see also Dr. J. Mitchell, Proc. G. S. iii. 4.

[7] Whitaker, Memoir Sheet 7 (Geol. Surv.), p. 69.

[8] G. Mag. 1881, p. 466.

Along the borders of the Thames Valley it is often a matter of difficulty to distinguish between the Middle Glacial gravels and those formed by the river in great measure from their destruction ; such is the case near Great Marlow, also at intervals along the valley as far as Southgate and Enfield.

At Danbury, in Essex, the Middle Glacial gravel occupies a high elevation, but the hill is coated with gravel and not formed by it, as Mr. W. H. Penning has traced the London Clay in gullies near the hill-top. Traces of gravel occur further south in Essex on Langdon Hill, in Middlesex on Hampstead Heath, in Kent on Shooter's Hill, etc. They are usually made up largely of flint and quartz pebbles, and are seldom of great thickness, varying from 2 to 12 feet.

The Tertiary hills of Berkshire, Surrey, and East Kent, between Reading and Canterbury, are capped by gravels of uncertain age.[1] In these gravels are found subangular pieces of quartz or rock-crystal called 'Bagshot Diamonds.'[2]

Deposits of loam and brickearth are associated with the gravels on the Chalk tracts of Buckinghamshire and Hertfordshire (see p. 449), and sometimes with those on the London Clay ; but it is not possible always to fix the ages of these beds. Thus, at Chelmsford there is a deposit of brickearth, which may be of Glacial age or Post-Glacial.

Chalky Boulder Clay.—The Great Chalky or Upper Boulder Clay of the Eastern counties is a clayey bed full of pellets or pebbles of Chalk, containing

FIG. 89.—SECTION AT WRITTLE, NEAR CHELMSFORD.

2. Chalky Boulder Clay. (Upper Glacial.)
1. Sand and Gravel. (Middle Glacial.)

also Chalk-flints, pebbles of flint, and blocks of various rocks (Septaria, Carboniferous Limestone, etc.), many of them scratched or grooved by ice-action. In thickness it varies from a few feet to 150 feet. It contains numerous fossils derived from different formations (chiefly Lias, Oxford Clay, and Kimeridge Clay), including *Gryphæa incurva*, *G. dilatata*, *Belemnites abbreviatus*, etc.[3]

[1] Wood, G. Mag. 1870, p. 19.

[2] T. R. Jones, P. Geol. Assoc. iv. 442 ; see also Buckland, T. G. S. v. 519.

[3] See list by John Brown, of Stanway, of specimens identified by J. de C. Sowerby and S. P. Woodward, Proc. G. S. iv. 165 ; Q. J. viii. 191, P. Geol. Assoc. i. 32 ; also Mag. Nat. Hist. ix. 42 ; J. Morris, G. Mag. 1868, p. 411 ; S. Woodward, Geol. Norfolk, p. 39 ; H. Walker, Glacial Drifts of Muswell Hill and Finchley, 1874, P. Geol. Assoc. ii. 289. See also E. Spencer, Proc. G. S. ii. 181.

The surface of the Boulder Clay is frequently 'piped' in the same way as the Chalk, a feature evidently due to a similar cause, namely, the dissolution of the chalky matter by carbonated water.

The Chalky Boulder Clay is well developed over the greater part of South Norfolk, and over much of Suffolk and Essex, in the country around Tivetshall, Eye, Framlingham, Halstead, Thaxted, Dunmow, Braintree, the Easters, and the Rodings, but it has not been met with south of the Thames, nor in the Thames Valley, although it extends to its northern margin near Brentwood and Epping. It occurs at Finchley, at Bricket Wood near Watford, and other places north of London, and around Buntingford, Biggleswade, Huntingdon, Horncastle, etc. (See p. 500.)

The character of this deposit is fairly uniform over a large area, but while spread out in extensive sheets over the higher grounds of South Norfolk, Suffolk, and Essex, it rests on different beds, and often descends to the bottom of the valleys on a level with the Alluvium. In Norfolk it is remarkable that over the greater part of the area where the Chalky Clay is developed, there is very little of the Lower Boulder Clay beneath it. The sequence of Upper, Middle, and Lower Glacial is the exception and not the rule.

A fine section of the Boulder Clay resting on Middle Glacial Sands is seen in the cliff between Kessingland and Pakefield; and we have at Corton [1] the evidence of Upper and Lower Boulder Clays. At Corton the latter bed is a very feeble and irregular accumulation compared with the Lower Glacial Clays at Happisburgh and Cromer, while in that area no Chalky Boulder Clay appears in the cliff-sections.

Inland in Norfolk there are a few pit-sections which show the sequence of Chalky Boulder Clay, Middle Glacial sand, and stony loam or Lower Boulder Clay, as near Strumpshaw Hill, Moulton, Upton, and South Walsham; but most of these sections show in the same pit the sand tapering away, and then the two Boulder Clays come together, and their separation is not a happy task. Fortunately in East Norfolk the Lower Clay maintains its character of a brown stony loam, so that whenever a section is exposed, it may usually be distinguished from the more chalky Upper Boulder Clay in that area; but westwards the Lower Glacial Clays become so like the Chalky Boulder Clay, that from the evidence of pit-sections, they cannot be separated one from the other.[2]

Looking at the beds, however, in a general way, we discern that two great divisions may be recognized—the Cromer Till and Contorted Drift, grouped together as Lower Boulder Clay, followed by sands and gravels; and the Chalky or Upper Boulder Clay, with associated sands and gravels, which will be described further on. The Lower Boulder Clay, as Mr. John Gunn has remarked, is characterized by boulders of an igneous type, and it often contains Pleistocene shell-fragments. It may have been derived from the north and north-east. The Upper Boulder Clay is characterized by Jurassic detritus, and was probably derived from the north-west. But the most important distinction, perhaps, is in the disturbances to which the Lower Glacial Beds have been subjected by the agent which formed the Chalky Boulder Clay.

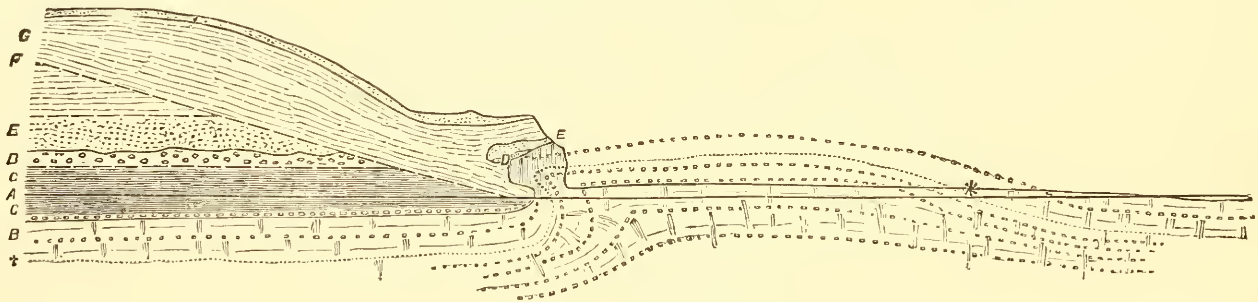
Sometimes the Chalky Boulder Clay rests on a substratum of sand that shows little or no disturbance; and, as a rule, with such junctions, the lower part of the Boulder Clay is sandy, and the line of division, though sometimes undulating, is distinct. Where the Boulder Clay rests on clay, the same distinct line may also be observed; but almost invariably where the underlying clay contains streaks or nests of sand, these are very much contorted. The fact is that the clay without these nests of sand would not well exhibit the contortions; while where sand alone is seen under the Boulder Clay, contortions may be absent because the deposit was of too yielding a nature to be acted upon. In one or two localities where marked lines of bedding occur in the sand, there are evidences of disturbance. On the whole, the beds beneath the Chalky Boulder Clay of Norfolk are more frequently contorted than not, and hence it may be concluded that the agent which formed this Clay was instrumental in disturbing the strata over which it was accumulated.

[1] See J. H. Blake, Horizontal Sections, Sheet 128 (Geol. Surv.).

[2] P. Geol. Assoc. ix. 111; see also F. J. Bennett, Proc. Norwich Geol. Soc. i. 252.

Fig. 90.—Section at right-angles to the Cliff through the westerly Chalk bluff at Trimingham, Norfolk.

(Clement Reid.) Scale 250 feet to an inch.



A. Level of low-water spring-tides.
B. Chalk, with sandy bed at +.
C. Forest Bed Series, etc.: seen in the cliffs a few yards north and south of this point.
D. Cromer Till: stiff lead-coloured boulder clay.
E. Fine chalky sands, much false-bedded.
F. Contorted Drift: brown boulder clay with marked bedding- or fluxion-structure.
G. The Beds above the white line were seen and measured by Mr. Reid.
* Chalk seen *in situ* on beach.

In parts of West Norfolk, between the Boulder Clay and the Chalk, the line of demarcation is most obscure: it is difficult to say where the one ends and the other begins. In these cases it appears evident that the Glacial Drift was formed chiefly from the Chalk of the district. In this way we may account for some of the very marly varieties of the Boulder Clay, which in places are little else than ground-up Chalk. Analysis of one of these chalky drifts, burnt for lime near Holt, showed 91 per cent. of carbonate of lime, and the Rev. O. Fisher has spoken of this drift as "an ancient manufacture of 'whiting' on a magnificent scale."[1] Mr. Reid observes that "The masses of reconstructed Chalk so common in the Contorted Drift are probably nothing but a later stage of the transported boulders, in this case so shattered and mixed with clay that they form a sort of transition to an ordinary Boulder Clay. From the very marly character of the Contorted Drift when traced westward, it seems not improbable that that portion of the deposit is continuous with, and passes laterally into, the Great Chalky Boulder Clay."[2] These remarks furnish a comforting explanation of the difficulties met with in the country around Fakenham. There, where the later Boulder Clay passed directly over the clayey Lower Glacial beds, it no doubt became incorporated with them, causing one contorted mass, and we cannot separate the two deposits.[3] (See Fig. 88.)

In other places we find the flint-layers of the Chalk disturbed, as if that rock had offered a local impediment, perhaps a low hill or cliff against which the icy agent impinged. Mr. Reid has explained the flexures in the Chalk at Trimingham as due to glacial action in the form of an ice-sheet. Mr. S. V. Wood previously called attention to disturbances in the Chalk at Litcham, and these he attributed to the passage of a glacier over the surface of the rock. Dr. J. E. Taylor drew attention in 1865 to a remarkable 'saddle-shaped' disturbance in the Chalk at Whitlingham (see Fig. 80, p. 468);[4] and a pit at Trowse, near Norwich, showed the Chalk uptilted and underlaid by Boulder Drift, so that the disturbance was evidently due to glacial agency. There are also sections near Wells, where the Chalk is similarly disturbed in connection with the Glacial Drift.[5] These facts help to explain how the huge isolated masses, or "boulders," of the rock may have been formed, and no doubt the Chalk at Trimingham furnishes the most striking evidence of their formation. Mr. Reid remarks: "If the ice-sheet, instead of flowing over the beds, happens to plough into or abut against them, it would bend up a boss of Chalk, as at Beeston. A more extensive disturbance, like that at Trimingham, drives before it a long ridge of the beds, and nips up the Chalk till, like a cloth creased by the sliding of a heavy book, it is folded into an inverted anticlinal. A slight increase of pressure, and the third stage is reached—the top of the anticlinal being entirely sheared off, the Chalk boulder driven up an incline, and forced into the overlying Boulder Clays."[6] While this view seems best to accord with the facts, it is right to mention that Mr. Mellard Reade believes that these boulders were severed from old cliffs by the expansive force of ice in fissures, and then shifted by coast-ice.[7] (See Fig. 90, also p. 503.)

In West Norfolk, south-west of Watton, and about 1½ miles north-west of Merton Church, there is a celebrated stone called the Merton Boulder, which measures nearly 12 feet in length, with a thickness and breadth of about four or five feet. The derivation of this rock was long a puzzle to Norfolk geologists, until Mr. Whitaker identified it as Lower Greensand of local origin.[8]

The most fertile tracts of the Eastern Counties are situated on Boulder Clay; to

[1] G. Mag. 1868, p. 551.

[2] See Geology of Fakenham, etc. p. 17.

[3] Geology of the Country around Cromer, pp. 115–117.

[4] G. Mag. 1865, p. 324, 1869, p. 508.

[5] P. Geol. Assoc. v. 513; G. Mag. 1881, p. 93; Q. J. xxxv. (Proc.), 106; Geol. Fakenham, pp. 9, 24.

[6] Geol. Cromer, p. 115; G. Mag. 1880, p. 61; see also O. Fisher, G. Mag. 1868, p. 544.

[7] Q. J. xxxviii. 222; A. J. Jukes-Browne, Ann. Nat. Hist. 1880; Lyell, Phil. Mag. (3), xvi. 355.

[8] Geol. Attleborough, etc., by F. J. Bennett, p. 10.

this is due their agricultural eminence. In the good old times it has been very extensively used as a manure, hence the number of old marl- or clay-pits scattered about the county, in the area occupied by Upper and Lower Boulder Clays. Some of the richest land in north-eastern Norfolk is situated on the Contorted Drift. Wheat is extensively grown on the heavier lands, and Barley on the lighter soils. Much of the best Barley, for which Norfolk is celebrated, is raised on thin chalky soils of the Lower Glacial Drift, in the neighbourhood of Stiffkey, Wells, and Burnham. Near St. Albans and Luton the strawplait industry is due to crops largely grown on the Glacial Drifts.

In the neighbourhood of Hardwick, Tivetshall, Diss, etc., bricks known as 'clay-lumps' are made from the Chalky Boulder Clay. The material dug is mixed with chopped straw, moulded, and then dried in the sun. Ordinary bricks are made in some localities from the Boulder Clay. A boulder of bituminous shale (probably from the Kimeridge Clay) was found at Anmer, in West Norfolk, and used as fuel.[1]

Plateau or Cannon-shot Gravel.—Scattered over the high grounds of Holt and Cromer, and resting on the Chalky Boulder Clay in many places in West Norfolk, at Hempton near Fakenham, at Wymondham, Tasburgh, Poringland, Strumpshaw, and Mousehold, near Norwich, there are great accumulations of coarse boulder gravel—gravel containing large blocks of flint and even paramoudras, all more or less rolled and knocked about. Some few igneous rocks occur also, as well as pebbles of quartz and quartzite. To these deposits the name Cannon-shot gravel was applied by Mr. Wood, because the majority of the stones in some places are "rolled into the shape and dimensions of the now obsolete cannon-shot of from 12lbs. to 32lbs. calibre." The gravel is from 1 to 45 feet thick.

The deposit seems in many instances to be intimately connected with the Chalky Boulder Clay, and it may perhaps have resulted in part from the melting away of the ice-sheet that formed the Clay; hence it has sometimes been termed Flood Gravel. It is, indeed, an accumulation that bears evidence of having been formed in a tumultuous way, but the Chalky Clay itself does not yield such large flint boulders in abundance. The question is, whence came the flints—for the deposit is not often found directly on the Chalk, otherwise we might account for it by ordinary marine action on a foreshore of that formation. It is possible that during later Eocene and Miocene times accumulations of flints were formed by subaërial action on the Chalk surfaces of West Norfolk, and that in Glacial times they furnished material for the gravels.[2] The accumulations of coarse gravel are, however, not of one age, as similar beds occur occasionally in the older Glacial Drifts. In some instances, too, these coarse gravels assume the form of Eskers, as near Blakeney, in Norfolk.[3] Mr. Whitaker has also noticed Eskers near Great Massingham. Near Wells, and also at Roydon, near Diss, the gravels contain large rounded blocks of Chalk as well as flint. The gravel at Wells has yielded remains of the Mammoth, while that near Diss contains many derived fossils.

The gravels are largely dug for mending roads, and the large flint boulders have been used for building, and even for paving some of the streets of Norwich, where, under the name of "cobbles," "Norfolk dumplings," or "petrified kidneys," they form stumbling blocks both for man and beast. S. Woodward, in his "Observations on the Round Towers of Norfolk,"[4] noticed that, with one exception (West Dereham), all these churches were built of flint boulders, and he stated his conviction that they owed their circular form, not to any peculiar style, but had been thus built from necessity, in consequence of the absence of freestone from the soil.

Trail.—In describing the character of the latest superficial deposits, the Rev. Osmond Fisher has treated of the 'warp of the drift,' so called by Mr. Trimmer. This warp or general surface soil is influenced in its character by the stratum on which it rests, but at the same time often contains ingredients which cannot have

[1] J. Gunn, P. Geol. Assoc. iv. 44.

[2] Trans. Norfolk Nat. Soc. iii. 444, 447.

[3] Proc. Norwich Geol. Soc. i. 263, and G. Mag. 1883, p. 438. See also Geol. Fakenham, etc. (Geol. Survey), p. 35.

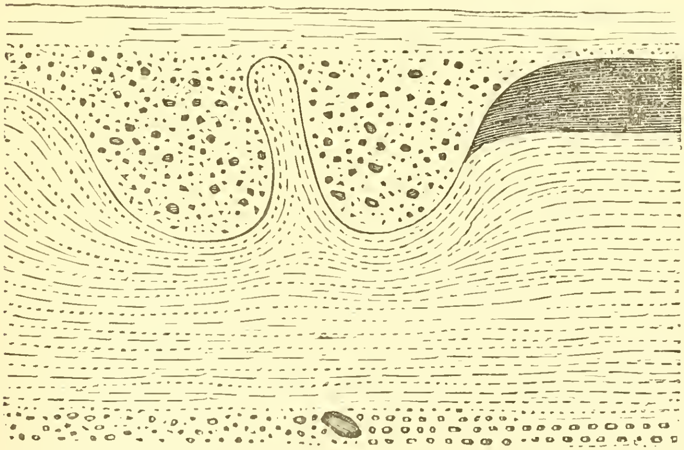
[4] Archæologia, xxxiii. 7.

been derived from it. Mr. Fisher has observed that the subjacent stratum, where it is of a soft nature, is often worn into furrows and hollows, distinct from the 'pipes' which are confined to soluble beds. The materials which fill these furrows he calls 'trail,' and it is noticeable that where pebbles occur, their axes, more frequently than not, deviate from the horizontal position. This feature arose, in his opinion, from the pebbles sinking through a muddy deposit, for the effect of friction would be to place them on end, while the same result would probably take place from the action of frost and thaw on loamy soils containing pebbles. Nevertheless, in some instances, according to Darwin, the vertical position of stones is caused by earthworms.

Mr. Fisher remarks that the contents of these furrows have contributed to form the warp, and thus we see why the surface-soil sometimes varies so remarkably

FIG. 91.—SECTION OF UPPER BEDS AT UPHALL BRICKFIELD, ILFORD, ESSEX. (Rev. O. Fisher.)

Thickness of beds shown about 8 feet.



5. Warp.
4. Clayey gravel. } Trail.
3. Re-deposited London Clay, with pebbles. } Trail.
2. Light-coloured yellowish sand (belonging to the Brick earth series), disturbed by the deposition of the Trail.
1. Pebbly band in which a tooth of *Elephas antiquus* was found.

over limited areas. The furrows are the tool-marks of the last agent which moulded the surface of the country;[1] and they are in many places suggestive of the action of ice, especially as the beds are not uncommonly dragged up or contorted. In fact in most instances the "furrows" appear to be due to contortion, and the gravelly beds that fill them are simply remnants of gravel that perhaps formerly occurred in some thickness. In some cases the contortions may be due to flexures produced by roots of trees, the melting of included fragments of ice (see p. 513), and to dissolution of the calcareous stones.[2]

These contorted surface-beds are of frequent occurrence in the Thames Valley deposits, and good instances are to be seen at Ilford (see Fig. 91), and also at Grays. They occur also at Culham near Oxford, between Walton and

[1] Q. J. xxii. 553; G. Mag. 1867, p. 193.
[2] See Bonney, Cambridgeshire Geology, p. 53.

Weybridge,[1] at Trumpington near Cambridge, and many other places.[2] The pebbly clay at Shooter's Hill, which in Mr. Goodchild's opinion was disturbed by Glacial action, is a similar instance.[3] Nor are these surface-contortions confined to Pleistocene deposits. The Chalk, where exposed at the surface in the valleys of the Yare and the Wensum, not unfrequently shows signs of disturbance ; the flint-layers are broken up, sand and stones are introduced, and the Chalk itself presents a rubbly appearance, to a depth of from 1 to 8 feet, and sometimes more. This disturbed Chalk is often spoken of as the "Glaciated Chalk" ; it passes gradually down into the undisturbed Chalk beneath. (See p. 421.) "Pipes" are abundant in it, and at Trowse it is burnt for lime, being considered to furnish better material than the undisturbed Chalk. Near Brandon it is known as 'dead loam.' In some cases the appearances may be due to the influence of the ice which formed the Chalky Boulder Clay; but in other cases the agent was of subsequent date. Remains of Mammoth and Red Deer have been met with in the disturbed Chalk near Norwich.[4]

The Lower Greensand at Great Hazeley in Buckinghamshire presents evidence of apparently similar surface-disturbance,[5] and this is sometimes to be seen in superficial beds of the Oolites. We have also the evidence of the Terminal Curvature of slaty rocks to show that these surface disturbances may have been produced at different dates. (See p. 494.) Surface disturbances moreover may in some cases be produced by the slipping of superficial accumulations or of the 'soil-cap' down the slopes of hills, a process analogous to landslips.[6] (See sequel.)

ALLUVIAL DEPOSITS.

The deposits of Modern rivers, lakes, and estuaries may be classed under the above heading. They comprise gravel, sand, brickearth or loam, clay, mud, and silt; peat, too, may be included, as it is formed in swamps along the borders of rivers, and may occur interstratified with other materials in fluviatile, lacustrine, or estuarine deposits. These Alluvial or Valley deposits are sometimes broadly divided into (1) Alluvium, being the latest sediments deposited by the river; and (2) Brickearth, Gravel and Sand, which, as a rule, occupy higher levels in the valley than the Alluvium, although they often form part of it.

Brickearth.—This consists of loam, a mixture of clay and sand in varying proportions ; in general it is of a brown colour mottled with red, and it is largely used for brickmaking.

Gravel.—The Gravels that are met with in our river-valleys, and which are evidently connected with similar areas of drainage, occupy various elevations with respect to the level of the present rivers and streams. This is natural, for they represent different stages in the excavation of the valleys, the beds at a higher level being older than those at a lower level. Thus in some instances it is found convenient to group the deposits as follows :—

Low-level Valley gravel. (Alluvium.)
High-level Valley or Terrace gravel.[7]

[1] Hudleston, Q. J. xlii. 170. [2] See J. Allen Brown, P. Geol. Assoc. viii. 173.
[3] P. Geol. Assoc. ix. 151. [4] Geol. Norwich (Geol. Surv.), p. 137.
[5] See also Fitton, T. G. S. (2), iv. 276.
[6] See also R. W. Coppinger, Q. J. xxxvii. 348, and F. C. J. Spurrell, Rivers and Denudation of West Kent, 1886, p. 30.
[7] The term High-level gravel has been applied to Glacial deposits.

It must, however, be borne in mind that as the source of a river is so much higher than its mouth, so are the deposits which it has formed at similar periods much higher in elevation as we proceed upwards along its banks ; therefore these divisions apply only to the relative heights of deposits at particular localities in a valley.

Great expanses of river-gravel are generally formed in districts where there is much old marine or glacial gravel, from which it has been largely derived : the stones therefore are interesting as relics of various epochs. In some instances, as before mentioned, Glacial gravel may merge into River gravel in the lower portions of a mountain valley ; but in many cases the wide-spread valley-deposits appear too extensive to have been formed by the modern rivers. In Prof. Prestwich's opinion the greater excavating powers of the rivers in the early part of the Post-Pliocene period, as compared with those of their representatives at the present day, were mainly due to a more rigorous winter climate, probably accompanied by a more abundant rain-fall and a greater tendency to floods.[1] He thus admits a kind of Diluvial action, as did also Mr. A. Tylor, who first suggested that at that time there was a 'Pluvial Period.'[2] This condition may have arisen from the elevation of the land. In the formation of valleys it must also be remembered that rivers pursue a serpentine course, and erode now on one side and now on the other, as evidenced by the alternate accumulations of gravel that bound their courses. (See sequel.)

Contortions in gravel are attributed by Mr. Prestwich to river-ice grounding on the soft deposits, while some of the larger blocks of stone in river-gravel may have been transported by river-ice.

Iron-pan.—Beds of gravel and sand of all ages contain much oxide of iron, and this is largely taken up by waters that filter through them, and when arrested by an impervious stratum the iron-oxide is deposited, and the gravel and sand become cemented into a hard rock or conglomerate known as iron-pan. (See p. 463.)

Bog Iron-ore.—In many instances, as remarked by Dana, the ferruginous matter is washed out of the deposits into low places or marshes, where it forms beds of cellular limonite, called "Bog Iron-ore." Such beds often contain nuts and leaves, petrified by the oxide of iron. The iron, when carried by the waters, is in solution as bicarbonate, or combined with organic acids derived from the soil. The change to limonite takes place where the waters have a chance to stand and evaporate. In this way vast beds of ore have been made.[3] Bog Iron-ore is also formed to some extent by Diatoms (*Gallionella ferruginea*), which according to Ehrenberg have the power of separating iron from water, and depositing it as hydrous peroxide within their siliceous framework.[4] Sands and gravels are sometimes coloured black, the fragments being coated with oxide of manganese ; in other cases artificial impurities have produced a similar discolouration, which is generally due to sulphide of iron.[5]

Gravel of different ages is largely dug for road-mending, etc. ; and some of the more pebbly varieties are employed for making concrete.

Pleistocene Alluvial Deposits.

These deposits are not always to be readily distinguished from those of Recent age, except by the organic and other remains

[1] Phil. Trans. 1864, pp. 251, 252 ; Rep. Brit. Assoc. for 1880, Trans. of Sects. p. 581 ; see also De la Beche, Geol. Manual, p. 30 ; Phil. Mag. 1829 (2), vi. 243 ; Conybeare, Proc. G. S. i. 148. On the subject of River Terracing, see Hugh Miller, jun., Roy. Phys. Soc. Edin. 1883, p. 263.

[2] Phil. Mag. April, 1853 ; G. Mag. 1881, p. 525 ; H. H. Howorth, G. Mag. 1883, pp. 356, 413 ; Godwin-Austen, Q. J. vii. 130.

[3] Manual of Geology, ed. 2, 1874.

[4] A. Geikie, Text-Book of Geology, ed. 2, p. 175 ; Lyell, Principles of Geology, ed. 11, vol. ii. p. 508.

[5] W. H. Hudleston and F. G. H. Price, P. Geol. Assoc. iii. 53.

which they contain. These have been previously noted. (See p. 477.)

In most cases the Palæolithic Implements and Mammalian remains are found in beds of sand, gravel, and brickearth, along the line of existing river-valleys, in some cases but little above the river; but in other instances they occur much above the present streams, and sometimes indicate different systems of drainage. These valley-deposits occur chiefly in the midland, eastern, southern and south-eastern counties: in the northern and north-western counties the Pleistocene mammaliferous deposits are for the most part confined to Caverns, a fact explained on the grounds that these areas were glaciated subsequently to those further south, and the old valley-deposits were to a large extent destroyed.[1]

Flint Implements obtained from gravel and sand are generally more or less polished and glossy, and they are sometimes discoloured yellow or brown. Dendritic markings and incrustations of carbonate of lime, which are frequently found on them, may be taken as proofs of antiquity.

One of the most northerly points at which river-deposits containing Pleistocene Mammalia have been found is in the Aire Valley, at Wortley, near Holbeck station, Leeds, where Hippopotamus, Mammoth, etc., were discovered by Mr. H. Denny.[2] The Drift at Overton, near York, has also yielded Hippopotamus, etc.[3] Mammoth, etc., have been found near Ashborne in Derbyshire, near Nottingham, at Leamington, Willoughby, and at Lawford near Rugby.[4]

Mammalian remains (Mammoth, etc.) have been obtained in the Soar valley at Leicester and Kegworth, at Leighton Buzzard,[5] in the Nene valley near Peterborough,[6] at Wellingborough, and at Bottesford, north-west of Grantham.

Palæolithic Implements were discovered in several localities in the valley of the Great Ouse, near Bedford, by Mr. J. Wyatt. At Summerhouse Hill, two miles east of the town, he found remains of Hippopotamus, Reindeer, and *Elephas antiquus*, etc., in the valley gravel;[7] and at Biddenham he found *Hydrobia marginata* and other shells, besides Mammalian remains and Flint Implements. Palæolithic Implements have not at present been found in valley-deposits north of the Ouse valley.

The Rev. O. Fisher has described a bed of gravelly silt at Barrington, south-west of Cambridge, that has yielded *Hippopotamus*, *Elephas antiquus*, *E. primigenius*, *Hyæna spelæa*, etc., also land- and fresh-water Mollusca.[8] A Palæolithic Implement has been found in the gravel at Barnwell by Mr. A. F. Grifith.[9] This gravel, which in places is largely made up of Chalk, has yielded many Mammalian remains, including *Rhinoceros tichorhinus*, etc., also *Corbicula fluminalis*, etc. In describing the beds Prof. Hughes has pointed out that burrowing animals like the Fox and Badger have sometimes introduced Recent bones of Sheep, etc., into the gravel.[10] Gravel of similar age occurs at Trumpington, and there are old river gravels near Newmarket, etc.[11]

[1] Evans, Ancient Stone Implements, etc., 1872; J. Geikie, Great Ice Age, ed. 2.

[2] A. Tylor, Q. J. xxv. 61. This paper contains many details of Quaternary deposits.

[3] J. E. Clark, Geol. Polyt. Soc. W. Riding, vii. 421.

[4] J. K. Worthington, Rep. Rugby School Nat. Hist. Soc. for 1881, p. 20; J. Shipman, Alluvial Deposits of Trent Valley, 1880, p. 17.

[5] T. R. Jones, Geologist, v. 471.

[6] Trimmer, Q. J. x. 343; Judd, Geol. Rutland, etc., p. 250; Jukes-Browne, Geol. S. W. Lincolnshire, p. 95.

[7] Q. J. xx. 187. See also Rev. H. M. De la Condamine, Q. J. ix. 271.

[8] Q. J. xxxv. 670.

[9] G. Mag. 1878, p. 400.

[10] G. Mag. 1883, p. 454.

[11] See also Penning and Jukes-Browne, Geol. Cambridge, pp. 82, 96, 98.

Many Palæolithic Implements have been obtained from old valley gravels in west Norfolk and Suffolk, near Thetford. In the former county the principal localities are along the valley of the Little Ouse, at Redhill, near Thetford, Whitehill a little lower down the valley, Broomhill in the parish of Weeting, and Shrub Hill in that of Feltwell. In Suffolk implements have been found at Gravel Hill, near Brandon, Santon Downham, Lakenheath, and Warren Hill, near Mildenhall; in the Lark Valley at Icklingham and Culford, near Bury St. Edmunds, and also at Hoxne, near Diss. The beds are so rich in places near Thetford and Brandon, that Mr. J. W. Flower stated he sometimes obtained as many as a hundred Implements at a time, when no doubt the gravels were specially worked.[1]

At Westley, near Bury St. Edmunds, Mr. H. Prigg obtained a fragment of a human skull, from brickearth which has yielded Palæolithic Implements and remains of the Mammoth.[2]

In 1876, Mr. S. B. J. Skertchly announced his discovery of Flint-implements beneath Boulder Clay in East Anglia.[3] He pointed out the occurrence of certain beds of brickearth, sand and gravel (Brandon Beds), that are overlaid by patches of Boulder Clay, and sometimes underlaid by it, in the latter case generally in the form of intruded tongues. These beds, he states, have yielded Palæolithic Implements or Flakes at Botany Bay near Brandon, Mildenhall Brickyard, High Lodge, Mildenhall, Bury St. Edmunds, West Stow, and Culford. Unfortunately the evidence upon which Mr. Skertchly based his conclusions has not been published in detail; it has been seriously questioned,[4] and no one else has been fortunate enough to find unquestionable Palæolithic implements *in situ* beneath a clear and definite accumulation of the Boulder Clay. The brickearth at Mildenhall Brickyard was at one time clearly overlaid by a small mass of Boulder Clay, which has been worked away in the digging of the brickearth; but Mr. Prigg informs me that he has obtained no Palæolithic Implements from the beds at this brickyard.

At Hoxne small pockets of Boulder Clay have been observed resting on the brickearth,[5] but the main mass of Boulder Clay underlies it. The section in 1878 was as follows:—

Gravel and sand	3 feet.
Brown loam passing down into blue sandy clay, with a seam of gravel that merged in the eastern part of the pit into the overlying gravel. In this seam of gravel Mr. C. Reid found a Palæolithic Implement	6 feet.
Chalky Boulder Clay.	

The occurrence of Flint Implements at Hoxne was recorded as early as 1797 by John Frere, but it was not until 1860 that attention was recalled to the subject.[6] In the present state of the evidence it is not safe to say that any Palæolithic Implements have been obtained in East Anglia from beds older than the main mass of the Chalky Boulder Clay, or from that Clay itself.

At Norwich there is a considerable accumulation of valley-gravel near the Great Eastern Railway Station at Thorpe, but this has yielded no Palæolithic implements and no remains of the Mammalia usually found in association with

[1] Q. J. xxv. 449.

[2] Journ. Anthrop. Inst. xiv. 51.

[3] G. Mag. 1876, p. 476; see also Manufacture of Gun-flints (Geol. Survey), p. 65; Geol. Ramble around Brandon, by M. Knights, Eastern Daily Press, Oct. 1876 (reprinted); and Prof. J. Geikie's Great Ice Age, ed. 2, p. 565.

[4] P. Geol. Assoc. ix. 111; H. Prigg, Proc. Norwich Geol. Soc. i. 165; Hughes, Proc. Cambridge Phil. Soc. iii. 16, and Journ Anthrop. Inst. vii. 162.

[5] Proc. Norwich Geol. Soc. i. 62; Geol. Norwich (Geol. Surv.), p. 110; T. Belt, Quart. Journ. Science, 1876; see also S. V. Wood, jun., Q. J. xxxvi. 499; xxxviii. 669, 672.

[6] Archæologia, xiii.; J. Evans, *Ibid.* xxxviii.; Prestwich, Phil. Trans. 1860; see also Trans. Norfolk Nat. Soc. ii. 581.

these ancient works of man. Indeed, the Implements that have been found in the river-gravels of East Norfolk are mostly of Neolithic type; the few Palæolithic implements recorded from this part of the county having been picked up on the surface of the ground.[1] On the coast, however, near West Runton, an implement was found by Mr. A. C. Savin, in old valley-gravel; and further west a large Palæolithic implement was found in the gravel at Wells, together with remains of the Mammoth.

The formation of the marshes north of Wells is, perhaps, connected with this subject. They appear to be the Alluvium of a valley which at one time was bordered on the north by hills that have been destroyed through the encroachments of the sea. The older Elephant- and Implement-bearing gravels of Wells and Runton may, perhaps, be remnants of the early gravels of the river which flowed along this valley. Possibly it was connected with the Ouse valley, which, at Bedford and other places, contains ancient deposits with Palæolithic implements and Pleistocene Mammalia. These suggestions might be extended further, in connection with the numerous Pleistocene organic remains dredged up in the North Sea, and more particularly off the Dogger Bank, a shoal under 10 fathoms, and about 120 miles N.N.E. of Cromer. From this bank many Mammalian remains have been obtained, that belong to the group which characterizes the old Thames-Valley deposits of Ilford and other places; and a large collection, now in the British Museum, was made by Mr. J. J. Owles, of Yarmouth.[2] When the Thames united its waters with those of the Rhine, and flowed over what is now the bed of the North Sea, the Ouse may also have been a tributary, and this old bank called the Dogger may be a relic of the period.[3]

At Copford in Essex beds of blue brickearth have been extensively worked, and this deposit is overlaid by peat and shell-marl with Freshwater and Land Mollusca, including *Corbicula fluminalis*, also Pleistocene Mammalia, to which attention was directed by John Brown of Stanway.[4] Remains of Bear, Beaver, Elephant, Hippopotamus, etc., have been recorded from the Copford deposit. Similar deposits occur at Marks Tey, Witham, at Ballingdon in the Stour Valley, and at Colchester in the Colne Valley.[5] The brickearth at Copford contains many concretions of carbonate of lime, termed "race." At Sutton Ness, on the estuary of the Stour, brickearth with *Corbicula fluminalis*, etc., occurs;[6] and at Ipswich remains of *Elephas antiquus*, *Rhinoceros*, etc., have been found.

At Clacton-on-Sea there is about 10 feet of gravel, underlaid by laminated clay and peaty beds (20 feet), full of vegetable remains, with marine, freshwater and land shells. Bones of several species of Mammals were found in sand at the base of this deposit. The Mammalian remains include *Felis spelæa*, *Elephas antiquus*, *Rhinoceros leptorhinus*, and *Hippopotamus*; and the Mollusca comprise *Cardium edule*, *Corbicula fluminalis*, *Unio littoralis*, *Paludina*, etc.[7]

At Lexden remains of Elephant, Rhinoceros and Insects have been found in peaty beds with much sand and gravel that occur beneath the brickearth.[8]

[1] Geol. Norwich (Geol. Surv.), p. 145; Geol. Diss, etc., by F. J. Bennett, p. 19.

[2] W. Davies, G. Mag. 1878, pp. 97, 443. According to S. Woodward, the Oyster Ridge off Happisburgh, and the Knole Sand off Yarmouth, have yielded many Mammalian remains, some however belonging to the Cromer Forest Bed Series. He mentioned that at one time the Rev. James Layton of Catfield had as many as 600 grinders of the Elephant! Geol. Norfolk, 1833; G. Mag. 1868, p. 319.

[3] P. Geol. Assoc. ix. 111; Geol. Fakenham, etc. (Geol. Surv.), p. 36; T. R. Jones, P. Geol. Assoc. viii. 344.

[4] Proc. G. S. iv. 164; Q. J. viii. 184; Mag. Nat. Hist. vii. 436, ix. 429; W. H. Dalton, Geol. Colchester, p. 5.

[5] J. Brown, P. Geol. Assoc. i. 29.

[6] Whitaker, Geol. Ipswich, p. 96; see also Morris, Mag. Nat. Hist. 1836.

[7] J. Brown, Mag. Nat. Hist. (2), iv. 197; O. Fisher, G. Mag. 1868, p. 213; Dalton, *op. cit.* p. 8.

[8] O. Fisher, Q. J. xix. 393.

Thames Valley Deposits.—The accumulations of gravel in the Thames Valley are of different ages, Pleistocene and Recent. In the higher portions of the valley the gravel is probably for the most part Recent, and it is largely made up of Oolitic material, as near South Cerney. In the neighbourhood of Oxford the gravel is more mixed in character, and contains much material derived from older Drifts. Thus, in speaking of the gravels at Maidenhead, Prof. Prestwich notes the occurrence of quartzites, etc., derived originally from the New Red conglomerates of the midland counties, the flint-pebbles were mostly derived from Eocene strata, while the subangular Chalk-flints give the measure of the wear and tear to which the stones were subjected when the river-deposit was laid down.[1] In some places the Thames Valley sands have been derived from the Tertiary sands.

Between Oxford and Gravesend the Thames Valley deposits occupy a considerable area, and especially around Staines, Colnbrook, West Drayton, Uxbridge, Brentford, Kew, London, and Barking. They rise to an elevation of 154 feet at Highbury Terrace, and 190 feet at Wimbledon. The beds have been divided as follows:[2]—

Recent.—Peat and Marsh Clay, etc. (Alluvium).

Pleistocene.	Upper Brickearth, 5 to 20 feet thick. Grays, Erith, Crayford, Wanstead, Tottenham, West Drayton, etc.
	Thames Gravel, 12 to 15 feet thick; with bands of sandy clay containing freshwater Mollusca at Brentford, Hackney, Highbury New Park, etc.
	Lower Brickearth, 20 to 30 feet, Ilford, Wickham, etc.

These divisions of the older Thames Valley-deposits are, however, very local, and although the Brickearth of Grays, Crayford, etc., was regarded by Mr. S. V. Wood, jun., as newer than that of Ilford, there are no marked distinctions between them. Moreover, he regarded the gravel of the Cray and Darent valleys as of the age of the Upper Brickearth. Both Upper and Lower Brickearths contain *Corbicula fluminalis*, etc., as well as many Mammalian remains.

The Thames gravel in its eastern development may be in part estuarine or even marine, especially the portions that border the eastern coast of Essex from Southend and Shoeburyness, northwards by Burnham, and Southminster. The Thames Valley deposits are probably all more recent than the Chalky Boulder Clay; for that deposit has in no case been found in the valley (see p. 507), and the valley gravels contain *Gryphæa* and other derived fossils which have probably been washed out of the Boulder Clay. At the same time these valley-deposits may be older than the Purple and Hessle Boulder Clays of Lincolnshire, etc. (See pp. 481, 498.)

Amongst the Mollusca recorded from the Brickearths are *Corbicula fluminalis*, *Cyclas cornea*, *Unio littoralis*, *Planorbis corneus*, *Paludina vivipara*, *Ancylus fluviatilis*, etc. The Mammalia include *Felis spelæa*, *Hyæna spelæa*, *Ursus ferox*, *U. arctos*, *Canis lupus*, *Bos primigenius*, *Bison priscus*, *Ovibos moschatus*, *Cervus megaceros*, *Elephas*, *Rhinoceros*, *Hippopotamus*, *Castor*, etc. (See list, p. 477.) Many Palæolithic Implements have been found associated with these Mammalia.

In the British Museum there is a tooth of the Mammoth found in 1731, at a depth of 28 feet beneath the surface in digging a sewer along Pall Mall. A more interesting record is the finding of an old flint implement and the tooth of a Mammoth (*before* 1715) near Grays Inn Lane. Palæolithic Implements and freshwater shells have also been found in the gravels of Hackney Down, Shacklewell, in the brickearth of Highbury New Park, and other places.[3]

[1] Q. J. xii. 131; Phillips, Geol. Oxford, etc., p. 456.

[2] S. V. Wood, jun. G. Mag. 1866, pp. 57, 99, 106; *Ibid.* 1868, p. 534; W. B. Dawkins, Q. J. xxiii. 91, xxxvi. 379; A. Tylor, G. Mag. 1868, p. 391; Morris, Q. J. vi. 201; Prestwich, Q. J. xi. 107; Goodchild, P. Geol. Assoc. ix. 151.

[3] J. E. Greenhill, P. Geol. Assoc. viii. 336, and Prehistoric Hackney, Hackney Micros. and Nat. Hist. Soc. 1881-83.

Ilford has long been celebrated for the number of Mammalian remains found in the pits at London-road Field and Uphall. For the collection of a large number of specimens found at Ilford we are largely indebted to Sir Antonio Brady and to Dr. Richard Payne Cotton.[1]

Attention was long ago directed to the fossils of the Thames Valley deposits by Prof. Morris, and he described the beds at Brentford, where W. K. Trimmer many years previously obtained Mammalian remains.[2] One of the most interesting localities in the Thames Valley deposits is on the south side of the river at Crayford, in Kent. In the brickearth the Rev. O. Fisher obtained a worked flint, and many remains of Mammalia.[3] Still more important and surprising is the discovery by Mr. F. C. J. Spurrell of a place where Palæolithic Implements were manufactured in this locality.[4] He discovered some flakes, which he fitted together and re-formed the mass of flint from which they were struck. These occurred beneath sand and brickearth with *Rhinoceros*, etc.

At Acton Flint implements and remains of Mammoth have been found by General Pitt-Rivers.[5]

Palæolithic Implements have also been found in the gravel capping the cliffs at Herne Bay. Near Reculvers there are freshwater beds with *Corbicula fluminalis*, etc.;[6] and similar beds occur at Faversham.

Mr. Godwin-Austen has described the gravel beds of the Wey valley near Guildford, at Peasemarsh, etc.; there Elephant remains have been obtained, and also Flint-implements.[7] Mammalian remains have likewise been found in the same neighbourhood in gravel about 100 feet above the river Wey.[8]

Gravel and sand with Mammoth, Rhinoceros, etc., and Palæolithic Implements, occur near Reading.[9] Similar remains are recorded by Prof. Prestwich from the Thames valley gravel at Summertown, Oxford, together with *Corbicula fluminalis*.[10] Pleistocene Mammalia have also been found at Wytham, Yarnton, Culham, Abingdon, etc., and near Thame.[11]

Prof. Prestwich has described a bed of Angular Drift on the Lower Chalk between Upton and Chilton, near Didcot. (See Fig. 64, p. 385.) The Drift consists of Chalk and flint-rubble with blocks of Sarsen stone. Bones of Mammoth, Rhinoceros, Bison, and Reindeer were met with in it; and in an intercalated mass of white marl, land- and a few freshwater-shells were obtained. This Drift he regards as analogous to the great 'Land-wash' or 'Head' which overlies certain Raised Beaches on our southern coast.[12] (See p. 494.)

In the valley of the Medway, at Aylesford, there are extensive deposits of gravel, containing remains of *Elephas antiquus*, *Rhinoceros*, etc.

Brickearth occurs at Deal, and in the valleys near Dover, Ramsgate, Canterbury, and Faversham. A superior kind of brickearth has, according to Mr. Bensted, been worked near Maidstone. It occurs in pipes and fissures in the Kentish Rag,

[1] H. Woodward and W. Davies, Geol. Mag. 1874, p. 390; H. Woodward, G. Mag. 1864, p. 241, 1868, p. 540; Catalogue of Pleistocene Vertebrata in Coll. Sir A. Brady, by W. Davies, 1874.

[2] Morris, Mag. Nat. Hist. 1836, p. 261, 1838, p. 539. Many sections in the Thames Valley deposits have been published by Mr. A. Tylor, Q. J. xxv. 83-95.

[3] G. Mag. 1872, p. 268; Mr. W. Davies has published a full list of the Mammals, etc., *Ibid.* 1879, p. 247; R. W. Cheadle and B. B. Woodward, Proc. W. Lond. Scient. Assoc. 1876, i. 92.

[4] Q. J. xxxvi. 544.

[5] Q. J. xxviii. 449; see also John Allen Brown, Q. J. xli. 192; and W. G. Smith, P. Geol. Assoc. viii. 124.

[6] Prestwich, Q. J. xi. 110.

[7] Q. J. vii. 278, xi. 114, xvii. 367.

[8] Lieut.-Col. H. H. Godwin-Austen, Q. J. xl. 599.

[9] E. B. Poulton, Q. J. xxxvi. 296; Dr. J. Stevens, P. Geol. Assoc. ix. 209.

[10] G. Mag. 1882, p. 49.

[11] Codrington, Q. J. xx. 374.

[12] Q. J. xxxviii. 127. See also H. H. Howorth, G. Mag. 1882, pp. 433, 509.

and is in part due to the dissolution of that rock, and in part to old Alluvium that has been preserved in these 'pipes.' It has yielded remains of Elephant, etc.[1]

At Folkestone Battery a bed of gravel called the 'Bone-bed' rests on the Lower Greensand, and is overlaid by a white loam used as brickearth. It has yielded remains of *Bison*, *Elephas primigenius*, *Hippopotamus*, *Hyæna*, *Rhinoceros*, etc.[2]

At Brighton, east of Kemp Town, the following succession of beds has been exposed :[3]—

		Feet.
Soil, etc.		
Pleistocene.	'Elephant Bed'	50 to 60
	Old sea-beach	5 to 8
	Sand	3 to 4
Chalk.		

The Elephant Bed, first described by Dr. Mantell, is provincially termed Combe rock ; it is chiefly made up of layers of Chalk and flint rubble, and may be in part of subaërial formation. It contains remains of *Elephas primigenius*, *Rhinoceros tichorhinus*, etc. ; and Mr. E. H. Willett obtained a Palæolithic implement from it. Remains of Mammoth have also been obtained from a brick-yard at Hove.

At Bognor, Littlehampton, and Worthing there are certain deposits of brickearth which have yielded Mammalian remains, *Elephas*, etc. ; and these are regarded as of the age of the Elephant-bed of Brighton. There is also at Selsea a superficial brickearth, which was regarded by Mr. Godwin-Austen as due to "the wash of a terrestrial surface under a far greater amount of annual rainfall than we have at present." (See p. 495 and sequel.)

At Fisherton Anger, about one mile west of Salisbury, the valley deposits of the River Wily have yielded remains of the Lemming, Mammoth, Reindeer, Hyæna, etc., and Palæolithic Implements. These drifts consist of high-level gravel containing flint-implements, but no organic remains ; and also at a lower level of brickearth, 10 to 20 feet thick, with fluviatile shells, underlaid by gravel which yields Mammalian remains. The Implements were discovered by Dr. H. P. Blackmore, who has also found specimens at Milford Hill, east of Salisbury.[4] Flint Implements have likewise been obtained from the Upper Test Valley, St. Mary Bourne, in Hampshire.[5]

In the Isle of Wight remains of Elephant have been obtained at Freshwater Gate.[6]

Here and there in the Avon valley, at Twerton, Larkhall near Bath, Bathampton and Freshford, small patches of gravel have yielded the remains of Rhinoceros, Mammoth, Musk Sheep, etc.[7] Pleistocene Mammalian remains have also been found at Taunton ; and in Wiltshire at Chisenbury, near Nether Avon, Westbury, Christian Malford and Foxham, near Chippenham.[8] Near Marlborough there is a deposit of brickearth, which is manufactured into bricks of a rich crimson colour.[9]

In the valley of the Severn there is much drift. At Cropthorne on the Avon, between Evesham and Pershore, Mr. Strickland, in 1834, obtained bones of *Hippopotamus*, *Rhinoceros tichorhinus*, *Elephas antiquus*, *E. primigenius*, *Ursus*,

[1] Morris, Mag. Nat. Hist. 1836, p. 593 ; W. H. Bensted, Geologist, v. 448, P. Geol. Assoc. i. 58 ; C. Le N. Foster and W. Topley, Q. J. xxi. 453 ; Topley, Geol. Weald, p. 179.

[2] S. J. Mackie, Q. J. vii. 257.

[3] Mantell, Fossils of S. Downs, p. 277, Proc. G. S. ii. 203 ; Dixon, Geol. Sussex, ed. 2, p. 112.

[4] Q. J. xx. 190 ; xxi. 250 ; Prestwich, Q. J. xi. 101.

[5] Joseph Stevens, A Descriptive List, etc., 1867.

[6] Bristow, Geol. I. of Wight, p. 101.

[7] C. Moore, Proc. Bath Nat. Hist. Club, 1870.

[8] R. N. Mantell, Q. J. vi. 314 : J. D. Pring, Q. J. xiv. 164.

[9] Whitaker, Q. J. xviii. 265.

etc.; also many land and fresh-water Mollusca,[1] including *Unio littoralis*, var. These remains occurred in beds of fine sand overlaid by gravel, 8 feet thick.

The valley gravels at Charmouth, near Lyme Regis, near Bridport, at Burton Bradstock and Loders have yielded remains of Mammoth; at Lyme the Rhinoceros has also been found, and at Motcomb the Hippopotamus.[2]

At Kentisbere a Palæolithic implement has been found by the Rev. W. Downes,[3] and a short time previously many specimens, fashioned out of Greensand chert, were obtained by Mr. W. S. M. D'Urban in a large ballast-pit in the Axe valley at Broom, not far from Hawkchurch, near Axminster.[4] Here there is nearly 30 feet of gravel.

There are many valley deposits whose age is uncertain, no Pleistocene Mammalia or other organic remains having been found in them.

The valley deposits of the Taff, Rhondda, and Cynon in Glamorganshire, have been described by Mr. A. Tylor.[5] In the neighbourhood of Hereford there are extensive beds of valley gravel in places 30 feet thick and 158 feet above sea-level.[6] (See Fig. 15, p. 105, and p. 493.)

The gravels of the Dart above Totnes have been described by Mr. Ussher. They contain large boulders of granite, quartz, grit, etc.: the absence of Cretaceous materials is noteworthy. At Holne Chase the river has excavated a gorge 60 feet or more in depth. These accumulations suggest a greater volume of water in former times than is now carried down by the river.[7]

In the Chalk districts of the east of England there are accumulations of gravel, chiefly made up of subangular and partially rolled flints, which occur in dry valleys: hence the beds are sometimes termed Dry-valley gravel. Beds of this character occur near Great Marlow and Henley-on-Thames, in Buckinghamshire, and they often merge into the Thames valley-gravels, although they are chiefly due to the direct subaërial waste in the Chalk combes. In Yorkshire the dry Chalk valleys north-west of Bridlington, near Weaverthorpe, Foxholes, and other places, contain gravel, sometimes 40 feet thick.

Recent Alluvial Deposits.

Under this heading we have grouped for the sake of convenience all the Modern accumulations of our river-valleys, including not merely the Alluvium, but also the Lacustrine deposits, Peat-beds and Submerged Forests, and the Estuarine *Scrobicularia*-clays. The deposits contain remains of Mammalia now existing in this country, or but recently exterminated from it,[8] as well as other organic remains belonging to species still living in England. (See p. 478.) They indicate some oscillations in the level of the land, as for instance in the succession of deposits met with in Porlock Bay.

Alluvium.—Those who wander along the banks of our rivers will observe the flats of marsh or meadow land that usually flank them, bordered now on one side, now on the other by a cliff, and marked off from the surrounding country which rises gently or abruptly

[1] Mem. H. E. Strickland, by Sir W. Jardine, 1858, pp. clxiv, 79, 95; Proc. G. S. ii. 95, 111; Hull, Geol. Cheltenham, p. 85; W. S. Symonds, G. Mag. 1868, p. 413; T. G. B. Lloyd, Q. J. xxvi. 202.

[2] T. Thompson, G. Mag. 1869, p. 206.

[3] G. Mag. 1879, p. 480.

[4] G. Mag. 1878, p. 37; Evans, Journ. Anthrop. Inst. vii. 499.

[5] Q. J. xxv. 66.

[6] T. Curley, Q. J. xix. 175.

[7] Ussher, Trans. Devon. Assoc. 1876.

[8] J. E. Harting, British Animals extinct within Historic Times, 1880.

from it. This tract of level ground forms what is called Alluvium, and it is evidently composed of material deposited by the river.

If we examine the river-banks we generally find a loamy or silty deposit with seams of gravel: sometimes the entire bank is composed of gravel, at others nothing but loam, very sandy clay or peaty mud, may be seen. In fact we see many kinds of *material* which may have been formed and deposited contemporaneously. In the finer sediments we may often find remains of the common river shells and perhaps a few land shells and bones of recent Mammalia, as well as Neolithic and later works of Man.

In clayey countries the Alluvium is often broad, and not always to be readily distinguished, as the ground may rise almost imperceptibly away from it. In mountainous regions the Alluvium is more marked, but the material composing it is generally very coarse, and in such tracts it often forms an irregular surface, especially as the streams are liable to become torrents. The level of the Alluvium naturally falls with the descent of the river, but it may generally be defined as that tract which would be flooded, should the river overflow its banks. Hence the term 'Level' is often applied to the meadows, moors, or marshes that form the Alluvial flats.

As each river (unless artificially checked) is continually changing its course in its valley, so is it easy to understand the great breadth of many valleys when compared with the size of their rivers or streams, for it does not follow that any river existed of sufficient bulk to fill its entire valley, but that the river has constantly changed its position, and worn away cliffs so as to form and occupy different portions of the valley at different times. If the land be stationary the tendency of the river is rather to widen than to deepen its valley, accumulations of gravel and coarser material being formed opposite to the cliffs. A considerable thickness of Alluvium is, however, suggestive of depression. Prof. Prestwich has pointed out that in all rivers subject to floods and carrying down much sediment, as for example the Severn in its lower course, three forms of sediment will be deposited: 1st, coarse gravel and shingle in the more direct channel through which the waters flow with the greatest velocity; 2nd, sand and fine gravel in those portions of the more direct channel where the velocity of the stream is checked from any cause; and 3rd, fine silt and sediment in those parts where the flood-waters out of the direct channel remain for a time in a state of comparative repose; such places are the lee-side of the hills, lateral valleys and plains, with any local depressions or hollows. None or little would accumulate in the main channel, as the scour of the retiring waters would there prevent its deposition.[1] In tidal channels like the Severn, near Aust, the mud occupies a conspicuously inclined bank at low-tide; and Prof. W. J. Sollas

[1] On the subject of Floods, see C. Walford, Journ. Statist. Soc. xli. 433; Prestwich, on the Holmfirth Flood, Q. J. viii. 225; W. Molyneux, Old River Courses and Floods of the Trent Valley, 1876.

has shown that marine organic remains, Sponge-spicules, tests of Foraminifera, and fragments of Echinoderms, may be carried high up an estuary and up rivers.[1]

The Alluvium where it approaches the sea is naturally of an estuarine character, and the beds so formed are known as *Scrobicularia*-clays, etc. Much Alluvium is actually below the sea-level, and is preserved only by artificial banks, or by natural barriers of Blown Sand. The term Warp is sometimes applied to tidal Alluvium. (See sequel.)

Alluvial soils are generally fertile, forming rich meadow and pasture land. The principal of these grazing-lands are situated on the banks of the Humber, Trent, Great Ouse, Yare, Thames, and Severn, and they include the flats bordering the Bristol Channel, in Somersetshire, and the Sussex levels.

The Alluvial silty deposits are sometimes of economic value, sand from the bed of the Thames being useful in brickmaking, while Portland cement has been made from Chalk mixed with river-mud from the mouth of the Thames, and other places. (See p. 419.) In some localities, as at Wells in Norfolk, bricks are made from Alluvial clay.

Peat. — Peat is an accumulation of vegetable matter, partly mineralized, and of variable composition and consistency. It has been formed in low-lying marshy areas of more or less stagnant water, bordering rivers or lakes ; and it has been formed in pools and marshy places on elevated moors and mountains. Hence it is sometimes divided into Hill Peat, and Bog or Marsh Peat. In many cases peaty beds in Alluvial deposits are derived from accumulations formed elsewhere: where peat has been formed *in situ* the beds are often termed Peat Mosses (or Morasses). Near the surface Peat is usually light-brown in colour, and spongy, while the plant-remains are but little altered; deeper down the substance is darker in colour, denser, and the plants are more decomposed; in places the Peat is quite black, and it is more or less earthy, especially in the lower part. As a rule, however, Peat contains but 3 per cent. of earthy matter, which may have been introduced by streams, and in some cases by wind; the greater part of the sediment that might have been carried in by streams having doubtless been filtered out by reeds and rushes that bordered the low-lying tracts in which it was accumulated.

Marsh Peat varies locally in composition, but is often formed to a large extent of the Bog-moss (*Sphagnum palustre*), together with Reeds (*Arundo*), Rushes (*Juncus*), Sedges (*Carex*), Ferns, and other more or less aquatic plants. In places other mosses (*Hypnum fluitans* and *H. filicinum*), Stoneworts (*Chara hispida* and *C. gracilis*), and the Bladderwort (*Utricularia vulgaris*) are important constituents of Peat. Stumps and prostrate trunks of Trees are sometimes met with at or near the base of the peat, in a more or less rotten state, and occasionally penetrated by the roots of marsh plants. These trees include the Oak, Scotch Fir, Alder, and Birch, and more rarely the Ash, Hazel, and Willow.[2]

[1] Q. J. xxxix. 620.

[2] W. Carruthers, P. Geol. Assoc. v. 8.

Peat beds vary in thickness from a few feet to 20 or 30 feet. The peat is largely dug for fuel, being cut in the summer season and stacked. It holds a large amount of water, but the slowness with which it parts with it is a great hindrance to its being largely worked. When peat accumulates on a clayey surface abounding in springs, the water sometimes oozes out beneath the peat, and between it and the natural soil in such quantities as to raise up the layer of peat so that it floats. Some areas of peat are known as Quaking Mosses, and these owe their vibration to a semifluid bottom, although some vibration is characteristic of all peaty grounds. If swelled by heavy rains these Quaking Mosses occasionally burst, as did the Solway Moss in 1772, when a flow of black peaty mud overwhelmed about 400 acres.[1] Peat is well known to store up water on mountains.

Lyell mentions that the formation of peat, when not completely under water, is confined to moist situations, where the temperature is low; and Prof. J. Geikie has pointed out that after the final isolation of Britain from the Continent, the ancient forests decayed, and peat-mosses largely increased on the higher grounds from which they are now disappearing.[2] On mountains the peat is often not more than 2 or 3 feet thick, and it is largely made up of Bog-moss and Heather; its growth depends in great measure on the dampness of the air.

Owing to the soft and yielding nature of some peaty deposits, coins, bones, or other substances may often sink into or through these 'sloughs,' and relics of various ages may thus be commingled. Peat, as a rule, is a good preserver of animal substances, but in some cases the humic and other acids met with cause their decay.

Submerged Forests.—While Raised Beaches indicate an upward movement in the land, there are many traces of old land-surfaces along our coasts, submerged or partly so, which contain fragments and stumps of trees, sometimes erect and with their roots embedded in the old soil on which they grew. Trees and some other Plants similar to those found in Peat, previously mentioned, occur in these Submerged Forests.

Such Submerged or Submarine Forests are not necessarily of the same age, although those to which we now draw attention are all probably Post-Glacial or Recent. On the other hand, the Cromer Forest Bed, which in places is partially Submerged, is of Pre-Glacial age, and earlier relics of terrestrial surfaces (not now Submerged) are met with in the Purbeck Beds, and in the Coal Measures.

In many cases, as remarked by Mr. Godwin-Austen and Mr. Whitaker, these Recent Submerged Forests are simply places where the sea is eroding the peaty Alluvium of a river-valley, for they frequently occur in prolongations of valleys which are now inlets of

[1] Lyell, Principles of Geology, ed. xi. ii. 510; Gilpin, Pict. Beauty, etc., 1772; T. R. Jones, P. Geol. Assoc. vi. 207.

[2] Trans. Roy. Soc. Edin. xxiv. 363.

the sea or tidal estuaries.[1] When, however, they pass beneath low-water level there is clear evidence of depression, and Mr. J. S. Gardner does not believe in the growth of forests behind dykes below the sea-level.[2]

The principal kinds of accumulations met with among our Recent valley-deposits having been described, the further notices of them are arranged as far as possible in geographical order.

A Submerged Forest has been observed off Cardurnock, on the Solway.[3]

The Recent deposits of the Lancashire coast between Liverpool and Fleetwood may be arranged as follows :[4]—

5. Blown Sand; and Tidal Alluvium (Upper *Scrobicularia*-clay), overlaid in places by Freshwater deposits with *Cyclas cornea* (Upper *Cyclas*-clay of Mr. De Rance).
4. Superior or Upper Peat and Forest Bed, 2 to 20 feet thick. Seen at Blowick, near Southport, and near Fleetwood.
3. Formby and Leasowe Marine Beds (of Mr. T. M. Reade), and Lower *Scrobicularia*-clay, Crossens, Seaforth, etc., 20 to 30 feet.
2. Inferior or Lower Peat and Forest Bed, Cheshire Coast, near Hoylake.
1. Shirdley Hill Sand and Presall Shingle (of Mr. De Rance); Washed Drift Sand (of Mr. Reade), 12 to 15 feet.

At Glazebrook Moss, Lancashire, there is a deposit of peaty beds about 18 feet in thickness, resting on Boulder Clay. The drainage of this area, as pointed out by Mr. Reade, caused the moss to sink about 8 feet. The same geologist has drawn particular attention to the submarine forest at the Alt mouth, Great Crosby, where there is evidence, in his opinion, of the trees being rooted on the spot.[5] He believes that the last change of level in south-west Lancashire was a downward one, and it did not take place within the past 2500 years.

Peat-beds occur also at Halsall, Sefton, Pilling, and Chat Mosses in South-west Lancashire.[6] In Cheshire peat-beds occur in Blake Mere and other mere-basins in the Drift Sand. In Derbyshire peat occurs on Kinder Scout, etc., in the Peak District, and in the far north there is much peat, even on the higher parts of the Cheviot Hills.

Peat deposits, with tree-stumps *in situ*, occur on both sides of the river Tees, at Redcar, Kildale, and West Hartlepool; and these in places become Submerged Forests.[7] On the high grounds of Yorkshire there is much peat, 20 feet thick in places on Egton High Moor and other Moors in East Yorkshire; and it occurs also in Wensleydale and near Ingleborough in West Yorkshire.[8]

In the Isle of Man certain lacustrine deposits of shell-marl occur in hollows of the Drift; and they have yielded remains of *Cervus megaceros*. Peat-bogs or Curraghs occur in some parts of the island, and a Submerged Forest has been noticed in Poolvash Bay.[9]

[1] Godwin-Austen, Q. J. xiii. 40; Dixon, Geol. Sussex, ed. 2, p. 25.

[2] G. Mag. 1885, p. 145.

[3] T. V. Holmes, Trans. Cumberland Assoc., Part vi.

[4] T. M. Reade, G. Mag. 1872, p. 111; Proc. Liverpool Geol. Soc. 1871; C. E. De Rance, G. Mag. 1873, 188, 1883, 506; Q. J. xxvi. 655, Superficial Geol. S. W. Lancashire (Geol. Surv.) p. 61; Joseph Boult, Speculations on Former Topography of Liverpool, Part 2, 1867; G. H. Morton, Geol. Liverpool, 1863.

[5] Q. J. xxxiv. 447, 808, xxxvii. 439; Proc. Liverpool G. S. 1877-78; Trans. Historic Soc. Lancashire and Cheshire, 1878; see also C. Potter, *Ibid.* 1876.

[6] De Rance, Superficial Geol. S. W. Lancashire, p. 69.

[7] A. C. G. Cameron, G. Mag. 1878, p. 351; W. Y. Veitch, Proc. Yorks Geol. and Polyt. Soc. 1863.

[8] Phillips, Rivers, etc., of Yorkshire, p. 38.

[9] J. G. Cumming, Q. J. ii. 344.

The occurrence of shell-marl containing *Limnæa*, etc., has been observed in a bog near Montgomery.[1] A Diatomaceous deposit was discovered in 1879 by Mr. W. F. Lowe in Llyn Arenig Bach, a lake about midway between Bala and Ffestiniog. The bed, which was exposed during the partial draining of the lake, is about 1 foot thick, and is overlaid by a black peaty deposit.[2]

Submerged Forests have been noticed at Llandrillo Bay,[3] Cardigan Bay, St. Brides Bay, and Swansea Bay. Sections of peat alternating with estuarine *Scrobicularia*-clay were recorded at the Swansea docks by Mr. M. Moggridge.[4] Turf-pits have been worked at Newcastle in Emlyn, Caermarthen, and peat-beds occur in many other parts of Wales.

Professor Buckman discovered in the bed of the Chelt, near Cheltenham, peat in which trees occurred with their roots still standing. The formation of the peat was probably caused by the trees falling across the stream and damming up the water, which then became a peat-bog.

Large tracts of Alluvium extend along the borders of the Bristol Channel between Chepstow, Newport, and Cardiff; between Berkeley and Portishead; and again near Clevedon, Weston-super-Mare, Burnham, Glastonbury, Bridgewater, Langport, and Ilchester, forming tracts that suggest the former presence of the sea in tidal creeks or estuaries.[5]

A Submerged Forest has been noticed at Holly Hazle, near Sharpness.[6] Further south the Somersetshire Levels exhibit a very variable series of beds. The following section at Huntworth near Bridgewater was noted in 1826 by W. Baker:—

	Feet.
Silt	16
Peat of irregular thickness, with Freshwater and Marine Shells, Bones, antlers of Deer, and Wood (Alder, etc.)	1
Soft silt	9
Gravel, containing Shells, Pottery, and bones of Horse, Ox, and Deer	1
Blue Clay, penetrated by roots and rootlets of plants	2
Red Marl, 29 feet below the surface, which was a little below the level of the highest spring-tides.	

At Shapwick the Alluvium, consisting of alternations of peat, clay, sand, and gravel, was proved to be 61 feet in thickness.[7]

After a long continuance of heavy rains, the river Parret and its tributary streams rise above their banks and flood large tracts of country; Langport then lies on the edge of a vast sheet of water, and Aller, close by, is an island. Glastonbury Tor is not quite isolated by Alluvium, although its appearance well merits the old name of the Isle of Avalon.

In brickyards at Bridgewater the celebrated Bath bricks are made, and these take their name (as I am informed by Mr. Ussher) from a Mr. Bath, the original manufacturer. These bricks, which are merely shaped in the form of an ordinary brick for the sake of convenience, and are used for scouring, polishing, knife-cleaning, etc., are made from a peculiar kind of sandy mud obtained from the bed of the river Parret, or from reservoirs into which the river overflows and leaves a deposit. This consists of siliceous sand, containing occasional remains of Diatomaceæ.[8]

Peat is very largely dug in the moorlands of Somersetshire, near Edington and Shapwick, between Glastonbury and Highbridge. Some of these beds have been

[1] Murchison, Proc. G. S. ii. 332.
[2] Science Gossip, Oct. 1880, p. 219.
[3] Miss Eyton, G. Mag. 1868, p. 352.
[4] Q. J. xii. 169.
[5] R. Chambers, Ancient Sea-Margins, p. 8.
[6] W. C. Lucy, Proc. Cotteswold Club, vi. 105.
[7] W. Bidgood, Proc. Somerset Arch. Soc. xxvi. (pt. 2.) 126.
[8] Geol. E. Somerset (Geol. Surv.), p. 160.

worked for fuel from the time of the Romans, and probably earlier, while others are of more recent formation. The peat-moors, or 'Turbary lands,' have an irregular distribution; and the peat, which in places is 14 or 15 feet thick, is due largely to the growth of the common sedge (*Carex*), whence Sedgemoor derives its name. The following Plants, according to Mr. Alfred Gillett, have assisted in the formation of the Peat in this district:—Cotton grass (*Eriophorum*), Bulrush (*Scirpus lacustris*), Willow herb (*Epilobium angustifolium*), Sedge (*Carex*), Bog moss (*Sphagnum palustre*), Heath (*Erica*), Bog myrtle (*Myrica gale*); and amongst the Ferns, *Osmunda regalis*, *Lastrea thelypteris*, and *Pteris aquilina*. It contains also the Sea Wrack (*Zostera marina*).[1] At Shapwick, where the pits are opened to a depth of about 5 feet, the peat is light on top, and darker, denser and better below. Beneath this there is about 3 feet of soft peaty earth with stools of trees, the wood being well preserved, and below is a pale grey buttery clay. Peat has also been observed on Blackdown (Mendip Hills), and near East Harptree.

Evidences of a Submerged Forest were noticed long ago at Stolford, near the mouth of the Parret;[2] and this may be connected with the peat-beds of the Somersetshire Levels.

In West Somerset a Submerged Forest has been observed in Porlock Bay, west of Minehead, and there the following order of beds was noted by Mr. Godwin-Austen:[3]—

6. Shingle bank.
5. Marine silt, with *Scrobicularia plana*.
4. Surface of Plant-growth, with roots of plants, stumps and trunks of trees.
3. Freshwater mud-deposit.
2. Forest-growth. (Oak, and probably Alder.)
1. Angular detritus.

In the Teign Valley or Bovey Basin, between Bovey Tracey and Newton Abbot, there are accumulations of sand and gravel locally known as 'Head,' which rest on the Eocene Bovey deposits. These are for the most part recent fluviatile and estuarine deposits (*Scrobicularia*-clay, etc.), and are partly made up of older gravels which border the basin. Near Kingsteignton a bronze spear-head, a wooden doll or idol, and several bones of Ox, Deer, etc., were obtained from one of the pits.[4] In the same valley above Newton Abbot a canoe has been found in a bed of clay; and this Mr. Pengelly regards as perhaps of Glacial age. (See p. 494.)

Numerous Submerged Forests have been noticed on the coasts of Devon; at Braunton Burrows, in Barnstaple Bay,[5] and in Torbay, at Blackpool, at North and South Sands in the Salcombe estuary, and in Bigbury Bay, etc. The Torbay Submerged Forest comprises peat-beds that have yielded Roman remains, and these beds rest on clay or estuarine mud, which contains relics of the Bronze period.[6]

On Dartmoor, near Tavistock, etc., there is peat in places 30 feet thick, and a peat-naphtha company was established at Prince Town.[7]

In Cornwall Submerged Forests have been noticed at Looe, Fowey, Mounts Bay, etc.[8]

The Stream-tin deposits of Par, Pentuan, Carnon, and other localities in Corn-

[1] See Rev. W. Phelps, Proc. Somerset Arch. Soc. iv. part 2, p. 91.
[2] L. Horner, T. G. S. iii. 380.
[3] Q. J. xxii. 1.
[4] Journ. Anthrop. Inst. v. 299; Q. J. xxxii. 234; Pengelly, Trans. Devon Assoc. 1875, vii. 200; *Ibid.* xv. 368; Brit. Assoc. 1886.
[5] Pengelly, G. Mag. 1869, p. 77; T. M. Hall, Q. J. xxxv. (Proc.) 106.
[6] D. Pidgeon, Q. J. xli. 9. See also Pengelly, G. Mag. 1870, p. 64.
[7] R. N. Worth, Trans. Devon Assoc. vii. 229.
[8] Ussher, G. Mag. 1879, p. 251.

wall, have attracted much attention, and the beds have been described by De la Beche, W. J. Henwood, J. W. Colenso, J. Carne, and others. The following Section at the Fowey Valley Works was noted by Mr. S. R. Pattison :[1]—

	Ft.	in.
Peat	14	0
Fine washed sand	2	6
Peat, containing Hazel-nuts, etc., and antlers of Deer	4	6
Sand and rounded stones, with much tin ... 1 ft. to	7	0
Peat, containing numerous trees, etc.	3	0
Granite, on the surface of which large quantities of tin were found.		

According to Mr. Ussher the Stream-tin beds may be about the age of the 'Head' (see p. 495), or formed during subsequent submergence. The Forest-growth was of later date.

Mr. P. O. Hutchinson has called attention to a Submerged Forest and to a peaty-bed near Sidmouth.[2]

At Poole Harbour a Submarine Forest has been observed ;[3] and Peat has been dug at Knighton Bottom, near Bournemouth.[4] Peat also occurs in the Forest of Woolmer.[5] Submarine Forests have also been noticed at Southsea and Portsmouth,[6] Bracklesham Bay, Pagham, Felpham, near Bognor, Pevensey Bay, and St. Leonards ;[7] and Peat occurs in the Lewes and Arundel levels. *Scrobicularia*-clay occurs at Pagham Creek (now reclaimed), and at Lower Lancing, east of Worthing.[8] (See p. 519.)

In the Isle of Wight, at Tollands Bay, there is a lacustrine deposit containing recent species of *Helix*, *Cyclostoma*, *Succinea*, *Limnæa*, *Planorbis*, etc.[9]

At Romney Marsh and the Sussex Levels the whole of the Alluvium is below the level of high-water at spring-tides, but the access of the sea is prevented by tracts of shingle bordering the marsh, which are partly piled above the level of high water, and by artificial banks which have been erected where no natural barrier of shingle exists.[10]

Cervus megaceros, *Bos primigenius*, etc., have been met with in the Alluvial deposits of the Kennet Valley.[11] Near Newbury the peat has been dug for fuel, etc. The following section of the beds was noted by Prof. T. R. Jones :—

Alluvium.
Shell-marl, called 'malm,' with freshwater Mollusca, 1 in. to 8 ft.
Peat, 10 ft. in places.
Shell-marl, with remains of Beaver, etc., 1 or 2 ft.
Gravel.

In the immediate neighbourhood of London, the Alluvium of the Thames valley does not occupy a very large area, but much of the land formed of it south of the river at Lambeth and Kennington is but little above the Thames high-water mark, and in Bermondsey parish there is land below this level. A considerable thickness

[1] Trans. R. Geol. Soc. Cornwall, vii. 34 ; this and many other sections are given in a paper by W. A. E. Ussher, Post-Tertiary Geol. Cornwall, 1879, pp. 27, 32, 44 ; G. Mag. 1879, p. 251.
[2] Trans. Devon Assoc. 1873 ; Nature, Oct. 21, 1880, p. 584.
[3] Lyell, Principles of Geology, edit. xi. ii. 536.
[4] W. B. Clarke, Proc. G. S. ii. 599.
[5] White, Nat. Hist. of Selborne, ed. by Bell, vol. i. p. 17.
[6] Sir H. James, Q. J. iii. 249.
[7] Mantell, Geol. Sussex, p. 288 ; Dixon, Geol. Sussex, ed. 2, p. 146.
[8] Dixon, Geol. Sussex, ed. 2, p. 81.
[9] Trimmer, Q. J. x. 54 ; Bristow, Geol. I. of Wight, p. 98.
[10] Drew, Geol. Romney Marsh (Geol. Surv.).
[11] Geol. Hist. of Newbury, 1854, p. 40 ; Geologist, v. 317.

of 'Made Earth' is found under all parts of the metropolis. (See sequel, under Soils.) A section near the Blackfriars Road was as follows: [1]—

Made Earth	7 feet.
Bluish clay, with freshwater Shells and vegetable matter	6 ,,
Earthy Peat	5 ,,

A section at the West India Docks exposed the following beds: [2]—

	Ft.	in.
Made Earth, about	12	0
Brown and blue clay, with peat, stems of trees, and shells	8	0
Sand and gravel	13	6
Pebbles and rolled clay, with broken shells, etc.		

At Tilbury Docks the Alluvium was proved to have a thickness of 57 feet 6 inches, and it consists of alternating beds of mud, clay and peat, with gravel at the bottom. A human skeleton was found at a depth of 32 feet, and this at the time was erroneously considered to be of Palæolithic age.[3]

Interesting sections of the recent Alluvial deposits near Walthamstow have been recorded by Dr. H. Woodward, who obtained remains of Beaver, etc., and noticed the probable influence of this animal in modifying the courses of streams, and in the formation of Alluvial flats.[4]

Mr. S. V. Wood, jun., has remarked that for a few miles on the east of London we find a bed of peat, containing the stems of trees, and resting on the Thames gravel or upon the Upper Brickearth. (See p. 517.) When this formation was opened up in forming the sewer through the Plumstead Marshes, stools of trees (yew, oak and pine) were exposed at the base of the peat, rooted into the gravel at a depth of some 20 feet below the surface of the marsh. This peat is overlaid by the marsh-clay formed by the river-mud before the stream was embanked.[5]

In the lower part of the Thames valley, at Sheppey, Shoeburyness, Foulness, and at the mouths of the Crouch, Blackwater, and Colne, there are considerable tracts of Alluvium. A neck of it separates Thanet from the mainland. Submerged Forests have been noticed on the Essex coast.[6]

A submerged peat-bed at Bawdsey, in Suffolk, has been described by Dr. J. E. Taylor,[7] who has also drawn attention to peat-beds in the Alluvium of the Orwell valley. The remains of Mammoth found in these recent deposits were no doubt derived.

Beds of Freshwater marl have been noticed at Soham Mere, also between Littleport and Downham, and at Apethorp, near Stamford.[8]

A small tract of Alluvium extends from near Hunstanton to near Weybourn on the coast of Norfolk. Remains of a Submerged Forest have been noticed at Holme Scalp and Brancaster, and at the former locality a polished celt (Neolithic) was found embedded in the trunk of a tree; [9] further east, near Wells, the Alluvial flats are in places flooded by the sea, and are known as Salt Marshes. (See p. 516.)

At Yarmouth the Alluvial or Estuarine deposits (penetrated in a well-boring)

[1] C. Evans, P. Geol. Assoc. i. 265; A. Bott, *Ibid.* 327; J. A. Coombs, *Ibid.* iii. 33 (Battersea, etc.); W. H. Hudleston and F. G. H. Price, *Ibid.* iii. 43 (New Law Courts); Whitaker, Surface-Geology of London, 1867, in Report of Medical Officer of Privy Council for 1866.

[2] W. T. Blanford, Q. J. x. 434.

[3] See T. V. Holmes, P. Geol. Assoc. viii. 392.

[4] G. Mag. 1869, p. 385, Trans. Essex Field Club, 1886.

[5] Geol. Mag. 1866, p. 62; see also P. Geol. Assoc. iii. 266.

[6] W. H. Dalton, G. Mag. 1876, p. 491.

[7] Geol. Mag. 1882, p. 573; Whitaker, Geol. Ipswich, p. 97.

[8] W. J. Hamilton, Q. J. vi. 451; P. Geol. Assoc. vi. 213.

[9] Gunn, Geol. Norfolk, 1883, p. 22.

have been estimated to have a thickness of 170 feet; but this may include some Pliocene deposits.

In the Cliff section at Mundesley on the Norfolk coast there is a freshwater deposit, known as the Mundesley river-bed, resting in a trough of the Glacial deposits. It consists, according to Prof. Prestwich, of sandy loam and black and brown peaty beds, containing Recent Freshwater shells, Insects and Fish-remains.[1] Remains also of *Emys lutaria*, and of the Red-throated Diver (*Colymbus septentrionalis*) have been obtained.[2] The lowest beds consist of subangular flint-gravel.

In West Norfolk remains of *Emys lutaria* were obtained at West or Hill Mere, near Wretham, and this was the first record of the occurrence of this freshwater Tortoise in England.[3]

A considerable area of Alluvium occurs in the district known as Holderness in Yorkshire; it forms the eastern borders of Lincolnshire, and also the Fenland.

At Hull the following is a general section of the beds:[4]—

	Feet.
Soil	1
Clay	6
Silt	23
Peat with large trees	2

Lacustrine deposits with *Cyclas cornea* (Cyclas-marls), *Bithynia tentaculata*, etc., have been detected at Holmpton, between Withernsea and Owthorne, and near Hornsea.[5]

At Hornsea the beds, seen at low tide, were thus noted by Prof. Phillips:—

Blue clay	2 or 3 feet.
Brown clay, *Anodon*	1 to 3 ,,
Laminated plant-bed	3 in.
Cyclas-marls	4 in. to 1 foot.
Peat and black root-bed	6 in.

In Holderness peaty beds occupy small lacustrine areas, which were formerly meres: while Shell-marl occurs at Driffield. Mr. Reid observes that often the name Mere is the only relic of the old meres for which Holderness was once so famous. Submerged or Buried Forests have been proved in wells and docks on the borders of the Humber (at Grimsby, etc.) to a depth of 50 feet beneath high water. There is also a second Buried Forest at about the present low-water level. The latter is the ordinary Submerged Forest seen on the foreshore.[6]

The Humber warp is a marine and estuarine silt and clay, which occurs above the Peat beds; it contains *Tellina Balthica*, *Scrobicularia plana*, *Mactra subtruncata*, *Littorina littorea*, *Bulla obtusa*, *Rissoa* (*Hydrobia*) *ulvæ*, etc.

Mr. Clement Reid remarks that "The amount of material annually removed from the Holderness coast by the sea may be estimated at about 6,000,000 tons, of which the greater part, probably 5,000,000 tons, is sand and mud. The coarser sand largely goes to form the sand-banks which block the Humber and North Sea, or the sand-dunes which cover Spurn Head and protect the Lincolnshire coast. But the fine mud and silt is carried to much greater distances. Not only are the Humber and Lincolnshire flats raised by it, but the enormous quantity of warp which is annually deposited in the Wash can have no other source; for there are no cliffs to yield it in Lincolnshire, and the mud of the Norfolk cliffs appears to travel principally to the southward. In the Humber, as in the Wash, the warp

[1] Geologist, iv. 68; Lyell, Phil. Mag. (3), xvi. 352; Reid, Geol. Cromer, p. 119.
[2] E. T. Newton, G. Mag. 1879, p. 304, 1883, p. 97.
[3] A. Newton, Ann. Nat. Hist. (3), x. 224; C. J. F. Bunbury, Q. J. xii. 355; F. J. Bennett, Geol. Attleborough, etc., p. 18.
[4] Phillips, Geol. Yorkshire, Part 1, ed. 3, pp. 66, 76.
[5] See also Morris, Q. J. ix. 321.
[6] C. Reid, Geol. Holderness, p. 77, 82, 86; Wood and Rome, Q. J. xxiv. 182; J. C. Hawkshaw, Q. J. xxvii. 237.

brought down by the rivers may be left out of account, for the bulk of it is probably deposited on their alluvial flats long before it reaches the estuary. More mud seems to be carried into the rivers by the tide than comes down them."

The silt consists of upwards of 70 per cent. of very fine sand, about 10 per cent. of alumina, and the remainder of carbonates of lime, magnesia, oxide of iron, and organic matter. This mud or warp is largely deposited between tide-marks, "thus tract after tract gradually rises to near the level of high-water, and is then protected by embankments and added to the area of the cultivated land." The rise and embankment of Sunk Island, now part of the mainland, is fully described by Mr. Reid.[1]

The tidal warp forms some of the richest land in Holderness. Large areas in the neighbourhood of the Humber have been raised and improved by artificial warping.

The deposits of the Fenland, including the Bedford Level, comprise a variable accumulation of sands and gravels, silts, and clays, with intercalated layers of peat. These deposits where they come to the surface give distinct characters to the landscape, the areas of silt and gravel being marked by numerous villages, while the peat presents a more even surface; it is for the most part devoid of hedgerows and no villages are situated on it.[2] In places, as between the Rivers Witham and Glen, the following general succession of beds may be traced:[3]—

Soil, peat, silt, or clay.
Peat or peaty clay.
Blue clay often 'buttery.'
Bottom peat.
Sand or gravel.

The gravels, clays and silts are marine, and thus the beds indicate changing conditions, the sea at one time having the mastery, and then there occurred changes during which land-surfaces appeared, for the newer peat, which is 3 or 4 feet thick, contains buried trees at its base. The silt and Buttery clay (so named from its consistency) contain *Scrobicularia plana*, *Tellina Balthica*, *Cardium edule*, and *Littorina littorea*. Marine gravels occur near Tattershall and Bourn. (See sequel.)

The Cambridgeshire peat has yielded remains of Brown Bear, Beaver, etc., and at Burwell Fen, about 10 miles from Cambridge, remains of *Bos primigenius* were obtained, in the frontal bone of which animal a Neolithic implement was partially embedded.[4] Peat has been dug near Chatteris, at Coveney and Burwell Fen, also at Billinghay between Sleaford and Tattershall.

TERRESTRIAL PHENOMENA.

Springs.

The occurrence of freshwater at different levels beneath the surface of the earth is dependent upon the rainfall and geological

[1] Geol. Holderness, pp. 105, etc.; see also E. Tindall, Geologist, iii. 40.

[2] Skertchly, Geol. Fenland (Geol. Survey); and The Fenland Past and Present, by S. H. Miller and S. B. J. Skertchly, 1878.

[3] A. J. Jukes-Browne, Geol. S. W. Lincolnshire, pp. 98, 106; Science Gossip, 1879, pp. 242, 265; Penning and Jukes-Browne, Geol. Cambridge, p. 112; Rev. E. Trollope, Proc. Geol. and Polyt. Soc. W. Riding, iii. 637.

[4] Dr. H. Woodward, G. Mag. 1869, p. 64; J. Carter, G. Mag. 1874, p. 492; see also Bonney, Cambridgeshire Geology, p. 58; Rev. L. Jenyns (Blomefield), Brit. Assoc. 1845.

structure.[1] Thus the rain falling on the ground filters through the porous rocks, or finds its way through joints and crevices in denser rocks, which generally exhibit its action in furrows and channels. It sinks until it is arrested by a stratum of clay or marl, and this, although only two or three inches thick, may, if continuous, be sufficient to retain the water, which either collects or issues at the outcrop of the strata on the side of a hill in the form of springs. Caverns and fissures in limestone rocks, such as the Carboniferous Limestone, constitute many underground watercourses. Much rain-water is absorbed by the soil and vegetation; but on clayey strata it either collects at the surface or forms natural channels, which carry it away in streamlets. The drainage of the land is therefore both superficial and subterranean. Moreover, rivers flowing over pervious rocks have in course of time clayed their own beds and rendered them water-tight; in other cases, however, notably on the Cotteswold Hills, a considerable diminution in volume of certain streams has been noticed, owing to their loss in passing over porous strata.[2]

The circulation of water above and below ground is an important study, the general direction in many cases being totally different. Hence in well-sinking attention must be paid to the nature and inclination of the strata, and to the circulation of underground waters.

Water may be obtained in valleys where there is an accumulation of gravel resting on clay. It may be obtained on hills and table-lands formed of alternations of pervious and impervious strata, provided the former come to the surface in places. Near an escarpment the water may be drained off by springs, or by the inclination of the strata, while faults may be instrumental in damming up or in draining off supplies.

The supply of water in wells depends more or less directly upon the rainfall, but the deeper wells, as a rule, are the more constant, because their sources of supply are more widespread.

The outcrop of a porous rock may receive a considerable quantity of water, which may be retained within it by the presence of clayey beds both above and below; and should the outcrop be very extensive, and the strata be characterized by a basin-shaped structure, the water will rise (sometimes above ground) to near the level of the outcrop of the water-bearing stratum, when tapped at or near the centre of the basin. Upon this kind of structure the system of Artesian[3] wells depends, and it is exemplified in the London Basin, where many wells are sunk into the Chalk which crops out to the north and south of the metropolis, contains at its base the impervious Chalk Marl, and

[1] See Prestwich, Water-bearing Strata around London, 1851; De Rance, Water Supply of England and Wales, 1882; Reports on Circulation of Underground Waters, Brit. Assoc. 1875–86; Reports Royal Comm. on Water Supply, (G. Mag. 1869, p. 414).

[2] J. H. Taunton, Proc. Cotteswold Club, vi. 305.

[3] So named from the old province of Artois (Artesium), in France.

is overlaid by the retentive Lower Eocene Clays. (See Fig. 70, p. 414.)

Intermittent springs are sometimes fed by cavities in the strata which are filled during rainy seasons, and gradually drained off by the springs: there is an intermittent spring at Tideswell in Derbyshire. They may be regarded as temporary outlets after unusually heavy rains.

The 'Bournes' or 'Nailbournes' are intermittent springs of the Chalk districts, being channels used during excessive rain-fall, when the line or plane of saturation of the Chalk rises to a higher level than usual. The Lambourn and the Winterbourn in Berkshire are examples of these overflows, and so are the Croydon Bourne, the Assendon, near Henley-on-Thames, and the Hertfordshire Bourne, which falls into the Bulbourne at Bourne End.[1] (See p. 421.)

Swallow Holes.—Sometimes on reaching a limestone formation, such as the Carboniferous Limestone, after passing over the outcrop of the Lower Limestone Shales, a stream will follow the clayey strata, and disappear beneath the Limestone in 'Swallet' or 'Swallow' Holes. Examples of these swallow holes occur at Downhead Mill, at Priddy, and at Charterhouse, near Blackdown, on the Mendip Hills. The exit of the streams may be traced with much probability to the following points: that of the Downhead stream to the limestone chasm about a mile east of the village of Downhead; that of the Priddy rivulet to Wookey Hole, and that of the Charterhouse brook to the foot of Cheddar cliffs.[2] A similar spring no doubt produces St. Andrew's Well, at Wells, in Somerset.

Subterranean rivers are frequent over the Carboniferous Limestone district of the north of England. Among these is the Manifold, which passes beneath the limestone hills about three miles south-west of Ecton mine in Staffordshire, and after traversing a cavern through the base of the limestone hills four miles in length, re-appears near Ilam. The River Aire, in Craven, Yorkshire, issues from Malham Tarn, a circular lake about a mile in diameter, on the summit of a lofty moor: proceeding thence, it descends through a subterraneous passage, and again issues at the foot of Malham Cove, a perpendicular limestone rock 288 feet high. During heavy rains the subterraneous passage is not sufficient to carry off all the water, the remainder of which makes its way over the surface, till it reaches the top of the rock and precipitates itself thence in a magnificent cascade.[3] *Keld* is a term applied to the large springs so common in limestone districts, where the water collected in the pot-holes and crevices of the rock runs out a full stream from a cave below.[4]

In the Carboniferous Limestone on Appletreewick Moor in the neighbourhood of Skipton (Craven district), there are hollows, like inverted cones, sometimes fifteen yards across, and of equal depth. An account of these has been published by Mr. L. C. Miall.[5] Thund Pot and Helm (Helln or Allum) Pot are amongst the largest. They are sometimes called 'Butter-tubs,' as between Swaledale and Wensleydale. The Swallow-holes or 'water-sinks' are of two distinct kinds, those due directly to chemical erosion (butter-tubs) and those to subsidence of an undermined crust (pots). Many of the latter occur around Ingleborough, at Weathercote, and near Chapel-le-Dale; these include Jingle Pot, Hurtle Pot, etc.[6]

[1] Whitaker, Mem. Geol. Surv. iv. 391; J. Evans, Trans. Hertfordshire Nat. Hist. Soc. ii. p. lvii; T. R. Jones, G. Mag. 1885, p. 148.

[2] Buckland and Conybeare, T. G. S. (2), i. 210.

[3] Conybeare and Phillips, Geol. Eng. and Wales, p. 397; see also P. Geol. Assoc. vii. 436; Dawkins, Cave-hunting, 1874, p. 47.

[4] Hughes, G. Mag. 1867, p. 349.

[5] G. Mag. 1870, p. 513.

[6] Dawkins, G. Mag. 1880, p. 514; Phillips, Rivers, etc., of Yorkshire.

Swallow-holes, known as 'man-holes,' are met with in the New Red Sandstone of Ripon;[1] they occur also in the Furness region.

In the Chalk country Swallow-holes are not uncommon, as near Canterbury, Farnham, Newbury, Hungerford, Corfe Castle (see Fig. 54, p. 347), etc., also in Hertfordshire.[2] They are from six to forty feet broad, and twenty to thirty feet deep, and funnel-shaped. Prof. Prestwich remarks that old Tertiary sand-pipes may have determined the formation of some of these Swallow-holes. Referring particularly to the Swallow-holes in Berkshire, Mr. Whitaker observes that they are formed by streams which, rising in the higher ground, flow down the escarpment of the Tertiary beds, until they reach the more pervious and jointed Chalk, or until they come within a short distance of that rock, when they work their way into it through the few feet of the softer overlying beds. In the course of time, through the chemical action of the carbonic acid in the water, and the mechanical action of the water itself, funnel-shaped basins are worn out in the Chalk and the beds above, the operation being made more easy by any pre-existing fissures. These hollows are generally thickly overgrown with vegetation. The streams may often be seen running through them, though sometimes they merely flow into a small pool, the level of the water in which remains the same, notwithstanding the constant flow. In Berkshire these Swallow-holes always occur at or near the junction of the Reading Beds and the Chalk, and they are therefore of much use in drawing the boundary-line between those formations, especially where there are no sections. The Mole, as is well known, sinks for a while in the Chalk south of Leatherhead.

Suggestions have been made to increase the supply of water in certain strata at a depth beneath the surface, by means of artificial Swallow-holes or 'Dumb-wells.'

In studying the water-bearing strata, it is interesting to trace their connection with the distribution of villages, for no doubt these were fixed according to the means of obtaining a supply of water, and one easily accessible, either from river or well. And the practice of well-sinking dates back to early historic times in Western Europe.

Prof. Prestwich has shown how the earliest settlements in and around London were dependent upon the geological structure, and for this reason. The London Clay, which occupies so wide an area, is covered to a large extent by the valley gravels, and here and there in the north of London by an outlying hill of Bagshot Sand. Wells sunk through these sandy and gravelly deposits were always supplied with water, which was kept up by the impervious London Clay. Hence the bare London Clay was unoccupied until the New River and other waterworks did away with the necessity for wells; and the clay districts of Holloway, Camden Town, Regent's Park, St. John's Wood, Westbourne Park, and Notting Hill, received town populations much later than Stepney, Hackney, Islington, Paddington, Kensington, Chelsea, and Camberwell, which are situated on gravel. In the same way on the outskirts of London a succession of villages grew up for miles on the great beds of gravel, ranging on the east to Barking, Ilford, and Romford; on the north, following the valley of the Lea, to Edmonton and Hoddesdon; and on the west, up the Thames valley, to Hammersmith, Ealing, Hounslow, and beyond.[3] Around Harrow, which stands on the Bagshot Sand, a large area of bare London Clay extends, which is still remarkably free from the encroachment of houses, particularly between Harrow and Ickenham on the west, and Edgware on the north-east. The few springs that occur in the London Clay are more or less charged with salts of iron.

Similarly, formations composed chiefly of limestones, sands, and sandstones, such as the Cornbrash, Corallian Beds, Upper Greensand, etc., are often marked in their outcrop by villages, while the Oxford Clay, Kimeridge Clay, and Gault in comparison form very thinly populated districts. Where large cities and towns are situated on Clay formations, there is usually much valley-gravel, as at London, Oxford, etc.

[1] A. C. G. Cameron, G. Mag. 1879, p. 575.
[2] Prestwich, Q. J. x. 222; Whitaker, Mem. Geol. Surv. iv. p. 100.
[3] Address to Geol. Soc. 1872.

Well-water at moderate depths, 100 to 200 feet, is usually colder in summer and warmer in winter than surface-water. In very deep wells the temperature of the water at some distance from the surface rises at about the same rate as that of the atmosphere in mines—1° for every 50 or 60 feet. Thermal springs no doubt arise from great depths, and in non-volcanic districts, according to Prof. Prestwich, they may generally be considered as natural artesian wells whose temperature is proportionate to the depth from which they rise.

Water penetrating the rocks often becomes charged with substances which are contained in them, such as salts of iron, lime, soda, magnesia, and sometimes sulphur, which is derived from the decomposition of iron-pyrites. Warm waters naturally take up larger proportions of mineral matter than do the cold springs.

The water of sandy and clayey districts is 'soft' like rain-water, but in limestone areas it becomes impregnated with carbonate of lime, and is called 'hard.' Hardness of water is also caused by sulphate of lime. Thus soft-water is usually obtained from the Bagshot Beds, Lower Greensand, Wealden Beds, Upper Carboniferous strata, from the Devonian rocks, Old Red Sandstone, Silurian and Cambrian gritty and slaty beds, as well as from the Igneous and Metamorphic Rocks. Whereas the water obtained from the Chalk, Oolites, Lias, and Carboniferous Limestone is hard: that from the Magnesian Limestone is very hard, and so also is that from the New Red Sandstone, which frequently contains gypsum. The waters that supply the fountains in Trafalgar Square, London, are derived from two wells sunk (300 and 395 feet) into the Chalk, and they contain carbonate of soda, sulphate of potash, etc.[1]

The relation between health and geology is a point which has in recent years received a good deal of attention. It is well known that gravelly, sandy, or chalky soils are more healthy than a clay foundation, because the former are pervious to water, and the latter is impervious. On the former there is less consumption than on the latter, as Dr. Buchanan and Mr. Whitaker have demonstrated; the artificial removal of sub-soil water has, however, done much to equalize the conditions.[2] Again, the water-supply is a most important subject, for in some villages and small towns the wells are liable to contamination. Situated, perhaps, on elevated ground, with a porous soil, they yet suffer because of the state of the drainage, the wells being shallow and the sewage from dead-wells or cess-pits, even the church-yards, draining into the water-bearing strata.

Tufa.—This is a deposit of carbonate of lime, known also as Travertin or Calcareous sinter, which is often formed by springs that issue from limestone strata. It frequently contains impressions of leaves and blades of grass, and specimens of the common land-snails, which have become as it were 'petrified.'

The rain absorbing carbonic acid from the atmosphere and from the soil, with the help also of vegetable acids, as humic and ulmic, dissolves portions of the limestone, which it parts with again when, on coming to the surface, it loses a portion of the carbonic acid. The amount of carbonic acid gas is generally less than 2 cubic inches per pint.

[1] De la Beche, Address to Geol. Soc. 1849, p. lxv; and Journ. Chem. Soc. i. 97.
[2] G. Mag. 1869, p. 499.

The tufa sometimes contains much earthy and sandy matter, and is often of a loose and friable nature, but sometimes, as near Dursley, in Gloucestershire, and near Matlock, it forms a hard and durable rock fit for building-purposes. Portions of old Berkeley Castle were built of Tufa from Dursley.[1]

Petrifying springs occur at Chalford near Stroud, Somerton on the Cherwell, North Ashton, Marston Lane near Oxford, at Chilton and other places in Somersetshire, at Matlock, at Alwalton Lynch near Peterborough, Stony Stratford, etc. The Dropping Well at Knaresborough is well known.[2] The deposit of tufa is made to form more rapidly by the water falling in spray on the objects to be incrusted, and among these birds-nests and flowers are favourite materials.

Tufa, derived from the Carboniferous Limestone, has been met with near Caerwys and Pwll Gwyn, also near Hawarden, in Flintshire,[3] at Prestatyn near Rhyl, and near Llangollen and Wrexham. It occurs near Spouthouse farm and at Southstone Rock, near Tenbury; at Portland;[4] at Tolland's Bay in the Isle of Wight; at East Malling and Boxley Abbey in Kent; and at Osbournby, in Lincolnshire.

Mineral Springs are of very varied nature; in fact there is an imperceptible gradation from waters whose mineral constituents do not unfit them for ordinary drinking purposes, to those which are highly charged with saline matter. When of Therapeutic value, they are Medicinal Springs, but this term has been indiscriminately applied. The term 'Spa' is often given to mineral springs, and takes its name from the town of Spa in Liege, at one time a place of great resort.

For more than three hundred years the medical properties of mineral waters have attracted the attention of the learned; but towards the middle and close of the last century, and for the first twenty-five years in this, there was a sort of rage for these waters. In hundreds of places in this country, where there had been detected waters containing a small percentage of iron-oxide, or saline matter, or which were seasoned with sulphur, there were advertised the virtues of a Spa. At many of these places baths were erected, while analyses of the waters were made, books and pamphlets were written on the subject, and people went to be cured of every kind of complaint: in the majority of cases these Spas are simply of local historic interest.[5]

Manufactories of various salts from Mineral Waters have been carried on at Leamington, Cheltenham, and other places.

While some springs on the whole manifest great uniformity in their composition, yet they are liable to vary in abundance and strength, and in the quantity of gases given off, such as nitrogen, carbonic acid gas, carburetted and sulphuretted hydrogen.

Mineral Springs have been classed as follows:—

[1] G. F. Playne, Proc. Cotteswold Club, vi. 81.
[2] P. Geol. Assoc. vii. 432.
[3] G. Maw, G. Mag. 1866, p. 253; see also *Ibid.* 1867, p. 305.
[4] Prestwich, Q. J. xxxi. 41.
[5] See The Spas of England (Northern and Midland Spas), by Dr. A. Granville, 2 vols. 1841.

CHALYBEATE, containing salts of iron (from the Greek, *chalubos*); with two divisions, *carbonated* and *sulphated*.

SULPHURETTED, containing sulphur, in the form of sulphuretted hydrogen. These springs are often called "stinking wells," and their flavour has been likened to that of "the washings out of a gun-barrel."

SALINE, containing salts of soda, lime, magnesia, etc. When chloride of sodium is the chief ingredient, the waters constitute BRINE springs; and when carbonate of lime is in excess, they are termed CALCAREOUS or PETRIFYING Springs.

THERMAL Springs are so called from their unusual or excessive temperature;[1] ordinary spring water being from 47° to 51°.

Warm and tepid springs occur at Buxton, Bakewell, Stoney Middleton, Matlock, Taafe's Well near Cardiff, Bath, Batheaston, and at Vincent's Rocks, Clifton, near Bristol.

The spring at Buxton, called St. Anne's Well, rises in the Carboniferous Limestone, has a temperature of 82°, and contains salts of soda and magnesia; the Romans made use of it. At Bakewell the temperature of the spring is 60°.

At Matlock Bath there are tepid springs having a temperature of 68°, and they were brought into notice about the year 1698. Their composition is as follows:—

	Grains per imp. gallon.
Chloride of sodium	4·57
Sulphate of magnesia	9·73
,, lime	2·04
Carbonate of lime	14·68
Silica	0·71

Taff's or Taafe's well at Eglwysilan, near Cardiff, rises from the Coal-measures, and contains salts of lime, magnesia and soda; it has a temperature of 65° and evolves nitrogen.[2]

At Clifton the Hotwell, which rises from the Carboniferous Limestone, contains as chief ingredients sulphate of soda, carbonate and sulphate of lime, and chloride of sodium. In temperature it varies from 70° to 76°.

The most important thermal springs are those of Bath, which are the hottest in England. They have, since the time of the Romans, been renowned for their sanatory properties. There are four springs, rising from the same source, and their temperature varies from 104° to 120° Fahr., but on the whole it is remarkably uniform at all seasons of the year. The discharge of the waters (about 385,000 gallons daily) has, so far as observation has gone, remained very constant; but the amount of salts, according to analyses, varies from 144 to 168 grains per imperial gallon. The following analysis of the Bath waters was made by Prof. J. Attfield:[3]—

Carbonate of lime	7·84
Sulphate of lime	94·10
Nitrate of lime	·56
Carbonate of magnesia	·56
Chloride of magnesium	15·24
Chloride of sodium	15·15
Sulphate of sodium	23·14
Sulphate of potash	6·70
Nitrate of potash	1·05
Carbonate of iron	1·21
Silica	2·70
	168·25

[1] It has been suggested that these sources of heat should be utilized. J. S. Gardner, G. Mag. 1885, p. 397; Judd, Volcanoes, ed. 2, p. 335.

[2] T. W. Thomas, Trans. Cardiff Nat. Soc. ix. 48.

[3] See also Merck and Galloway, Mem. Chem. Soc. iii. 272; Capt. M. Heriot, Proc. Bath Nat. Hist. Soc. iii. 163; Dr. R. B. Falconer, Baths and Mineral Waters of Bath, ed. 7, 1881.

Iodine, Lithium, Strontium, Copper, and some organic matter are likewise present. Dr. Daubeny ascertained that the daily evolution of nitrogen gas amounts to 250 cubic feet in volume; carbonic-acid gas is also given off, as well as a small amount of oxygen.

The waters unquestionably rise from a great depth; they have been tapped at about the junction of the Keuper and Rhætic beds, and there is no doubt that they spring through faults or fissures in the subjacent Carboniferous rocks, as was originally suggested by William Smith. Regarding them as natural artesian wells, Prof. Prestwich calculates from their temperature that the depth from which they rise is about 3500 feet; in this case they may be supported by the Lower Limestone Shales.[1]

Referring to the large quantity of nitrogen gas constantly being disengaged, Dr. Daubeny has remarked that the same gas is freely evolved from most thermal springs, the majority of which are associated with volcanoes, and that it is likewise evolved from volcanoes, both in an active and a dormant condition. The Bath springs, in his opinion, were therefore probably connected in some manner with the cause of volcanic action; and Prof. Judd has remarked that they relieve the earth's crust of an amount of heat, perhaps equal to that of a considerable volcano. The study of the Bath springs opens up a number of interesting questions, for while the mineral ingredients of these and other springs is due in great measure to the presence of some of them in the rocks through which the waters pass; yet, at the same time, as Sir Charles Lyell observed, mineral springs may derive an inexhaustible supply, through rents and porous rocks, from the leaky bed of the ocean. Nor is this theory unreasonable, if we believe that the contiguity of nearly all the active volcanoes to the sea is connected with the access of salt-water to the subterranean foci of volcanic heat.[2]

The composition of sea-water from the Channel is as follows:[3]—

	Grains per Imp. Gallon.
Chloride of sodium	1964·16
Chloride of potassium	15·31
Sulphate of lime	98·46
Carbonate of lime	2·31
Chloride of magnesium	256·66
Sulphate of magnesia	160·70
Bromide of magnesia	2·05
Iodine	traces
Ammonia	traces
	2499·65

The components of sea-water are to a large extent original (see p. 2), but many ingredients are brought in by rivers, etc. Moreover, it is interesting to note that Forchhammer has detected silver, copper, and lead in Corals; copper, zinc, and iron in the ashes of Sea-weeds; cobalt and manganese in the Sea-wrack (*Zostera marina*); and cobalt in fossil Sponges from the Chalk. These observations are in a measure confirmed by Mr. John Murray, who states that almost every element is contained in sea-water, many of them, however, in exceedingly minute quantities.[4]

The possible influence of sea-water on our underground waters is indeed a subject of the greatest importance, especially as we find chloride of sodium in

[1] Q. J. xlii. 305; Prestwich, Geology, Chemical and Physical, p. 166.

[2] See Daubeny, Remarks on Thermal Springs and their connection with Volcanoes, 1832; Lyell, Address to Brit. Assoc. 1864; Judd, Volcanoes, p. 219.

[3] Schweitzer, Phil. Mag. 1839, xv. 58; G. Forchhammer, Phil. Trans. 1865, p. 203.

[4] Nature, Oct. 15, 1885, p. 583.

waters which have, so far as is known, no access to salt-bearing rocks. It has moreover been conjectured that much sea-water may be stored up underground, in reservoirs or in the porous strata, and that such water may have come from the ocean, not merely from direct leakage at the present day, but at various epochs when the land was submerged. Indeed, we know that in certain places bordering the sea-coast, as in Durham, the well-water is saline.

In the Northumberland coal-field there are springs impregnated with common salt;[1] this is the case with the waters at Moira, in Leicestershire, derived from the Coal-measures, which contain 3700 grains of chloride of sodium in an imperial gallon; also at Pensnet Chace, in the South Staffordshire Coal-field; and again at Twerton and Radstock in the Somersetshire Coal-field.[2] (See also p. 240.)

Among the older rocks, springs containing much chloride of sodium have been met with in the 'killas' at Huel Seton, Camborne in Cornwall,[3] and in the Skiddaw Slates on the south-west side of Derwentwater.[4] In the former case the temperature of the water is 94°. Perhaps more puzzling is the occurrence of similar springs in strata above the New Red rocks, and which appear to have no direct connection with these saliferous strata. Such springs have been met with at St. Clement's Brewery, Oxford,[5] in many parts of Wiltshire, at Melksham, Swindon, etc.: and these saline waters have been encountered in the Oolitic rocks. At Swindon, a well sunk by the Great Western Railway tapped saline waters in the Forest Marble at a depth of 730 feet from the surface, and the spring contained 1824 grains of chloride of sodium in the imperial gallon. These waters are no doubt 'artesian' in their nature, and they may be accumulated in basins in the Carboniferous rocks from which they issue through faults and fissures in the overlying strata.[6]

Attention has been called to some thermal waters in the Fenland near Chatteris; these were met with in shallow wells about 10 feet deep, and their temperature was from 69° to 74°. In these cases Mr. F. W. Harmer was of opinion that the waters must have a deep-seated origin. Other cases, however, have been pointed out where warm water has been pumped out of farm-yard wells, and owes its temperature to fermenting manure.[7] Another source of mineral impurity in the waters of shallow wells arises from the artificial manures spread over the land; and in this way sulphate of magnesia has been shown to enter into the composition of some well-waters.

A 'Burning well' was discovered in 1711 at Broseley, and this phenomenon was due to petroleum, which issued from the Coal-measures into a well, and was occasionally ignited.[8] A petroleum spring has been observed at Pitchford, in Shropshire.

It is not necessary here to attempt to enumerate all the 'Spas' that have been met with in this country; it is desirable, however, to mention some of the more important mineral springs.[9] These

1 N. J. Winch, T. G. S. iv. 51.

2 C. E. De Rance, Trans. Manchester Geol. Soc. Dec. 1884; J. McMurtrie, Proc. Bath Nat. Hist. Club, vi. 84.

3 J. A. Phillips, Treatise on Ore Deposits, 1884, p. 121.

4 J. C. Ward, Geol. N. part of Lake District, p. 53.

5 Prestwich, Geol. conditions affecting the water-supply, etc., Oxford, 1876, p. 44; Ashmolean Soc. 1876.

6 See Q. J. xlii. 306

7 O. Fisher, G. Mag. 1871, p. 42; see also Skertchly, Geol. Fenland (Geol. Survey), p. 243.

8 J. Randall, G. Mag. 1865, p. 233.

9 See B. Allen, The Natural History of the Chalybeat and Purging Waters of England, 1699 and 1711; Dr. J. Elliot, An account of the Nature and Medicinal Virtues of the Principal Mineral Waters of Great Britain and Ireland, 1781; E. Lee, The Mineral Springs of England, 1841; and Dr. J. Macpherson, Our Baths and Wells, 1871. See also E. J. Waring, Bibliotheca Therapeutica, vol. ii. 1879.—Mineral Waters of Great Britain, pp. 775–804.

are as follows, the Saline springs being marked (S), the Sulphuretted (Su), and the Chalybeate (C):—

Northumberland.—Shotley Bridge Spa (C).
Cumberland.—Gilsland Spa, Shap Wells (Su).
Durham.—Houghton-le-Spring (S).
Yorkshire.—The Sulphuretted springs of Low Harrogate and the Chalybeate springs of High Harrogate; these issue from a deep source along an anticlinal axis of the Carboniferous rocks.[1] Scarborough (S), Croft Spa and Dimsdale near Darlington, Askerne near Doncaster, Lockwood Spa near Huddersfield, Clitheroe (S), Ilkley, Starbeck Spa near Knaresborough (S), Hovingham Spa near Ripon (S).
Lancashire.—Wigan (Su), Tarleton (C).
Derbyshire.—Wirksworth. (See also p. 536.)
Leicestershire.—Saline waters are obtained from a pit in the Moira coal-field, at a depth of 593 feet, and they are used in baths at Moira and Ashby-de-la-Zouch;[2] there are also mineral springs at Neville Holt and Burton Lazars.
Nottinghamshire.—Orston (S).
Lincolnshire.—Woodhall Spa (Iodine), Stamford (C).
Rutlandshire.—Tolthorpe Spa (C).
Northamptonshire.—Wittering Spa (C), Kings Cliffe (C), Astrop Spa, east of Kings Sutton.
Oxfordshire.—Chadlington (Su), Northleigh (C), Shipton-under-Wychwood (C).
Warwickshire.—Leamington (containing sulphate of soda, chloride of sodium, and chloride of lime): water obtained from wells 20 to 60 feet deep.
Shropshire.—Moreton (S).
Worcestershire.—Malvern, Holywell (S), and St. Ann's well (S); Tenbury.
Gloucestershire.—Cheltenham (chloride of sodium, sulphate of soda), Wickwar (S), Stow-in-the-Wold (C).
Wiltshire.—Holt (S), Road (S), Purton (S). (See also p. 538.)
Somersetshire.—Glastonbury Tor (C), Queen Camel (Su), Alford Well near Castle Cary (S), Capland Spa near Ashill (C).
Dorsetshire.—Nottington and Radipole near Weymouth (Su).
Devonshire.—Victoria Spa, Plymouth.[3]
Isle of Wight.—Sandrock, Niton (C).
Sussex.—Brighton (C).
Kent.—Tunbridge Wells (C), Bromley (C).
Surrey.—Epsom (sulphate of magnesia), Beulah Spa, Norwood (S).
Berkshire.—Sunninghill (C).
Buckinghamshire.—Dorton, near Brill (C).
Middlesex.—Hampstead (C), Cold Bath Fields, London (C). (See p. 534.)
Hertfordshire.[4]—Barnet (C).
Essex.—Dovercourt (C), Hockley Spa near Rayleigh (C), Tilbury (S).
Huntingdonshire.—Somersham (C).
Norfolk.—Thetford, Aylsham, and Hunstanton, etc.[5] (C).
Wales.—Builth, Llanwyrtyd, King Arthur's Well at Caernarvon (C), Vale of Conway (C), Llandrindrod (S), Builth.[6]

There are many healing springs whose virtues are entirely legendary: these are often termed Holywells, while many were dedicated to Saints. Some also are known as 'Wishing Wells,' such at those at Walsingham in Norfolk, but the present meaning of the appellation may be different from the original. Prof. T.

[1] P. Geol. Assoc. vii. 426; Prof. T. E. Thorpe, Phil. Mag. (5), ii. 50; C. F. Strangways, Proc. Geol. and Polyt. Soc. W. Riding, 1883.
[2] Mammatt, Ashby Coal-field, 1834.
[3] R. N. Worth, Trans. Devon Assoc. vii. 230.
[4] See R. A. Pryor, Trans. Watford Nat. Hist. Soc. i. 106.
[5] Trans. Norf. Nat. Soc. iii. 318, 525.
[6] Murchison, Proc. G. S. ii. 89.

Rupert Jones has observed that the names 'wishing well' and 'wish well' are recognized as containing the Celtic word for water (perhaps spring), and therefore they were probably Pre-historic, being at places of old occupation. The suffix *well*, met with in a number of village names, is rarely connected with a spring, it usually signifies an abode.[1] In the case of Clerkenwell, Shadwell, etc., the name has been applied to local wells or springs of water.[2]

The use of the Divining Rod for purposes of finding water is still a subject of faith with some individuals. In their work on wells and well-sinking (p. 27), Messrs. J. G. Swindell and G. R. Burnell state, "It is, however, undoubted that some persons are keenly sensitive to change of humidity, and hence possess special powers, apart from that due to knowledge of locality." But as the Divining Rod has been employed also for finding various metals as well as coal, it may fairly be regarded as the superstition of an age that, strange to say, is not yet bygone.[3]

On the eastern borders of Lincolnshire there are certain 'Blow wells,' some due to the rush of sea-water at incoming tides, driving sand or the air out of cavities in the strata, and forcing it upwards to the surface. Near Selsea, on a branch of the old Harbour of Pagham, there used to be a remarkable 'Hushing Pool,' due simply to the bubbling and hissing produced by the disengagement of the air from the gravel before the incoming tide.[4] 'Blowing wells' have been observed in some parts of the north of England, as near Preston, from which currents of air issue, and this phenomenon is due to changes in atmospheric pressure.[5]

Caverns.

Caverns are formed in most limestone strata: whether inland or near the sea-coast. Many no doubt originate by the enlargement of fissures along planes of joints or faults, and consist of a succession of chambers at different levels. They owe their origin to the chemical action of carbonated water, aided also by the mechanical disintegration of the limestone by frost and other meteoric agencies. In this respect they differ from sea-worn caves, which are found in different kinds of rock, both calcareous and siliceous, and are formed chiefly by mechanical wear and tear. The material removed from inland caverns is for the most part carried away by underground streams, in solution and in suspension. Some portions of the material are often re-deposited in the form of stalactitic and stalagmitic accumulations, in mud or loam (Cave Earth), pebbles and angular detritus (breccia). Bones, too, frequently occur, some of which may have been introduced from above ground, while others may have belonged to animals or men that formerly inhabited the cavern.

There is, however, no doubt that many of our Caverns were occupied at several successive periods, from Pleistocene and Palæolithic to early British times and even later. In some cases the

[1] See Trans. Norf. Nat. Soc. iii. 526.

[2] Isaac Taylor, Words and Places, ed. 6, p. 105.

[3] See Geol. East Somerset (Geol. Survey), p. 168; A. C. Pass and E. B. Tawney, Proc. Bristol Nat. Soc. (2) i. 60; G. Agricola, De Re Metallica, 1621.

[4] P. J. Martin, Q.J. xii. 135; C. Reid, Geol. Holderness, p. 128.

[5] J. Rofe, G. Mag. 1867, p. 106; A. Strahan, Nature, 1883, pp. 375, 461.

accumulations of different periods are sealed up and separated by deposits of stalagmite. But it must be remembered that caverns were not only used as habitations, but also for burial. Sea-caves were rarely occupied by man—except perhaps in the form of smugglers.

Caverns are most abundant in the Carboniferous and Devonian Limestones, but they are met with in some of the limestones of Oolitic age, and also in the Magnesian Limestone.

Stalactites and Stalagmites.—The deposits of carbonate of lime found adhering to the roof or lining the walls of caverns are called Stalactites, those covering the floor are called Stalagmites. Small and friable stalactites are frequently seen hanging from limestone arches, where their formation is rapid; or they may be formed from the mortar cementing bricks, in similar situations.

The stalactites in caverns are formed by the deposition, film by film, of some of the carbonate of lime which the rain-water has taken up in solution while penetrating the limestone. This incrustation in process of time attains considerable dimensions, and the stalactites and stalagmites sometimes meet, although the increase is often scarcely perceptible to the human eye in a lifetime. Such deposits indicate a pause in the formation of the particular part of the cavern in which they occur; but their accumulation naturally varies with the rainfall and the subterranean flow of the water.

Cox's famous cavern at Cheddar, in the Carboniferous Limestone of the Mendip Hills, is unequalled in England for the beauty of the stalactites which hang in fantastic shapes from its roofs and arches, or the stalagmites which grow in equally irregular forms from its floors and ledges. The cavern is not a large one, for in size it is surpassed by many others in the Mendip Hills, but its ornamentation renders it the most attractive one. By a little stretch of imagination one recognizes the wonderful things pointed out by the guide—here a petrified goose, there a loaf of bread, now a font and a monkey, then a nun and the Black Prince, a jelly glass, some drapery, a mummy, a turkey, a tongue, a flitch of bacon (this is generally present in a stalactite cavern), a great number of pillars, and a Hindoo Temple!

The Yordas Cavern, Kingsdale, near Ingleton, is famous for its stalactites;[1] a cavern with stalactites was discovered in 1860 at Greenhow, near Pateley Bridge, in Yorkshire; and other caverns with stalactites occur at Tenby and in Caldy Island.

Near Matlock, in Derbyshire, the Cumberland and Rutland Caverns contain a few stalactites, some also may be seen at Poole's Cavern, Buxton; but most of those that formerly existed have been broken off and carried away. The High Tor Cavern is a fissure 600 feet long, from 2 to 7 feet wide, and 150 feet deep. The Peak Cavern, near Castleton, is noted for its size. The Speedwell Cavern is an old lead mine, opening into a fine cavern; the water which traverses it is connected with the Peak Cavern. There are large Caverns at Clapham, in Yorkshire. Wookey Hole, in Somersetshire, is, however, deserving of mention on account of its size. One chamber is nearly 80 feet in height. A still larger Cavern, that of Goatchurch, in Burrington Combe, is mentioned by Prof. Dawkins; while the Lamb Cavern, near East Harptree, in part an old lead-mine, has recently been re-opened.

It will be impossible to enumerate all the Caverns, but the more important ones which have yielded bones must be noticed. Of these Caverns, some are simply

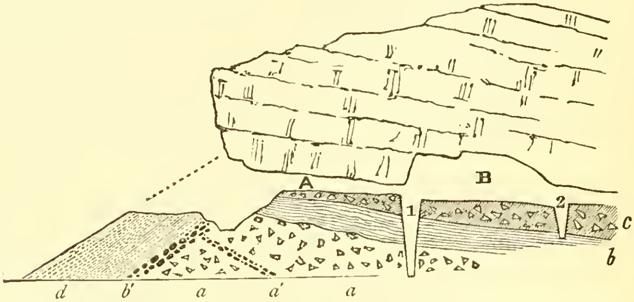
[1] W. B. Dawkins, Cave-Hunting, p. 64. See also Phillips, Rivers, etc., of Yorkshire, p. 30.

fissures in the Limestone. The principal Pleistocene and Recent Mammalia have been previously enumerated. (See pp. 477, 478.)

At Kirkdale Cavern, in Yorkshire, remains of Hyæna (indicating 300 animals), Wolf, Cave Lion, Cave Bear, Elephant, Rhinoceros, Reindeer, Irish Elk, Bison, Hippopotamus, etc., have been found. The Cave was discovered in 1821, and described by Dr. Buckland.[1] It is formed in the Corallian rocks, and is situated between Helmsley and Kirkby Moorside, on the border of the Vale of Pickering. It was evidently the resort of Hyænas, for the bones of many of the other Mammalia had been dragged in and gnawed by them. (See p. 333.)

FIG. 92.—VICTORIA CAVE, SETTLE, YORKSHIRE.

(R. H. Tiddeman.) Scale, 1 inch to 54 feet.



d. Talus, the dotted line showing its upper surface previous to the explorations.
c. Upper Cave-earth.
b′. Glacial drift.
b. Laminated clay.
a′. Bone-bed containing the older Cave-mammals.
a. Lower Cave-earth.
1. 25-foot shaft. 2. 13-foot shaft.
A. and B. indicate different chambers.

The Settle Cave (1450 feet above the level of the sea) was discovered in 1838, and has since been explored chiefly by Mr. R. H. Tiddeman.[2] The upper bed in it was formed of stones which had fallen from the roof; then beneath came a black bed, containing charcoal, and highly artistic enamelled ornaments, showing a date of occupation that was post-Roman. To these succeeded layers six feet in thickness, in which were found remains of a more ancient race, their flint knives, harpoons, etc. Beneath these deposits, classed as Neolithic and Roman, the following beds were determined :—

Upper Cave-earth, with Badger, Reindeer, Horse, etc.

Laminated Clay, with a few small well-glaciated boulders.

Lower Cave-earth, with Hyæna, Bear, *Elephas antiquus*, *Rhinoceros*, *Hippopotamus*, *Bos primigenius*, and a human fibula? Some doubt has been thrown on the identification of this human bone; but Mr. Busk, while disposed to regard it as an abnormally large human fibula, thought it would be unsafe to build any strong conclusions upon it.

The clay found in the cave was regarded by Mr. Tiddeman as of Glacial age. Many Pleistocene remains have also been found in a fissure in Raygill quarries near Skipton.[3]

[1] Reliquiæ Diluvianæ, 1823.
[2] Brit. Assoc. 1874, 1875; The Work and Problems of the Victoria Cave, 1875; G. Mag. 1873, p. 11; see also J. R. Dakyns, G. Mag. 1877, p. 439.
[3] Proc. Geol. and Polyt. Soc. W. Riding, 1880.

Remains of the Lynx (*Felis lynx*) have been obtained by Mr. James Backhouse from a rock-fissure in the Carboniferous Limestone of Teesdale, in Durham.[1]

Pin Hole, Church Hole, and Robin Hood's Cave in the Magnesian Limestone of Creswell Crags, Derbyshire, have been explored by the Rev. J. Magens Mello, while the Mammalian remains have been described by Mr. Busk and Prof. Boyd Dawkins. The succession of beds was as follows:—

5. Surface soil, with Roman and Mediæval pottery.
4. Limestone-breccia, with bones of Reindeer, Horse, Hyæna, *Rhinoceros tichorhinus*, Flint flakes, etc.
3. Cave-earth, with similar bones, also those of Bear and Cave Lion, together with quartzite implements.
2. Red sand, etc., with remains of Reindeer, Bison, and *Elephas primigenius*.
1. Sand, with blocks of limestone.

Among other remains found in beds 1 to 4, were the *Machærodus*, Leopard, Polecat, Wild Cat, Fox, Wolf, Irish Elk, and Hare. Among the works of Man there was the incised figure of a horse cut on a fragment of bone.[2]

The Dream Cavern, near Wirksworth, in Derbyshire, has yielded bones of Rhinoceros, etc. A fissure communicating with a basin in the Limestone at Windy Knoll, near Castleton in Derbyshire, explored by Mr. Rooke Pennington, yielded many specimens of Bison and Reindeer, also Grisly Bear, Fox, and Wolf. It had apparently been a drinking place, where these animals had been engulphed.[3]

A Cavern in Great Ormes Head has yielded Recent (Pre-historic) remains of Man, etc.[4]

Near St. Asaph there are Caves at Cefn and Pont-newydd, which were explored by Edward Stanley (Bishop of Norwich), in 1832, and more recently by Prof. Hughes and the Rev. D. R. Thomas.[5]

At Cefn the Cavern, in the Carboniferous Limestone, has yielded *Elephas antiquus*, *Rhinoceros tichorhinus*, *Hippopotamus major*, *Bos*, *Cervus*, *Felis spelæa*, *Ursus spelæus*, etc. At Plas Heaton, near St. Asaph, remains of the Glutton and other animals have been found.

A Cavern near Tremeirchion has yielded many bones, and furnishes evidence of its occupation by Hyænas. There are Bone-caverns also at Ffynnon Beuno and Cae Gwyn, in the Vale of Clwyd,[6] which have been explored by Dr. Hicks and Mr. E. B. Luxmoore. From these many Pleistocene Mammalian remains have been obtained, including about 400 teeth of Rhinoceros, 500 of Horse, 180 of Hyæna, and 15 of Mammoth. Several Flint implements have also been found in association with the bones. The most important evidence, however, is that the Bone-earth at Cae Gwyn is overlaid by Boulder Clay. The Beds were as follows:—Below the soil, for about 8 feet, a tolerably stiff Boulder Clay, containing many ice-scratched boulders and narrrow bands and pockets of sand. Below this about seven feet of gravel and sand, with here and there bands of red clay, having also many ice-scratched boulders. The next deposit was a laminated brown clay, and under this was found the bone-earth, a brown, sandy clay with small pebbles and with angular fragments of limestone, stalagmite, and stalactites. During the excavations it became clear that the bones had been greatly disturbed by water action, that the stalagmite floor, in parts more than a foot in thickness, and massive stalactites had also been broken and thrown about in all positions, and that these had been covered afterwards by clays and sand containing foreign pebbles. This seemed to prove that the caverns, now 400 feet above Ordnance datum, must have been submerged subsequently to their occupation by the animals and by man. In Dr. Hicks'

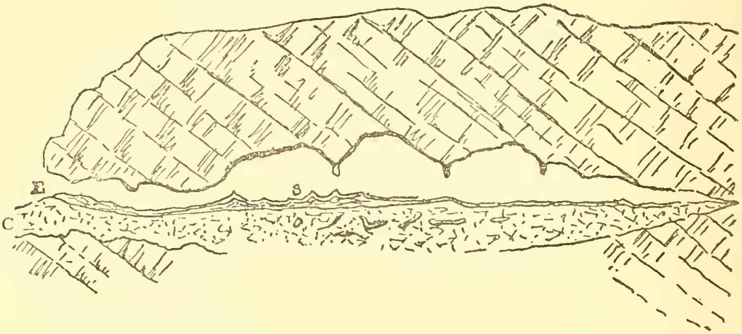
[1] W. Davies, G. Mag. 1880, p. 346.
[2] Q. J. xxxi. 679; xxxii. 240; xxxiii. 579, 589; xxxv. 724.
[3] P. Geol. Assoc. v. 188, Q. J. xxxi. 238.
[4] Canon A. H. W. Ingram, G. Mag. 1885, p. 307.
[5] Proc. G. S. i. 402; Journ. Anthrop. Inst. iii.; see also Trimmer, Practical Geology, p. 400; D. Mackintosh, Q. J. xxxii. 91.
[6] H. Hicks, Q. J. xlii. 3, G. Mag. 1885, p. 510.

opinion the contents of the cavern must have been disturbed by marine action during the great submergence in mid-Glacial times, and afterwards covered by marine sands and by an upper Boulder Clay, identical in character with that found at many points in the Vale of Clwyd.[1] The palæontological evidence suggests that the deposits in question are not Pre-Glacial, but may be equivalent to the later Pleistocene deposits of our river-valleys.[2] (See p. 481.)

Coygan Cave, near Laugharne, Caermarthen, explored by Dr. Hicks,[3] and Hoyle's Mouth, or Oyle Cave, near Tenby, explored by Mr. W. A. Sanford and the Rev. H. H. Winwood, have yielded some Mammalian remains. In the former there were found bones of Mammoth, Rhinoceros, Hyæna, Cave Lion, etc.[4]

A Hyæna-den has been found at Great Doward, Whitchurch, near Ross.[5] It is called King Arthur's Cave.

FIG. 93.—SECTION OF THE COYGAN CAVE, NEAR LAUGHARNE, CAERMARTHENSHIRE. (Dr. H. Hicks.)



E. Entrance.
S. Stalagmite.
C. Red earthy soil, with bones of Mammoth and Rhinoceros, and Flint Flakes.

The promontory of Gower, in Glamorganshire, composed largely of Carboniferous Limestone, contains many ossiferous caves and fissures. These were explored during the years 1858-61 by Dr. Hugh Falconer and Lieut.-Col. E. R. Wood.[6] Among the spots examined were Raven's Cliff, Bosco's Den, Long Hole, etc., and the Mammalian remains included *Ursus spelæus*, *Hyæna spelæa*, *Rhinoceros tichorhinus*, *Elephas antiquus*, *E. primigenius*, and *Cervus tarandus*. In Bosco's Den about 750 shed-antlers of the Reindeer were met with. Paviland is also a noted locality in this district: here are two large caves, accessible at low-water, or by dangerous climbing. Goat's Hole was explored by Dr. Buckland in 1823, and here, according to Prof. Dawkins, evidence of human interment in Pleistocene deposits has been obtained. The Crawley Rocks in Oxwich Bay formerly contained a bone-cavern, which in the process of quarrying the Limestone was entirely obliterated.

Longberry Bank Cave, near Penally, in Pembrokeshire, explored in 1866 by the Rev. H. H. Winwood, furnished evidence of its occupation in later Prehistoric

[1] Rep. Brit. Assoc. for 1886; G. Mag. 1886, p. 566; see also Trimmer, Brit. Assoc. for 1838, Sections, p. 86; A. Strahan, Geol. Rhyl, etc. (Geol. Surv.), p. 33.
[2] See also Hughes, G. Mag. 1886, p. 489, Q. J. xliii.
[3] P. Geol. Assoc. ix. 7.
[4] G. Mag. 1865, p. 471, 1867, p. 307; see also Geologist, v. 115, vi. 47; and E. L. Jones, Q. J. xxxviii. 282.
[5] Rev. W. S. Symonds, G. Mag. 1871, p. 433.
[6] Q. J. xvi. 487.

times, containing remains of Man, *Bos longifrons*, Goat, Badger, Dog, and shells of the Limpet, Oyster, and Mussel.

At Durdham Down, near Bristol, many Pleistocene Mammalian remains were formerly obtained from a fissure in the Carboniferous Limestone.[1]

In Somersetshire, a bone-cavern near Wookey Hole has yielded flint-implements, and bones of Mammoth, Woolly Rhinoceros, Cave Lion, Hyæna, etc. Its exploration was commenced in 1859 by Prof. W. Boyd Dawkins and the Rev. J. Williamson.[2] There are many other caverns in the Mendip Hills, at Banwell, Sandford Hill, Bleadon, Hutton, Uphill, etc., explored many years ago by the Rev. D. Williams, Mr. W. Beard, and others. Whitcombe's Hole in Burrington Combe, was occupied, according to Prof. Dawkins, in the Iron Age; but in most cases the earlier Mammalian remains were, in his opinion, introduced into the caves from the surface by streams.[3]

In 1858 a cavern was discovered in the Devonian Limestone at Windmill Hill, Brixham, near Torquay. It was explored in 1858 and 1859, under the superintendence of Mr. Pengelly, and showed the following succession of beds:—

4. Stalagmite.
3. Limestone Breccia.
2. Cave Earth, reddish loam with angular fragments of limestone.
1. Shingle bed with pebbles of different rocks.

Remains of the Mammoth, Tichorhine Rhinoceros, Horse, Ox, Red Deer, Reindeer, Roebuck, Cave Lion, Cave Hyæna, Cave Bear, Brown Bear, Grisly Bear, Fox, Hare, and Lemming, etc., also Worked Flints, were obtained from it.[4]

In Kent's Cavern, Torquay, all these species have been met with in the cave-earth, and in addition *Machærodus latidens*, Wolf, Dog, Glutton, Badger, Bison, Irish Elk, Beaver, Seal, etc. This was one of the Caverns first systematically explored, a task undertaken during the years 1825–29 by the Rev. J. MacEnery, whose labours at the time were not sufficiently appreciated. In 1865 a new and thorough exploration of the Cavern was undertaken by the British Association, and carried on until 1880; and for the constant supervision of the workings and record of the facts we are indebted to Mr. Pengelly. He has determined five marked beds of variable thickness and extent in this cavern as follows:—

5. Black Mould, 3 to 12 inches, with remains of Sheep, Flakes, and Strike-lights.	(Ovine.)
4. Granular stalagmite, coeval with the Tichorhine Rhinoceros. 1 inch to 5 feet. 3. Cave Earth, with *Hyæna spelæa*, etc., and flint implements.	(Hyænine.)
2. Crystalline stalagmite, 12 feet thick in places. 1. Breccia, with remains almost exclusively of Bear, and flint implements.	(Ursine.)

Several inscriptions have been noticed in the Cavern by Mr. Pengelly, the oldest of which bears the date of 1571.

The flint and chert implements found in the breccia and cave-earth are very dissimilar, the former being much ruder, than the latter, which were ovoid and lanceolate in form, very elaborate, and were associated with bone implements and ornaments. These facts, in Mr. Pengelly's opinion, prove the tenancy of the cave by two distinct races of men, and furnish evidence of a long lapse of time between them. Both the races of men were coeval with extinct Pleistocene animals, but

[1] E. Wilson, Proc. Bristol Nat. Soc. v. (1886).
[2] Q. J xviii. 127; xix. 260; G. Mag. 1865, p. 44.
[3] On the Caverns of Burrington Combe, 1864.
[4] See Prestwich, Phil. Trans. 1873; Pengelly, Trans. Devon Assoc. vi. 775; Trans. Plymouth Inst. v. 341.

they nevertheless represented two distinct civilizations.[1] Other caverns occur at Chudleigh, Newton Abbot, etc.[2]

At Yealmpton, not far from Yealm Bridge, near Plymouth, a Cavern in the Devonian Limestone was explored in 1832 by Mr. J. C. Bellamy. Remains of Elephant, Rhinoceros, Hyæna, Bear, and Glutton have been found.[3] Other caves at Oreston were discovered by Mr. Whidbey (1816–22); and these caves were the first systematically explored in this country.

Fissures containing bones are not unfrequently met with, as at Bath and at Portland, in the Oolitic limestones.

That Cave-deposits of Pliocene and earlier periods have not been discovered is due perhaps to the fact that no Caverns of such antiquity have escaped denudation.

Blown Sands.

On coasts where a great quantity of sand is accumulated, and where the land is comparatively flat, hillocks or 'dunes' of sand are raised along the shore, and the ground for some distance inland is coated with a sandy soil. These hillocks are caused by the wind blowing away the sand exposed at low tide; hence the deposits are sometimes known as Æolian Drift. Very often the beds of Blown Sand contain marine as well as common land shells, or fragments of shells, as on the hill above Sennen Cove, overlooking Whitesand Bay (Land's End), and on the Warren at the mouth of the river Exe. Wind 'ripple marks' are sometimes met with.

Sand-dunes rise to heights of 40 or 50, and rarely to upwards of 80 feet; but the slope is never more than 30°.[4] They are frequently protected by the Marram grass, *Psamma* (*Arundo*) *arenaria*.

In Cornwall, Blown Sand occurs at Lelant, Phillack, and Gwythian Towans, in St. Ives Bay, at Perran north-east of St. Agnes Head, and at Constantine Bay, near Falmouth.[5] On the north coast of Cornwall a considerable tract of cultivated land has been overwhelmed by Blown Sand. The church of St. Piran, in Perranzabulo (or Perran in Sabulo), was at one time smothered in sand; but through the shifting of this covering, the church was partially exposed in 1870. Gwythian church was also smothered. The sand is largely composed of comminuted sea-shells, and Mr. Richard Edmonds has obtained at Phillack Towans many specimens of land-shells. In places the sand has become sufficiently indurated (partly by oxide of iron) to be of use for building-purposes.[6]

The formation of sandstone is instructively illustrated by recently-consolidated sand at Newquay in Cornwall, and many similar examples exist around our western coasts, where hills of Blown Sand prevail. The water percolating

[1] Pengelly, Trans. Devon Assoc. 1868-1884: G. Mag. 1867, p. 430; MacEnery, Cavern Researches, edited by E. Vivian, 1859. Mr. MacEnery's collection is now in the British Museum.

[2] Pengelly, Trans. Devon Assoc. vi. 46.

[3] Col. Mudge, Proc. G. S. ii. 399.

[4] Topley, Pop. Science Review, xiv. 133.

[5] Towan (towyn) means *Downs* or *Sand Hills*; Les Landes, or 'barren heaths,' form a sandy district on the south-west coast of France, hence Lelant, Edmonds, Trans. Plymouth Inst. iii. 22; Ussher, Post-Tertiary Geol. Cornwall, p. 35.

[6] H. Boase, Trans. R.G.S. Cornwall, ii. 140.

through the upper layers of shelly ferruginous sand, dissolves the carbonates of lime, or of iron, which are re-deposited as cementing materials, on the evaporation of the water as it filters through the lower strata of the porous accumulation.[1]

Near the Land's End the surfaces of the granite are in places worn and polished by Blown Sand.[2]

Blown sand occurs at Braunton Burrows, again at Burnham and Woodspring in Somersetshire, near Candleston Castle, South Wales, and at Barmouth.

Blown sand hills fringe the coast between Bootle near Liverpool, and Crossens near Southport, rising to a height of 70 or 80 feet. In the opinion of Mr. T. Mellard Reade they cannot have taken less than 2500 years in accumulating. At Formby they extend inland for nearly two miles. In this district, and in that of Wirral, there are sand dunes, the base of which Mr. De Rance found to consist of a bed of sandy silt, the result of wind blowing sand into pools in which peat was forming. This bed contains *Bithynia tentaculata*, and is known as the Bithynia Sand.[3]

Blown Sand occurs at Walney Island, and again on the Lancashire coast there are the Leven Sands, between Ulverston and Cartmell. Further north hillocks of Blown Sand are found south of Seascale, near Drigg, and at the mouth of the river Irr, in Cumberland. At this locality certain "vitreous tubes" or Fulgurites due to the action of Lightning have been found to extend to a depth of 40 feet in the Sand.[4] Fulgurites, which are formed by the fusion of the grains of loose sand, are sometimes more than 2 inches in diameter. One specimen of Fulgurite found in the Drift Sand of Macclesfield extended to a depth of 22 feet.[5]

The Shirdley Hill Sand, named by Mr. De Rance in 1869, from a hill near Ormskirk, is regarded as partly marine, but mainly Blown sand, belonging to the ancient sand dunes of an old line of coast. It is to be seen in cliffs on the north bank of the Mersey between Hale and Garston.[6] There is a ridge of sand hills on the north coast of the Isle of Man.

The "Links" on the coast of Northumberland are hillocks of Blown Sand from forty to seventy feet high, and one hill, at the mouth of the river Lyne, is stated by Mr. Topley to rise to a height of eighty-seven feet. Blown Sand occurs north and south of Hartlepool, at Holy Island or Lindisfarne, at Sancton in Yorkshire, and again at Donna Nook and Spurn Head in Holderness.

On the borders of the Lincolnshire Marshland,[7] and along the Norfolk coast, north of Burnham, Holkham, and Wells, there are picturesque hillocks of Blown Sand, known in the latter county as Meals. Similar hills occur also at Bacton, Eccles, and Winterton. Eccles Church, in 1839, was partially smothered in Blown Sand, but this has been drifted further inland, so that now the ruins of the church are on the foreshore.[8] Much sand is blown against and over the top of the hills near Cromer, while the cliffs themselves are in places wasted by the winds blowing sand from veins or seams in the Contorted Drift.

On the western borders of Norfolk and Suffolk, Sand-floods have been experienced on several occasions. Thus in the year 1668, part of Santon (*Sand town*) Downham, between Brandon and Thetford, was overwhelmed by sands from a warren five miles to the south-west. This sand had, in the course of a century, travelled four miles, and covered more than one thousand acres of land.[9] The sandy wastes of West Norfolk, known as the Breck District, and which were the

[1] Hunt and Rudler, Descriptive Guide to the Museum of Practical Geology, ed. 4, p. 36.

[2] R. W. Fox, Q. J. xi. 549.

[3] De Rance, Superficial Geol. S.W. Lancashire, p. 111.

[4] Trans. G. S. ii. 528; v. 617; G. D. Gibb, Geologist, ii. 195.

[5] A. H. Green, Memoir on Sheets 81 N.W. and S.W. (Geol. Surv.), p. 76.

[6] De Rance, G. Mag. 1883, p. 506; Superficial Geol. S. W. Lancashire, p. 58; Strahan, Geol. Chester, p. 30.

[7] Jukes-Browne, Science Gossip, 1879, pp. 242, 265.

[8] See Lyell, Principles of Geology, ed. 12, vol. i. p. 518.

[9] T. Wright, Phil. Trans. iii. 722; see also F. J. Bennett, Geol. Diss, etc. (Geol. Surv.), p. 15.

haunts of the Bustard until the early part of the present century, are partly formed by wind-drifted Glacial Sand.

Much Blown Sand also occurs at Lowestoft, and it sometimes inundates the gardens of the houses that face the sea to the south of the Harbour.

Between Sandwich and Deal there are sand hills, also at Romney, on the south of Hayling Island, and between Christchurch, Bournemouth, and Poole Harbour, in Dorsetshire, where the dunes rise to a height of sixty feet. Low hills of Blown Sand occur south of Weymouth, at Exmouth, and at Slapton, south of Dartmouth.

Soils.

Soils present great diversity in character and composition, and they form an irregular covering over the greater part of the country. They are intimately connected with the last denudations of the country, and with the present action of the sun, frost, rain, and streams, combined too with the deposit from decaying vegetable and animal matter, the voidings of worms, and the burrowings of these and other animals such as moles. The roots of trees exercise great influence in breaking up the strata near the surface. The wind, too, exerts much influence on the soil, drifting sea-sand often for some distance inland, and distributing finer particles of dust over the whole of the land;[1] also in stormy weather it carries saline matter far inland from the sea. It has been remarked, in poetic language, that the very dust we tread upon was once alive; and in many respects this is true, at any rate of the dust of coal and ashes, as well as of limestone and flint, which are so largely used for mending roads.

The diversity of soils, however, may be considered as primarily due to the nature of the underlying geological formation or 'sub-soil,' from which they have been most largely constructed—hence the fact, expressed by Arthur Young, that soils vary mainly according to contours, for over great part of our country the strata are approximately horizontal. The sub-soil is the disintegrated portion of the rock below, and this often forms a 'brash,' a term applied to the rubble formed on the limestones, especially on the Oolitic strata. Hence, among soils there are those of a brashy, marly, clayey, loamy, sandy, and gravelly nature, and mould. The soils of each geological formation have been alluded to, so far as possible, in the text describing them, and where the soil is simply or mainly due to a disintegration of the sub-strata, its nature will be understood.

The influence of soils on Agriculture is, of course, all-important, but their fertility is greatly equalized by manuring and draining. Thousands of acres, according to Mr. J. Bravender, are at this moment, to all outward appearances, fertile, which are not permanently so, but which have been artificially made productive—these if neglected would eventually return to a state of sterility. The heavy lands,

[1] Reid, Geol. Holderness, p. 118; G. Mag. 1884, p. 165.

formed of stiff clay, are, as a rule, most expensive to cultivate, requiring much drainage and top-dressing with marl or lime. They are best adapted for pasture and dairy-farmimg, although wheat and beans are largely grown on them. The loams, and especially the calcareous loams, form the richest soils. The light sandy and gravelly soils are often barren, forming heaths and warrens which offer a pleasant contrast to the cultivated scenery. Over many districts the soil is of a "mixed" character, varying constantly from field to field; and this is generally due to the irregular character of the sub-strata. This is more especially the case with the Glacial Drifts, which are included under the comprehensive name of Superficial Deposits, the importance of whose influence on Agriculture was so persistently urged by Joshua Trimmer.

In Agriculture, moreover, the elevation of the land, the rainfall, and other conditions are naturally of great importance.[1] The depth of soil is liable to vary, not only in accordance with the nature of the underlying rocks, but also with the shape of the ground and the influence of rain in removing it. On sloping ground the soil is liable to variation from the material washed down by rains; while in some regions composed of Granite, Slate, hard Sandstone, and Limestone, the rocks stand out in bare crags.

Made Soil.—Under London and other large cities and towns a considerable accumulation of artificial soil is generally met with in sinking wells, in digging foundations, etc. This 'made soil' comprises the materials of old buildings, and road-metal, as well as rubbish and gravel that have been employed to fill up low damp ground. Burnt earth, a relic of the Great Fire of 1666, has in some instances been observed under London, in the 'made soil,' which in places is nearly 30 feet thick.[2]

Mould.—The formation of mould or humus is due partly to the decay of vegetable matter, and to meteoric influences, but very largely to earth-worms building up a soil as it were by the material ejected from them. As first taught by Darwin, its homogeneous nature, when overlying different kinds of subsoil, is due to the labours of worms in casting up the soil, and thus allowing stones and other solid fragments to subside; so that in old pasture-land not a single stone perhaps will be found within some inches of the surface, and one can understand why farmers are averse to breaking up such tracts.[3]

Peaty earth is sometimes formed on heaths and commons where the decay of the plants gives rise to an accumulation of partly decomposed vegetable fibre, mixed with sand. On low-lying alluvial ground, the soil is often black and peaty, in some cases originating from the weathering of a mass of peat below, in other cases being a swampy accumulation of decaying vegetable matter, mixed with alluvial debris. This forms what is called Bog earth. (See also Peat, p. 522.)

Rainwash.—The material washed down from higher to lower grounds, on the slopes of hills and mountains, is termed 'Rainwash' or 'Landwash,' to distinguish it from the Alluvial deposits of streams. It naturally varies from coarse 'Angular detritus' to sand, loam, and clay, but it is essentially of local origin. With it may be included the 'Head' previously noted (see p. 495), and other forms of 'talus' like the 'Screes' of loose detritus accumulated at the foot of steep scarps of rock, while Landslips on a small scale are intimately associated. (See sequel.)

Clay-with-Flints.—This consists of stiff brown and red clay containing large unworn flints, and at its base displaying generally a few inches of black clay with black-coated flints. Occasionally pebbles of flint, quartz, and other rocks, occur in the accumulation, due to some former capping of Drift gravel or of Tertiary beds.

The Clay-with-flints is mainly confined to the Upper Chalk tracts, for, as pointed

[1] F. J. Lloyd, Science of Agriculture, 1884; J. Morton, Nature and Property of Soils, ed. 4, 1843; J. Bravender, Indications of Fertility or Barrenness of the Soil, Journ. R. Agric. Soc. v.; Trimmer, Practical Geology, p. 22; Q. J. vii. 19, 37; Journ. R. Agric. Soc. xii. 445; North British Review, Feb. 1852.

[2] Whitaker, Surface-Geol. London, 1867 (in Report of Medical Officer of the Privy Council for 1866).

[3] Proc. G. S. ii. 574, T. G. S. (2), v. 505; Formation of Vegetable Mould, 1881.

out by Mr. Whitaker,[1] it is in great part due to the dissolution of the Chalk by water holding carbonic acid, whereby the flints and earthy matter were left ; it is also in part due to relics of Tertiary or Post-Tertiary clays. On the surface the flints are much broken up by natural agencies and by the plough, and sometimes, as near High Wycombe in Buckinghamshire, the fields exhibit a soil of little else than broken flints ; and one would fancy that hardly anything could grow in such places ; but good crops of turnips and mangels are obtained. Even where the flints are picked off, they soon 'grow' again, if, indeed, any appreciable difference is made.

Sometimes the Clay-with-flints stretches over the margin of the Upper Chalk resting on the Lower division. In such cases we may look upon it as a residuum of the Upper Chalk which formerly existed there. On the Chalk range of Purbeck we find occasional accumulations of flints ; but the clayey matrix, if it ever occurred there, would soon be washed away, owing to the steepness of the slopes. (See Fig. 54, p. 347.)

The Clay-with-flints lies very irregularly on the Chalk, filling 'pipes,' so that sometimes bare Chalk appears in one place, whilst a clayey deposit twenty or thirty feet in thickness may occur close at hand. It is also noteworthy how trifling a depth of soil serves to hide the Chalk in a field when hard by a pit shows scarcely a trace of any superficial covering on the rock. This is noticeable on parts of Salisbury Plain. Where the pipes penetrate obliquely into the Chalk, the section in the face of a cliff or quarry sometimes shows merely a circular pocket some way below the surface. (See pp. 422, 493.)

While conspicuous in the South of England, over portions of Hampshire, Surrey, Kent, Berkshire, Buckinghamshire, and Hertfordshire, the Clay-with-flints is but little developed in Yorkshire, Lincolnshire, Suffolk or Norfolk. As Mr. S. V. Wood, jun., remarked, it appears to cover those tracts of Chalk land which were not affected by great submergence during the Glacial period, and which were not occupied by Land-ice.[2]

MARINE DEPOSITS.

The Pleistocene and Recent Marine Deposits include the modern accumulations of sand and shingle along our coasts, certain inland deposits of a similar nature that contain marine shells of existing species, and Raised Sea-beaches. The distribution of sediment beneath the sea does not come within the province of this woik, although the subject is of the highest interest to geologists.[3]

These deposits sometimes contain Mammalian remains, as at Silloth Dock, where *Bos primigenius* was found. Here and there considerable accumulations of recent marine shells occur, as at Shellness, by the River Stour, north of Sandwich, and at Shellness in Sheppey. The beds are worked for making paths.

Teignmouth,[4] Weymouth, and Yarmouth are partly built on recent Marine accumulations. The bank on which the last-named town was built did not become habitable until after A.D. 1000.

Calcareous sands are sometimes compacted by rain. Prof. A. H. Church has directed attention to an instance at Bude-Haven, in Cornwall, of the consolidation

[1] Explan. Sheet 7 (Geol. Surv.), p. 64 ; Barrois, Ann. Soc. Géol. du Nord, vi. 340.

[2] G. Mag. 1883, p. 340.

[3] On this subject see R. A. C. Godwin-Austen, Q. J. vi. 71 ; A. Delesse, Lithologie du Fond des Mers, 1872 ; Lebour, P. Geol. Assoc. iv. 158.

[4] G. W. Ormerod, Q. J. xlii. 98.

of sea-sand by means of land-springs.[1] The shell-sand at Bude has been largely used for agricultural purposes; while sand from the Warren at Exmouth has been employed for moulding. At Babbacombe Bay portions of the shingle beach are cemented into a conglomerate by calcareous springs; and near Llandrillo Bay there is a mass of similar conglomerate with recent marine shells.[2]

Springs charged with much iron-ore that issue from cliffs by the sea frequently cement the shingle and sand into a hard stone: instances occur near Bolt Head, as observed by the Rev. J. Pulliblank. The decomposition of old pistols and nails has frequently given rise to masses of ferruginous conglomerate, that may be picked up on the beach, as near Cromer.[3]

The influence of Sea-water in producing a slight amount of alteration in rocks that have been long exposed to its influence is a subject deserving attention. Mr. J. A. Phillips observes "that while the slates of Botallack are highly magnesian, the sea-water which percolates through them into the workings of the mine has lost three-fourths of its magnesium. Similar effects appear to have been produced at Huel Seton, where the amount of magnesia in the rock bounding the great cross course, which is traversed by the modified sea-water constituting the well-known "lithia-spring," is twice as large as it is in the normal killas of the locality.[4]

The induration of rocks on the sea-coast has been noticed in Glamorganshire (see p. 266); in Yorkshire (Lower Estuarine Series);[5] and at Hunstanton.[6]

Sea Beaches.

The pebbles of a sea-beach may be shaped directly from the rocks which form the cliffs, they may be derived from old beds of conglomerate, or from more recent beds of gravel or shingle or stony clay that constitute the whole or a portion of the cliffs. Again, they may be derived in any one of these ways, and have travelled a considerable distance from their source. The majority of the stones on our beaches, whether pebbles or subangular fragments, are formed of Chalk-flint, quartz, quartzite, and various kinds of sandstone; stones of a more or less siliceous nature, standing the wear and tear of course much better than limestones. Locally we find limestones and fragments of other rocks derived from adjacent cliffs; even clay-pebbles or clay-balls are not unfrequent on coasts where the cliffs are formed of clay. Sometimes these clay-balls when rolled about attach to themselves numbers of small pebbles, and appear like masses of pudding-stone. Such clay-pebbles may be seen near Cromer, Lyme Regis, etc.

Many stray pebbles whose origin might otherwise be difficult to account for, may be brought as ballast, or be due to the shipwreck of vessels carrying stone, or to the unlading of stone to be used for various purposes. Thus Plymouth Limestone is brought to Bridport Harbour for road-metal, and fragments of it are sometimes found on the beach.

On many parts of the coast agates, carnelians, and other pebbles capable of being polished for ornamental purposes are collected. At Aberystwyth agates and

[1] Journ. Chem. Soc. (2), i. 30.

[2] Miss Eyton, G. Mag. 1868, p. 352.

[3] S. Woodward, Mag. Nat. Hist. ix. 47; see also W. S. Gresley, G. Mag. 1886, p. 11.

[4] Q. J. xxxi. 324.

[5] C. F. Strangways, Explan. Sheets 95 S.W. and S.E. (Geol. Surv.), p. 3.

[6] Rose, Phil. Mag. (2), vii. 185.

jasper give employment to lapidaries.[1] Between Torquay and Teignmouth Limestone-pebbles with Devonian Madrepores are picked up. (See p. 237.) The Isle of Wight and Brighton pebbles consist chiefly of chalcedonic Chalk-flints containing the Sponge *Siphonia (Choanites) Koenigi* and much hydrous peroxide of iron. (See p. 416.) At Eastbourne, also, many flint-pebbles are collected for sale.[2]

The travelling of shingle beaches is promoted by wind-waves and influenced by the set of the tides and currents, and by the configuration of the coast,[3] and there is not unfrequently a conflict between the sea and a river. The results necessarily depend upon the general power of each agent. Usually the breakers gain, so as to produce a long line of shingle, turning the course of the river, until the latter obtains support from a hard cliff, and is no longer forced aside, or the river perhaps percolates through the shingle. Such is the case along the southern coast of Devon between Exmouth and Axmouth.

There is a noteworthy 'Pebble Ridge' at Northam Burrows (Appledore), in Barnstaple Bay, derived from the Culm-measures of Hartland Point, etc.[4]

On the Suffolk coast the Orford beach is a remarkable one : the general direction is south-west, and it has diverted the river Ore or Alde about ten miles to the south.[5] In the time of Henry VIII. the mouth of the river was opposite Orford Castle ; these changes have been brought about by the alteration of the coast-line and the destruction of land. (See sequel, regarding Dunwich.) At Weybourn, in Norfolk, there is a beach extending westwards to the mouth of Blakeney Harbour.

There is much shingle stretching from Sandwich northwards to Pegwell Bay. To the south-west, the shingle about Romney Marsh, including Dunge Ness Beach, is three miles long and one to four miles wide, and formed of pebbles which have come from the west. It is heaped up in "fulls" or ridges, which mark old high-water levels. Romney Marsh was originally a sandy bay ; there used to be a harbour at the foot of Lympne Hill, and ships have sailed along the river Rother (anciently Limen), past Appledore.[6] The shingle at Lydd was probably the shore-line in Roman times ; since then the shingle-point has advanced towards the south-east, four miles seawards, in a direct line.

At Hengistbury Head a shingle bank one mile in length was formed in 20 years, and has since been increasing at an annual rate of about 40 yards.[7]

Chesil Bank.—A continuous bank of shingle extends from Bridport Harbour and Burton Bradstock to Portland. It varies from 170 yards wide and 22 feet high near Abbotsbury to 200 yards wide and 42 feet high at Portland. From Burton Bradstock to Abbotsbury it touches the shore, but eastwards, for upwards of ten miles, it is separated from the land by the Fleet, and to this portion the name Chesil Bank is now generally restricted. The pebbles increase in size eastwards from sand and fine shingle at the western extremity of the beach, to pebbles three to four

[1] W. Keeping, G. Mag. 1882, p. 256.

[2] Rev. A. N. Malan, Nat. Hist. Notes, iii. 112. Moss-agates have not been found in England and Wales, although they occur in Scotland : they are varieties of chalcedony enclosing moss-like forms of oxide of manganese and iron, and green earthy chlorite. On the subject of quartz pebbles, which when rubbed together give an electric spark, see C. Tomlinson, P. Geol. Assoc. i. 243.

[3] De la Beche, Geol. Manual, p. 73 ; H. R. Palmer, Phil. Trans. 1834, p. 567.

[4] Pengelly, Trans. Devon Assoc. 1868 ; Sedgwick and Murchison, Proc. G. S. ii. 442.

[5] J. B. Redman, Proc. Inst. Civ. Eng. xxiii. 191 ; Whitaker, Geol. Ipswich, p. 98.

[6] F. Drew, Geol. Folkestone, etc. (Geol. Surv.), p. 18.

[7] T. Codrington, G. Mag. 1870, p. 23.

inches in diameter under Portland. They consist of Chalk-flints, Greensand chert, Portland rocks, quartzite (from the Budleigh Salterton pebble-bed), Devonian grits, quartz, porphyry, granite, jasper, etc. ; all have probably come from the west, and chiefly from strata between Exmouth and Lyme Regis.

Several theories have been proposed to account for the formation of the Chesil Bank. That the Isle of Portland, acting as a natural groyne or breakwater, was essential to the collection of the material, all admit: the eddy tide produced by that promontory serves to divert the travelling of the shingle, so that the pebbles are driven westwards again along the shore, and by "wear and tear" gradually diminish in size until we reach Bridport Harbour and Eype. West of Eype the shingle ordinarily travels from west to east. The partial separation of the bank from the land has been the source of much discussion. Messrs. H. W. Bristow and W. Whitaker consider that the Chesil Bank may have been formed at first in the same way as the ordinary shingle beaches of our coast, and that what was once an ordinary beach, banked up against the land, has been since separated, as a bank or bar, by the denudation of the land behind it. This they consider due to the action of the streams which originally filtered through the shingle, turning eastwards before doing so, as do other streams further west on the Devon coast. In time these streams gradually united and formed a long channel (the Fleet) between the beach and the mainland : and this water may have been materially widened by tidal action, which would also assist it in cutting back the land.[1]

Prof. Prestwich considers that the Shingle is chiefly derived from the materials of the Raised Beach, of which a remnant still exists on the Bill of Portland, and from the submerged portions of the beach to the west. The pebbles, however, on the Chesil Bank at Portland are much larger than those which make up the mass of the Raised Beach at Portland Bill. Some have thought that the larger pebbles were moved more readily than the smaller ; but the diminution in size of the pebbles is probably due to wear and not to sorting by the sea, for tiny Budleigh pebbles may be observed in the beach at Bridport Harbour which must have travelled westwards from Portland. The fine shingle east of this harbour is extensively dug and sent away for making paths, for concrete, etc. ; but the material taken away is said to be readily replaced by the sea.

Raised Beaches.

These Beaches consist of accumulations of sand and shingle which have been formed by the sea, but yet occupy such a height above the present reach of the breakers as to necessitate the opinion that changes of level in the land have taken place since their deposition. They generally contain recent marine Mollusca, and are often well stratified and compacted.

As Mr. Kinahan has pointed out, littoral deposits may be accumulated at varying levels at the present day, owing to the variations in tide heights in different localities. Therefore if we find raised beaches occupying different elevations in a certain district, it does not necessarily follow that the land has been unequally uplifted since the formation of the beaches:[2] moreover, the horizontal nature of most Raised Beaches suggests uniform upheaval.

[1] Bristow and Whitaker, G. Mag. 1869, p. 433 ; Sir John Coode, Proc. Inst. Civ. Eng. 1853 ; Pengelly, Trans. Devon Assoc. 1870 ; Kinahan, Q. J. xxxiii. 41 ; Codrington, G. Mag. 1870, p. 23 ; Prestwich, Proc. Inst. Civ. Eng. xl. 1875, Q. J. xxxi. 33 ; Damon, Geol. Weymouth, 1884, p. 167 ; see also P. Geol. Assoc. ix. 205.

[2] G. Mag. 1876, p. 78. See also Harkness, Proc. G. S. iv. 178.

Some of our Raised Beaches may be connected with oscillations that occurred in the Glacial period. (See p. 481.) Long ago, in describing the raised marine beds on the Devon coast, and commenting upon the paucity of the Molluscan remains contained in them, Mr. Godwin-Austen suggested that the period of these raised deposits may have been one less favourable than the present to the development of marine life, owing, perhaps, to a lower temperature.[1]

Many Raised Beaches have probably been destroyed in recent times, owing to the destruction of cliffs composed of the softer strata, for it will be observed that most of these beaches repose on hard rocks. Some instances formerly regarded as "ancient marine terraces" are now known to be "lynchets" or terraces of cultivation, etc.[2] (See sequel.)

Raised Beaches are not uncommon along the coasts of Devon and Cornwall, occurring at Hope's Nose and the Thatcher Stone near Torquay, Slapton, the Hoe at Plymouth,[3] St. Blazey Bay (Polkerris), Falmouth Bay, The Nare, Coverack Cove (flints), in and near Mount's Bay, Cape Cornwall, St. Ives Bay, Towan Head, near Trevose Head, near Pentire Point, and Barnstaple[4] extending from Braunton Burrows to Baggy Point.

Holes considered to be bored by *Pholas* have been noticed in the Devonian Limestone at Petitor, Babbacome, and near Kent's Cavern, Torquay, at heights of 200 feet and upwards above sea-level.[5]

Raised beaches occur at Weston-super-Mare, at Rhos Sili Bay, Gower, and the Mumbles, near Swansea. On the Dorsetshire coast the Raised Beach at Portland Bill is well known, shells occur on the eastern portion of the beach, which attains an elevation of from 25 to over 50 feet.[6] There are also Raised Beaches at Portsdown Hill,[7] in Jersey, and at Saltburn (35 feet above high-water mark), on the north-east coast of Yorkshire.

Among the Pleistocene marine deposits we may include certain beds at Selsea, the Nar Valley, March, Kelsea Hill, and Hessle, which are approximately of the same age. (See p. 481.)

The deposits at Selsea are as follows:[8]—

Brickearth (probably of subaërial formation).
Marine clay and yellow clayey gravel, with Boulders. (See p. 495.)
Mud-deposit with *Lutraria rugosa*, etc. (Lutraria clay), and Mammalian remains.

[1] T. G. S. (2), vi. 433. See also Q. J. vii. 118.

[2] See R. Chambers, Ancient Sea-margins, 1848; Mackintosh, Scenery of England and Wales, 1869.

[3] The deposits at the Hoe may be of Alluvial origin, see R. N. Worth, Q. J. xxxii. 236; C. Spence Bate, T. Devon Assoc. vii. 150.

[4] Sedgwick and Murchison, Proc. G. S. ii. 441; Pengelly, Trans. Devon Assoc. 1868; Ussher, G. Mag. 1879, pp. 166, 203; Post-Tertiary Geol. Cornwall, p. 16.

[5] Pengelly, Trans. Devon Assoc. 1866; A. Tylor, Q. J. xxii. 465; Mackintosh, G. Mag. 1867, p. 296.

[6] Whitaker, G. Mag. 1869, p. 438; W. Gray, P. Geol. Assoc. i. 146; Pengelly, Trans. Devon Assoc. 1870; J. C. Mansel-Pleydell, Proc. Dorset Nat. Hist. Soc. i. 2; Prestwich, Q. J. xxxi. 29.

[7] Prestwich, Q. J. xxviii. 38.

[8] Godwin-Austen, Q. J. xiii. 40; Dixon, Geol. Sussex, ed. 2, p. 82; R. Etheridge, Address Geol. Section Brit. Assoc. 1882; Lyell, Student's Elements, 1871, p. 158; A. Bell, Mag. Nat. Hist. July, 1871.

Upwards of 70 species of Mollusca, all Recent forms, have been obtained from this Mud-deposit, and they have a somewhat more southern aspect than those of the present English Channel. They include *Pholas crispata*, *Saxicava*, *Scrobicularia plana*, *Cardium edule*, *Nucula nucleus*, *Pullastra aurea*, *Tapes decussata*, *Pecten maximus*, *P. opercularis*, *P. polymorphus*, *Ostrea edulis*, *Trochus cinerarius*, etc. The Mammalia include *Elephas primigenius*, *E. antiquus*, etc.

Mr. T. Codrington has described the remains of an old sea-bed at Avisford and Waterbeach, near Goodwood, with marine shells, at from 80 to 100 feet above the sea-level.[1] Near Brighton the old sea-beach (see p. 495) is from 8 to 12 feet above the present beach, and has been traced by Prof. Prestwich past Arundel to Chichester and Bourne Common, where it is from 100 to 140 feet in height.[2]

At Roxholme, near Sleaford, and at Holbeach, sandy beds with marine shells have been observed.[3] Marine gravels and sands occur also near Tattersall, Bourn, Whittlesey, March, and other places, and they are known as "Fen Gravels." *Corbicula fluminalis*, also remains of Rhinoceros, Mammoth, etc., have been found at some localities.[4] (See pp. 499, 530.)

Brickearth of the Nar.—This deposit, so well known through the labours of Mr. C. B. Rose, occurs in West Norfolk, in the valley of the Nar (a tributary of the Great Ouse).[5] The brickearth, a bluish sandy clay, has been traced from Narford to West Bilney and Watlington. It has a thickness of 20 feet or more, and contains, amongst other shells, *Turritella terebra*, *Aporrhais pes-pelicani*, *Littorina littorea*, *Natica nitida*, *Ostrea edulis*, *Tellina Balthica*, *Scrobicularia plana*, etc. Bones of Rhinoceros, Mammoth, etc., also occur. The shells are in fine preservation; and there can be little doubt that the deposit was formed in an estuary.

At Hunstanton, near the gas-works, there are ballast-pits showing sand and gravel (Hunstanton gravel), with recent species of marine shells, *Ostrea*, *Cardium*, *Mytilus*, *Nassa*, *Buccinum*, etc. Near the pier there is a similar accumulation about 10 feet above high-water mark, which has been described as a Raised Beach.[6]

Deposits of marine sand and shingle containing sea-shells occur in some places inland at about the present sea-level, and sometimes beneath it, and indicate the extension of the sea over the area, in comparatively recent times.

Burtle Beds.—Recent marine deposits have been found in the Somersetshire moorlands, and being at one time well exhibited at Burtle, near Glastonbury, they were termed by De la Beche the Burtle Beds. At several places in the moorland the ground rises into gentle hills, generally banks of New Red Marl, with fringing and outlying beaches composed of sand with recent marine shells. The species include *Trochus zizyphinus*, *Patella vulgata*, *Littorina littorea*, *Hydrobia* (*Rissoa*) *ulvæ*, *Nassa reticulata*, *Pholas candida*, *Cardium edule*, *Tellina Balthica*, etc.[7] These old lines of beach may be traced along many parts of the border of King's Sedgemoor, at Sutton Mallet, Chedzoy, Weston Zoyland, and Middle Zoy, of which places the three latter retain, in the etymology of their

[1] Q. J. xxvi. 547. See also Meyer, Q. J. xxvii. 82 (Portsmouth).

[2] Q. J. xv. 215.

[3] Rev. E. Trollope, Proc. Geol. Polyt. Soc. W. Riding, p. 637; Jukes-Browne, Geol. S. W. Lincolnshire, pp. 102, 104.

[4] Skertchly, Geol. Fenland, p. 183.

[5] Phil. Mag. (2), vii. 196; G. Mag. 1865, p. 8.

[6] Seeley, Q. J. xxii. 470; Wood and Harmer, Supp. to Crag Mollusca, p. 28; Jukes-Browne, Q. J. xxxv. 415; B. B. Woodward, P. Geol. Assoc. viii. 100.

[7] Geol. E. Somerset (Geol. Surv.), p. 103; E. T. Newton, Cat. Tertiary and Post-Tertiary Fossils, Mus. Pract. Geol. p. 84.

names, the evidence of their former maritime position.[1] Near Middlezoy the sands are occasionally dug by the road-side, and afterwards the holes are filled up with Red Marl.

The Formby and Leasowe Marine beds, described by Mr. T. Mellard Reade, occur in the neighbourhood of Formby and Hightown, between Liverpool and Southport. They consist of marine silt, etc., and underlie the Superior Peat and Forest Bed in south-west Lancashire.[2] The Preesall Shingle, of Preesall Hill, east of Fleetwood, has been described by Mr. De Rance as an old beach; it contains recent marine shells, and has been worked for gravel.[3] (See p. 524.)

[1] Buckland and Conybeare, T. G. S. (2), i. 309.
[2] Proc. Liverpool G. S. 1871–72, 1881–82.
[3] Superficial Geol. S. W. Lancashire, p. 61, G. Mag. 1883, p. 506.

VOLCANIC PHENOMENA.

A study of the geological history of England and Wales clearly proves that our country has during several epochs in the past been affected by great volcanic eruptions. The fiery records are preserved more particularly in the hilly country that lies to the north and west; and they are to be deciphered from the old lava-flows and ash-beds, and the altering or metamorphism of neighbouring strata. Long ages have elapsed since the last of these eruptions, but as the pleasures of the imagination more often exceed those we realize, so a study of the relics of ancient Vulcanicity amid the mountains of North Wales, the lakes of Cumberland, or the tors of Dartmoor, may yield greater enjoyment than the ascent of some temporarily dormant volcano.

We must not, however, feel disappointment if we find no distinct craters, for so long a time has elapsed and such changes have taken place since the last eruption affected our land, that the heaps of volcanic material then formed around the vents have been swept away by the agents of denudation. Nevertheless, in some places we have the 'basal wrecks' of old volcanoes, and evidence of the channels through which material escaped to the surface in 'plugs' of solidified lava. Veins and flows of lava may be traced here and there at all levels and in puzzling relationships to the rocks amid which they lie, and these have, in most cases, been bent and uplifted and weather-beaten, so as to lose all semblance in their present outlines to the volcanic centres of which they once formed part.

The only modern witnesses we have of phenomena which may be connected more or less directly with the causes of volcanic action are in Thermal Springs like those of Bath, in the evidences of recent upheaval and depression such as are furnished by Raised Beaches and Submerged Forests, and in Earthquakes which now and again, unexpectedly and sometimes painfully, arouse attention to the instability of the Earth's crust.

The most generally accepted view of volcanic phenomena is that they are caused by the percolation of water to the heated interior of the earth, a view supported by the proximity of most volcanoes to the sea-coast, and by the fact that coast-lines are in most cases lines of weakness in the earth's crust.[1]

A theory propounded by Mr. Mallet was that volcanic action resulted from the heat induced during the contraction of the earth's mass from cooling, that it arose in short from the crushing or shrinkage and fracture of the rocks, leading to much friction and the development of heat.[2] The Rev. O. Fisher, on the other hand, regards volcanic energy as the motive power of this contraction.

[1] See Prestwich, Proc. Roy. Soc. 1885, p. 253; Judd, Volcanoes, ed. 3; and works by Scrope, Daubeny, and others. On the subject of subterranean temperature, see Smyth, Address to Geol. Soc. 1868.

[2] R. Mallet, Phil. Trans. 1873; O. Fisher, Physics of the Earth's Crust; see also Sir J. Herschel, Proc. G. S. ii. 548, 596; T. S. Hunt, Q. J. xv. 495.

Fig. 94.—Section touching the Southern Edge of Brent Tor.
(F. Rutley.)

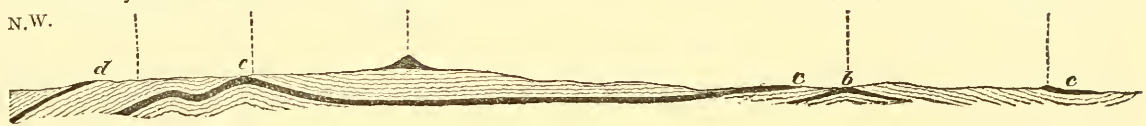
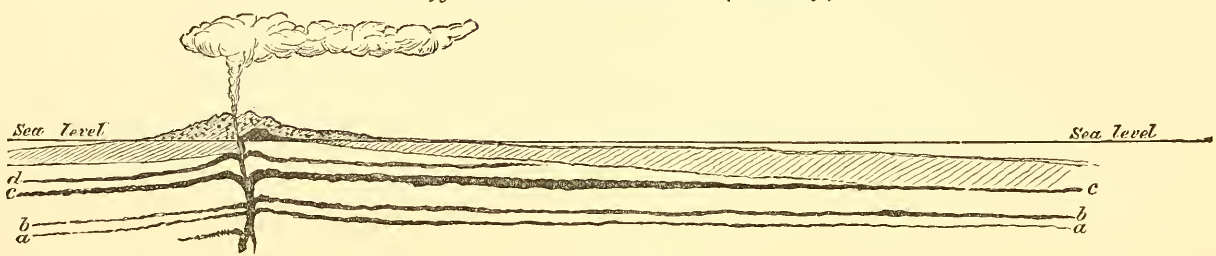


Fig. 95.—Brent Tor Restored. (F. Rutley.)



The black portion of the cone represents all that remains of it, the shaded portion of this as well as that beneath the line of sea-level having been denuded. *a*, *b*, *c*, and *d* represent volcanic beds.

Earthquakes.—Earthquakes are waves propagated in the earth's crust from certain centres of disturbance in or beneath it. In most cases the underground pressure appears to act on a centre, the force dying away in ripples in continually widening circles, or extending further in some directions according to the nature of the rocks affected.

The majority of earthquakes, according to Prof. Milne, are due to explosive efforts at volcanic foci; and the greater number of these explosions take place beneath the sea, and are probably due to the admission of water through fissures to the heated rocks beneath. Those which make themselves known to us are no doubt, and fortunately so, of a comparatively mild form; but others are often sufficiently violent to rupture the earth's surface. At the same time the earth's horizontal movement is usually only the fraction of a millimetre ($\frac{1}{25}$ in.), seldom exceeding 3 or 4 millimetres, while the vertical movement is rarely more than one millimetre.

While earthquakes accompany and often precede volcanic eruptions, so they sometimes cease to occur when the outburst takes place; but it is remarkable that they are felt in our own country, and in other lands far away from active volcanoes. Hence, if due to similar causes, the subterranean forces must in these instances exhaust themselves in producing the earthquakes, and they may be regarded as "an uncompleted effort to establish a volcano."[1] Some earthquakes, however, may be simply due to shrinkage and fracture of the earth's crust, and of such disturbances we have abundant evidence in the joints, faults, and contortions seen in our rocks in many places. The oxidation of metallic substances in the interior of the earth is also admitted to be a likely source of local disturbance.

On April 22, 1884, an earthquake occurred, the most serious that has happened in this country for four centuries; its intensity was about one-twentieth that of the Lisbon earthquake of 1755. Originating in the neighbourhood of Colchester, this subterranean disturbance made itself felt over an area estimated at about 50,000 square miles. The shock was over in ten or twenty seconds, according to various accounts; but the results were of a very destructive character in Colchester and the immediate neighbourhood, the main line of damage being between Wivenhoe and Peldon. It was felt in various directions with decreasing force. At Ipswich, and throughout Suffolk, it was perceived, and the shock extended as far as Yarmouth, Norwich, Lynn, Cambridge, Ely, and Boston; to Northampton, Leicester, and Wolverhampton; and even as far as Stroud, Bristol, and Street in Somersetshire. It was felt near Reading, in and around London, at Ryde, Portsmouth, near Brighton, Hastings, Dover, at Rochester, and Wesgate-on-Sea.

There is no evidence to connect this earthquake directly with volcanic phenomena, and it may rather be attributed to one or more subterranean rents produced by shrinkage, which led to no material shifting of the rocks, and which, owing to the tenacious nature of the subsoil at Colchester, chiefly London Clay, did not manifest itself in any conspicuous manner at the surface. No perceptible change of surface-

[1] J. Milne, Earthquakes, 1886, pp. 76, 275, 295; R. Mallet, The Earthquake Catalogue of the British Association, 1852–1858, Reprinted 1858; Prestwich, G. Mag. 1870, p. 541; C. Walford, Journ. Statistical Soc. xli. 482.

level was noticed, but there was a marked though temporary change in the level of underground waters in the district most affected by the shock.[1]

Britain has, during long periods of its geological history, formed portions of a continental area near the sea-margin ; hence it has been liable to volcanic activity and to fluctuations in level.[2] According to Mr. Godwin-Austen, the coast from Lewes Levels to Chichester Harbour, and on to Hurst Castle, exhibits signs of undergoing elevation at the present day. The coast of the Isle of Wight, opposite, seems, on the contrary, to be suffering depression ; whilst the back of the island exhibits some curious signs of local oscillation. At Sidmouth there is evidence of subsidence now going on at the rate of one inch in ten years.[3] Reference has been previously made to some of the causes of upheaval and depression (see p. 4), the earth's crust being subject not merely to oscillations of a more or less permanent character,[4] but to minute vibrations (earth tremors), which appear to be due to fluctuations in barometric pressure.[5]

ERUPTIVE AND METAMORPHIC ROCKS.

During the past twenty years the study of Eruptive rocks has made great progress, and, so far as the rocks in England and Wales are concerned, we are particularly indebted to Mr. S. Allport, Mr. David Forbes, Dr. H. C. Sorby, Mr. J. A. Phillips, Mr. F. Rutley, the Rev. J. Clifton Ward, Prof. T. G. Bonney, Mr. Thomas Davies, Mr. J. J. H. Teall, and Mr. G. A. J. Cole.

The study requires much special knowledge and training, and it is perhaps attended with a greater amount of minute detail than the ordinary field-geologist can appreciate. For it is desirable to determine not only the many varieties of rock and their composition, but also the physical condition of their mineral components: so that microscopic and sometimes also chemical investigations are needed.[6]

Dr. A. Geikie remarks that the characters by which an eruptive rock may be distinguished are partly lithological and partly structural. Among the more important of them are the predominance of silicates, mica, augite, olivine, etc. ; a prevailing crystalline structure ; the frequent presence of vitreous and devitrified matter, visible macroscopically[7] or microscopically ; and the occurrence of porphyritic, cellular, pumiceous, slaggy, and amygdaloidal and fluxion structures. These characters are never all united in the same rock. On the whole, the most

[1] R. Meldola and W. White, Report on the East Anglian Earthquake, 1885, pp. 183, 209 ; R. Meldola, P. Geol. Assoc. ix. 20 ; H. B. W., Trans. Norfolk. Nat. Soc. iv. 31 ; Kinahan, Proc. Royal Dublin Soc. iv. 318.

[2] See J. S. Gardner, G. Mag. 1885, p. 145 ; Milne, Earthquakes, p. 344 ; Hughes, Later Movements of Elevation and Depression (Victoria Inst.).

[3] P. O. Hutchinson, in Topley's Report on Erosion of Sea Coasts, Brit. Assoc. 1885.

[4] See also Babbage, Proc. G. S. ii. 73 ; and Sir J. W. Dawson, Address Brit. Assoc. 1886.

[5] G. and H. Darwin, Brit. Assoc. 1881 ; Milne, Earthquakes, p. 310.

[6] Rutley, Study of Rocks, ed. 3, 1884 ; and The Felsitic Lavas of England and Wales (Geol. Survey), 1885 ; J. J. H. Teall, British Petrography (in course of publication) ; Bonney, Addresses to Geol. Soc. 1885, 1886 ; D. Forbes, Q. J. xxvii. 311 ; Kinahan, Handy-Book of Rock Names, 1873. The works of Foreign authors must also be studied.

[7] The term is applied to characters visible by the eye in hand-specimens.

trustworthy lithological evidence of the eruptive character of a rock is the presence of glass, or traces of an original glassy base.[1]

In early geological times volcanic action was probably more general and more intense than it is now, but Dr. A. Geikie has remarked that, so far as the records are concerned, we find no evidence of a diminution of volcanic energy in the British area; moreover, the earth's crust has been thickening, and greater force would be required to disrupt it. The earliest evidence of volcanic eruptions is to be found in the later Archæan rocks (Pebidian of Dr. Hicks, Lower Cambrian of Dr. A. Geikie). In the Upper Cambrian period (Ordovician or Lower Silurian) much volcanic material was poured out in North Wales and the Lake District, partly on land and partly beneath the waters, and this material is estimated to be about 5000 feet thick. The eruptive rocks of Cader Idris were formed during the Arenig period, and those of Snowdon in the Bala period; and the volcanoes of these old times were probably much larger than those of the present day.

Among the Devonian rocks in Devonshire, and the Lower Old Red Sandstone in Berwickshire and the Cheviot Hills, we find evidence of considerable eruptions; and again, in the Carboniferous period in the 'Toadstone' of Derbyshire there is evidence of volcanic disturbance, which was manifested also at the close of that period. Perhaps the interval between the Carboniferous and Permian periods was marked by the protrusion of the granitic masses of Dartmoor and other tracts in the south-west of England, as well as by some of the basaltic dykes of the north of England; while the activity of the volcano of Brent Tor may have been produced during the period of the Lower Culm-measures. Then followed comparatively tranquil times during the deposition of the Lias and Oolites, the Cretaceous rocks, and the earlier portions of the Tertiary Strata. Ultimately the disturbances in the Hampshire and London Basins were produced, perhaps in Miocene times, when there was great volcanic activity in the west of Scotland and north-east of Ireland.

While we have briefly indicated the contemporaneous outbursts of volcanic material, some of the stratified rocks which furnish no such evidence have in later periods been affected by intrusive rocks, as in the Oolitic district of Yorkshire, where there are dykes of Tertiary age. Nevertheless, while intrusive and interbedded rocks may naturally belong to the same general period, "it cannot always be affirmed that a given mass of intrusive igneous rock, now denuded and exposed at the surface, was ever connected with any superficial manifestation of volcanic action,"[2] for these masses often represent incompleted volcanoes.

Eruptive rocks, as will be presently stated more fully, are divided into two groups, termed the Basic and Acid. To account for these broad distinctions Durocher framed the hypothesis that beneath the earth's crust there are two 'magmas' of heated matter from which erupted material is derived. The lower

[1] A. Geikie, Text-Book of Geology, ed. 2, p. 524.
[2] A. Geikie, Text-Book of Geology, ed. 2, p. 522.

of these is supposed to be rich in basic constituents, and may be in part metallic, while the upper zone is richer in silica. Nevertheless, many of the chief differences in eruptive rocks are due to the fact that they have solidified under different conditions, and they do not debar us from the inference that the two groups of eruptive rocks may often have arisen from the same deep-seated sources.

The fact that some masses of native iron resembling meteorites have been found in association with basaltic rocks in Greenland has been taken to indicate that they might have been derived during volcanic outbursts from the interior of the earth.[1]

Happily, all rocks may be said to shade one into the other, and it might be possible to collect a series of specimens to show a transition from Granite to a modern lava, while the ultimate chemical composition might not vary very much.[2] The term Trap is an indefinite, and therefore sometimes very convenient, term applied to Eruptive rocks which cannot be distinctly identified in the field.[3] As our sedimentary strata were originally derived from the original crystalline (Igneous) rocks which formed the earliest land, so they contain to some extent similar chemical ingredients, and thus the metamorphism of certain strata may result in molecular changes which would produce a rock similar to one directly of igneous origin.[4] Both Eruptive and Metamorphic Rocks may be of any age; and there is no material distinction between the older and newer. The old notion that Granite was always the oldest rock has long since been exploded. In the Dartmoor district it is of Post-Carboniferous or Permian age; and in the western islands of Scotland there is granite of Tertiary age.

Whether any strictly primitive rocks are now exposed at the earth's surface is not known, for the origin of the oldest crystalline schists and granitic rocks is uncertain. Although some of these rocks may be closely related to the upper or siliceous magma, yet in many instances the granitic masses appear to be the 'roots' or 'cooled reservoirs' from which volcanoes have in early times been supplied;[5] in these cases the granite would be of a more or less intrusive character. Other instances may occur where granitic masses had no direct connection with volcanoes. But the oldest rocks, whether of igneous or aqueous origin, have been so crushed or 'sheared' and altered by mechanical pressure (regional metamorphism), as well as hydrothermal action, that their origin remains in many cases an enigma; for both crystalline and sedimentary rocks have in places been converted into schists.[6]

[1] Rutley, Study of Rocks, 1879, p. 34; Sir J. W. Dawson, Address to Brit. Assoc. 1886; Judd, Volcanoes, pp. 312, 318. On the subject of Meteorites, see p. 5 of the present work; also T. M. Hall, Mineralog. Mag. iii. 1; Dr. W. Flight, G. Mag. 1875, 1882; D. Forbes, G. Mag. 1872, p. 229.

[2] See Judd, Volcanoes, pp. 57, 61, 145.

[3] The word Trap was used by Bergmann, from *trappa*, Swedish for a flight of steps, because many rocks of this class occur in great tabular masses of unequal extent, so as to form a succession of terraces or steps on the sides of hills. Lyell, Elements of Geology, ed 6, p. 587.

[4] These rocks are sometimes termed 'Hypozoic' when they occur as fundamental rocks beneath fossiliferous strata.

[5] J. C. Ward, Q. J. xxxii. 28; Judd, Volcanoes, p. 145; Bonney, Address to Geol. Soc. 1886, pp. 87, 110.

[6] See B. N. Peach, Proc. R. Phys. Soc. Edin. ix. 22.

Through the kindness of Mr. Frank Rutley I am enabled to give the following condensed account, which he has prepared, of the Eruptive and Metamorphic Rocks (pp. 563–568):—

Metamorphic Rocks.—Sedimentary deposits which have undergone any very marked physical or chemical change are usually spoken of as 'Metamorphic Rocks,' but it is often difficult to define their precise claim to this name, since some, in which the alteration is but an incipient one, would not be generally termed metamorphic, while others, in which the same processes have produced a more strongly developed change, would, by many Geologists, be regarded as fit recipients of the title. As a rule, rocks which have undergone any more or less definite alteration from the contact or proximity of heated masses of eruptive rock are considered to be metamorphosed. But there is also very extensive metamorphism to be met with in rocks far removed from any intrusive masses, the changes being partly of a chemical and partly of a mechanical nature, the latter resulting from the movements of rock-masses. The crystalline schists have chiefly been produced by such regional metamorphism.

Chlorite Schist, Mica Schist, Talcose Schist, Schorl Schist, Hornblende Schist, Gneiss, etc., etc., are generally regarded as Metamorphic rocks. Most of these schists or slates contain quartz or sandy matter which usually forms fine folia separating the other mineral components, so that the rock is frequently made up of thin but more or less distinct layers which differ in mineralogical composition. This differentiation into layers of dissimilar character is termed foliation. Foliation may occur in eruptive rocks as well as in those which are regarded as metamorphic, and planes of foliation do not, therefore, always represent planes of bedding. Foliation, indeed, has been frequently found to coincide with cleavage.

Eruptive or Igneous Rocks.—These rocks have resulted from the solidification of molten matter which has been forced upwards from great depths in the interior of the earth, and has either risen through pre-existing fissures or faults, in which case it forms dykes, or it has been intercalated between beds of sedimentary rock, or has formed large irregularly shaped bosses. Again, it may have reached the earth's surface, and have passed out of a volcanic vent either in the form of a lava flow or the matter may have been ejected as ashes or lapilli, which have been deposited perhaps on a land surface, or, falling upon the water, have subsided as sediment. In either case they may exhibit stratification. Molten matter may also be erupted beneath the sea. The Igneous or Eruptive rocks are separated by some petrologists into two groups, which (at the suggestion of Bunsen) are respectively termed 'Basic' and 'Acid.' The former group embraces those rocks which contain under 60 per cent. of Silica; those in which the percentage of Silica is greater being classed in the Acid Group. This classification is of course a purely arbitrary one, and some writers recognize an intermediate group of rocks in which the Silica ranges from 55 to 66 per cent. This group includes the phonolites and some trachytes and andesites.

The minerals that usually enter into the composition of rocks which contain over 60 per cent. of Silica are the following:—Quartz, Orthoclastic Felspar, and sometimes Plagioclastic Felspars, such as Microcline, Oligoclase, and Albite.

Micas, either Potash Mica (Muscovite) or the Magnesian Micas (Biotite and Phlogopite), and occasionally Lithia Mica (Lepidolite). Minerals of the Amphibole Group, such as Hornblende, Actinolite, Smaragdite, etc. Schorl, Apatite, Sphene, Garnets, Magnetite, Titaniferous-iron, etc., are often present. Epidote, Pyrites, Limonite, Talc, Serpentine, Steatite, Chlorite, Kaolin, etc., etc., which are of frequent occurrence, have mostly been formed subsequently to the consolidation of the rocks in which they are found: they cannot therefore be regarded as normal components of those rocks, except perhaps in a few instances, but have resulted from the alteration of some of the original components, or from the infiltration of fresh substances in solution. Their secondary origin is most clearly discernible when they occur as pseudomorphs after definitely developed crystals of other minerals. Such pseudomorphs are of frequent occurrence in many eruptive rocks, but are often so minute that in the absence of microscopic examination they would evade detection.

The minerals that most commonly occur in those eruptive rocks which contain less than 60 per cent of Silica are the following:—

Plagioclastic Felspars; including Oligoclase, Albite, Anorthite, and Labradorite, all of which crystallize in the triclinic system. Leucite, Nepheline, Augite, Diallage, Hypersthene, Enstatite, Olivine, Hauyne, Nosean, Apatite, Magnesian Micas, Chalybite, Magnetite, Titaniferous-iron, Hæmatite, Limonite, Pyrites, Oxides of Manganese, such as Pyrolusite, Psilomelane, Wad, etc., Serpentine, Steatite, Greenearth, Chlorite, Calcspar, Aragonite; Zeolites, such as Mesolite, Stilbite, Heulandite, Analcime, Natrolite, Scolezite, Thompsonite, Phacolite, etc., etc. Chalcedony and Agates frequently form geodes in the vesicular cavities of some volcanic rocks.

In sedimentary rocks which have undergone subsequent alteration from the contact or proximity of eruptive masses, the most commonly occurring minerals are the following:—

Garnets, Staurolite, Andalusite, Chiastolite, Kyanite, Chlorite, Mica, Talc, Steatite, Calcspar, Quartz, Magnetite, Pyrites, etc.

There are some rocks with a schistose structure, and often exhibiting foliation, which it is difficult to regard as eruptive rocks, and to which it is equally difficult in all cases to assign a sedimentary origin, since some are at times seen to graduate into truly eruptive, and others into rocks of an unquestionably sedimentary character. And there are other schistose rocks that have no doubt been originally ejected from volcanic vents in the form of fine ashy material and lapilli, which also have a sedimentary character due to the assorting and deposition of these materials in waters once adjacent to the seat of volcanic activity: such rocks consequently possess affinities partly to eruptive and partly to sedimentary rocks.

Hornblende Schist for example comes under the first clause, as it is sometimes seen to pass into Diorite.[1]

Mica Schist may be taken as an example illustrative of the second clause, as it is often seen to pass into ordinary slates; while some Basalt-Tuffs, etc., may afford fair instances of matter of eruptive origin deposited as a sediment.

In the present state of knowledge it is *convenient* to group all the Schistose rocks together, although their origin has, no doubt, in many instances differed very widely.

The following lists will serve to give some idea of the general mineral composition and physical character of the rocks of most common occurrence, and for convenience they will be arranged in two groups, the Eruptive and Schistose.

[1] Mr. J. J. H. Teall has also noted the partial conversion, on a small scale, of dolerite or diabase into hornblende schist in a dyke near Scourie in Sutherlandshire, Q. J. xli. 133.

ERUPTIVE ROCKS, CONTAINING UNDER 60 PER CENT. OF SILICA.
(BASIC ROCKS.)

Chief Mineral Components or Lithological Affinities.

A.

Dolerite.—Labradorite, Olivine, Magnetite, Titaniferous-iron. Augite is frequently present.

Basalt.—A more compact form of Dolerite.

Andesite.—A similar rock, but one in which Augite takes the place of Olivine. More or less glassy matter is usually present.

Nephelinite.—A Basalt in which the Labradorite is replaced by Nepheline.

Micaceous Basalt.—A Basalt containing Magnesian Mica.

Leucitophyr.—A rock allied to Basalt, in which the Labradorite is replaced by Leucite.

Diabase.—Plagioclastic Felspar (probably Oligoclase), Augite, Chlorite, Magnetite, and Titaniferous-iron. This rock (named by Alex. Brongniart in 1813) is regarded by some petrologists as an altered condition of Basalt or Andesite.

Melaphyre.—A name given to Basalts of Palæozoic and Mesozoic age. Melaphyres do not differ from the more recent basalts, except in the fact that many of the original component minerals have undergone decomposition or alteration.

Porphyrite.—A term which includes structural varieties of Andesite, Diorite, and a Mica-trap known as Kersantite. These Porphyrites are respectively named Augite-porphyrite, Hornblende-porphyrite and Mica-porphyrite, and they are all characterized by having a Micro-crystalline or Crypto-crystalline ground mass, in which Porphyritic Crystals occur.

B.

Picrite.—Olivine, Augite, and Magnetite, or Titaniferous-iron.

Lherzolite.—Olivine, Enstatite, Augite, Magnetite, or Titaniferous-iron, and frequently Picotite. *Picrite*, *Lherzolite*, and one or two other rocks in which Olivine is a dominant constituent, are often included under the term Peridotite.

Gabbro.—Plagioclastic Felspar (often Labradorite), Diallage, Magnetite, etc. *Olivine Gabbros* are also occasionally met with.

Hypersthenite.—A similar rock to the above, but containing Hypersthene instead of Diallage.

Norite. — Plagioclastic Felspar, Enstatite, etc. Since the Pyroxene in Norite and in Hypersthenite is rhombic, it is usual to include both rocks under the name Norite. The Norites sometimes contain Olivine.

Diorite.—Plagioclastic Felspar, Hornblende, Magnetite, etc.

By the term Greenstone, Diorite (a name given by Haüy) is now usually implied ; formerly both Dolerites and Diorites were included under the name.

The rocks in the Group marked A. often occur as lava flows as well as in the form of dykes, volcanic pipes or feeders, and bosses. They are consequently of an unquestionably volcanic nature. The rocks in the Group marked B. do not occur as lava flows, but simply as dykes or as bosses. Although they are at times seen to graduate into the volcanic rocks of the Group A., still they do not appear to have ever been poured out as lava flows at the surface, but have probably solidified at considerable depths, and are only now exposed by the denudation of a vast amount of once superincumbent rock. They would therefore be spoken of as Plutonic rocks in contradistinction to the Volcanic rocks which solidified at or nearer to the surface; but both groups have no doubt often originated from the same foci, and may be regarded as approximately similar matter, which has solidified under different conditions of cooling, pressure, etc., inducing a difference in physical and mineralogical character.

ERUPTIVE ROCKS CONTAINING OVER 60 PER CENT. OF SILICA.
(ACID ROCKS.)

Chief Mineral Components or Lithological Affinities.

B.

Granite.[1]—Orthoclase (sometimes Plagioclastic Felspars, as oligoclase and microcline), Mica (sometimes Potash Mica, sometimes Magnesian Micas, and frequently both), Quartz. Schorl, Sphene, Magnetite and Pyrites, etc., etc., often present.

Pegmatite or Graphic Granite —Coarsely crystalline varieties in which the quartz often assumes a peculiar arrangement within the felspar, which rudely resembles Oriental writing. Frequently poor in, or destitute of, Mica.

Syenitic Granite.—A rock similar to ordinary Granite, except that it contains Hornblende, often in considerable quantity. This rock is frequently designated Syenite, or, more correctly, Quartz-syenite.[2]

Syenite.—Orthoclase and Hornblende.

Granulite or Leptinite.—Orthoclase and Quartz, usually with garnets. It frequently has a foliated or fissile structure, and hence is regarded as a metamorphic rock, and is classed with those rocks which present a schistose character.

Felstone or Felsite.—Orthoclase and Quartz, occurring as a fine admixture, the separate minerals not being discernible by the naked eye, and scarcely by microscopic examination. Such a substance is termed felsitic. The devitrification of Obsidian results in felstone. Hälleflinta may be included with the Felstones.

Felspar Porphyry.[3]—A felsitic matrix, containing distinct crystals of Orthoclase.

Minette or Mica Trap.—A felsitic matrix, containing crystals of Magnesian Mica and small Orthoclase crystals, usually with some Magnetite or Titaniferous Iron, etc.[4]

Quartz-Porphyry or Quartz-Felsite.—A felsitic matrix, containing distinct crystals of Orthoclase and Quartz. (Elvan.)

A.

Gneiss.—A foliated rock, having the same mineral composition as granite. It frequently graduates into sedimentary rocks, and hence is regarded as a metamorphic rock.

Phonolite. — Orthoclase (Sanidine), Nepheline, Hornblende, Hauyne, Nosean, Augite, Plagioclastic Felspar, Pyrites, etc., often present.

Trachyte.—Sanidine and Plagioclastic Felspars, Hornblende, Augite, and Magnesian Mica—frequently Tridymite. Rhyolite is sometimes included in this group. There are also *Quartz-Trachytes* or *Dacites*.

Pitchstone.—Variable in composition, sometimes containing more and sometimes less than 60 per cent. of Silica. As a rule Pitchstone approximates to the felspars in composition. It often contains felspar and magnesian mica, crystals and microliths of augite, and other minerals. On analysis Pitchstones afford a considerable amount of water.

Obsidian.—A more vitreous condition of Pitchstone; it usually contains microliths, chiefly of felspar.[5]

[1] The red or grey colour usually depends upon the colour of the felspar.

[2] The name Syenite was originally given by Pliny to the hornblendic granite of Syene in Egypt.

[3] *Porphyries* are generally known by the name of the larger disseminated crystals as Quartz Porphyry; but in other cases we speak of Porphyritic Granite. The term Porphyry is now almost obsolete.

[4] Minette may be regarded as a mica-syenite. The term mica-trap also includes Kersantite, which differs from minette in that the felspars are plagioclastic, and it is therefore allied to mica-porphyrite.

[5] Since Pitchstones, Obsidians and other vitreous rocks frequently exhibit perlitic structure, it has been proposed to abandon the term Perlite. Q. J. xl. 345. The term Perlitic is applied to delicate spheroidal cracks that often occur in vitreous and in devitrified lavas.

The rocks in the group marked B. are called Plutonic, since they have originally solidified at a considerable depth from the surface. Some of them form large tracts of land, others occur only over limited areas, as bosses, and dykes.

The rocks in the group marked A. are clearly Volcanic, since they occur not merely as bosses and dykes, but also as lava flows.

As with the rocks in the first table, so also with the two groups in this: they probably graduate into one another, and have no doubt often originated from the same deep-seated sources, although the different depths at which they have solidified have exercised an important influence on their physical and mineralogical characters.

Schistose Rocks.—These rocks have a schistose or fissile structure, splitting more or less regularly in planes parallel either to bedding, cleavage, or foliation. In many instances they exhibit a foliated structure, and where this is the case the rock usually splits in directions approximately coincident with the planes of foliation. In cases where the rock has originally been deposited as a sediment, the foliation may coincide either with planes of bedding, or with planes of cleavage; but it should be borne in mind that planes of foliation do not *necessarily* imply the existence, or the former existence, either of planes of bedding or of cleavage planes, although they very frequently do so.

The following are some of the most common schistose rocks:—

Volcanic Ashes.[1]—In these the mineral components may sometimes be identified with comparative ease, but they are frequently made up of very fine fragments or flakes, which in the main consist of felspathic material, the species of the felspar being occasionally undeterminable, and probably, in many cases, mixed. Fragments of Hornblende, Augite, etc., are often present. These rocks are sometimes well cleaved, and afford good roofing slates, as in the English Lake District. The minute structure and mineral composition of some of them have been described by Dr. H. C. Sorby and others. Such ashes may have been ejected from a terrestrial or a subaqueous crater, and in the former case may have been showered down on a land surface or have been deposited under water as sediment.

Basalt Ash or *Basalt Tuff.*—This rock has much the same mineral composition as basalt. Indeed we may regard it as basaltic matter ejected in the form of ash and lapilli, instead of having been poured out as a lava flow. In some lava flows it is possible that cleavage may have been superinduced, and so have lent a schistose character to the rock, in which case the fissile structure would serve rather to screen than to elucidate its origin.

Greenstone Ash.—Much of the rock called Greenstone Ash may probably be safely referred to the above. The term, however, as formerly used, was not erroneous, since Basalt and Diorite were then included in the term Greenstone.

Aphanite Schist.—A fine-grained rock of eruptive origin, with a fissile structure. This fissile structure may imply lamination, and favour the supposition that the rock originated as ashy matter, and was deposited under water. On the other hand, it may imply cleavage. The affinities of Aphanite Schist are probably basaltic. It is an ill-defined but a vague and useful term. The same remark may apply equally to the expression Volcanic Ash. No serious exception can, however, be taken to the use of these terms in the field.

Hornblende Schist.—The components are for the most part Hornblende and Quartz, often showing a foliated arrangement, but sometimes the two minerals have crystallized out very irregularly, and occasionally the quartz is very poorly represented, or is totally absent, in which case the rock becomes Hornblende Rock.

[1] The terms Agglomerate and Volcanic breccia are sometimes used for these ejectamenta. They are also spoken of as Pyroclastic Rocks.

Schorl Schist.—A foliated rock composed of Schorl and Quartz.

Mica Schist.—Often foliated, composed mostly of Mica and Quartz. The mica is generally Muscovite, but sometimes it is a Magnesian Mica. Occasionally felspars occur, in which case the rock becomes gneissic in character, and may even pass into true gneiss. Garnets are common in Mica Schist. Passages have been observed from ordinary slate, etc., into it; it is therefore spoken of as a Metamorphic rock. A passage of Dolerite into Mica Schist has also been described by Mr. Teall.[1]

Sericite Schist.—A Mica Schist in which the Muscovite is represented by Sericite, an altered condition of that mineral.

Talc Schist.—Often foliated, composed mainly of Talc (hydrous bisilicate of magnesia), and Quartz. Garnets, Actinolite, Chlorite, Pyrites, etc., are frequently present. As in the case of Mica Schist, passages from this rock into Slate, etc., have been observed.

Chlorite Schist.—Sometimes foliated, and composed mainly of Chlorite (hydrous silicate of magnesia, alumina, and protoxide of iron), with some quartz, and frequently with some felspathic, micaceous, or talcose material. Magnetite, Pyrites, and Chalybite are also of common occurrence. It sometimes passes into Serpentine, Talcose Schist, Mica Schist, etc.

Serpentine.—Chemical composition, Hydrous Silicate of Magnesia. This may represent a very highly altered condition of rocks rich in magnesia, such as the Peridotites. Still it is also possible that soluble magnesian salts may at times have been infiltered into rocks whose original constitution was very different, and which may have contained little or no magnesia. Serpentine often contains Chromic Iron, Garnets, and other minerals. It sometimes passes into Chlorite Schist, Talc Schist, etc., etc. In many eruptive rocks minerals, such as Olivine, Augite, Hornblende, etc., have undergone considerable change, and are now only represented by pseudomorphs of Serpentinous material.

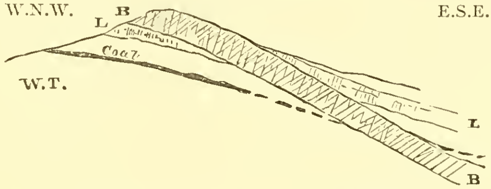
The vesicular structure, so common in some rocks, occurs almost exclusively in those that have been poured out as lavas or ejected as lapilli. It is, however, met with occasionally in the upper portions of dykes, but the structure is not exhibited in rocks which have solidified far beneath the earth's surface (Plutonic Rocks). Vesicular structure is due to the presence of bubbles of gas, steam, air, or fluid, forced into the molten, pasty mass, either prior to or during ejection or emergence from a volcanic vent, or it is due to the development of steam by the passage of heated rock over a damp surface, or it is caused, possibly, even by the actual disengagement of gases generated by the decomposition of substances contained within the rock itself. Minute cavities containing gases and fluids occur, however, in some of the minerals composing Plutonic, as well as in some of those which compose Volcanic rocks. These are, as a rule, purely microscopic in dimensions, and do not impart a vesicular character to the rocks in which those minerals occur. The cavities in Pumice are elongated vesicles, and the vesicular structure is sometimes well developed in Basalts. Vesicles in a rock are often filled by substances such as Calcspar, Greenearth (an earthy variety of Chlorite), Zeolites, etc., which have gained access to their present tenements by infiltration in solution. Rocks spotted with such filled-up vesicles are spoken of as amygdaloidal (because they are often almond-shaped), this adjective being prefixed to the name of the rock (*e.g.* Amygdaloidal Dolerite). A somewhat similar structure may, however, result at times from the segregation of certain minerals in a rock during its solidification. Still, as a rule, the different origin of these structures is clearly discernible. F. RUTLEY.

[1] Q. J. xli. 133.

In the following pages the Igneous and Metamorphic rocks are described geographically rather than chronologically, for the precise age of many of the Eruptive rocks has not yet been determined.

The Cheviot Hills are formed partly of andesites and porphyrites (lavas and tuffs) 1500 to 2000 feet thick, and partly of Sandstones belonging to the Lower and Upper Old Red Sandstone. (See pp. 121, 143, and Fig. 16, p. 114.) The chief focus of eruption appears to have been near Cheviot, and the beds were

FIG. 96.—SECTION THROUGH WARD'S HILL, NEAR ROTHBURY. (W. Topley.)



L. Great Limestone. B. Whin Sill.

mostly subaqueous. The volcanic rocks which form much of the higher ground are of Lower Old Red Sandstone age. There are also intrusive rocks, quartz-felsites, and augite-biotite-granites.[1] Melaphyre or Dolerite occurs at Stichill among the Tuedian Beds.

The basaltic rocks of the north of England occur either as dykes, cutting vertically through the sedimentary rocks, or as beds or sheets lying among them. The term "Whin" is locally applied to rocks hard enough to be used for road-metal, and the term "Sill" is applied to rocks that occur in layers more or less parallel with the associated beds.

The Great Whin Sill, which forms so striking a feature on geological maps, is a mass of intruded diabase, which occupies various positions in the Carboniferous Limestone and Yoredale rocks in Northumberland, Cumberland, and Durham. Messrs. Topley and Lebour observe that this rock is best known in Teesdale, especially in the two fine waterfalls of High Force and Cauldron Snout. It also appears along the face of the Pennine escarpment, and is beautifully exposed in the "Nicks" which furrow the face of that range. It is sometimes only twenty-four feet in thickness, but it is as much as 120 feet at Alston Moor, and over 200 feet in Teesdale (see Figs. 96, 97); it frequently alters the beds above it as well as those below, and in certain places portions of the sedimentary rocks have been assimilated. Its exact age is as yet undetermined; it may have been formed at the close of the Carboniferous period.[2] Where easily accessible, the whinstone is used as road-metal; its decomposition gives rise to a ferruginous clay.

The name "Harkess Rocks" is given to the low-lying foreshore between the Bamburgh boat-house and Budle Point, in Northumberland; and there the rocks consist of whinstone, sandstone, shale and limestone. The greater part of the eruptive rock belongs to the Great Whin Sill, and is directly connected with the range of basaltic outbursts of which the Spindlestone Crags, the rock on which Bamburgh Castle stands, and the Farne Islands form part.[3] The Beadnell basaltic

[1] J. J. H. Teall, G. Mag. 1883, pp. 100, 145, 252; Johannes Petersen, *Ibid.* 1884, p. 226; A. Geikie, Trans. Edin. Geol. Soc. ii.; J. Geikie, Good Words, 1876.

[2] Topley and Lebour, Q. J. xxxiii. 406; C. T. Clough, G. Mag. 1880, p. 433; Q. J. xxxii. 466. See also T. G. Bonney, P. Geol. Assoc. vii. 104; J. J. H. Teall, Q. J. xl. 640, British Petrography, Plates xii. xiii.; Sedgwick, Trans. Cambr. Phil. Soc. 1824.

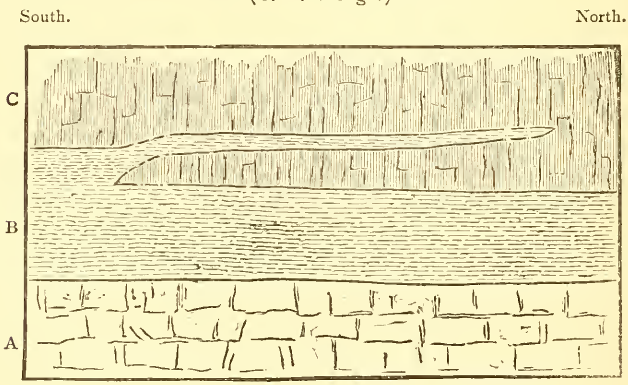
[3] G. A. Lebour and M. Fryar, Proc. N. of Eng. Inst. Mining Engineers, vol. xxvi.

Dyke traverses the Bernician rocks on the coast further south. In the north of England the term Dyke is likewise applied to faults; thus the Burtreeford Dyke, so named from Burtreeford in Weardale, and which occurs also in Teesdale, is simply a fault that displaces the strata at some points as much as 800 feet.[1]

There are many other Dykes of Eruptive rock in the north of England which have been fully described by Mr. Teall.

The Cleveland, Cockfield, and Armathwaite Dyke commences six miles south of Whitby, and extends across the Eden Valley, a distance of more than 90 miles in a W.N.W. direction. It is intrusive in the Lias and Oolites, and is probably of Tertiary age. It is a dark grey or bluish-grey rock, an augite-andesite, 18 to 80 feet wide, and sometimes forms a conspicuous feature in the landscape. In some localities where it does not reach the surface it has been proved in colliery workings; but coal in proximity to the eruptive rock becomes anthracitic and ultimately worthless. The rock is quarried in many places.[2] (See p. 181.)

FIG. 97.—DIAGRAM SECTION AT THE HIGH FORCE, TEESDALE. (C. T. Clough.)



C. Basalt.
B. Shale 14 to 20 feet. } Yoredale Series.
A. Limestone. }

The Hett Dyke extends from the escarpment of Magnesian Limestone at Quarrington Hill, east of Durham in a W.S.W. direction, through the Coal-field. It occurs in the Coal-measures, but does not, however, penetrate the Permian strata. It consists of diabase, which is probably contemporaneous with the rock of the Great Whinsill. In thickness it varies from 6 to 15 feet. It was formerly quarried between Tudhoe and Hett, and has subsequently been worked by shafts.[2]

The High Green Dykes near Bellingham are formed of Diabase. The Acklington Dyke penetrates the Carboniferous rocks at Broomhill Colliery near Acklington. It has a thickness of about 30 feet, and is composed of Augite-andesite, and has been traced westwards into the Cheviot porphyrites. This Dyke also is probably of Tertiary age. The Dykes of Morpeth, Hebburn, Tynemouth, Brunton, Seaton, and Hartley are composed of Melaphyre, and closely resemble one another. The Hebburn Dyke emerges from beneath the Magnesian Limestone near Cleadon, and passes in a N.N.W. direction by Hedworth and Hebburn to the Tyne at

[1] W. Gunn and C. T. Clough, Q. J. xxxiv. 27.

[2] J. J. H. Teall, Q. J. xl. pp. 210-238; see also C. F. Strangways and G. Barrow, Geol. Whitby and Scarborough (Geol. Surv.), p. 50; and J. W. Kirkby and J. Duff, Nat. Hist. Trans. Northumberland, iv. 193; Lebour, Geol. Northumberland, ed. 2, 1886.

Walker, where it enters Northumberland. It was formerly quarried north of the Boldon Hills: it is about 44 feet thick in places, and is not known to penetrate any formation later than the Coal-measures. The Tynemouth Dyke is exposed at the base of the Castle Rock, Tynemouth: it is 10 feet wide, and cuts the Coal-measures. The Coley-hill Dyke near Newcastle is possibly connected with that at Tynemouth: the rock was formerly worked for road-metal. Another, termed the Brunton Dyke, occurs near Whitfield in West Allendale. Several parallel dykes known as the Seaton and Hartley Dykes may be seen on the shore between those localities, and also inland at Shankhouse collieries: these rocks are quarried for road-metal. The Morpeth Dyke crosses the Wansbeck near Morpeth.

Mr. S. Allport has described the rocks, formerly called "Greenstone," that constitute the axis of the ridge of which Ercal Hill and the Wrekin form the greater portion. They comprise an extensive series of regularly stratified agglomerates and ashes, alternating with masses of altered pitchstones or felsites. At Lea Rock he obtained interesting examples of ancient spherulitic pitchstones (Rhyolites); and these he considered were originally identical with some of the glassy volcanic rocks ejected during recent geological periods.[1] The Wrekin Volcanic series (including the Lilleshall beds) is grouped by Dr. Callaway as Archæan.[2] (See p. 44.)

There are many volcanic rocks in the Lake District, some of which were investigated by the Rev. J. Clifton Ward.[3] Sir A. C. Ramsay stated his belief that the Cumbrian volcanoes were mainly subaërial, since some 12,000 feet of ash- and lava-beds have been accumulated in Cambrian times (Volcanic series of Borrowdale), without any admixture of ordinary sedimentary material, except quite at the base. Mr. Ward believed also that *one* of the chief volcanic centres of the district had been close to the present site of Keswick; the low craggy hill called Castle Head, formed of diabase, representing the denuded stump or plug of an old volcano, which may have been as large as Etna. Another vent may have been at Friar's Crag, by Derwentwater. On Eycott Hill, north-east of Keswick, much porphyritic lava (dolerite) is developed, with but little ash, and the beds attain a thickness of nearly 3000 feet. In these beds Prof. Bonney has observed a variety of Enstatite.[4] Mr. Ward has observed that the metamorphism among the Cumbrian rocks increases in amount as the great granitic centres are approached; and that it took place mainly at the commencement of the Old Red Sandstone period, when the rocks must have been buried many thousands of feet deep. Thus, the Skiddaw Slate, on approaching the granite of the Caldew valley or Skiddaw forest, passes into chiastolite slate, and this again into a rock of a schistose character (miscalled Hornblende slate), which has been used for making sets of musical stones, several of which may be seen in Keswick. The schist (or spotted-schist) passes into Mica-schist: hence there is a complete passage in the field from unaltered clay-slate, through chiastolite slate and spotted schist, to mica-schist. The junction between mica-schist and granite is well defined, but the latter sends out veins into the adjoining rocks. The granite is of a grey colour, consisting of white felspar, dark mica and quartz. (See pp. 78, 80.)

The Criffel granite in Kirkcudbrightshire is a rock of which fragments occur in the Drift of the North of England and North Wales; it contains a good deal of black mica.[5] The Eskdale granite is coarse-grained with pale felspar, often tinged of a reddish hue. At Wastdale Head it occurs over a small tract at the foot of Kirk Fell and Lingmell, probably connected with the main mass of Eskdale granite, along the axis of Wastwater. The granite of Dufton is seen at Banky Close, on the north-west flank of Dufton Pike. A small granitic mass has also been worked at Holebeck, Black Comb.

The granite of Wastdale Crag and Wastdale Pike, south of Shap, consists of a ground-mass of quartz, felspar, and black mica, porphyritically enclosing large

[1] Q. J. xxxiii. 449.

[2] Q. J. xxxvi. 536; xxxviii. 119; xlii. 481.

[3] Geology of the northern part of the English Lake District, 1876; Q. J. xxxi. 405, 568, xxxii. 2, 7; Goodchild, P. Geol. Assoc. ix. 471.

[4] G. Mag. 1885, p. 76.

[5] See D. Mackintosh, Q. J. xxxv. 425.

crystals of pinkish-red orthoclase. From its beautiful appearance it is extensively wrought for ornamental purposes. It is of special interest from the number and wide distribution of the erratic blocks which have been derived from it.[1] (See p. 487.) At Ennerdale (Pillar rock, etc.) and Buttermere there is a syenitic granite, and at Carrock Fell there is felstone-porphyry. The former rock was considered by Mr. Ward to be metamorphic, and likewise the quartz-felsite of St. John's Vale, a rock quarried for paving, etc., at Threlkeld.[2]

In the Kendal and Sedbergh districts mica-traps have been noticed, including minette, kersantite, micaceous diorite, porphyrite, etc.; these do not penetrate rocks of later age than Silurian.[3]

Mr. Ward has observed that on the coast between Castletown and Poolvash, in the Isle of Man, there may be seen "a small, ancient volcano, dissected and laid bare." The Volcanic rocks extend from Scarlet Point to Poolvash, a distance of about a mile and a quarter, and consist almost wholly of ash and breccia, with dykes of basalt. The Stack of Scarlet shows the finest development of basalt, forming a dyke, which in places is about fifty feet wide; and this intrusive rock, in Mr. Ward's opinion, represents an original line of eruption.[4]

Igneous rocks are largely developed in North Wales. According to Sir A. C. Ramsay, west, south, and east of Dolgelly, masses of 'greenstone' have been protruded amid the strata, the irregular forms of the igneous rocks being in some degree due to the contortions of the Lingula Flags, among which they lie. The Tremadoc Slates are overlaid by great accumulations of volcanic ashes and lava flows, extending in a crescent form round the Lower Cambrian, Lingula, and Tremadoc beds. and forming the heights of Cader Idris, the Arans, the Arenigs, etc.; while Sir A. C. Ramsay observes that most of the rocks between Bettws-y-Coed, Moel Siabod, Llyn-Ogwen, and Conway, are the actual equivalents of the slender band of Bala limestone, near Bala, and of the slates and insignificant ashy bands that underlie it. (See pp. 72, 73). Moel Siabod and Carnedd Llewelyn show at their summits great masses of 'greenstone' intruded amidst the fossiliferous grits and slates of the Bala formation, although they sometimes coincide with the lines of bedding Snowdon, Moel Hebog, and Y-Glyder-fawr are formed largely of beds of felspathic porphyry associated with fossiliferous grits and volcanic ash-beds, with occasional intruded masses of 'greenstone.' (See Fig. 10, p. 68).

Lava-flows of Bala age occur in the pass of Llanberis, etc. The Gimblet Rock at Pwllheli is a Diabase.[5] Felstones have been noted at Aran Mowddwy, Glaslyn, and Capel Curig; but many of the so-called felstones of North Wales were, in Mr. Rutley's opinion, originally lavas of a highly glassy type. Perlitic and spherulitic structures are met with in the lavas of the Glyder-fawr, North Wales,[6] and spherulitic rhyolites occur at Digoed, near Penmachno.[7] The spherules (lithophysen) which occur in these rocks often attain considerable dimensions and have been carefully investigated and described by Mr. Cole.

Numerous bosses of 'greenstone' occur in the Lleyn promontory in North Wales. The greenstone dykes which occur in the slate quarries of Penrhyn and Llanberis are considered by Sir A. C. Ramsay to be of later date than the contortions of the strata that produced the cleavage in them, and they are probably Post-Carboniferous.[8]

[1] J. A. Phillips, Q. J. xxxvi. 9; H. A. Nicholson, Geol. Cumberland and Westmorland, 1868, p. 41.

[2] Q. J. xxxii. 25; see also Nicholson, Q. J. xxv. 435.

[3] Aveline and Hughes, Explan. Sheet 98 N.E. (Geol. Surv.), p. 16, 98 S.E., p. 41; T. G. Bonney and F. T. S. Houghton, Q. J. xxxv. 179.

[4] G. Mag. 1880, p. 5.

[5] This and other North Wales Rocks were investigated by E. B. Tawney, G. Mag. 1880, pp. 207, 452, 1882, p. 548, 1883, pp. 17, 65; see also Ramsay, Geol. North Wales, ed. 2, 1881; Q. J. ix. 170; Sedgwick, Q. J. iii. 135; Bonney, Q. J. xxxviii. 289.

[6] F. Rutley, Q. J. xxxv. 508; Felsitic Lavas of England and Wales, p. 15.

[7] G. A. J. Cole, Q. J. xli. 162, xlii. 183.

[8] See also G. Maw, G. Mag. 1868, p. 125.

The Penmaenmawr stone near Caernarvon is a quartziferous Diorite or Enstatite-Diabase, which, from its toughness, forms a valuable paving material, and is extensively used for building-purposes and road-making.[1] It occurs as an intrusive mass in the Upper Cambrian (Ordovician) rocks near Llanfairfechan, in Caernarvonshire.

The occurrence of boulders of hornblende-picrite has been noted at Pen-y-Carnisiog, Anglesey, in Caernarvonshire, and near St. Davids.[2]

In Anglesea the green 'Mona Marble' of Rhoscolyn, Holyhead and neighbouring coast, is a serpentine.[3]

In the neighbourhood of Old Radnor the Woolhope Limestone is disturbed and altered by eruptive rocks, and especially near the Stanner Rock, east of that town.[4] This Rock, according to Mr. Cole, is composed of graphic granite, passing into pegmatite, and in the same district he has noticed the occurrence of Diabase, Quartz-Felsite, etc. Syenite occurs at Hanter Hill, south-east of Old Radnor; and the Llanelwedd stone, north of Builth, is one among several exposures of eruptive rocks.

In the Breidden Hills, north-east of Welshpool, there are many eruptive rocks; they comprise an older series of andesitic lavas, and a newer series of intrusive diabases, etc.[5]

The eruptive rocks that occur in the district of St. Davids, in South Wales, are among the oldest in the country. They have previously been described (see pp. 37–41), hence it is only desirable to add that Dr. Hicks has brought forward evidence to show that the newest of the Pebidian rocks must have been folded, cleaved, and have undergone great structural changes before the Lower Cambrian conglomerate was deposited. He maintains that the position of the great felsitic series (Arvonian) is certainly between the Dimetian and Pebidian, but it is difficult to determine whether it should be classed as of Pre-Pebidian age.[6] The acceptance of these views leads naturally to the conclusion that there is a more marked break between the Archæan and Cambrian rocks than has been suggested previously (see p. 22).

Mr. F. Rutley has noted the occurrence of devitrified obsidians with perlitic and spherulitic structures, among the eruptive rocks of Skomer Island, off the coast of Pembrokeshire.[7]

Hornblendic gneiss, together with granitic and syenitic rocks, mica-schists and quartzites, occur in the Malvern range, and are intersected in places by intrusive dykes of pegmatite.[8] (See p. 36.)

Basaltic rocks that penetrate the Carboniferous and older rocks occur in Shropshire and South Staffordshire. In the latter county the basalt, locally known as the "Green Rock," contains a large proportion of a green chloritic mineral. It occurs in sheets between the Coal-measures from the base of the Rowley Hills and Barrow Hill, through the centre of the district up to Wolverhampton, Bilston, and Bentley.[9] The basalt or dolerite of Rowley Regis forms a hill 820 feet above

[1] J. A. Phillips, Q. J. xxxiii. 423; T. H. Waller, Midland Nat. viii. 1; Teall, Q. J. xl. 656.

[2] T. G. Bonney, Q. J. xxxix. 254, xli. 515; John Plant, G. Mag 1884, p. 48; Teall, Brit. Petrography, Plates iv. vi.

[3] T. G. Bonney, Q. J. xxxvii. 40; Teall, Brit. Petrogr. p. 125.

[4] W. S. Symonds, Records of the Rocks, 160; Murchison, Proc. G. S. ii. 85; Cole, G. Mag. 1886, p. 220.

[5] W. W. Watts, Q. J. xli. 532; Murchison, Siluria, edit. 5, p. 80.

[6] Q. J. xlii. 356; see also A. Geikie, Q. J. xxxix. 294, 325; and T. G. Bonney, Q. J. xlii. 361. Prof. J. F. Blake has proposed to create a new 'system,' the 'Monian,' after one place of their development (Anglesey), for the Dimetian and other Pre-Cambrian rocks; but this seems an unnecessary burden to our already too copious nomenclature. Brit. Assoc. 1886.

[7] Q. J. xxxvii. 409; see also Felsitic Lavas of England and Wales, p. 18.

[8] Rutley, Q. J. xliii.

[9] S. Allport, G. Mag. 1869, p. 115, 1870, p. 160; Bonney, Q. J. xxxii. 140; Jukes, South Staffordshire Coal-field, ed. 2, pp. 120, 126; D. Forbes, G. Mag. 1866, p. 25; J. R. Wright, T. G. S. (2), iii. 487; Teall, Brit. Petrogr. Pl. xi.

sea-level; the rock is a dark, close-grained, and often columnar rock; it forms a capping on the Coal-measures, and it was considered by Jukes to represent a lava-flow during the Coal period. The Rowley Rag, as it is called, is largely quarried for road-mending: similar rock occurs at Barrow Hill, two miles west of Dudley. (See p. 188.) The hard grey dolerite of Pouk Hill, near Walsall, is more strikingly columnar than that of Rowley. Titterstone Clee Hill in Shropshire is capped by a mass of columnar dolerite; and Knowle Hill near Kinlet is formed of a mass of dolerite overlying altered sandstone. These rocks and also basalt from Little Wenlock and Arley Wood, near Shatterford, have been described by Mr. S. Allport. The Cornbrook Coal-field, as before mentioned, is to a large extent covered by basalt, from 60 to 150 feet thick, and in some places the coal is altered and 'sooty.' The rock is of considerable value as a paving-stone. (See p. 190.)

The intrusive diorites in the Warwickshire Coal-field closely follow the bedding-planes of the strata;[1] one of these rocks is known as the Griff-stone, from Griff hollow, south of Chilvers Coton, near Nuneaton. The diorites penetrate the Hartshill quartzite and overlying Stockingford Shales between Atherstone and Nuneaton. (See p. 66.) Volcanic tuff (Andesites), with intrusions of quartz-porphyry, and diabase, grouped as the Caldecote series, occur at Caldecote Hill, north-west of Nuneaton: these beds are regarded as Archæan by Prof. Lapworth. (See p. 45.) In the same district, further east, there are syenitic rocks (quartz-syenite), etc., grouped as the Croft series, from Croft, between Leicester and Hinckley. Syenitic rocks occur also at Huncote, Sapcote, Stoney Stanton, and Potters Marston (Barrow Hill quarry), east of Hinckley.

In Charnwood Forest many Igneous rocks are exposed. (See p. 45.) These have been investigated by the Rev. E. Hill and Prof. T. G. Bonney, but they speak of their age as uncertain, though some are possibly of the Old Red Sandstone period. Most conspicuous among these rocks are the hornblendic granites of Quorndon, Mount Sorrel; and the Syenites of Groby, Bawdon Castle, Markfield, Cliff Hill, Garendon, and Long cliff. Syenite has also been proved at Baron Park, west of Leicester, and this appears to be intrusive. Bardon Hill is formed of felstone. Outliers of the Charnwood Forest rocks occur at Enderby (syenite and slate), Narborough (quartz-felsite), and at Croft Hill and other places previously mentioned.[2] (See p. 45.)

Allusion has previously been made to the 'toadstone' of Derbyshire. (See p. 159.) Near Matlock there are two bands of this contemporaneous basalt or dolerite in the Carboniferous Limestone: they are pierced by the railway-tunnel through High Tor, and are to be seen on the "Heights of Abraham." Mr. Allport observes that the toadstone is an amygdaloidal basalt, regularly interbedded with the Carboniferous Limestone, and was evidently a contemporaneous lava-stream, partly scoriaceous, and partly of a compact basaltic structure. Generally the cavities have been filled with carbonate of lime or other minerals, thus forming an amygdaloid; other specimens, however, have empty cavities, and are as vesicular as recent lavas.[3] The beds average 60 or 70 feet in thickness, and preserve their courses for many miles; but they are often much decomposed.

Basalt occurs in the Tortworth district, in Gloucestershire, at Charfield Green and Damory Bridge, and at Crockley's farm the rock has yielded large geodes of chalcedony and quartz, known as "buns." In Somersetshire eruptive rocks occur at several points in the Mendip Hills: at Middle Hope or Woodspring Hill, at Swallow Cliff and Uphill railway-cutting (basalt or amygdaloidal dolerite),

[1] S. Allport, Q. J. xxxv. 637; A. Strahan, Brit. Assoc. 1886, G. Mag. 1886, p. 540 (with notes by F. Rutley), Geol. Surv. Map, 63 S.W., with revisions by A. Strahan; T. H. Waller, Brit. Assoc. 1886.

[2] Q. J. xxxiv. 225. Analyses of several of the rocks have been made by E. E. Berry, Q. J. xxxviii. 197. See also W. J. Harrison, Midland Naturalist, vii. 7, 41, and Geology of Leicestershire, etc., 1877; S. Allport, G. Mag. 1879, p. 481; Rev. T. N. Hutchinson, Rep. Rugby School Nat. Hist. Soc. for 1876, p. 34.

[3] G. Mag. 1870, p. 159; Q. J. xxx. 547; Jukes, G. Mag. 1867, p. 468; Teall, Brit. Petrogr. Pl. ix.

at Downhead on the Mendip Hills (felstone containing much magnetite and a little hornblende), and at Stoke Lane (devitrified porphyrite with a devitrified base). Volcanic breccia occurs at Wrington Warren.[1] At Adscombe, near Nether Stowey, there is a compact fragmentary rock, possibly volcanic ash (as suggested by Mr. F. Rutley), which has been worked for building purposes. Syenitic rock ("Pottle stone") occurs at Hestercombe, near Taunton[2] (see p. 141); and intrusive felstone is met with near Bittadon, in North Devon.[3]

At Washfield, north-west of Tiverton, is a peculiar volcanic ash considered by De la Beche to have been formed during the accumulation of the Triassic series by volcanic ejections falling into the water in which the sands and other detritus were being accumulated. Referring also to certain large masses of quartz-porphyry that occur in the New Red breccias of South Devon, and which do not distinctly resemble any rocks found *in situ* in the district, he thought they also might have been ejected from volcanic vents and mingled with the sediments of the New Red series.[4] Basaltic rocks, sometimes amygdaloidal, occur more particularly at or near the base of the Red rocks at Posbury, south-west of Crediton, Thorverton (Thorverton stone) near Silverton, at Dunchideock and Pocombe (Pocombe stone), south-west of Exeter.

Near Newton Abbot and Totnes there are many exposures of igneous rock amidst the Devonian slates: some appear to be intrusive and others are contemporaneous, and they are frequently marked by hilly features, the result of their resisting denudation more than the Devonian slates. The Ashprington Series of Mr. Champernowne (see p. 135) includes many volcanic rocks.[5]

In Babbacombe Bay there is intrusive dolerite;[6] and similar rock occurs at Black Head, near Torquay. Yarner Beacon, near Dartington, is formed of gabbro.

Brent Tor, near Tavistock, is perhaps one of the best preserved of our volcanic vents, inasmuch as the basal portion of the original cone remains. (See Figs. 94, 95.) De la Beche originally described the main features of this district, suggesting that there was the site of an old volcano: the rocks have since been described in detail by Mr. Rutley.[7] The eruptions probably took place in early Carboniferous times, during the deposition of the Culm-measures, for the lavas are interbedded with strata that are most likely of this age, if they are not Devonian.

Granite is largely developed in Cornwall and Devon: it is usually of a grey colour, and often contains schorl. The Cheesewring granite is quarried under the hill on which the Cheesewring is situated, near Liskeard, and was used in the construction of the London Docks, Westminster and Waterloo Bridges, etc. Granite also is quarried at Lamorna Cove, west of Penzance, Penryn, Falmouth, Carn Brea, St. Austell, Par, Hensborough,[8] Bodmin, Gready near Lostwithiel, Calstock, Padstow, etc. It is extensively used for building-material.

The Roche-rocks between Bodmin and Truro are on the borders of the granitic area. St. Michael's Mount is formed of granite, while the tidal isthmus is formed of slates. Porphyritic granite occurs at Lanlivery and Luxulyan (Luxullian or Luxulion), south-west of Lostwithiel. The rock, which has been named Luxulyanite (Luxullianite), is a porphyritic rock, consisting of large crystals of pink orthoclase-felspar, and small crystals of quartz, in a ground-mass of schorl, or black tourmaline. Prof. Bonney regards it as a peculiar metamorphic form of

[1] F. Rutley, in Geol. E. Somerset (Geol. Surv.), pp. 208–212; J. Slade, P. Geol. Assoc. vii. 112; Moore, Q. J. xxiii. 451; H. H. Winwood, Proc. Bath Nat. Hist. Soc. iii. 90.
[2] L. Horner, T. G. S. iii. 348.
[3] Bonney, G. Mag. 1878, p. 207.
[4] Proc. G. S. ii. 198; Report Geol. Cornwall, pp. 199, etc.
[5] S. Allport, Q. J. xxxii. 423; De la Beche, Proc. G. S. i. 33.
[6] See W. A. E. Ussher and A. Champernowne, P. Geol. Assoc. viii. 442, 458.
[7] F. Rutley, Q. J. xxxvi. 293; and The Eruptive Rocks of Brent Tor, 1878; De la Beche, Report Geol. Cornwall, etc., pp. 51, 70.
[8] See J. H. Collins, The Hensbarrow Granite District, 1878.

the normal granite of the country.[1] This rock was used for the Duke of Wellington's sarcophagus in St. Paul's Cathedral.

Granite has been raised on Dartmoor at the extensive quarries of Foggen Tor, near Prince's Town, also at Fremator, near Tavistock, at Hey (High) Tor, etc. Dartmoor granite was employed in constructing the Thames embankment.

The decomposition of granite has at various periods given rise to accumulations of clay, the purer kinds of which are known as Kaolin or China Clay. This clay results from the decomposition of the felspar and mica in the granite, but the term China Stone is sometimes applied to the material when it retains much of the quartz and is in a less advanced state of disintegration. On the other hand, the term Arkose is applied to a felspathic grit, due to the disintegration of Granite and the subsequent cementing of the materials *in sitû*, or nearly so: quartz and felspar predominate in this material, and mica is sometimes present.

Extensive deposits of China Clay (Cornish or Porcelain Clay) occur at St. Austell, Hingston Down near Calstock, and at Morley and Lee Moor near Plympton, in Devonshire. The clay is employed in the manufacture of porcelain and porcelain fire-bricks; it is used in paper manufactories and in bleaching establishments.[2] (See also p. 444.)

Granite has been quarried at Lundy Island; the Gannet Stone (Ganiston) is a variety worked on the northern part of it. The island, which is about 3½ miles long, and from 500 to 600 feet above the sea-level, is formed chiefly of Granite, excepting the south-east corner, which is Devonian clay-slate. (See p. 129.) The granite appears to be bedded, occurring in great piles or "cheeses," features due to the joints and weathering. Dykes of greenstone also occur in the island.[3]

From the Channel Islands large quantities of granite are exported, chiefly for use as London road-metal. It is obtained from the quarries of Mont Mado and La Perruque in Jersey, and from Guernsey and the little island of Herm. Pink and grey granite is imported from St. Sampson's Bay in Guernsey, and known as Guernsey or St. Sampson's stone. At Jersey china clay has been obtained, and bricks are made. There is much gneiss in the southern part of Guernsey, while the northern part is largely made up of Diorite and Syenite, with Granite and Hornblende Gabbro ("Bird's Eye"[4]). Gneiss occurs in Sark, and also Hornblendic Schist, which may be of Archæan age. (See p. 46.) Syenite occurs also in Alderney and Sark.

The Scilly Isles comprise about one hundred and forty-five islets or rocks, of which St. Mary, the largest, is about 3 miles long by 2½ miles broad, attains a height of about 204 feet above the sea-level, and occupies an area of about 1640 acres. It is almost exclusively granitic, but shows traces of clay-slate. The Gulf or Wolf rock, situated between the Land's End and the Scilly Islands, is formed of phonolite. The granite is of coarse appearance, and is therefore not largely quarried.[5]

Mr. Allport has observed that on approaching either of the granite masses of Cornwall, the clay-slates become more and more indurated, and they are traversed by numerous quartz-veins: mica and schorl make their appearance in the slates, and at the junction of the two rocks, their slaty character has in many cases been obliterated. At Mousehole, St. Michael's Mount, and Cape Cornwall, the mass of granite cuts sharply through the slates, and has thrown out numerous veins, both large and small, which have penetrated them in various directions. In all such cases the slates have evidently been greatly altered along the line of junction;

[1] Mineralogical Mag. i. 215; Address to Geol. Soc, 1886, p. 59; see also Pisani, Comptes Rendus, 1864.

[2] See G. Mag. 1867, p. 241; P. Geol. Assoc. viii. 479; R. Hunt and F. W. Rudler, Guide Mus. Pract. Geol. ed. 4, p. 141.

[3] T. M. Hall, Trans. Devon Assoc. 1871.

[4] Rev. E. Hill, Q. J. xl. 404; J. A. Birds, G. Mag. 1878, p. 79; MacCulloch, T. G. S. i. 12; A. de Lapparent, Bull. Soc. Geol. France (3), xii. 284; Prof. G. D. Liveing, Proc. Cambr. Phil. Soc. iv.; C. Noury, Géologie de Jersey, 1886.

[5] Rev. F. F. Statham, Geologist, ii. 12; De la Beche, Mem. Geol. Survey, i. 233, and Report, pp. 161, 494; Joseph Carne, Trans. R. G. S. Cornwall, vii. 140.

and fragments of them have not unfrequently been torn off, and are now enclosed in the granite. There can be no question, therefore, that the granite here presents all the characters of an intrusive igneous rock.[1]

At Wicca Pool, Zennor, veins of granite penetrate the mica-slates, and fragments of the latter, that have been detached from the general mass, have become enclosed in the granite.[2] In Devonshire the slaty rocks are altered in places in proximity to the granite. (See p. 199, and Fig. 30, p. 194.)

The term "Elvan" is used in Cornwall and Devon for varieties of quartz-felsite or quartz-porphyry, generally of a whitey-brown colour, that occur in veins or dykes. These dykes vary in width from a few feet to several fathoms, and traverse both granite and slates; they often coincide in direction with lodes.[3] At the Caradon Mines hand-specimens can be obtained showing the junction of elvan and granite. (See p. 566.)

Elvans vary considerably in texture; sometimes they are of a fissile nature. These rocks have been obtained from the Land's End, from Marazion near Penzance, near Helston, Penryn, Truro, Pentuan (Pentuan Stone), Lanivet, St. Neot's, St. Dennis, Camelford, Oakhampton, Rowborough (Rowborough stone) between Plymouth and Tavistock, etc. Elvan is a very durable stone, and is well adapted for building-purposes and for road-metal.

In Central and Eastern Cornwall Mr. J. A. Phillips has found lava-flows so interbedded with the slates and schists as to indicate that they were contemporaneous. The lavas sometimes assume a distinctly schistose structure. Most of the so-called "greenstones" appear to be altered dolerites. On St. Cleer Downs the "hornblende slates" graduate imperceptibly from crystalline dolerite on the one hand, into clay-slates on the other; and instances are by no means wanting where a rock is massive and crystalline near the centre of its outcrop, while externally it is schistose and without visible crystals. Mr. Phillips adds that this schistosity in igneous rocks is often exceedingly puzzling, as it is sometimes impossible to determine where foliated traps cease and where metamorphosed slates begin.

Dolerites are exposed west of St. Austell, and quarried for road-metal at Hill Head, near Camelford, and Trelill, St. Kew. In places they are called "Dunstones." Their age is generally greater than that of the granite. Some of the so-called "greenstones" of western Cornwall are gabbros or dolerites and hornblendic or chloritic slates:[4] and these slates or schists are possibly of Archæan age. (See p. 46.) Mr. Rutley has described some augite-andesites from the neighbourhood of St. Minver, near Padstow.[5]

Serpentine, which is a hydrous silicate of magnesia, etc., is so called from the fancied resemblance of the rock to a serpent's skin. It occurs both as a mineral and as a rock. It is generally regarded as the most beautiful of the ornamental stones of this country, and even in its natural position, in the Lizard district, and especially in Kynance Cove, the varied hues of the rock appear in pleasing contrast with the white sands of the beach. Red and green varieties of serpentine are found, and the rock contains also diallage, veins of steatite, asbestus, etc. (See p. 568.) It may be seen also at Coverack and Kennack Coves, at Mullion, Cadgwith, St. Keverne, Nare Point, Poltreath, Porthalla, and Polkerris. In De la Beche's opinion the rock was a product of metamorphism,[6] and this view has been supported by Mr. J. H. Collins,[7] by Prof. W. King, and Dr. T. H. Rowney:[8] but Prof. Bonney is of opinion that it was originally an igneous rock, intrusive among the hornblende schists, and broken through in places by granitic dykes.

[1] S. Allport, Q. J. xxxii. 407; see also J. A. Phillips, Q. J. xxxi. 338.
[2] J. A. Phillips, Q. J. xxxvi. 9.
[3] J. A. Phillips, Q. J. xxxi 334.
[4] J. A. Phillips, Q. J. xxxi. 328, xxxii. 155, xxxiv. 471; S. Allport, Q. J. xxxii. 407; L. Horner, Q. J. x. 359.
[5] Q J. xlii. 392.
[6] Report Geol. Cornwall, etc., p. 30. See also Teall, Brit. Petrogr. Pl. xv. and p. 104.
[7] G. Mag. 1885, p. 298, 1886, p. 359; Q. J. xl. 458.
[8] Phil. Mag. (5), i. 280.

Gabbro occurs at Coverack Cove, and extends to Manacle Point, and Crousa Down. In places it penetrates the serpentine in veins and dykes, and is also itself traversed by veins of granite and diorite. Mr. Teall has pointed out that the foliation of the gabbros in this district is due to pressure- or regional-metamorphism.[1]

The Clickertor Rock, near Menheniot, is an intrusive serpentine with veins of carbonate of lime and chrysolite. It is described by Mr. Allport as an interesting example of the conversion of an intrusive olivine-dolerite into a mass of imperfectly formed serpentine.[2]

Soapstone or steatite is a variety of talc, and it has been used at Swansea in the manufacture of porcelain, and in other places for various ornamental purposes. It is found associated with serpentine in the Soapstone Rock near Mullion, in the Lizard district ; and is also met with in Caernarvonshire, Anglesey, Cumberland, and Herefordshire.

MINERAL VEINS AND METALLIFEROUS DEPOSITS.

Mineral veins are deposits of mineral matter that usually occur in faults, but sometimes in other fissures, or joints in stratified and eruptive rocks. Those only which yield valuable ores are termed Lodes or Metalliferous veins; for the veins of quartz that frequently traverse the older strata are appropriately termed Rock veins. The term "ore" is applied to the metals when found in combination with other substances; and metalliferous deposits occur not only in lodes, but also in beds, seams, and pockets, as nodules, and as detritus in the stratified rocks. The ores worked in England and Wales are chiefly those of Lead, Zinc, Tin, Copper, and Iron.[3]

The material forming the greater part of the lode or vein apart from the ore worked, composed of quartz, calc-spar, or other non-metallic substances, is called the Gangue, Matrix, or Vein-stuff; the material at or near the outcrop of the lode is called the Gossan ; the surrounding rock is known as the Country ; and certain siliceous bands bordering the lode are sometimes termed the Capel (or Caple). The Gossan (or Gozzan) is usually of an ochreous nature, as it is much charged with iron-ores, derived from pyrites. In different parts of the country, however, many local terms are used, and the same term may be applied in different senses.

Veins vary in width from one to twenty-four feet and upwards, and they take various directions, spoken of sometimes by the miners as running at different hours, as nine or twelve o'clock, according to the sun-dial.

Metalliferous deposits occur in rocks of all ages, but lodes are more abundant in eruptive and metamorphic rocks, and especially near the junction of Palæozoic and intrusive rocks. Thus, mountain regions possess greater mineral wealth as a rule than low-lying countries.

[1] Bonney, Q. J. xxxiii. 884, xxxix. 23 ; F. T. S. Houghton, G. Mag. 1879, p. 504 ; Teall, G. Mag. 1886, p. 481, Brit. Petrogr. Pl. xviii.

[2] Q. J. xxxii. 423 ; De la Beche, Report, pp. 79, 96.

[3] See J. A. Phillips, Treatise on Ore Deposits, 1884 ; R. Hunt, British Mining, 1884 ; D. C. Davies, Treatise on Metalliferous Minerals and Mining, ed. 3 ; J. H. Collins, Principles of Metal Mining, 1875 ; C. Le N. Foster, Article 'Mining' in Encylop. Brit. vol. xvi. 1883.

The mining districts of Cornwall and Devon [1] are grouped around the granitic masses, and Mr. J. A. Phillips considers that they for the most part originated subsequently to the consolidations of the elvan-courses. He observes that both the sedimentary and igneous rocks of Cornwall are traversed by innumerable mineral veins, which, although principally composed of siliceous materials, contain ores of tin, copper, lead, and various other metals. Veins yielding ores of tin and copper have usually a direction approximating to east and west, and are seldom found at any considerable distance from the junction of the granite and killas, particularly if elvan-courses do not occur in the neighbourhood. These veins, which are called "lodes," are intersected, nearly at right angles, by others known as "cross-veins" (or "cross-courses"), which sometimes yield lead or iron ores, but are otherwise, excepting in the immediate vicinity of lodes, usually unproductive.[2]

The metallic worth of lodes is liable to much variation, while their mode of occurrence is subject to uncertainty, owing to the 'throws,' 'shifts,' and 'heaves' (faults) which affect the strata in which they occur. Surface indications are seldom considered very trustworthy evidences for mineral wealth at a depth, and it sometimes happens that the capel (or cab) is more valuable than the 'leader' or lode itself. Alluvial deposits, however, often furnish good evidence of the ores contained in the rocks of a district.

Dr. C. Le Neve Foster has shown that near Redruth and Camborne the lodes are not always fissures containing mineral matter, but may be tabular masses of rock, altered and rendered metalliferous. Indeed, he is disposed to believe that at least half the tin-ore of Cornwall is obtained from such masses of stanniferous altered granite. These lodes may be termed "Tabular stockworks." The name "Stockwork" (from the German *Stockwerk*) is usually applied to large masses of rock impregnated with metallic ores, or intersected by a number of mineral veins at short distances apart, sometimes crossing one another in all directions. It probably owes its origin to the method of working formerly often adopted for such deposits, which were wrought by chambers arranged in *tiers* or *stories*.[3] Dr. Foster recommends the following definition:—"A mineral vein or lode is a tabular mineral mass formed, more or less entirely, subsequently to the enclosing rocks."[4] In Cornwall the term Huel (or Wheal) signifies a mine-work.

Much of the material forming mineral veins is no doubt due to ordinary aqueous deposition, or to segregation from the neighbouring rocks, but in regard to the formation of the metallic minerals much uncertainty exists; sea-water, as before mentioned, contains traces of various metals, and thermal waters are known to convey the soluble salts of some of them (see p. 537); but both chemical and electrical action may have been instrumental in producing our mineral veins.

The majority of 'precious stones' have been formed in rocks that have been subjected to intrusions of eruptive matter; but no 'gems' of any importance are found in England or Wales.[5]

[1] See J. H. Collins, Handbook to the Mineralogy of Cornwall and Devon, 1871; W. J. Henwood, Trans. R. G. S. Cornwall, v.; De la Beche, Report on Geol. Cornwall, etc., 1839.

[2] Q. J. xxxi. 320.

[3] Q. J. xxxiv. 652, 654, 658.

[4] G. Mag. 1884, p. 513.

[5] See Judd, Volcanoes, ed. 2, p. 146; Morris, Gems and Precious Stones, Pop. Sc. Rev. vii. 123, 1868.

As previously suggested, there appears to be some relation between lodes and the rocks they traverse; and Mr. Wallace has maintained that the lead-veins of Alston Moor, etc., are due to segregations resulting from the decomposition of the wall-rocks of the veins, and to aqueous deposition from above. There the most important are the Rake-veins, which run east and west, while 'cross-veins' run north and south; veins that branch off laterally are known as Flots, and streaks of ore met with in the rocks are known as Pipe-veins.[1]

Iron Ores.

The occurrence of iron-ore in stratified rocks may be said to be universal, for their colouring is largely due to it. Rusty brown tints are due to hydrated peroxide of iron; brighter red tints, and sometimes darker stains, are due to anhydrous peroxide of iron; greenish colours are produced by the protosilicate, and bluish tints are imparted by bi-sulphide of iron. (See pp. 275, 285, 408.) Iron-ore has been found in profitable quantities in many formations, but sometimes only in limited areas: it occurs in beds, and nodules, and frequently in veins and pockets. Native iron is found in meteorites, but usually associated with nickel and other substances.

Among the ores, hæmatite (anhydrous peroxide or 'red oxide') occurs in crystalline form as specular iron or iron-glance, in an earthy form as raddle or reddle, and reniform, mammillated, or nodular as kidney-ore. Limonite (hydrous peroxide or 'brown oxide') occurs in a mammillated or stalactitic form as 'brown hæmatite,' and in an earthy form as ochre and bog iron-ore. (See p. 513.) Göthite is a crystalline form, possessing the same composition. Magnetite (peroxide and protoxide) possesses magnetic properties, and is known sometimes as 'Lodestone.'

Spathose iron-ore (siderite or chalybite, essentially carbonate of protoxide of iron), is a mineral whose composition is subject to considerable variation, the carbonates of lime, magnesia, and protoxide of manganese frequently replacing to a greater or less extent the carbonate of iron. Moreover, this carbonate of iron is frequently associated with certain argillaceous impurities which interfere with its crystallization, and give rise to the dark-coloured massive varieties called *clay-band* or *clay-ironstones*. These impure argillaceous carbonates,—which are so profusely distributed throughout our Coal-measures, partly as regular seams of variable thickness, and partly as nodular concretions,—constitute the ore which, in this country, yields nearly two-thirds of our iron.[2] (See p. 203.)

Mr. Bauerman observes that the septaria, or cement-stone nodules, found in the London Clay, may be regarded as clay-ironstones, in which the protoxide of iron is in great part replaced by lime.

Some clay-ironstones exhibit a concretionary form, called 'cone in cone' as the seam of ironstone breaks into conical forms with the bases of the cones at top and bottom of the seam, and their apices pointing towards each other. The surfaces of these cones are corrugated by small horizontal fretted wavelets, or ridges, rather resembling those on the outside of some stalactites, and each cone is concentrically enveloped by several coats, the surface of each being similarly corrugated.[3] According to Mr. Sorby, this has been produced by concretionary crystallization after the deposition of the rock.[4] (See p. 177.)

Spathose iron-ore is worked in the Devonian rocks of the Brendon Hills in

[1] Wallace, The Laws which Regulate the Deposition of Lead Ore in Veins, 1861; Prestwich, Geology, Chemical and Physical; see also Robert Were Fox, Proc. G. S. iii. 9.

[2] R. Hunt and F. W. Rudler, Guide to Mus. Pract. Geol. ed. 4, p. 109; R. Meade, Coal and Iron Industries of the United Kingdom, 1882.

[3] Manual of Geology, by J. B. Jukes and A. Geikie, 1872, p. 312.

[4] Brit. Assoc. 1859; see also J. Dickinson, on 'Jackstones' at Merthyr Tydvil. Q. J. ii. 131; J. Young, Min. Mag. vi. 13; Trans. Geol. Soc. Glasgow, viii. 1, 1886; Gresley, G. Mag. 1887, p. 17; and Rev. J. Yates on 'Curl,' T. G. S. v. 375.

Somersetshire, in Cornwall, and in the Carboniferous rocks at Weardale in Durham, etc. Magnetic iron-ore occurs near Hey Tor in Devonshire. Red and brown oxides of iron have been worked in the Carboniferous rocks, etc., of the Furness District, etc. (see pp. 83, 163), Northumberland, Llantrissant in Glamorganshire, Bristol, and in the Forest of Dean; in the Devonian rocks of Restormel (where fine specimens of Göthite have been obtained), and other places in Cornwall.

Iron-ores (chiefly brown ores) have been obtained from the Lower Greensand of Seend in Wiltshire, and Tealby in Lincolnshire; from the Wealden Beds of Sussex and Kent (clay-ironstone); the Corallian Beds of Abbotsbury in Dorset, and Westbury in Wiltshire; from the Northampton Sand of Wellingborough, etc.; and from the Dogger of Rosedale in Yorkshire (magnetic iron-ore); from the Middle Lias of Fawler, etc., in Oxfordshire, Grantham and other places in Lincolnshire and Leicestershire, and the Cleveland district in Yorkshire (carbonate of iron, etc.); the Lower Lias of Scunthorpe, etc., in Lincolnshire; and from the Triassic rocks of Somerset, etc.

Pyrites, iron-pyrites (bisulphide), occurs in most strata; it is not available as a metallic ore, but is used in the preparation of sulphate of iron and sulphuric acid, hence it is sometimes known as 'sulphur-ore.' In Cornwall the name 'mundic' is applied to various forms of pyrites, although it should properly be restricted to arsenical pyrites. Marcasite is a species which crystallizes in prismatic or rhombic forms, some of which are known as 'Cockscomb pyrites': fine examples occur at Folkestone.

Iron, as employed in the arts, for the manufacture of 'hardware,' etc., contains carbon in variable proportion. Cast-iron, or pig-metal, is hard and comparatively brittle, and contains from 2 to 6 per cent. of carbon; wrought or malleable iron is nearest to the pure metal, and contains little or no carbon; while steel contains an amount of carbon intermediate between that in wrought and cast iron.[1]

Both red and brown oxides of iron are used in the preparation of pigments; and hæmatite, when reduced to powder, is used for polishing. (See pp. 220, 232.)

Lead Ores.

Native lead is of rare occurrence, but it has been found at Alston Moor, and some other localities. Galena (sulphide) is the more important ore; the purer varieties contain upwards of 86 per cent. of the metal, but silver is usually present, and is extensively extracted. Cerussite (carbonate) is largely used for white paint (as an artificial preparation), and is known as white-lead-ore. Minium (red oxide) is of the same composition as 'red lead,' but the latter is always prepared artificially. Among other lead-ores there are anglesite (sulphate) and pyromorphite (phosphate). Lead-mining has been carried on in this country since early British and Roman times.

In Cornwall and Devon the lead-ores occur in the Devonian 'clay-slate' in regular veins or lodes, mostly in the cross-courses running north and south. There are lead-mines at Menheniot and Herodsfoot, near Liskeard, in Cornwall, and at Beer Alston and Combe Martin in Devon.

There are lead-mines in the Cambrian rocks of Cardiganshire, Merionethshire, Montgomeryshire, and Shropshire, and in the Carboniferous rocks of Denbighshire and Minera in Flintshire. In the Isle of Man the mines of Foxdale and Laxey are situated near the junction of slates and granite. In Northumberland, Durham, Westmoreland, Cumberland, Yorkshire, and Derbyshire, much lead-ore has been obtained from the Carboniferous rocks. The East and West Allendale and Derwent mines, and those of Weardale, Teesdale, and Alston Moor are the more important sources. From the 'lead-measures' of Alston Moor in Cumberland upwards of 4000 tons have been obtained in one year.[2] (See pp. 163, 167.)

[1] Bauerman, Treatise on the Metallurgy of Iron, ed. 5, 1882.

[2] T. Sopwith, P. Geol. Assoc. i. 314; J. Morris, G. Mag. 1869, p. 317; De Rance, *Ibid.* 1873, pp. 64, 303; Goodchild, Trans. Cumb. Assoc. vii. 107.

In Somersetshire it is chiefly the refuse and slag left by the 'old miners' that is now smelted; and the material has been dug near Priddy and East Harptree.

Type-metal is made of an alloy of lead and antimony.

Zinc Ores.

Zinc has not been found native. The ores include blende or 'Black Jack' (sulphide), calamine (carbonate), and smithsonite (hydrous silicate).

Zinc-ores are met with in the Triassic, Carboniferous, Devonian, and Cambrian rocks; and they have been worked in Cornwall, on the Mendip Hills in Somersetshire, at Holywell in Flintshire, in Denbighshire, Cardiganshire, the Isle of Man, at Alston Moor and various other localities in Cumberland, Westmoreland, and north-west Yorkshire. Brass is an alloy of zinc and copper.

Copper Ores.

Copper is found native in Anglesey and in the Devonian and other rocks of Devon and Cornwall: and has been in use since prehistoric times, especially in the form of bronze, an alloy of copper and tin. (See p. 480.) Copper-pyrites or chalcopyrite (sulphide of copper and iron), copper glance or redruthite (sulphide of copper), cuprite (red oxide), and malachite (green carbonate), are among the principal ores of Copper.

Copper-ores are worked in the neighbourhood of Tavistock (Devon Great Consols), Redruth (Dolcoath, and Fowey Consols), Caradon, Callington, and other places in Devon and Cornwall; at the Parys Mountain and Mona mines near Amlwch, in Anglesey; and they have also been met with at Ecton on the borders of Staffordshire, at Alderley Edge in Cheshire, and near Ulverston.

Tin Ore.

Tin is not known in a native state. The principal ore is tin-stone or cassiterite, sometimes known as black-tin (binoxide). Wood-tin is a fibrous form of it. Tin, like copper, has been known from very early times; but the term Cassiterides or Tin Islands, applied sometimes to the Scilly Isles, was probably used in very early times for the Land's End district, as no productive veins of tin-ore, and no old workings, are to be found in those isles.[1] Thus, a tin-trade was carried on by the Phœnicians upwards of 2000 years ago, and it is considered probable that up to the eleventh century the whole of the tin-ore was derived from the 'stream-works' and the washings of stanniferous sands and clays.[2] The stream-works are in alluvial or estuarine deposits, which contain rounded fragments of tin-ore (stream-tin) derived from the rocks of the district.[3] (See p. 526.)

Tin-ore occurs in the 'Devonian' rocks and granite of Cornwall, and has been largely worked near Redruth, Camborne, St. Ives, etc. At the Botallack mine both tin- and copper-ores are obtained. Britannia metal and pewter are alloys of tin with antimony.

Gold.

Gold occurs native, or alloyed with other metals.[4] According to Mr. W. W. Smyth, it was worked by the Romans at Gogofau, near Pumpsant, west of Llandovery, in the Arenig rocks, where it occurred in quartz-veins.[5] It is now worked

[1] Ussher, G. Mag. 1879, p. 35.
[2] D. C. Davies, Treatise on Metalliferous Minerals, etc.
[3] W. J. Henwood, Journ. R. Inst. Cornwall, 1873; G. Mag. 1873, p. 317.
[4] A. G. Lock, Gold: its occurrence and extraction, 1882, p. 726.
[5] Smyth, Mem. Geol. Surv. i. 480.

near Dolgelly, on the north side of the river Mawddach, Merionethshire, where, at the Clogau quartz-lode and Gwynfynydd mines it has been obtained from quartz-veins in the Lingula flags and older Cambrian rocks;[1] it has also been found in small quantities in the alluvium of this district. The total weight of gold obtained in Merionethshire, from 1844 to 1866, amounted to 12,800 ounces, having an average value of £3 4*s*. per oz.[2] (See p. 62.)

The occurrence of gold has been noticed in the tin stream-works of Ladock, in Cornwall, while an auriferous quartz-rock has been observed at Davidstowe in north Cornwall.[3] In Devonshire gold has been detected at North Molton, in Somersetshire at Clevedon, and in Lancashire at Seathwaite, near Broughton-in-Furness.

Silver Ores.

Silver occurs native, but is generally found combined with lead-ore (galena). There is no silver-mine proper in Great Britain; but the presence of silver mills in Cardiganshire was mentioned by Ray in 1691, and silver-lead ores were worked in Britain before the Roman invasion. Silver-ores have been met with in Cornwall, at Beer Alston in Devon, at Alston Moor in the Carboniferous rocks, in mines at Caldbeck in Cumberland, and in Sark; but the highest yield has been from the Great Laxey lead-mine in the Isle of Man. Argentite (sulphide of silver) occurs in Cornwall, fine examples having been obtained at Huel Newton and Huel Ludcott.

Manganese Ores.

These include pyrolusite (binoxide), psilomelane (hydrous peroxide), manganite (hydrous sesquioxide) and dialogite (carbonate); they occur chiefly in Cornwall, Devon, Somersetshire, and Merionethshire.

The dendritic or arborescent markings (resembling trees, etc.) found on the faces of cracks and joints in many rocks are often due to manganese-ore. (See p. 244.)

Graphite.

Graphite, plumbago, or black lead, although not a metalliferous mineral, may yet be mentioned here. It occurs at Borrowdale and Bannerdale in Cumberland, in Cornwall, and in the Isle of Man. It is a crystallized form of carbon, containing about 91 per cent. of it, with silicate of alumina, sesquioxide of iron, etc. It is used in the manufacture of black-lead pencils, crucibles, etc. In Cumberland it is known as "wad," and the wad-holes near Seathwaite in Borrowdale, occur in the Borrowdale series, and were worked in the sixteenth century: they now constitute the only black-lead-mine in England.[4]

Graphite probably originated from vegetable matter, which has undergone great alteration at a considerable depth beneath the earth's surface.

Platinum has been detected in veins of Keuper Sandstone in Shropshire, and ores of antimony, bismuth, and cobalt have been obtained in Devonshire and Cornwall. Nickel occurs in association with meteoric iron.[5]

[1] A. C. Ramsay, Q. J. x. 242; Murchison, Silurian System, p. 367; T. A. Readwin, Mineralog. Mag. 1879; D. Forbes, Phil. Mag. 1867.

[2] J. A. Phillips, Treatise on Ore Deposits, p. 204.

[3] S. R. Pattison, Q. J. x. 247.

[4] J. C. Ward, Geol. Lake District (Geol. Surv.); J. Postlethwaite, Mines and Mining of the Lake District, 1877.

[5] For an account of the Minerals of England and Wales, see R. P. Greg and W. G. Lettsom, Manual of the Mineralogy of Great Britain, etc., 1858; T. M. Hall, Mineralogists' Directory, 1868; H. W. Bristow, Glossary of Mineralogy, 1861; F. Rutley, Mineralogy, 1874; H. Bauerman, Text-Book of Descriptive Mineralogy, 1884.

DENUDATION AND SCENERY.

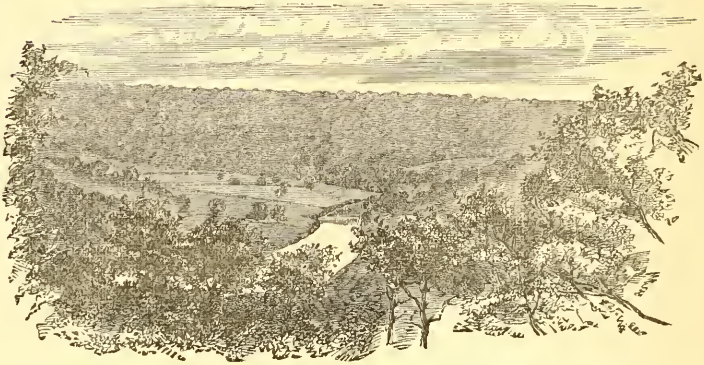


Fig. 98.—View of the Wye, looking towards Monmouth. From a photograph taken at King Arthur's Cave, Great Doward, near Symonds Yat.

No subject is more fascinating to students of Geology than Scenery. In contemplating the present landscape, we see but one picture in a series of dissolving views which the science reveals, and that take us back in imagination to the dim and distant past. The chief aim of the Geologist, indeed, is to portray these scenes in ancient geography, to discern the varied features of the land and water, their successive occupants, and the changeful climates that the earth's surface has witnessed since first it became habitable.

The question has often arisen whether the pleasure and the emotion evoked on the contemplation of beautiful scenery are not likely to be marred by scientific explanations; and no doubt some who have glanced through the preceding pages will regard the Geology of England and Wales as a mass of uninteresting and tedious detail. They must remember, however, that the object of this work is to record the facts from which the pleasanter deductions may be made,—these last it is which lend a charm to the investigation of details; and as Principal Shairp has remarked, while "there is a poetic glow of wonder and emotion before Science begins its work, there is a larger, deeper, more instructed wonder when it ends."[1]

Those who have made themselves familiar in the field with the general characters of the rocks in England and Wales, will easily recognize their intimate relation with the form of the ground. Broadly speaking, we have two main types of scenery: the mountainous and more hilly districts of Wales, the north and west of England, largely composed of slates, grits, limestones and eruptive

[1] On Poetic Interpretation of Nature, 1877, p. 43.

rocks; and the midland, eastern, and south-eastern portions of the country, comprising broad vales of clay-land, alternating with long ranges of hills or escarpments (formed chiefly of limestones), of which the Oolites of the Cotteswold Hills and the Chalk Downs are conspicuous examples.[1] Turning to the features of the coast, we find that the harder rocks stand out in headlands, while the softer strata have been worn away in bays: so that our first impressions are that hill and dale, like promontory and bay, are mainly due to the relative positions of harder and softer strata. When we seek an explanation of the shaping of the ground, our attention is naturally directed to the destruction or denudation now in progress, on the one hand by the sea encroaching upon our coast-line, and on the other by the rivers carrying away in solution and in suspension solid matter derived from the land; and we may conclude that the features are due to the relative resistance of the harder and softer strata to the forces of denudation. No doubt rain, rivers, sea, and glaciers also, have been at work in various geological epochs on the land that has appeared over what is now the area of England and Wales; and individuals who are of a prophetic turn of mind may calculate how long it would take under present circumstances for the whole of our land to be washed away into the sea.[2] In studying our scenery, however, we are concerned rather with the origin of the present features, than with their future modifications, and we soon learn that the forces which have helped to mould them are manifold; indeed, adequately to explain the subject, it is necessary to consider the history and physical changes of the country since the earliest geological times.

In the first place the rocks, most of which were deposited under water, have been upraised; many of them indeed have been uplifted and depressed again and again at successive periods; consequently they have been exposed to wear and tear at different times. The texture, more especially of the older rocks, has been hardened by the pressure of overlying deposits, or altered by the intrusion of eruptive rocks. Hence, when ultimately exposed at the surface by upheaval and by the denudation of superincumbent strata, these old rocks are better able to withstand the denuding agents, than newer strata that are less indurated. But the texture and composition of rocks have an important influence on scenery apart from their age, for different strata may be locally hardened by chemical and other agencies, and in any case clays, sandstones, and limestones are differently acted upon by the agents of destruction. The shapes of our hills and valleys, moreover, are due in part to the way in which the strata have been uptilted,

[1] On the subject of English Scenery and Geology, see Pop. Science Review, Jany. 1875; A. C. Ramsay, Physical Geology and Geography of Great Britain, ed. 5, 1878; D. Mackintosh, Scenery of England and Wales, 1869; Col. G. Greenwood, Rain and Rivers, ed. 2, 1866; A. Geikie, Lectures on Scenery of British Isles, Nature, 1884.

[2] See A. Geikie, G. Mag. 1868, p. 249; Geographical Evolution, in "Geological Sketches at Home and Abroad," p. 336; Trans. G. S. Glasgow, iii. 153; and T. M. Reade, Chemical Denudation, 1879.

to their inclination and crumpling, as well as to the faults, fissures and joints by which they are affected; for these latter form lines of weakness that may initiate the direction of the drainage.[1]

In mountain groups the strata, as a rule, are much folded and contorted, forming ridges and irregular features, as in North Wales and in the Lake District; in escarpments the beds, as a rule, are gently inclined, as in the Chiltern Hills: while in table-lands and plains the rocks are usually flat and undisturbed, as in portions of the moorlands of East Yorkshire, and in Salisbury Plain. The connection between scenery and disturbance is, however, varied. Synclinals are apt to resist denudation, while anticlinals may have had broken and fissured summits readily acted upon by atmospheric agents: so that, as in Snowdon, we sometimes find the higher grounds to be formed by what was geologically a depression, while tracts originally elevated have been converted into valleys, as we find them (more or less modified) in the valley of the Weald and in the vale of Wardour.[2] Valleys of this description, like that of Kingsclere and Burghclere in Hampshire, were originally described as 'Valleys of Elevation.'[3] (See pp. 390, 426.)

Scenery is thus due to many causes: to the accumulation of the strata, their consolidation, and the occasional intrusion of eruptive rocks; to their upheaval and disturbances; and to erosion at various periods.

The features that were produced in Palæozoic times have all been more or less effaced. The very oldest rocks, so altered that we scarce know their real origin, and the earliest sands and mud, now hardened into quartzite and slate, are remnants of old sea-bottoms and of old lands whose extent can but vaguely be conjectured. The Cambrian and Silurian rocks, which form so much of Wales and the Lake District, were folded and upheaved before the Carboniferous rocks were laid down, and probably in Devonian times, for in North Wales and Cumberland there is a marked break between the uppermost Silurian rocks and the Upper Old Red Sandstone or basement Carboniferous conglomerate; and these old rocks, hardened as they must have been, have stood up in many places as land-tracts during later periods, yielding up material time after time, so that they are truly but weather-beaten relics of much more extensive areas.[4]

[1] See G. H. Kinahan, Valleys and their Relation to Fissures, Fractures and Faults, 1875.

[2] See Topley, G. Mag. 1866, p. 438; D. C. Davies, P. Geol. Assoc. iv. 340.

[3] Buckland, T. G. S. (2), ii. 119.

[4] The student who desires further information on the ancient physical geography of the British Islands, should consult E. Hull, Contributions to the Physical History of the British Isles, 1882; A. C. Ramsay, Physical Geology and Geography of Great Britain, ed. 5, 1878; R. A. C. Godwin-Austen, Q. J. xii. 38; P. M. Duncan, Formation of Main Land-Masses, Proc. R. Geogr. Soc. xxii.; J. Geikie, Geographical Evolution of Europe, Scottish Geogr. Mag. 1886; and J. J. H. Teall, G. Mag. 1880, p. 349. For topographical descriptions and references, see W. J. Harrison, Geology of the Counties of England and of North and South Wales, 1882.

From the time of the Upper Old Red Sandstone onwards to that of the Coal-measures, while the conditions changed from lacustrine to marine, and from marine to estuarine and terrestrial, there were over parts of this area continuous accumulations of strata; but the close of the Carboniferous period was attended by marked changes, for many of our so-called Coal-basins were then formed, by the crumpling and subsequent denudation of the strata. Dartmoor was uplifted, the Devonian rocks were much folded, while the Culm-measures of Devonshire, more yielding in nature, have been remarkably contorted. The Mendip anticlinal was raised, and its extension through the Steep and Flat Holmes to the Old Red Sandstone and Carboniferous rocks of south Glamorganshire is well marked, although eastwards its prolongation is a matter of speculation, being now concealed by newer strata. The disturbances which have culminated in the Pennine escarpment must then have been initiated, and on the whole, what may be termed the 'back bone' of our country was formed.

The strata grouped as New Red Sandstone, which were deposited on the folded and eroded surfaces of the older rocks, commenced a new era, and they are the earliest members of that series of strata which, on the whole, lies with marked regularity and in sequence from the western and north-western highlands towards the east and south-east, forming the foundation of the second type of scenery previously mentioned. Parts of Cornwall, Devon, the Malvern area, Wales, and the Lake District, perhaps also of Charnwood Forest, and of areas in the south-east of England, appeared above water during portions of the Secondary era. The New Red Rocks, Rhætic Beds, Lias and Oolites were accumulated over this midland and south-eastern area, sometimes overlapping one another, and again occupying more restricted areas. Here and there on the Mendip Hills, and in South Wales, we find the marginal deposits of the Trias, Rhætic Beds, and Lias, and even of the Inferior Oolite to the east of the Mendips, while some of these deposits, as Sir A. C. Ramsay suggested, may have entirely surrounded the old land of Wales. But the actual extent of most of the later Jurassic strata is in this country a matter of speculation. In Yorkshire we find evidences of the proximity of land more abundant than in the more southerly developments of the Oolitic series. The highest strata (Purbeck) exhibit the incoming of freshwater conditions that prevailed over a more limited area, and were succeeded by the thick freshwater accumulations of the Wealden formation. The physical conditions that attended these strata were followed by partial subsidence, which allowed the sea to encroach over a large area, producing the detrital sediments of the Lower Greensand; and these overstep many of the Jurassic strata, which were wasted over a plain of marine denudation. This is in some measure supported by the fact that no old river-valleys are met with on this plain of Jurassic rocks. Later still the marine deposits of Gault and Upper Greensand overspread the Lower Greensand, and continued the plain of marine denudation across the entire Jurassic series, on to and over the New Red rocks of Devonshire, so as in fact to abut against the Devonian, Carboniferous, and Granitic rocks of Devonshire, if not also against the older rocks further north. It is difficult to say to what extent the older rocks were buried up by these Cretaceous sediments, but probably the Chalk itself overspread the greater part of what is now England and Wales.

As we pass from the Cretaceous to the Eocene period, we begin to discern the framework of much of our present scenery. The Chalk which stretched far west was upheaved on that side, while it was covered by much sediment and suffered much destruction to the south and east; for Chalk cliffs must have been formed on the margin of the Eocene seas. At the same time, rivers of considerable magnitude helped to denude the Chalk inland, and to bring down muddy sediments from the higher ranges of the hills. This was also the case in the Bovey Basin, and later on in Upper Eocene or Oligocene times, when estuarine and freshwater conditions for a time prevailed. Then great disturbances took place whereby the Chalk and Lower Tertiary strata of the Isle of Wight and Dorsetshire were uptilted and folded along the remarkable uniclinal axis they now present; and the Wealden and other anticlinals were produced. (See p. 426.) These disturbances, followed by denudation, led to the formation of the North and South Downs, and to the separation of the London and Hampshire Basins. Thus the lie of the Secondary strata and their general southeasterly inclination has had a marked effect on the configuration of the land, modified as it is by the undulations in the southern and eastern counties.

The denudation of the Chalk tracts was partly carried out in later Eocene and Miocene times by subaërial agencies; and extensive sheets of loose flint-gravel and clay-with-flints may then have been formed.

In Pliocene times the sea spread over portions of the south and east of England, in the latter area forming cliffs in the London Clay and Chalk, the debris of which helped to make up portions of these newer Tertiary strata: but no remains of these old cliff-lines are preserved.

The only evidences we have of river-deposits in Pliocene times are in the Fluvio-marine portions of the Crags, and in the Cromer Forest Bed Series. In the latter case England formed part of the continent, and the Thames, if it then existed, joined its waters to an extension of the Rhine, which flowed over what is now the North Sea. No Pliocene deposits have, however, been met with in the Thames valley. Then came the Glacial epoch, with its mantles of ice, its coast-ice, and ice-bergs, spreading far and wide the material derived from many a formation, and re-depositing old superficial accumulations, due to the waste of the land by subaërial agents in previous ages. The valley of the Severn was probably much enlarged at this period, while the Thames must have marked out its course much as it is now.[1]

During the Glacial Period old river-valleys were in many

[1] See J. G. Goodchild, P. Geol. Assoc. ix. 153.

instances choked up and obliterated—some of these in course of time have been re-opened, in other cases the drainage formed new and independent channels. Thus, Mr. Mellard Reade has shown that the Mersey between Warrington and New Brighton runs over an old Pre-Glacial valley now filled with later Drifts.[1] On the whole, their distribution gives a clue to the fact that the more marked features of our country were sketched out in Pre-Glacial times, although the minor features have been very much altered by the varying character of the superficial deposits: and this is especially the case in Norfolk and other eastern counties, where the Pre-Glacial scenery has been almost entirely effaced by accumulations of Drift.

Thus the building up of our land has been a long and complicated process, while the scenery that has resulted is naturally varied. The principal features presented by each formation have been previously noticed, and so marked are the relations of the rocks to hill and dale that a geological map conveys to the geologist a very good idea of the physical features of a country.

In illustration of this subject it may prove useful to give the following classification of Hills and Vales:—

Hills.[2]

The Primary or Palæozoic ranges would include the following:—

Cheviot Range (Lower Carboniferous and Igneous): Cheviot, 2767; Peel Fell, 1964.

Cumbrian Mountains (Cambrian and Igneous): Scawfell Pikes, 3229; Helvellyn, 3118; Skiddaw, 3054; Saddleback (Blencathra), 2847.

Cambrian Mountains (Cambrian and Silurian): Snowdon, 3571; Carnedd Llewellyn, 3469; Cader Idris, 2959; Plynlimmon, 2463.

Pennine Chain (chiefly Millstone Grit and Lower Carboniferous rocks on Silurian, extending from the Cheviots to Staffordshire and Derbyshire): Cross Fell, 2927; Whernside, 2384; Mickle Fell, 2580; Ingleborough, 2361; Pendle Hill, 1831; Penyghent, 2270; Kinderscout, Peak district, 1981.

Isle of Man (Cambrian), Sneifeldt, about 2000.

Longmynd (Cambrian), 1674.

Caradoc Hills (Cambrian and Igneous), 900 to 1200.

Wrekin, Shropshire (Igneous, Archæan, Cambrian), 1320.

Lickey and Clent Hills, Worcestershire, (Cambrian, etc.), 900 to 1028.

Abberley Hills, Worcestershire (Cambrian, etc.), 900.

Malvern Hills, Worcester Beacon (Gneiss), 1396.

May Hill (Silurian), 965.

Charnwood Forest, Leicestershire (Archæan, Igneous, etc.), Bardon Hill, 852.

Clee Hills, Shropshire (Basalt and Coal-measures, etc.): Brown Clee, 1805; Titterstone Clee, 1750.

Vans of Brecon and Black Mountains, Brecknock Beacon (Old Red Sandstone), 2862.

Mendip Hills, Blackdown (Old Red Sandstone), 1067.

Ocrynean Chain:

- *Devonian Ranges:* Quantock Hills (Devonian), Will's Neck, 1262; Exmoor (Devonian), Dunkerry Beacon, 1690; Dartmoor (Granite), Yes Tor, 2050; Amicombe Hill, 2000; Cawsand Beacon, 1792.
- *Cornish Highlands* (Granite): Brown Willy, 1368; Rough Tor, 1298.

[1] Proc. Liverpool G. S. 1872, Q. J. xxxix. 84, Proc. Liverpool Lit. and Phil. Soc. 1872.

[2] The heights are given in feet.

The Secondary or Mesozoic ranges would include :—

North York Moors (Lias and Oolites) : Cleveland Hills, Burton Head, 1480 ; Rosebury Topping, 1022 ; Hambleton Hills (Corallian Beds), 1000 ; Howardian Hills (Lower Oolites), 580.

Edgehill (Marlstone), 826.

Cotteswold Hills (Oolites) : Broadway Hill, 1040 ; Leckhampton Hill, 978 ; Cleeve Cloud, 1093 ; Bredon Hill, 979.

Yorkshire Wolds (Chalk), Wilton Beacon, 805.

Lincolnshire Wolds (Chalk), south of Caistor, 549.

East Anglian Hills (Chalk), Gog Magog, 302.

Chiltern Hills (Chalk), 820.

Berkshire Downs (Chalk), Inkpen Beacon, 972.

Hampshire Downs (Chalk), Butser, near Petersfield, 882.

Wiltshire Downs : *Marlborough Downs* (Chalk), 887 ; Long Knoll, Maiden Bradley (Chalk), 948 ; Alfred's Tower, Stourton (Upper Greensand), 800.

Blackdown and Haldon Hills (Upper Greensand), 600 to 850.

Dorsetshire Hills (Upper Greensand) : Pillesdon Pen, 934, Lewesdon Pen, 927 ; (Chalk) Bullbarrow, near Blandford, 927, Purbeck ridge, 654.

Wealden Heights : Crowborough Beacon (Hastings Beds), 803 ; Leith Hill (Lower Greensand), 967 ; Hind Head (Lower Greensand), 894.

North Downs (Chalk), Limpsfield, 876.

South Downs (Chalk), Ditchling Beacon, north of Brighton, 813 ; Chanctonbury Ring, north of Worthing, 784 ; Duncton Down, between Arundel and Midhurst, 837.

The Tertiary strata make no regular lines of hills, but the higher grounds form picturesque tracts, as near Bagshot, Weybridge, etc., while the isolated hills of Creech Barrow (see Fig. 71, p. 423), Harrow, Hampstead, Highgate, Langdon Hill, Shooters Hill, etc., command extensive views.

Vales.

In the *Palæozoic rocks* are the Vales of Radnor, Teifi, and Towey in South Wales (Cambrian and Silurian) ; the Vales of Llanrwst and Conway (Silurian), and Llangollen (Silurian and Carboniferous), in North Wales ; and the Vale of Kendal (Silurian) in Westmoreland.

In the *New Red Sandstone strata* are the Vales of Exeter and Taunton (Taunton Dean), Wrington, Berkeley, Clwyd (Denbighshire), Trent, York, and Eden.

In the *Lias*, the Vales of Marshwood, Ilchester (partly Alluvium), Glamorgan (partly Carboniferous, etc.), Gloucester and Cheltenham, Moreton, Evesham, Red Horse[1] (Warwickshire), Belvoir, Catmoss (Oakham), Mowbray and Cleveland (Yorkshire).

In the *Oxford Clay* are the Vales of Blackmore (Dorset) and Bedford.

In the *Kimeridge Clay* are the Vales of Wardour (Wiltshire and Dorsetshire, partly Portland and Purbeck), Shaftesbury (Dorset), and Pickering (Yorkshire).

In the *Wealden district* is the old Vale of Holmsdale or Valley of the *Gault*, and the long plain of the *Weald Clay*.

In the *Gault* and *Upper Greensand* are the Vales of White Horse (near Shrivenham and Wantage, see p. 421), Aylesbury (partly also Kimeridge Clay and Chalk Marl), and Pusey or Pewsey, and Warminster in Wiltshire.

In the *Chalk* and *Eocene strata* there is the Vale of Kennet in Berkshire.

Plains.

The indefinite areas termed Plains are chiefly Secondary and more recent. Thus, the Cumbrian Plain (including the Vale of Eden), the Cheshire Plain, the

[1] The Vale of Red Horse was so termed from a figure cut in the ferruginous sands of the Middle Lias ; it is now obliterated. C. T. Clough, Rep. Rugby School Nat. Hist. Soc. 1871, p. 17.

Plain of York, the North and South Clays (between Gainsborough and Nottingham), and the Severn Valley are chiefly *New Red Sandstone*. The central plain of England is chiefly *Liassic*, with much *Drift*. Salisbury Plain (400 to 600 ft. high) is *Chalk*. The Eastern Plain is chiefly *Chalk* covered with *Drift*. The Lower Thames Valley chiefly *Tertiary* and *Alluvium*; the Fenland (Bedford Level, etc.), Somersetshire Levels (Sedgemoor, etc.), Romney Marsh, Holderness, etc., chiefly *Alluvium* and *Drift*.

We see, therefore, that the age of the formations has to a large extent affected the main features, and, in this country, at any rate, we find a transition from the hills and mountains composed of Palæozoic rocks to the Fens and Levels formed of Alluvium.

Mountains, in the first instance, are produced by great folds of the earth's crust, due rather to its contraction than to direct upthrust; and the materials composing them have been subject to much mechanical alteration, exhibited in slaty cleavage, and other forms of 'shearing.' They are often lines of weakness, being associated with eruptive rocks, granitic masses and dykes of intrusive material. Consequently, in many cases they have been subject to repeated oscillations, although they have, on upheaval, often continued to occupy the same prominent positions. Nevertheless, while these grand features are due firstly to great lines of elevation, their present forms have been shaped by denudation.[1]

Many years ago Sir Andrew Ramsay noticed that in constructing a section across Wales, through the more hilly or mountainous regions, a line might be drawn from one end to the other which would touch, or nearly touch, all the more important elevations. The whole of the rocks of Palæozoic age which form these regions are much disturbed or contorted, being bent into folds, and at the same time irrespective of the shape of the hills. He demonstrated that while filling up the valleys in imagination, there yet remained a vast amount of material that had been removed above the plane which touched the tops of the hills. This line indicated to him a 'Plain of Marine Denudation,' formed before the tract was elevated to its present position, and probably in Carboniferous times during a period of gradual submergence.[2]

Such plains of denudation are now in process of formation on many parts of our coasts, as at Watchet or near the mouth of the Thames at Southend, where the sea is destroying the cliffs and leaving a platform of rock (whether stone or clay) barely covered at low tide. The plain formed in Wales was of course a very extensive one, and then, after the area was elevated, atmospheric denudation came into play. The old disturbances in the rocks may have partly affected the character of the plain of marine denudation, which does not necessarily mean a dead-level, and gentle curves or slight ridges of the harder rocks may have been left as a guide to the agents of subaërial denudation.[3] Moreover,

[1] See T. M. Reade, Origin of Mountain Ranges, 1886; A. Geikie, Mountain Architecture, 1877; Murchison, Address to Geol. Soc. 1843, p. 78; Lyell, *Ibid.* 1850, pp. 24, 38; C. Callaway, G. Mag. 1879, p. 216; J. Geikie, Scottish Geogr. Mag. 1886; see also Midland Naturalist, 1881, iv. 5.

[2] Mem. Geol. Survey, i. 297.

[3] See also E. Hull, G. Mag. 1867, p. 569.

rents, joints, and fissures in the rocks no doubt gave a first direction to many of the valleys, which have been enlarged by rain, and streams, and rivers, and even by glaciers. So that really the main features of Wales, as we now see them, are due chiefly to fresh-water denudation, although there is every reason to suppose that the sea exercised some modifying influence on the land during the long course of ages and the many changes that have occurred since later Palæozoic times.

In attempting to explain the origin of the main features in our country, by a study of the agents now at work, we must remember that all the features along the coast have not been produced by the sea, nor have all the features inland been sculptured simply by rain and rivers or other agents of what is called Subaërial denudation.[1] We must be prepared, in fact, to acknowledge help on all sides. Subaërial agents inland may be at work in modifying features that were broadly sketched out by the sea, while the sea is evidently in many places altering or destroying the features that have in past times been produced by rain and rivers. Rain, frost, and springs greatly assist the sea in wasting the cliffs; the former produce the landslips, the sea removes the fallen material. A sun-dried crack allows water to penetrate; frost, by its expanding action, severs the bed: even lightning may exercise some influence in shivering masses of rock. The influence of glaciers, which are well known to have existed on the high grounds of Wales and the north of England, has been spoken of, and some of the valleys have been considerably modified, if not to a great extent formed, by them.

In late years much discussion has arisen respecting the relative influence of marine and subaërial agents in modifying the surface of the land. The majority of the formations indeed were accumulated on the sea-bottom: though we do here and there, and particularly in the Coal-measures, in the Wealden beds, and in the Glacial Drift, find evidence of terrestrial and fluviatile deposits. But the amount of sediment and material in solution brought down by rivers far exceeds that worn away from the land by the sea, and we must remember that so many changes have taken place, that the old soils, river-sediments and lake-deposits have been, except in a few instances, obliterated, for the land has been continually destroyed to form new strata on the ocean-bed.

Cliffs formed by the sea are cut indifferently through many formations in succession; its tendency is to form long and comparatively straight lines of cliff in homogeneous strata; neither valleys nor narrow and winding inlets are produced by the sea, although it sometimes occupies and enlarges them, while small valleys and combes are frequently cut off abruptly by the sea-cliffs.[2]

The shape of the British Isles is, in a great measure, although

[1] The term Meteoric Abrasion, used by Mr. G. P. Scrope, has been adopted by Mr. G. H. Kinahan.

[2] O. Fisher, Q. J. xvii. 2; W. Whitaker, On Subaërial Denudation, G. Mag. 1867; Jukes, *Ibid.* 1866, p. 233.

not entirely, due to the action of the sea, the irregularities being for the most part produced by the alternation of hard and soft rocks, the former constituting the headlands, the latter the bays. The indentations of the coast are more prominent on the western and southern coasts, because there the alternation of rocks of varying texture is more marked than on the east. Recent elevation and depression, as evidenced by Raised Beaches and Submerged Forests, have naturally modified the influence of the sea. That Britain once formed part of the Continent was naturally surmised by early writers, on account of the similarity of the Chalk cliffs of Dover and Calais; while Verstegan, in 1605, inferred the former connection, from the occurrence of the Wolf, observing that no man "would ever transport any of that race for the goodness of that breed, out of the Continent into any Isles."[1] The English Channel is due mainly to depression rather than excavation.[2]

Islands have been formed through denudation by sea and rivers, and by depression; but there are some areas which, although they retain the name, are no longer islands, and have been united to the mainland by the accumulation of material, by elevation, or by artificial barriers, while other so-called islands never have been isolated.

Sir A. C. Ramsay believes that the Isle of Anglesey was separated from the mainland by a great glacier or ice-sheet which came from the north-east, although for a time it was joined to the mainland by an undulating plain of Boulder Clay; but the effects of faulting and depression, combined with the action of the sea, have had considerable influence on the form of the Menai Straits, whose physical features, in Mr. Strahan's opinion, appear to have existed in more or less their present form in Pre-Glacial times.[3]

The Isle of Purbeck is not really an island, being only to some extent isolated by the inlet of Poole Harbour, and by streams. Portland, too, is connected with the mainland by the Chesil Bank, based on Kimeridge Clay. Barry and Sully Islands, on the coast of Glamorganshire, are connected with the mainland at low-tide; so also are Holy Island or Lindisfarne, off the Northumberland coast, and St. Michael's Mount in Cornwall.[4] These instances of promontories, more or less isolated from the mainland, are instructive as showing how islands may be produced by the denudation of the softer strata.

Thanet, Ely, and Axholme in Lincolnshire, were islands in comparatively recent times, as also the little isle of Athelney in the Somersetshire moorlands; but Glastonbury Tor—the old Isle of Avalon—is not quite surrounded by Alluvium. The Isle of Ely, formed of Lower Greensand on Kimeridge Clay, is said to have been an island 800 years ago, at the time of the Norman Conquest. The town of Eye in Suffolk is situated on a low hill surrounded by Alluvium, proving that, as its name suggests, it was once surrounded by water or marshy land. Portsmouth is connected with the mainland by Alluvium; so also is Selsea. Sheppey in Kent, Hayling and Thorney Islands in Hampshire, and Walney Island in Lancashire, were probably connected with the mainland in recent geological times.

Lundy Island, and the Steep and Flat Holmes in the Bristol Channel, as well as the Isle of Man, have been formed chiefly by the denudation of areas previously connecting them with the mainland.

The Isle of Wight has doubtless been formed by denudation and depression; before the Chalk ridge of the Isle of Wight was separated from that of the Isle of Purbeck, the rivers draining into Southampton water, and into what is now the

[1] Restitution of Decayed Intelligence, in Antiquities concerning the English Nation, etc.

[2] Godwin-Austen, Q. J. vi. 87; see also Ami Boué, Q. J. xii. 325.

[3] Ramsay, Q. J. xxxii. 116. See also Sedgwick, Proc. G. S. iv. 222; H. Hicks, Q. J. xxxii. 121; A. Strahan, Q. J. xlii. 386.

[4] See D. Pidgeon, Q. J. xli. 9.

Solent, flowed eastwards through Spithead, which was then an estuary.[1] The pointed rock from which the Needles took their name disappeared before 1782. (See p. 418.)

The Channel Isles stand out like the peaks of a submerged tract of land; indeed, an elevation of about thirty fathoms would expose a large area including all the islands and rocks.[2] The Scilly Isles, according to tradition, originally formed part of the land of Lyonesse or Lethowstow, which stretched far west of the Land's End.[3]

The waste of the sea-coasts is of considerable interest to geologists and also to landed proprietors.

Commencing in Northumberland, we find records of numerous lands having been destroyed near Bamborough and Holy Island, and at Tynemouth Castle; while at Hartlepool, and other parts of the Durham coast, the sea has made considerable inroads.[4]

On the Yorkshire coast the destruction is great along the Lias and Oolites, while the Chalk cliffs of Flamborough Head stand out prominently, although the beds are worn in places into caves and needles; further south, in the softer strata of the Holderness coast, the annual loss of land has been estimated at from $2\frac{1}{2}$ to 5 yards, and the villages of Auburn, Hartburn, Hyde, Kilnsea, and Owthorne have been destroyed. Nevertheless, as pointed out by Mr. Reid, while the sea is wasting the coast in one part, it is redepositing the material and helping to build up land in another part; and if the loss in the past 200 years has been about 16 square miles (3 miles of which was poor sandy land), yet the total gain in the same period has been 60 square miles, all of which is exceptionally rich. As, however, the new lands, when formed as islands, become Crown property, these beneficial changes are not appreciated by the landowners.[5]

Portions of the Fenland were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt containing marine shells, that have again been converted into productive lands.

On the north Norfolk coast near Cromer, the waste of land has been estimated at about two yards a year, and the villages of Shipden, Wimpwell and great part of Eccles have been destroyed. At Winterton the sea has, however, receded, and there is an inland cliff protected by blown sand.

The physical evidence and historical records indicate that the marsh-lands which occupy large tracts near the mouths of the rivers Bure, Yare, and Waveney formed at one time portions of an estuary, at the mouth of which were situated the islands of Lothingland, East and West Flegg. In the course of time this mouth became contracted by the growth of sand-banks, one of which stretched southwards from East Flegg; after A.D. 1000 this bank became sufficiently sound for a settlement to be made upon it, and the present town of Yarmouth was founded. It was then separated from Caistor by a channel called Grubb's Haven, which was closed about the reign of Edward III. When the channels at the mouth of this estuary were choked, the influx of the tide became more and more restricted, the rivers in the drier seasons occupied but narrow channels, and these in course of time were embanked and the marshes became dry land.

Lowestoft Ness is increasing, but further south, Dunwich, at one time a flourishing city with 12 churches, has but one of these buildings left. Aldborough has lost much ground, and the town of Orwell, east of Harwich, has been destroyed. At Dovercourt the cliffs have suffered much, and the old church of Walton-on-the-Naze, which in the year 941 was some distance inland, has been washed away.[6]

[1] Rev. W. Fox, Geologist, v. 452; see also T. Codrington, Q. J. xxvi. 544.

[2] The Channel Islands, by D. T. Ansted and R. G. Latham, 1862, p. 6.

[3] Ussher, G. Mag. 1879, p. 32.

[4] Lyell, Principles of Geology, ed. 11, i. 514, 516.

[5] See Reid, Geol. Holderness, pp. 94–111; Phillips, Rivers, etc., Yorkshire, pp. 122, 276.

[6] Rev. W. B. Clarke, Proc. G. S. ii. 514; Lyell, Principles, ed. 11, i. 521; J. B. Redman, Proc. Inst. C. E. xxiii.

The Dogger Bank, north-east of Cromer (see p. 516), as well as the Goodwin Sands, probably mark the former extension of the land; the latter tract is reputed to have been overwhelmed by the sea about 1099. Fishermen employed in trawling in the North Sea frequently bring up bones of the Mammoth and other animals, derived from submerged deposits or from the waste of the old lands.[1]

At the time of the Roman occupation, Reculvers (Regulbium) was a military station and a seaport, while the Isle of Thanet was then separated from the rest of Kent by a navigable channel. In the reign of Henry VIII. Reculvers Church was nearly one mile from the sea, but at the beginning of the present century it was abandoned as a place of worship, on account of its insecurity; and it would no doubt have disappeared if the cliffs had not been protected artifically from further destruction.[2]

The Chalk cliffs of Thanet lose on an average about three feet per annum; further south Pegwell Bay has been excavated out of the softer Eocene beds. Sandwich was at one time a port of debarkation; Richborough, also a port in Roman times, is now surrounded by pastures; while Stourmouth, formerly the mouth of the Stour, is now four miles from the sea.[3] Romney Marsh or Dungeness has increased at the rate of nearly six yards annually for two centuries previously to 1844, the shingle being derived from the west. (See p. 552.) The old town of Winchelsea, situated to the west of Romney Marsh, was destroyed in the reign of Edward I., the mouth of the Rother stopped up, and the river diverted into another channel.[4]

On the coast near Hastings, and westwards, much destruction has been going on; between Brighton and Newhaven the annual loss is estimated at 3 feet. Again, from Brighton westwards to Portsmouth the land has lost much; for between the years 1260 and 1340 sixty acres of land were destroyed at Felpham, and a similar quantity at Middleton.[5] Pagham Harbour has, however, been reclaimed.

Beachy Head is a headland of Chalk; while westwards the Portland rocks form Durlston Head, St. Albans Head, and Portland. Allusion has previously been made to the romantic coves along the Dorset coast (see p. 346). There is a natural arch at Durdle Door, and other arches formed by the sea may be seen at "London Bridge," near Torquay (Devonian), the Thurlestone Rock (New Red Sandstone), west of Kingsbridge; there are also arches at the Land's End, arches and needles in the Carboniferous Limestone on the Pembrokeshire coast, also near Holyhead, in the Isle of Man, etc. Their formation is sometimes due in part to the inclination and jointing of the beds, and sometimes to the occurrence of softer shaly beds between harder beds of limestone, etc. Caves are formed by the sea in any hard rocks; caverns are formed by subaërial agents only in calcareous rocks.

Along the Dorset coast there has been much loss, especially in the cliffs of Lias clay between Bridport Harbour and Lyme Regis, a loss largely due to the numerous landslips; while east and west of Lyme Regis, and especially at the Church Cliffs, there has been considerable artificial destruction of the land by the removal of the Lower Lias limestones, a proceeding which is much to be deprecated.

Torbay has been excavated in the Triassic rocks between two headlands of Devonian Limestone, etc., and extensive encroachments are still in progress in the bay. Start Point stands out by reason of its being composed of metamorphic rocks harder than the Devonian Slates.

Penzance itself is a granitic promontory no doubt once like Dartmoor surrounded on every side by Slates, whose almost entire removal has been effected by the sea.

Near Westward Ho! the sea has for several years been encroaching on the land at the rate of about 10 yards a year.[6]

[1] Captain J. B. Martin, Proc. G. S. iii. 138.

[2] Dr. J. Mitchell, Proc. G. S. ii. 7.

[3] I. Taylor, Words and Places, ed. 6, p. 236; see also J. R. Green, Making of England, 1881.

[4] Lyell, Principles, ed. 11, i. 533.

[5] Mantell, Geol. Sussex; see also Dixon, Geol. Sussex, ed. 2, pp. 16, 114.

[6] H. G. Spearing, Q. J. xl. 474.

The coast-line is indented, as might be expected, at the mouths of rivers where the action of the waves is increased by contraction, producing the estuaries of the Thames and the Bristol Channel, the estuaries of the Dee and Mersey, and the Solway Firth. In the Bristol Channel much destruction of the coast is taking place near Watchet, and this is facilitated by the workings for alabaster, and by the removal of beach pebbles of limestone for lime-burning. Between Aust Cliff and Porlock Bay the Triassic marls and sandstones have been most easily denuded ; while the harder Carboniferous Limestone and Devonian rocks stand out more boldly ; again on the north side of the channel, Swansea, Oxwich, and Caermarthen Bays are excavated in the Coal-measures.

The indentations further north in the coasts of Wales and Lancashire (Cardigan and Morcambe Bays, etc.) are due to the varying texture of the rocks.[1]

Notwithstanding the great erosion of our coast-line, it is satisfactory to find that in many places additions are being made both naturally and artificially, so that, according to Mr. Topley, it is probable that the total land-area of England and Wales is as great now as it was 500 years ago.[2]

The waste of the land by subaërial agents, although greater, is not so conspicuous as that caused by the sea. Much denudation is subterranean, for the action of rain and springs is chemical as well as mechanical. The denudation by rivers can be estimated by the amount of solid matter which they annually discharge into the sea, a subject to which attention was directed in 1852 by Alfred Tylor.[3] Such estimates are often surprising. Thus Mr. E. Witchell has calculated that 200 tons of solid matter are annually removed in apparently clear water from every square mile of the Cotteswold country, while a large quantity of solid matter is also removed in suspension.[4] The formation of caverns and hollows in limestone rocks, and the many mineral springs, testify to the subterranean denudation of the strata. Many land-springs too carry away mud and sand from the strata through which they sink before issuing at the surface, and in this way they may gradually lower the general level of a tract of ground without influencing in any marked way the surface configuration. The influence of streams in forming deep underground channels may be frequently witnessed in cliff-sections, where porous strata rest on clayey beds. In other cases where the strata below have been dissolved away, falls of earth or subsidences of the ground take place from time to time.

Local subsidences of the land are produced both naturally and artificially. In the former case by dissolution of the strata, and in the latter case by excavations for Coal, Chalk, etc.

In the salt-districts of Cheshire the dissolution of the rock-salt by springs, near Northwich and other places, has caused alarming subsidences, and these have sometimes given rise to meres, such as those of Great Budworth, Pick, and Rothorne.[5] (See p. 241.)

[1] See J. E. Thomas, Prize Essay upon the Encroachment of the Sea between the River Mersey and the Bristol Channel, 1867.

[2] Address Geol. Assoc. Nov. 1886, Nature, Nov. 11, p. 38 ; see also Reports on Erosion of Sea-coasts, Brit Assoc. 1885, 1886.

[3] Q. J. ix. 47, G. Mag. 1875, p. 443.

[4] Proc. Cottesw. Club, 1867, p. 225.

[5] G. W. Ormerod, Q. J. iv. 269 ; G. Mag. 1874, p. 259 ; T. Ward, Nature, Oct. 14, 1880, p. 560.

On the Durham coast at Sunderland, and between Hartlepool and Ripon, similar subsidences have occurred; these are due to the dissolution of the Magnesian Limestone, which is riddled with caverns and cavities. In one case a pit was formed from 80 to 100 feet deep and 200 feet in diameter.[1] In some parts of Yorkshire cavities occur, which are due to dissolution of the Corallian limestone.[2]

In many Oolitic and other limestones, gullies are formed by the enlargement of joints and faults, and clay and other materials are washed in from above (see p. 346); moreover, the dissolution of calcareous rocks sometimes produces joggles or apparent faults which do not affect the underlying strata.

Other cases of subterranean denudation occur in the sudden sinkings of ground where "Pipes," "Earth-pots," or "Sand-galls," have been formed in the Chalk (see p. 422), and the strata after a time "cave in."[3] In this way the Meres of West Norfolk may have originated. They occur in a country where Chalk is covered with sand and Boulder Clay, and granting that a huge pipe had been formed in the Chalk, then the washing in of Boulder Clay may have "tamped" the hollow, in much the same manner as some of our ponds are rendered water-tight; while the Meres themselves depend for their supply of water partly on the direct rainfall and partly on the level of saturation of the Chalk. Mannington Mere, near Aylsham, is said to have been formed in this way by subsidence.[4]

Natural conical pits due to dissolution of the Chalk occur at Affpuddle and Piddletown Heaths in Dorsetshire, and in many other places.[5]

Landslips or 'Founders' are due to the action of rain and streams, and sometimes of the sea in undermining strata and causing the superincumbent beds to slip over those subjacent. They occur along escarpments and cliffs, especially where the strata dip towards the valley or sea as the case may be, and where porous beds are based on clays. The action of rain in loosening the porous beds, and that of frost in producing vertical cracks parallel to the line of cliff or escarpment, greatly tend to promote landslips. Earthquakes may also set them in motion. (See p. 512.)

"The founder most usually occurs where the following triple combination of strata affords the most favourable circumstances: 1. a superstratum of porous rock; 2. an interstratum of loose sand; and 3. an argillaceous substratum impervious to water. In such an arrangement of beds, the rain penetrating through the porous rock, and arrested by the impervious clay, must be *impounded*, as it were, in the intermediate sand, often nearly converting it into a mass of quicksand. Where the slope of adjoining escarpments exposes this quicksand on the surface, copious land-springs will gush forth, and carry away in different seasons greater or less quantities of the loose material though which they flow; and thus, in process of time, the superincumbent rock will become partially undermined."[6]

Some of the most striking Landslips occur along the south coast of Devon and the coast of Dorset between Sidmouth and Lyme Regis. There the Chalk and Upper Greensand stretch over the denuded edges of the Lower Lias, Rhætic beds, and Red Marl, which are of a clayey nature. The Cretaceous beds in places dip slightly towards the sea, and numerous springs are given out at the junction of the Greensand with the impervious strata; portions of the lower sandy beds of the Greensand moreover would be actually removed by springs. Therefore we have every condition favourable to the production of landslips, as previously mentioned,

[1] Rev. J. S. Tute, G. Mag. 1868, p. 178; A. G. Cameron, Brit. Assoc. 1881; G. A. Lebour, G. Mag 1885, p. 513.

[2] C. F. Strangways, Explan. Sheets 95 S.W. and S.E. (Geol. Surv.), p. 19.

[3] See Prestwich, Q. J. xi. 64; Trimmer, Q. J. x. 231.

[4] Trans. Norfolk Nat. Soc. iii. 452, 642; F. J. Bennett, Geol. Attleborough (Geol. Surv.), p. 17.

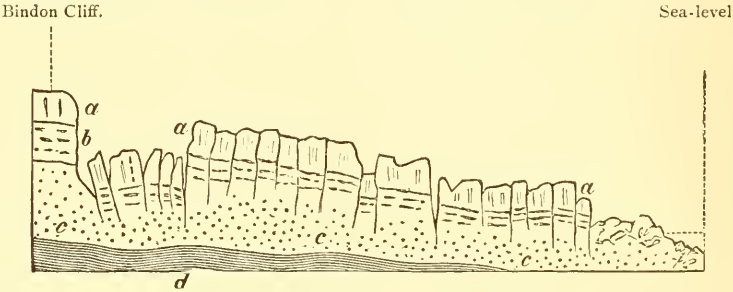
[5] O. Fisher, Q. J. xv. 187; see also G. Mag. 1865, p. 101; J. Evans. G. Mag. 1868, p. 443; T. V. Holmes, P. Geol. Assoc. ix. 105

[6] W. D. Conybeare and W. Dawson, Memoir and Views of Landslips, 1840.

and they have occurred in great magnitude along the coast at different periods. A landslip occurred at Beer Head in 1790. The great landslip of Dowlands and Bindon, near Lyme Regis, took place at Christmas, 1839 (see Fig. 99); the length of the great chasm caused by this founder was 1000 yards, the breadth 300 yards, and the depth varied from 130 feet to 210 feet, while twenty-two acres of land were sunk in the chasm.[1] (See also Fig. 40, p. 252.) Landslips have occurred on Portland in 1665, 1734, 1750, and 1792, and also at St. Albans Head; these have been promoted by joints and fissures in the rocks. Landslips have taken place inland at Hermitage, in the Vale of Blackmore, in 1583; and near Selborne in Hampshire in 1764.

In the Isle of Wight the beautiful scenery of the Undercliff between Blackgang chine and Bonchurch near Ventnor, has been produced by the Chalk and Greensand foundering over the Gault Clay, which for this reason has been called 'the blue slipper.' There is an Undercliff of old date, known as the Warren, at East Wear Bay, near Folkestone, and a landslip occurred hereabouts in 1716. Landslips have also taken place near Beachy Head, and to the east of Hastings.[2]

FIG. 99.—DIAGRAM SECTION OF LANDSLIP NEAR LYME REGIS.



a. Chalk. *b.* Chert Beds. *c.* Sands. } Upper Greensand. *d.* Lias and Rhætic Beds.

The overthrow in 1275 of the nave of the church on Glastonbury Tor has been attributed to an earthquake; but as the tower was not affected, it may be that the foundations of the church were partially undermined by springs carrying away portions of the Oolitic sands on which the church was built.

In the neighbourhood of Bath and along the Cotteswold Hills[3] vast masses of the Great Oolite are frequently spread over the slopes of the Fuller's Earth, and the Inferior Oolite is similarly tumbled in places over the Lias.

Large landslips have taken place in the Upper Ludlow rocks of Marcley Hill, Herefordshire, in 1575, and near Ludlow (see p. 101); in the Woolhope district, the Upper Ludlow rocks, owing to their jointed nature and steepness of dip, have frequently tumbled into the valleys.

East of Buildwas Bridge, near Coalbrookdale, a landslip occurred in 1783, in the Wenlock Limestone. Many landslips have occurred in Derbyshire, at Mam Tor (see p. 167), and around the Peak district, where the Kinder Scout Grit is underlaid by shales.[4]

Landslips have occurred along the coast between Flamborough Head and Filey Point, where the Chalk and Speeton Clay are exposed; many have taken place

[1] A model of this landslip by Mr. W. Dawson may be seen at the Museum in Jermyn Street, London. Fig. 99 is partly taken from a drawing by Mr. Dawson, see Conybeare and Dawson, *op. cit.*; and George Roberts, Account of the Mighty Land-slip of Dowlands and Bindon, ed. 5, 1839.

[2] Weaver, T. G. S. ii. 192.

[3] G. F. Playne, Proc. Cotteswold Club, 1868, p. 230; E. Witchell, *Ibid.* p. 223.

[4] E. Hull and A. H. Green, Q. J. xx. 253.

along the Norfolk coast between Happisburgh and Weybourn, among the Glacial Drifts, and again in Sheppey where the cliffs are formed of London Clay. Railway-engineers are perhaps too familiar with some forms of landslips.

We may now turn to the Escarpments of the Oolites and Chalk. The term "escarpment" is applied to the elevated country formed by the outcrop of certain strata, or to the bounding ridge of a formation or bed, beyond which it does not extend, except in the form of outliers. Escarpments usually follow the strike of the strata, and hence keep to one formation, but their persistence is modified by faults and local diversities in the elevation of the beds; they form the highest ground of an area with more or less even summits; while escarpments of successive formations run in more or less parallel lines for long distances, with intervening vales.[1] They are usually composed of porous rocks, such as limestone, sandstone, and sand; in fact the form of hills largely depends on the character of the rock and its 'angle of repose.'

Thus the North and South Downs are 'escarpments' of the Chalk. The Cotteswold Hills are the 'escarpment' of the Oolites, and they really consist of several minor escarpments, but that of the Great Oolite is more prominent near Bath, and the Inferior Oolite near Cheltenham. (See Figs. 43 and 44, p. 281.) The Polden Hills, in Somersetshire, are the 'escarpment' of the Lower Lias and Penarth Beds. (See Fig. 39, p. 250.) In the Carboniferous rocks the scars and terraces of the Yorkshire dales may be cited, some formed of limestone, others of alternations of sandstones and shales making ridges and hollows.

The origin of Escarpments has been a fertile source of discussion, and is a subject by no means easy to explain in a few sentences: we have to consider the former extension of the strata, their upheaval, and then the agents that have denuded them.

We have to regard the Chalk as formerly extending over the denuded plain of Jurassic rocks to which reference has previously been made, and we may conclude that the escarpments in these older rocks (in the midland and southern counties at any rate), were formed after the recession of the Chalk.[2] Moreover, the Chalk escarpment, as Sir A. C. Ramsay has remarked, being more easily wasted than that of the Oolites, its recession eastwards has been more rapid.

The denudation of the Chalk over the area of what is now the Severn valley may have been commenced in Eocene times, by rain, rivers, and even by estuarine agency, although we have no evidence to infer purely marine action; but it is possible that on the original upheaval of the Chalk tracts, covered as they were to some extent by Tertiary beds, the waters draining off the land may have marked out channels that were afterwards occupied by rivers. Moreover, the uptilting no doubt produced fissures and faults that directed the early lines of drainage.

[1] See W. Whitaker, On Subaërial Denudation, G. Mag. 1867 (paper reprinted with additions).

[2] See also S. V. Wood, jun., Phil. Mag. 1864, G. Mag. 1881, p. 502.

The denudation of the Chalk over the south-eastern counties must have been partly effected by the sea in Eocene times, forming a plain of marine denudation; later on, in Miocene times, after great disturbances had taken place, both Chalk and Eocene strata were denuded over large areas by subaërial agents, and the old Chalk cliffs formed in Eocene times were effaced; while still later, in Pliocene times, the Wealden anticlinal and the Chalk and Eocene tracts of the Eastern counties must have been considerably denuded by the sea.

The origin of river valleys is intimately connected with the formation of escarpments, especially when we take into account the remarkable fact that many rivers flow through a series of escarpments more or less at right angles to the strike of the beds, and over or along their dip-slopes. This, as taught by Mr. Jukes and Sir Andrew Ramsay, is due to the fact that the rivers commenced their courses before the escarpments had been worn back.[1] Thus the general inclination of the strata from the Severn valley towards the south-east of England naturally gives a direction for the flow of the Thames, supposing it to have commenced on a plain when the Chalk and Eocene strata also extended much farther west.

Again, when the Wealden anticlinal had been formed, and its summit had been worn down, the rivers commenced their courses over a plain that no doubt sloped gently northwards and southwards from the central line of elevation, for in this way only can the rivers have excavated their channels in the Chalk downs. Once marked out, these channels have been retained, while the influence of rain and lateral streams has excavated the broad vales of Gault and Weald Clay that intervene between the ridges of Lower Greensand and Hastings Beds.[2] The many minor features due to the relative resistance of the rocks, the modified influence of rain and streams on porous and impervious strata, the possible effects of faults and fractures caused during the formation of the Wealden anticlinal, must all be taken into consideration in elucidating the origin of the diversified scenery. For when subaërial agents commence their work on a tract formed of rocks of varied texture, the waters will sink through the porous strata flowing in different directions underground, according to the joints and fissures in the beds, and to the presence of impervious beds. Thus some rainwaters that have fallen on an escarpment may be drained off in the shape of springs in the vale below the ridge, while other waters may be carried far underground along the dip-slope. The material carried away in suspension, and that in solution derived from the calcareous rocks, will tend to lower the general level of the country; on the other hand, the impervious strata will be eroded

[1] Jukes, Q. J. xviii. 378; Ramsay, Q. J. xxviii. 148, xxxii. 219; see also Phillips, G. Mag. 1864, p. 229.

[2] See C. Le N. Foster and W. Topley, Q. J. xxi. 443; Topley, Geol. Weald; Ramsay, Phys. Geol. and Geogr. Gt. Britain, ed. 5; S. V. Wood, jun. Q. J. xxvii. 3; W. Hopkins, T. G. S. (2), vii. 1; C. Barrois, Ann. Soc. Géol. du Nord, iii. 75; Spurrell, Rivers and Denudation of West Kent, 1886.

on the surface by rain and streams. The denudation is therefore both superficial and subterranean.

Escarpments, as before mentioned, are almost invariably formed of porous beds resting on clays or marls, and although the inclination of the strata is usually away from the outcrop, the waste of the ridges or their recession is due to springs carrying material in solution and suspension, gradually undermining the beds, and producing landslips of greater or less extent. They are wasted also by means of rainwash, angular detritus, and other forms of talus, such as the 'screes,' the material being carried away by streams that flow in the vales on the impervious strata.[1] Thus Chalk flints derived from the waste of the Chalk escarpment are carried down by some of the lateral streams into the Wealden area, and thence into the main streams that run through the 'trumpet-shaped' valleys in that escarpment,—valleys that have been formed by the Darent, Medway, and Stour.

In many portions of the Chalk tracts we find dry valleys or Combes: similar hollows occur in the Inferior Oolite of the Cotteswold Hills. In the latter case the beds were formerly overlaid by Fuller's Earth clay, and streams flowed over the retentive capping, and aided in forming the Combes; while in the case of the Chalk the denudation may have commenced when that formation was overlaid by Tertiary clays.[2] The removal of these clays has allowed the rainfall to sink in at once instead of being collected to form streams, and thus dry-valleys remain where but little or no surface denudation is now carried on.

The gorge of the Avon at Bristol was no doubt formed before the surrounding low-lands of Lias and New Red rocks had been excavated, and before the river had cut its deep and picturesque channel through the Oolites between Bradford-on-Avon and Bath.[3] The Wye (see Fig. 98), the Dart, and other rivers must also have commenced their courses through the harder rocks, before the softer strata along their courses had been reduced to their present relative levels.

The courses of streams have in some instances been modified by changes of level, by barriers raised by the sea, etc. The Trent in ancient times passed through the Oolitic escarpment at Lincoln,[4] while the Waveney formerly flowed into the sea at Lowestoft. (See also p. 594.)

The sources of streams may be above ground or subterranean. Where the water-parting is formed of impervious strata, separate streams may rise near together, as in mountain regions and also in

[1] The term Talus is used to designate the heaps of loose material that have accumulated (by natural or artificial means) at the base of a cliff or quarry; the term Screes (or Glidders) is applied to the natural accumulations of rocky debris that are found on the slopes or at the foot of mountains and cliffs.

[2] See E. Witchell, Proc. Cottesw. Club, 1867, p. 227; and Dixon, Geol. Sussex, ed. 2, p. 103.

[3] See Jukes, G. Mag. 1867, p. 444: Morgan, Proc. Bristol Nat. Soc. (2), iv. 171.

[4] Jukes-Browne, Geol. S.W. Lincolnshire, pp. 90, 100; see also Q. J. xxxix. 596, xl. 160.

low-lying districts formed of Glacial Drift. On the borders of Norfolk and Suffolk, the Little Ouse and the Waveney appear to rise in a marshy tract at Lopham Ford; this feature may perhaps have originated from the parting of one stream or from the wasting back of the Boulder Clay that formerly separated two drainage areas. Streams must often find a water-parting underground, and to their divergence in this way may be attributed the formation of outliers, which are patches of a formation that have been separated from the main mass or escarpment by denudation. We may see them in various stages of formation in the spurs of the Oolitic ranges, and the isolated knolls or outliers probably owe their preservation to slight undulations in the strata, which have influenced the direction of the springs in their underground courses. Brent Knoll and Glastonbury Tor are remarkable examples, and they both exhibit evidence of gentle synclinal structure. (See Fig. 39, p. 250.)

Where a formation is shown over an area surrounded by newer strata, the exposure is termed an Inlier, and this is usually initiated by disturbance or irregular undulations, as in some of the 'Valleys of Elevation' previously mentioned. In other instances we find masses of older rocks encircled by newer formations, standing out like islands, as in the hills of Carboniferous Limestone near Wells in Somerset that rise through the New Red Rocks and Lias. Here we see the scenery of older periods revealed by denudation in more recent times.

It will be easily understood why the Alluvium should form such scenery as it does—belts of low-lying meadow land bordering the rivers and streams. It must be remembered, however, that changes of level greatly affect denudation and deposition. A slight submergence would cause a river to flood its banks and deposit sediment, whereas elevation would tend to make it deepen its channel and so remove more material. A river, as is well known, is incessantly changing its course in however small a degree, and when we see broad flats of Alluvium bordering a small stream, it does not follow that the stream ever entirely filled that wide channel, but that in the course of time it has occupied different positions in it. (See pp. 513, 521.) The nature of the river valleys of course depends upon the character of the rocks traversed by the stream, bold cliffs being commonly formed in hard rocks, but hardly ever in soft strata. Hence, we often find rivers apparently doing little towards the excavation of their valleys, and in fact only shifting material they have previously accumulated. This may be due to the depression or low elevation of the tract, or to a diminished rainfall, and in part to alterations in the surface strata from denudation, whereby larger areas of porous rocks are laid bare at the surface, so that much of the rainfall is carried away underground. (See also Fig. 1, p. 1.)

The Broads (so named from the Anglo-Saxon *Brædan* 'to broaden') form a distinct feature in East Norfolk. They are expanses of freshwater that occupy the lower reaches of the river-valleys, sometimes in the direct course of the streams, but more often separated from them by a high bank of reeds, sedges, and rushes, through which one or more narrow channels have been artificially cut. The depth of the broads does not appear to exceed fifteen feet; as a rule it is about eight feet. In Hickling Broad the depth is for the most part sufficiently shallow to allow any one to walk upon its gravelly bottom. All observers agree that the broads are slowly becoming shallower, partly by the growth and decay of certain plants, partly by the deposit of earthy sediment. The valleys marked out by the rivers were by recent depression extensively flooded, and widened, and deepened by estuarine action; but the mouth of the estuary became choked up by sandbanks about A.D. 1000 (see p. 594). The character of the area was thereby changed; the waters, now entirely fresh, could no longer fill the valleys, and Broads were left in the hollows here and there. To some extent their preservation has been due to the retentive character of the sub-strata, as most of them are based on the laminated clays of the Norwich Crag Series or on Lower Glacial brickearth. Some Broads have been artificially enlarged by the digging of peat, and others, like Fritton and Ormesby, are preserved by artificial dams.[1]

The alternation of hard and soft strata along a river course may lead to the formation of a lake, the softer strata being worn away, and the harder forming barriers at either end. Lakes, indeed, may be due to various causes or a combination of causes, such as depression, and to faulting and disturbance of strata. Sir A. C. Ramsay regards Llanberis lake and Llyn Ogwen, as well as some other lakes in North Wales and Anglesey, to be due to Glacial erosion,[2] while the Rev. J. Clifton Ward has advocated the Glacial origin of some of the rock-bound lake-basins of Cumberland and Westmoreland.[3] Moraines may form barriers and produce lakes (see Fig. 84, p. 491); and the sea also may raise up accumulations that check the drainage of the land and cause flooding over low-lying areas. Small sheets of water may also collect among hillocks of Blown Sand where these accumulations are based on low-lying and more or less retentive strata; and meres may be formed by subsidence due to the dissolution of strata. (See pp. 596, 597.) In other countries, and in ancient times in this country, volcanic action and the unequal elevation of parts of the sea-bottom have produced extensive lacustrine areas.

Waterfalls are sometimes produced by the passage of a stream or river along its channel, from hard rocks to soft, the latter being worn away, while the former beds stand out as ledges; they may also be formed where a stream runs out to sea over a cliff. Sedgwick pointed out that in mountains composed of horizontal strata of varied induration, waterfalls are abundant, and he

[1] Trans. Norf. Nat. Soc. iii. 458; S. Woodward, Hist. Norwich Castle, 1847.
[2] Q. J. xviii. 202.
[3] Q. J. xxx 96, xxxi. 157; see also W. Hopkins, Q. J. iv. 75, and R. Harkness, Q. J. xxii. 485.

instanced the great waterspout of Hardra Foss near Hawes in Yorkshire.[1]

The Scale Force, Crummock Water (known as the 'Queen of Waterfalls'), the Stock Gill, Ambleside ('the gem of the Lake District'), and the Lodore Falls, Borrowdale, near Keswick ('the English Niagara'), are due to streams gushing down the mountain-sides over rocks of varying hardness.

The 'Chines' of the Isle of Wight, and the 'Bunnies' of Hampshire, are gullies which have been formed by the action of springs in making their way over the soft strata of the cliffs into the sea. Mr. J. S. Gardner says the sides of some of these gullies are upwards of 100 feet high, and of most picturesque appearance; the ridges separating them, formed by snow-white sand, look quite Alpine with their sharply-cut peaks; while the ribbon-like and netted surface, caused by weathering, produces a singular and striking effect.[2] On the Dorsetshire coast at Golden Cap, and on the Norfolk coast, near Trimingham, deep gullies may also be seen.

The Tynedale escarpments and Yorkshire Dales were formed for the most part in Pre-Glacial times by subaërial agents, although the prominent rock-features have here and there been much modified by Glacial action.[3] Deep semicircular recesses known as Coums, Corries or Cirques, are found in most glaciated mountain districts, and, in Mr. Goodchild's opinion, they may have been formed by the eddying of ice.[4]

In Limestone-districts, especially in the Carboniferous Limestone of Derbyshire, Glamorganshire, and Somersetshire, the power of rain-water holding carbonic acid is very great in dissolving the rock and forming caverns (see p. 540), and it has been shown that some of the dales and ravines may have originated from them.[5] In any case these deep valleys have been formed in part by the dissolution of the rock, and by streams, assisted by the mechanical action of frost. Dove Dale, the Winnats (Windgates), near Castleton, and Gordale,[6] are well-known features in the Limestone districts. The course of the rivers underground through swallow-holes has been before alluded to, and the material they would thus remove cannot be inconsiderable. (See p. 532.) At Caldbeck, in Cumberland, there is a spot known as the Howk, where the river has made a passage through a thick limestone, so as to form a natural bridge; this overlooks a waterfall.

The origin of the narrow winding gorge in the Carboniferous Limestone at Cheddar has been a source of some discussion. The popular notion of a rent or violent disruption is at once disproved by a glance at the dip of the strata, which is regular on both sides of the chasm, while the idea that the sea was the agent is also an assumption unwarranted by the nature of the gorge itself. That the Cheddar Cliffs originated in a fissure or cavern in the Carboniferous Limestone may be safely assumed. The dips in the Limestone strata, taken by Mr. J. H. Blake, show a trifling variation on either side of the gorge, on the one side from 19° to 24°, and on the other from 15° to 23°; all are in the same direction of south. or a few degrees east of south. One fact that will immediately strike an observer is, that nearly all the material removed has been taken from one, the northern side of the ravine. (See illustration, p. 30.) This is important, for it demonstrates that the dip of the beds exercised a great influence upon the formation of the cliffs, of which the highest point is about 420 feet. The fissure originally would become a line of drainage, and the water running through it, partly underground, would, not only by mechanical action, but also by chemical agency, dissolve and wear away the limestone. Frost, too, is an active agent in disintegrating fragments from the sides of the ravine; and (on account of the southerly dip) on the

[1] T. G. S. (2), iv. 73, 89.
[2] Q. J. xxxv. 220.
[3] Hugh Miller, jun., Nat. Hist. Trans. Northumberland, 1880, vii.
[4] J. G. Goodchild, G. Mag. 1875, pp. 323, 356, 486; W. Gunn, G. Mag. 1876, p. 97.
[5] J. Phillips, G. Mag. 1864, p. 230; Dawkins, *Ibid.* 1865, p. 81.
[6] P. Geol. Assoc. vii. 436.

northern side its influence being far greater, large masses of the limestone would be dislodged and fall by mere gravitation into the gorge. The formation of these Cliffs may have commenced before the Lower Secondary strata were denuded in the vale of Wrington, so that the stream which helped to shape them would have run over an old plain of deposition or denudation, just as the Avon did when it commenced to form the gorge at Clifton.

The surface of the Carboniferous Limestone is frequently weathered into curious hollows and fantastic shapes, used for Rustic work. These features are met with in exposed situations, and are often found on the removal of the turf, near Cheddar and other places in Somersetshire, near Denbigh, around Ingleborough, at Clints Crags near Cockermouth, at Orton Scar near Appleby, etc.

By far the larger number of holes and irregular cavities or honeycombed surfaces in limestone are undoubtedly due to atmospheric (chemical and mechanical) wear and tear, for in many cases fossils stand out in relief in the hollows; but owing to the presence of *Helix nemoralis* and other land-snails in them, some cavities have been attributed to the action of Mollusca. Long ago Dr. Buckland, and subsequently M. Bouchard-Chantereaux, advocated the boring powers of these animals;[1] and Mr. John Rofe considers that the radula of snails, which is a chitinous membrane bearing a long series of teeth, is capable of producing small cavities in limestone rocks.[2] More evidence is perhaps needed on this point, although, as snails may not always obtain from plants sufficient calcareous matter for their shells, they may have some object in rasping away at limestone rocks. Certainly they thrive best in districts where these rocks are developed.[3]

Curious irregular hollows are sometimes met with in the Great Oolite, and these appear in many cases to be due to the weathering out of organic remains, such as branching Corals or Sponges. (See remarks on Dagham stone,[4] p. 301.) Lichens are also agents of disintegration, and sometimes originate small cavities in stone.

The occurrence of large masses of loose rock may be due to the jointage of beds and their being weathered out *in situ*; other rocks may jut out naturally and be weathered into fantastic shapes, and not only may pluvial action influence them, but in some cases wind carrying sand will exert great power in furrowing or in polishing rocks. (See notes on Greywethers, p. 448.) Large blocks of stone may also have been brought from a distance by a glacier or iceberg and so deposited. (See p. 483.) On the other hand, boulders transported by Glacial agency and deposited on the Carboniferous Limestone, are sometimes found on pedestals of that rock, due to the protection locally afforded by the boulder to the subjacent rock; these are known as 'Pedestal Blocks.'[5]

In areas formed of granite the hills are often surmounted by piles of stone like boulders, for which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by atmospheric action, for the edges and angles of jointed-masses waste away more rapidly than the sides. Thus spheroidal blocks are weathered out *in situ*, and often form Logans or Rocking Stones.[6]

The Nutcracker, a Logan in Lustleigh Cleave, in Devonshire, is situated on the side of the hill, and has rolled down from above. The best known Logan is that situated in Cornwall, near Castle Treryn, St. Levan. It rocks only in one direction, and a quantity of loose quartzose gravel may be found near the points

[1] Buckland, Proc. G. S. iii. 430; Bouchard-Chantereaux, Ann. des Sc. Nat. (4), xvi. 197; Rev. John Hodgson, Hist. of Northumberland, Part 2, i. 193; Sir W. C. Trevelyan, Edin. Phil Journ. xl. 396; Mackintosh, G. Mag. 1870, p. 48; Bonney, *Ibid.* 1869, p. 483, 1870, 267, 1872, 315; Proc. Somerset Arch. and Nat. Hist. Soc xix. 50; Hugh Miller, jun., Nat. Hist. Trans. Northumberland, vii. 1880, p. 69; Miss E. Hodgson, G. Mag. 1867, p. 405; see also *Ibid.* pp. 297, 404, and Hughes, Proc. Chester Soc. Nat. Sc., 1885, p. 19.

[2] G. Mag. 1870, p. 4.

[3] See Meyer, quoted by Topley, Geol. Weald, p. 256.

[4] S. P. Woodward, G. Mag. 1867, p. 405.

[5] Hughes, Q. J. lxii. 534.

[6] See T. R. Jones, Geologist, ii. 301; Sedgwick, Proc. G. S. ii. 184.

of contact, marking the progress of disintegration. In size it is about 17 feet in length and $32\frac{1}{2}$ in circumference about the middle part; the weight appears to be about 65 tons. There are 7 logan rocks in the parish of Zennor.[1]

The various Tors of Cornwall and Dartmoor are similar exhibitions of the weathering of Granite. The Cheesewring occupies the highest ridge of a hill to the north of Liskeard, and this curious pile is about 15 feet in height. Helmen Tor, on Dartmoor, is a rugged hill composed of blocks of granite, several of which rock with ease; there are also the Ripon Tors, and Hey Tor near Bovey Tracey, which is very conspicuous from the country around Torquay and Newton Abbot.

Small 'Rock-basins' occur on many of the Tors and isolated masses of granite on Dartmoor, and these (which have been attributed to the Druids!) are probably due to atmospheric action, which commenced in irregularities on the surface of the granite, and may have been assisted by a spheroidal structure in the rock, as well as by the friction of loose fragments of quartz and felspar.[2] In the Scilly Isles there are many remarkable forms known as the Devil's or Giant's Punch Bowl on St. Agnes, and the Kettle and Pans on St. Mary's.[3]

Remarkable weathered rocks have been formed in the Millstone-grit, as at Brimham Crags in Yorkshire, and the Hitching Stone on Sutton Moor, near Keighley.[4] (See p. 170.) The "Buckstone," near Monmouth, is a huge rock formed of Old Red Sandstone, which had become a rocking-stone by continual waste of its base of attachment: it was unhappily thrown down in 1885.[5] Some prominent bosses of rock may have been in part formed by the action of Blowing Sand.[6]

The influence of atmospheric agents on sandstone cliffs is well shown in the Midford Sands at Bridport Harbour, in the New Red Sandstone of Dawlish and Teignmouth; while the Valley of rocks near Lynton is formed in hard Devonian rocks. (See p. 125.) The weathered rocks near Tunbridge Wells have been previously mentioned (see p. 363), and also the Agglestone, near Studland, which is an isolated remnant of Lower Bagshot Beds, locally hardened. (See Fig. 101, and p. 444.)

We have attempted to describe the origin of the principal physical features of our country and some of its minor features. We have seen that the past is so intimately linked with the present, that the modern aspects of the land form but the latest chapter in the series of geological events. But while the present contours have been marked out by various physical agents, to them alone our scenery is but partially due, for without Nature's clothing the aspect would indeed be bare and desolate.

We have noted the great influences at work during the Glacial Period, together with the extensive accumulations then spread over the surface of the country, that have tended so much to diversify the soil rather than the contour. To changes that occurred towards the close of this period, we attribute the banishment of many of the characteristic Pleistocene forms of animal- and plant-life from the surface of our land; but although various Mammalia

[1] G. W. Ormerod, Q. J. xxv. 273; Dr. J. MacCulloch, T. G. S. ii. 66; R. Hunt, Geol. and Nat. Hist. Repertory, i. 29; G. Mag. 1873, p. 317.

[2] G. W. Ormerod, Q. J. xv. 16; Geologist, ii. 368; E. W. Brayley, Phil. Mag. Nov. 1830.

[3] De la Beche, Report Geol. Cornwall, p. 451; J. Carne, Trans. R. G. S. Cornwall, vii. 146.

[4] J. R. Daykns, G. Mag. 1879, p. 96.

[5] Phillips, Manual of Geology, 1855, p. 470.

[6] A. H. Green, C. Le Neve Foster and J. R. Dakyns, Geol. N. Derbyshire, p. 40; Hull and Green, Q. J. xx. 253.

and even Man himself appear to have been driven away, yet observations made on the vitality of seeds preclude the inference that many Plants were exterminated, for even in modern railway-cuttings numerous forms unknown to a district, or previously

FIG. 100.—VIEW OF LINCHETS, NEAR WORTH, ISLE OF PURBECK.

FIG. 101.—THE AGGLESTONE, NEAR STUDLAND.

destroyed, spring up from the newly-exposed subsoils. Be this as it may, when the Glacial conditions were passing away, and before vegetation had again covered the land, denuding forces must have acted with greater facility than is now possible. So soon, however, as the conditions became favourable, and while our land still formed part of the Continent, the various animals and plants that compose our modern fauna and flora made their homes on British soil. To plant-life the aspect of our land is of course most largely indebted, and the earlier settlers included the Oak, Ash, Willow, Poplar, Alder, Birch, Beech, Hornbeam, Pine, Holly, and Yew, some specially suited to moist alluvial tracts, others to clayey soil, and a few to dry sandy elevations. Forests of Oak probably occupied the greater part of our low-lying clay districts, while the underwood consisted of Hazel, Blackthorn, Hawthorn, Elder, Brambles, and Briars.

While at one time the entire country was a tract of woodland, heath, and swamp, so soon as it came to be inhabited and enclosures were made by the settlers, the land outside the homesteads, or that 'beyond jurisdiction,' was termed the 'Forest.' Hence many original tracts thus designated, such as Dartmoor Forest, were not necessarily well-wooded, although most of them probably were. As the Forest-land came in time to be separated into distinct areas, each division received its name, and some of these names are still retained; but the areas have become more and more broken up, so that most of the old historic forests have been split up into a few scattered woods, or tracts of heathland.

Among the old forests of England on the *Palæozoic strata* were Charnwood Forest, the Forests of Dean, Exmoor, Dartmoor, Mendip, Wyre, Clun, Hayes, the Black Forest (between Crickhowel and Hay), Weardale, Teesdale, Milburn, Lune, Bowland, Stainmoor, Richmond (Yorkshire), Skiddaw and Riddlesdale (Northumberland); on the *New Red Sandstone strata*, Delamere Forest (around Northwich and Chester), the Forest of Arden (Warwickshire), Needwood Forest (Staffordshire), Sherwood Forest (Nottinghamshire), North Petherton Forest (around Bridgewater); on the *Liassic strata*, Neroche Forest (including that of Ashill, to the West of Ilminster); on the *Oolitic strata*, Salcey and Whittlewood Forests (Northamptonshire), Braydon Forest (west of Cricklade), Wychwood Forest (north-west of Oxford), Selwood Forest (between Frome and Wincanton), and Gillingham Forest (Dorset); on the *Wealden strata*, St. Leonards and Tilgate Forests (near Horsham and East Grinstead); on the *Gault* and *Greensand*, Woolmer Forest (east of Selborne), Ayles or Alice Holt Forest (east of Alton); and on the *Tertiary strata*, the New Forest (Hampshire), Bere (north of Portsmouth), Savernake Forest (Wilts), Windsor Forest (Berkshire), and Epping and Hainault Forests (Essex). In early times the Wealden *Sylva Anderida* was the largest English Forest.

By the cutting down of forests the rainfall has been locally modified, while man has influenced the physical conditions in other ways, by the embankment of rivers, the building of sea-walls, and extensive systems of drainage. Owing to the numerous enclosures and other causes many of the wild animals became exterminated, but their former presence is sometimes indicated in the names of places.[1] While man has thus in many ways modified the surface of the land, he has diversified its aspect by hedgerows, and by the introduction of numerous trees, notably the Common Lime, the Horse Chestnut, Acacia, Plane, Spruce Fir, Larch, Cedar, Lombardy Poplar, Mulberry, and Laburnum;[2] and in many respects our Parks

[1] J. E. Harting, British Animals, 1880.
[2] Trans. Norfolk Nat. Soc. iii. 456.

and Plantations are more beautiful than the comparatively monotonous natural Forests of temperate regions.

In the various settlements, in the growth of villages, and the development of towns, we may trace the direct influence of the geological structure and physical features, for upon these depend the mining, manufacturing, and agricultural industries.[1]

In some districts, composed of soft and yielding sandstone strata, the original trackways made by man have become cuttings 15 to 20 feet deep, known as 'Hollow ways,' which are often overhung by trees and bushes. Although in many instances roads have been deepened artificially to improve the gradient, yet in the cases to which attention is now directed, the absence of tipped material on either side of the lanes, and the fact that the crests of the hills have not been deepened, prove that the excavations have not been made altogether artificially. In wet weather these roads are the beds of temporary streams or torrents, and considerable denudation must take place. Indeed, granted an original track-way, it seems simply a matter of time, perhaps of centuries, to produce by natural agencies, aided no doubt by traffic, the curious and picturesque lanes which abound in these soft strata.[2] They occur in the Old Red Sandstone of Herefordshire, in the New Red rocks of Somerset and Devon, in the Oolite Sands near Yeovil, in the Wealden strata of the south-eastern counties,[3] in the Upper Greensand near Devizes, and one marked instance may be seen in the Drift sands south of Calthorpe church near Aylsham, in Norfolk.

Agricultural operations have in some instances produced marked features in the landscape. Remarkable ridges or terraces, known as linchets or lynches, are not uncommon on the slopes of the Chalk, Oolitic, and Liassic escarpments, and on the outlying portions of these formations. Some authors have attributed them to marine action, but there is not the slightest evidence to support such a notion, which is indeed refuted by the varying inclination and distribution of the ridges.[4] They may occasionally be due to landslips, or to a natural accumulation of rain-wash. It has, however, been pointed out that such ridges would be rapidly formed when in early times (on the arable Common-field system) nothing was more usual than for the owner or occupier to possess and cultivate several distinct strips or breadths of land separated from one another by the lands of others. When a hill-side formed part of the open field, the strips were almost always made to run more or less horizontally along it. Each upper cultivator will naturally have taken care not to allow the soil of his strip to descend to fertilize his neighbour's below, and by forming boundary furrows with a slight ridge of soil between, he would pave the way for a bank of earth which in the course of years increases into a linchet several feet in height. In some cases on the steep Chalk downs, terraces for ploughing appear to have been artificially cut.[5]

Examples of these Linchets may be seen from the rail-road at Luton in Bedfordshire, and between Cambridge and Hitchin, on the Chiltern Hills, Clothall in Hertfordshire, Chesham in Buckinghamshire, on the South Downs, near Mere in Wiltshire, at Crewkerne, Yeovil, Brent Knoll, and Glastonbury Tor in Somersetshire.[6] Many of them may be noticed on the hills east of Bridport. Here in some places narrow strips of cultivated land, still enclosed by hedgerows, fringe the higher slopes of the hills, ranging one above the other, and varying

[1] See also Topley, on Parish Boundaries, etc., Journ. Anthrop. Inst. iii. 32.

[2] P. Geol. Assoc. ix. 208.

[3] Rev. Gilbert White, Nat. Hist. of Selborne, Letter v. 1789; Topley, Geol. Weald, p. 380.

[4] See D. Mackintosh, G. Mag. 1866, pp. 69, 155; and Scenery of England and Wales, 1869, p. 84.

[5] G. P. Scrope, G. Mag. 1866, p. 293, 1869, p. 535; F. Seebohm, The English Village Community, 1883, p. 5.

[6] See Dugdale's Monasticon Anglicanum, vol. i. p. l, view of the Tor after Hollar, about 1650.

in length, breadth, and inclination. Rarely the strips stretch across the hills, as indicated by hedgerows still remaining near Walditch ; but in other cases, where no hedgerows exist and the land has been turned into permanent pasture, the slopes present the features of linchets. In the Isle of Purbeck, near Langton and Worth (see Fig. 100), also near Abbotsbury, many linchets occur.

On Portland the soil in some parts is now cultivated in narrow strips ; thus in the space of a quarter of a mile, north of the Higher Lighthouse, there were in 1884, thirty-five strips of land, averaging twelve yards in width, but some only six yards, on which corn, grass, potatoes, etc., were grown. In other places as near Rugby, where ploughed land has been converted into pasture, the ridges between the master-furrows have become more prominent by the action of moles, etc.

Our country, as we have seen, contains probably a fuller record of the earth's history than any other tract of land of equal extent. Had not such a series of changes taken place, it is unlikely that so many useful kinds of building-stone and clay, that so much wealth of coal, of metalliferous deposits, and other natural products, would have been furnished out of about sixty so-called elementary substances. To these facts no doubt our country in part owes its position among the nations; while by its isolation, and by the erosion of its coast-line, resulting in so many natural harbours, great advantages have also been gained.

The diversity of scenery, unsurpassed in this respect by any other region, is itself a result of the physical changes we have attempted to describe, and when we proceed to picture the many scenes that our tract of land has witnessed in the past, we find their counterparts in all climes and conditions of the present. Volcanoes, Glaciers, Coral Reefs, huge Lakes and Rivers, have all played their parts in the history; and the rocks and fossils, the varied forms of hill and dale, remain as monuments of these changes. Moreover, not the least interesting branch of the subject is to compare the forms of life now existing in distant portions of the world, with those found in different formations, and to trace in the present seas and oceans, and on the present continental areas and islands, lingering types of successive ages in the past.

In certain Boulder Clays and Gravels we find the relics of conditions similar to those affecting Greenland and Labrador at the present day. We may picture tropical and subtropical surroundings in our Eocene strata. We have but to go into a Chalk-pit to study the conditions of the deepest ocean-bed. In the freestone quarries of the Oolitic hills we sometimes find the evidence of old coral reefs, and many of the organic remains forcibly remind us of the existing flora and fauna of Australia. If we turn to the Red cliffs of Dawlish and Teignmouth, or to the salt-mines of Cheshire, the scene changes to large lakes such as the Caspian and Aral—lakes formerly connected with the sea. Again, we can study sub-tropical vegetation in the heaps of refuse thrown out from our Coal-mines; whilst in still earlier periods we find that the scene constantly changes—the secretions of the Coral polype, the sands of the sea-shore, the sediment formed in lakes, and the lava and ashes of volcanoes, all form part of our Welsh and Cumberland mountains; and when we clamber over these old hills, and know that they are older than even the Alps and Himalayas, we can feel that the story of English and Welsh Geology may well vie in interest with that of any other part of the world.

To inquire how such changes were brought about is the object of Geology, the 'why' and the 'wherefore' come not within its ordinary province; but those who in their rambles along the country lanes or over the hills of our beautiful island, can decipher some of the Records of the Rocks, will find much material for pleasant meditation in the higher realms of Philosophy.

ADDENDA ET CORRIGENDA.

Page 111. Footnote No. 5, *for* Davies *read* Davis.

,, 143. Footnote No. 1, *for* 1857 *read* 1867.

,, 152, 158. For *Saccamina* read *Saccammina*.

,, 162. Line 3 from top, for description of Carboniferous Limestone at Clapton, see Prof. C. Lloyd Morgan, Proc. Bristol Nat. Soc. (2), v. 31.

,, 247. Line 4 from bottom, *for* at Rugby *read* at Lawford, near Rugby.

,, 267. Line 4 from bottom, *after* Stratford-on-Avon *insert* and Rugby.

,, 293, 296, 297. Powerstock is pronounced and often spelt 'Poorstock.'

,, 348. Line 19 from bottom, *for* Shotover Hill *read* Great Hazeley.

,, 430. Line 11 from top, *for* Charlton *read* Croydon.

,, 447. Top line, *for* Dorsetshire *read* Hampshire.

,, 449. For full account of Greywethers, see Prof. T. Rupert Jones, Wilts Mag. xxiii. 122.

,, 516. Line 11 from bottom, *for* Sutton Ness *read* Stutton Ness.

,, 524. Line 19 from top, *for* Presall *read* Preesall.

,, 547. Line 15 from bottom ; Donna Nook is in Lincolnshire.

Re[d] Wales.

	1	27	28	29	30	31	32	33	34
	Sub-Wealden Boring, Battle.	Melton Mowbray.	Elmsthorpe, Leicestershire.	Rugby.	Wytham, near Oxford.	Burford Signett, near Witney.	Swindon.	Foryd, near Rhyl.	Rampside, Westmoreland.
Made Ground, Alluvium, etc. . . .	—	—	—	—	—	—	8	58	
Glacial Drift, etc.	—	149	10	10	—	—	—	40	96
Pliocene	—								
Bagshot Beds	—								
London Clay	—								
Oldhaven Beds	—								
Woolwich and Reading Beds	—								
Thanet Beds	—								
Chalk	—								
Upper Greensand	—								
Gault	—								
Lower Greensand	—								
Purbeck Beds	180								
Portland Beds.	60								
Kimeridge Clay.	1120	—	—	—	—	—	64		
Corallian Beds	480	—	—	—	—	—	40		
Oxford Clay.	65	—	—	—	273	—	573		
Cornbrash.	—	—	—	—	10	—	18		
Forest Marble.	—	—	—	—	33	—	33		
Great Oolite.	—	—	—	—	132	148			
Inferior Oolite.	—	—	—	—	14				
Lias	—	212	—	458	171	598			
Rhætic Beds	—	26	—	10	—	10			
New Red Sandstone . .	—	170	450	667	—	428	—	499	1512
Carboniferous	—	—	980	—	—	225	—	149	572
Old Red Sandstone and Devonian	—								
Silurian	—								
Total depth in feet. .	1905	557	1440	1145	633	1409	736	746	2180

1. J. F. Blake, P. Geol. A. 21.
Sussex, ed. 2, pp. xx
2. H. Willett, in Dixon's
3. J. G. Swindell and G. I
4. C. J. A. Meyer, Q. J. x
5. T. W. Shore and E. W Q. J. xxxv. 812; Dalton, G. Mag.
6. Rev. A. Irving, G. Mag
7. J. W. Judd and C. Ho Surv.), p. 150.
8. W. Whitaker, Trans. C p. 143.
9. Prestwich, Q. J. xxxiv.
10. W. H. Shrubsole, P. G
11. Whitaker, Guide, p. 21 list. Soc. for 1868, p. 41. For
12. Prestwich, Q. J. xxxiv. 95.
13. Whitaker, Guide, p. 20 upply, 1876, p. 29; Phillips, Geol.
14. Prestwich, Q. J. xii. 13
15. Whitaker, Guide, p. 21
16. Whitaker, Guide, p. 20
17. Whitaker, Guide, p. 20
18. Whitaker, Mem. Geol.

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APPENDIX I.

Records of some of the more important Well Sinkings and Borings in England and Wales.

	1 Sub-Wealden Boring, Battle.	2 Rottingdean, near Brighton.	3 Chichester.	4 Portsmouth.	5 Southampton.	6 Brookwood.	7 Richmond.	8 Caterham.	9 Crossness, near Erith.	10 Sheerness.	11 Chatham.	12 Meux's Brewery, London.	13 Mile End, London.	14 Kentish Town, London.	15 Loughton.	16 Turnford, near Cheshunt.	17 Ware.
Made Ground, Alluvium, etc.	—	—	23	—	2	3	10	—	39	47	27	22	21	—	—	35	14
Glacial Drift, etc.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pliocene	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bagshot Beds	—	—			74	170	60										
London Clay	—	—	60	290	304	371	160	—	—	307	—	64	84	236	167	30	—
Oldhaven Beds	—	—	—	—	—	—	—	149									
Woolwich and Reading Beds	—	—	97	118	84	90	—	—	47	148	—	51	41	62	36	50	—
Thanet Beds		—		—	—	-	24	—	51		?	21	55	27	40	—	—
Chalk	—	958	874	629	853	250	671	307	637	303	682	656	654	645	651	670	544
Upper Greensand	—	10	?	—	—	—	16	55	65	—	—	28	20	13	30	31	77
Gault	—	312	—	—	—	—	201	343	176	—	193	160	—	131	172	164	160
Lower Greensand	—	5	—	—	—	—	10	20	—	—	41	—	—	—	?	—	1
Purbeck Beds	180																
Portland Beds	60																
Kimeridge Clay	1120	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Corallian Beds	480	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oxford Clay	65	—	—	—	—	—	—	—	—	—	22	—	—	—	—	—	—
Cornbrash		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Forest Marble	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Great Oolite	—	—	—	—	—	—	87	—	—	—	—	64	—	—	—	—	—
Inferior Oolite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lias	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhætic Beds	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
New Red Sandstone	—	—	—	—	—	—	208	—	—	—	—	—	—	188	—	—	—
Carboniferous	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Old Red Sandstone and Devonian	—	—	—	—	—	—	—	—	60	—	—	80	—	—	—	30	
Silurian	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
Total depth in feet	1905	1285	1054	1037	1317	884	1447	874	1075	805	965	1146	875	1302	1096	1010	831

	18 Moulsham, Chelmsford.	19 Harwich.	20 Combs, near Stowmarket.	21 Yarmouth.	22 Carrow, Norwich.	23 Holkham, near Wells.	24 Scarle, between Newark and Lincoln.	25 Owthorpe, near Nottingham.	26 Grantham.	27 Melton Mowbray.	28 Elmsthorpe, Leicestershire.	29 Rugby.	30 Wytham, near Oxford.	31 Burford Signett, near Witney.	32 Swindon.	33 Foryd, near Rhyl.	34 Rampside, Westmoreland.
Made Ground, Alluvium, etc.	3	—	—		12	20	—	—	—	—	—	—	—	—	8	58	
Glacial Drift, etc.	64	25	57	170	—	—	10	—	28	149	10	10	—	—	—	40	96
Pliocene	—	—	—														
Bagshot Beds																	
London Clay	186	23	—	310													
Oldhaven Beds																	
Woolwich and Reading Beds	83	30	-	46													
Thanet Beds	30	—	—														
Chalk	202	890	817	57	1152	643											
Upper Greensand	—	?	10	-	6												
Gault	—	61	11	—	36	10											
Lower Greensand	—	—	—	—	—	70											
Purbeck Beds																	
Portland Beds																	
Kimeridge Clay	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64		
Corallian Beds	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40		
Oxford Clay	—	—	—	—	—	—	—	—	—	—	—	—	273	—	573		
Cornbrash	—	—	—	—	—	—	—	—	—	—	—	—	10	—	18		
Forest Marble	—	—	—	—	—	—	—	—	—	—	—	—	33	—	33		
Great Oolite	—	—	—	—	—	—	—	—	—	—	—	—	132	148			
Inferior Oolite	—	—	—	—	—	—	—	—	—	—	—	—	14				
Lias	—	—	—	—	—	—	65	13	804	212	—	458	171	598			
Rhætic Beds	—	—	—	—	—	—	66	34	21	26	—	10	—	10			
New Red Sandstone	—	—	—	—	—	—	1879	1186	—	170	450	667	—	428	—	499	1512
Carboniferous	—	69	—	—	—	—	10	244	—	—	980	—	—	225	—	149	572
Old Red Sandstone and Devonian																	
Silurian																	
Total depth in feet	568	1098	895	583	1206	743	2030	1477	853	557	1440	1145	633	1409	736	746	2180

1. J. F. Blake, P. Geol. Assoc. vii. 358; Topley, Geol. Weald, p. 43; Dixon, Geol. Sussex, ed. 2, pp. xxiii, 6, 153.
2. H. Willett, in Dixon's Geol. Sussex, ed. 2, p. 115.
3. J. G. Swindell and G. R. Burnell, Wells and Well Sinking, p. 83.
4. C. J. A. Meyer, Q. J. xxvii. 81; see also J. Pilbrow, Q. J. xvi. 447 (Gosport).
5. T. W. Shore and E. Westlake, Brit. Assoc. 1882.
6. Rev. A. Irving, G. Mag. 1886, p. 355.
7. J. W. Judd and C. Homersham, Q. J. xl. 724, xli. 523.
8. W. Whitaker, Trans. Croydon Micros. Club, 1886, p. 48.
9. Prestwich, Q. J. xxxiv. 913; Whitaker, Guide Geol. London, ed. 4, p. 21.
10. W. H. Shrubsole, P. Geol. Assoc. v. 361.
11. Whitaker, Guide, p. 21, Q. J. xlii. 30.
12. Prestwich, Q. J. xxxiv. 912; Whitaker, Guide, p. 20.
13. Whitaker, Guide, p. 20.
14. Prestwich, Q. J. xii. 13; Whitaker, Guide, p. 20.
15. Whitaker, Guide, p. 21.
16. Whitaker, Guide, p. 20.
17. Whitaker, Guide, p. 20; Etheridge, G. Mag. 1879, p. 287.
18. Whitaker, Mem. Geol. Surv. iv. 432.
19. Prestwich, Q. J. xiv. 249; Whitaker, Guide, p. 21.
20. Whitaker, Guide, p. 21.
21. Prestwich, Q. J. xvi. 450.
22. Geol. Norwich (Geol. Surv.), p. 163.
23. Whitaker, Proc. Norwich Geol. Soc. i. 17.
24. Hull, Proc. Inst. Civ. Eng. xlix; E. Wilson, Q. J. xxxv. 812; Dalton, G. Mag. 1887, p. 48.
25. Jukes-Browne, Geol. S.W. Lincolnshire (Geol. Surv.), p. 150.
26. W. H. Holloway, in Geol. S.W. Lincolnshire, p. 143.
27. De Rance, Rep. Brit. Assoc. for 1883.
28. De Rance, *Ibid.* for 1875.
29. J. M. Wilson, Rep. Rugby School Nat. Hist. Soc. for 1868, p. 41. For Northampton, see H. J. Eunson, Q. J. xl. 495.
30. Prestwich, Geol. conditions affecting Water Supply, 1876, p. 29; Phillips, Geol. Oxford, p. 296.
31. De Rance, *op. cit.* for 1878.
32. E. T. Newton and H. B. W., Q. J. xlii. 287.
33. De Rance, *op. cit.* for 1885.
34. Specimens in Oxford Museum.

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APPENDIX II.

SYNOPSIS OF THE ANIMAL KINGDOM, WITH ESPECIAL REFERENCE TO THE FOSSIL FORMS.

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Of the Geological Survey of England and Wales.

EXPLANATORY NOTES.

This table is founded on the classifications proposed by Prof. Huxley, with such modifications as are rendered necessary by recent discoveries.

The groups generally regarded as orders and sub-orders are printed in thick type on the left of each page; and on the right will be found examples of each of these groups arranged in the following manner:—First (in small type), one or more of the best known living forms, where these exist; next (IN CAPITALS), one or more genera which are living at the present day, and occur also as fossils; and lastly (*in italics*), a few of the more important forms which are known only as fossils.

An asterisk (*) is placed before those genera which have not been found fossil in Britain.

A note of interrogation (?) after a genus shows that there is some doubt as to the group in which it should be placed.

SYNOPSIS OF THE ANIMAL KINGDOM.

PROTOZOA.

Monera.	Protamœba.
Protoplasta.	Amœba.
Gregarinida.	Gregarina.
Catallacta.	Magosphæra.
Infusoria.	Paramœcium.
	(Protamœba to Paramœcium: No fossil forms.)
Foraminifera.	GLOBIGERINA, NUMMULITES, ORBITOLITES, SACCAMMINA, *Orbitoides*, **Eozoon* ?
Radiolaria.	
a. **Heliozoa.**	Actinophrys. (No fossil forms.)
b. **Cytophora.**	Acanthostaurus, Thalassicolla, *ANTHOCYRTIS, *PODOCYRTIS (POLYCISTINA).

[The Monera, Protoplasta, Foraminifera and Radiolaria are sometimes included in one group called Rhizopoda.]

METAZOA.

INVERTEBRATA.

I. *ZOOPHYTIC SERIES.*

1. PORIFERA OR SPONGIDA.

Myxospongiæ.	Halisarca. (No fossil forms.)
Ceratospongiæ.	Ceratina, **Spongites* ?
Silicispongiæ.	
a. **Monactinellidæ.**	SPONGILLA, CLIONA.
b. **Tetractinellidæ.**	GEODIA, PACHASTRELLA, *Ophiraphidites*, *Stelletta*.
c. **Lithistidæ.**	*Chenendopora*, *Hallirhoa*, *Jerea*, *Siphonia*.
d. **Hexactinellidæ.**	Euplectella, *Cephalites*, *Cœloptychium*, *Protospongia*, *Receptaculites*, *Ventriculites*.
Calcispongiæ.	*Pharetrospongia*, *Raphidonema* (= *Manon*), *Tremacystia* (= *Verticillites*).

2. CŒLENTERATA.

A. *HYDROZOA.*

Siphonophora. Physalia. (No fossil forms.)
Discophora. Carmarina, **Rhizostomites* (Impressions found in the Solenhofen Slates.)
Hydrophora. Hydra, Tubularia (Pipe-coralline), Sertularia, HYDRACTINIA, *Dictyonema, Didymograptus, Monograptus, Oldhamia?*
Hydrocorallina. Stylaster, MILLEPORA, *Stromatopora.*

B. *ACTINOZOA.*

1. CORALLIGENA.

Octocoralla (or **Alcyonaria**).
a. **Pennatulidæ.** Pennatula (Sea-pen) *Graphularia, Protovirgularia.*
b. **Gorgonidæ.** *CORALLIUM (RED CORAL), GORGONIA, *ISIS, MOPSEA.
c. **Alcyonidæ.** ALCYONIUM (DEADMEN'S-FINGERS).
d. **Helioporidæ.** Heliopora, *Heliolites, Plasmopora, Polytremacis, Propora, Alveolites? Chætetes?* (The last two are perhaps Polyzoa.)
e. **Tubiporidæ.** Tubipora (Organ-pipe Coral), *Syringopora, Aulopora? Halysites?*

Hexacoralla (or **Zoantharia**).
a. **Actinidæ.** Actinia (Sea-anemone). (No fossil forms.)
b. **Antipathidæ.** Antipathes, **Leiopathes.*
c. **Zoanthidæ.** Zoanthus. (No fossil forms.)
d. **Perforata.** BALANOPHYLLIA, DENDROPHYLLIA, *EUPSAMMIA, MADREPORA.
e. **Fungida.** Fungia, *Anabacia, Micrabacia, Thamnastræa.*
f. **Aporosa.** Astræa, Seriatopora, CARYOPHYLLIA, FLABELLUM, MÆANDRINA, OCULINA, *POCILLOPORA, *Holocystis, Parasmilia, Sphenotrochus, Thecosmilia, Trochocyathus, Turbinolia, Favosites?*

Rugosa (or **Tetracoralla**). *Acervularia, Amplexus, Calceola, Cyathophyllum, Lithostrotion, Strombodes, Zaphrentis.*

[The Madreporaria, or Stony Corals of authors, include the Perforata, Fungida, Aporosa, and Rugosa.]

2. CTENOPHORA.

Beroë. (No fossil forms.)

II. *ECHINODERMAL SERIES.*

ECHINODERMATA.

Holothuridea.	Holothuria (Sea-cucumber), Synapta, CHEIRODOTA, *Achistrum.*
Asteridea.	Cribella (Star-fish), GONIASTER, *Astropecten, Palæaster, Palæocoma.*
Ophiuridea.	Ophiocoma, OPHIURA (BRITTLE-STAR), *Eucladia, Ophioderma, Protaster.*
Echinidea.	ECHINUS (SEA-URCHIN), BRISSUS, CIDARIS, PYGASTER, SPATANGUS, *Ananchytes, Melonites, Micraster.*
Crinoidea.	PENTACRINUS (SEA-LILY), COMATULA (=ANTEDON), *Actinocrinus, Apiocrinus, Cyathocrinus, Eucalyptocrinus, Hystricrinus, Platycrinus.*
Cystidea.	*Apiocystites, Cryptocrinus, Echinoencrinites, Pleurocystites, Sphæronites.*
Edrioasterida.	*Agelacrinites, Edrioaster.*
Blastoidea.	*Astrocrinus, Codonaster, Pentremites.*

III. *ANNULOID SERIES.*

1. TRICHOSCOLICES.

Turbellaria.	Planaria, Polycelis.	No fossil forms.
Rotifera.	Hydatina, Floscularia.	
Trematoda.	Aspidogaster, Bucephalus, Distoma.	
Cestoidea.	Tænia (Tape-worm), Echinococcus.	

2. ANNELIDA.

Myzostomata.	Myzostomum. (No fossil forms.)
Gephyrea.	Sipunculus, **Epitrachys*?
Hirudinea.	Hirudo (Leech). (No fossil forms.)
Oligochæta.	Lumbricus (Earthworm). (Some of the fossil worm-burrows may have been made by members of this group.)
Polychæta.	
a. **Errantia.**	Aphrodita, Nereis, Polynöe, *Arabellites, Eunicites.* (Tracks and burrows probably made by members of this group are found in many formations.)
b. **Tubicola.**	Arenicola, Sabella, SERPULA, SPIRORBIS, *Arenicolites, Cornulites, Vermicularia.*

IV. *ARTHROZOIC SERIES.*

1. NEMATOSCOLICES.

Nematoidea.	Ascaris (Thread-worm), Gordius (Hair-worm), *MERMIS.
Nematorhyncha.	Chætonotus. (No fossil forms.)
Acanthocephala.	Echinorhynchus. (No fossil forms.)

2. CHÆTOGNATHA.

Sagitta. (No fossil forms.)

3. ARTHROPODA.

A. *ONYCHOPHORA.*

Prototracheata.	Peripatus. (No fossil forms.)

B. *MYRIAPODA.*

Protosyngnatha.	**Palæocampa.*
Chilopoda.	*LITHOBIUS, *SCOLOPENDRA (CENTIPEDE).
Archipolipoda.	*Acantherpestes, Archidesmus, Euphoberia, Kampecaris, Xylobius.*
Diplopoda (or Chilognatha).	*IULUS (MILLIPEDE), *POLYDESMUS, *POLYXENUS.

C. *INSECTA.*

Thysanura.	Lepisma, Podura, **Dasyleptus*?
Orthoptera.	
a. **Orthoptera genuina.**	BLATTA (COCKROACH), GRYLLUS (CRICKET), *FORFICULA, LOCUSTA, MANTIS.
b. **Pseudoneuroptera.**	EPHEMERA (MAY-FLY), TERMES, LIBELLULA (DRAGON-FLY).
c. **Physopoda.**	*THRIPS.
d. **Mallophaga.**	Philopterus (Bird-louse). (No fossil forms.)
Palæodictyoptera.	*Archæoptilus, Brodia, Etoblattina, Gryllacris, Lithomantis, Lithosialis,* **Anthracoblattina,* **Blattina,* **Dictyoneura,* **Eugereon,* **Fulgorina,* **Phthanocoris,* **Palæoblattina.* (The last named is from the "Middle Silurian," of Calvados, and is the oldest known Insect.)
Rhynchota.	CIMEX (BUG), NEPA (WATER-SCORPION), APHIS, CICADA, *NOTONECTA.
Diptera.	Pulex (Flea), CULEX (GNAT), *MUSCA (HOUSE-FLY), TIPULA (CRANE-FLY), SIMULIUM.
Lepidoptera.	(Butterflies and Moths) Papilio, Gonepteryx, *VANESSA, SPHINX, *Palæontina.*
Neuroptera.	Limnophilus (Caddis-fly), MYRMELEON (ANT-LION).
Hymenoptera.	APIS (BEE), VESPA (WASP), CYNIPS, FORMICA, MYRMICA.
Coleoptera.	(Beetles) BUPRESTIS, CICINDELA, DERMESTES, HYDROPHILUS, MELOLONTHA, *Curculioides*?

D. *ARACHNIDA.*

Pentastomida.	Pentastoma. } No fossil forms.
Arctisca or **Tardigrada.**	Macrobiotus. } No fossil forms.
Pycnogonida.	Nymphon. } No fossil forms.
Acarina.	*ACARUS (MITE), *ORIBATES, *TROMBIDIUM.
Araneina.	EPEIRA (SPIDER), LINYPHIA, **Protolycosa.*
Arthrogastra.	Scorpio (Scorpion), Chelifer (Pseudoscorpion), *Eoscorpius, Eophrynus, Architarbus, Palæophoneus.*

E. *CRUSTACEA.*

I. GNATHOPODA.

a. MEROSTOMATA.

(Placed by some authors in Arachnida.)

Eurypterida.	*Eurypterus, Glyptoscorpius, Hemiaspis, Pterygotus, Slimonia.*
Xiphosura.	Limulus (King-crab), *Belinurus, Cyclus, Prestwichia.*

b. BRANCHIOPODA.

Trilobita.	*Acidaspis, Agnostus, Ampyx, Angelina, Asaphus, Calymene, Cheirurus, Encrinurus, Homalonotus, Illænus, Ogygia, Phacops, Phillipsia, Trinucleus.*
Phyllopoda.	Apus, BRANCHIPUS, *Ceratiocaris, Dithyrocaris, Estheria, Hymenocaris, Peltocaris.*
Cladocera.	DAPHNIA (WATER-FLEA).

c. LOPHYROPODA.

Ostracoda.	BAIRDIA, CANDONA, CYPRIS, CYTHERE, *Beyrichia, Cypridea, Entomis, Primitia.*
Copepoda.	Cyclops. (No fossil forms.)

[The Phyllopoda, Cladocera, Ostracoda, and Copepoda are sometimes included in one group, the Entomostraca.]

II. PECTOSTRACA (OR ANCHORACEPHALA).

Rhizocephala.	Peltogaster, Sacculina. (No fossil forms.)
Cirripedia.	Lepas (Barnacle), BALANUS (ACORN-SHELL), POLLICIPES, SCALPELLUM, VERRUCA, *Turrilepas.*

III. MALACOSTRACA (or THORACIPODA).

a. EDRIOPHTHALMIA.

Amphipoda. Talitrus (Sand-hopper), Cyamus, Caprella, *Necrogammarus*, *Prosoponiscus*.

Isopoda. Oniscus (Wood-louse), *Archæoniscus*, *Bopyrus*, *Palæga*.

b. PODOPHTHALMIA.

Stomapoda. SQUILLA, *Pygocephalus* ?

Anomoura. Pygurus (Hermit-crab), *Dromilites*, *Homolopsis*.

Brachyura. CANCER (CRAB), *Eucorystes*, *Necrocarcinus*, *Palæocorystes*, *Xanthopsis*.

Macroura. Homarus (Lobster), Palæmon (Shrimp), *Anthrapalæmon*, *Enoploclytia*, *Eryon*, *Glyphea*, *Hoploparia*, *Scapheus*.

V. *MALACOZOIC SERIES.*

1. MALACOSCOLICES.

A. *POLYZOA* (or *BRYOZOA*).

1. PTEROBRANCHIA.

Podostomata. Rhabdopleura (marine). (No fossil forms.)

2. ECTOPROCTA.

Phylactolæmata. Lophopus, Plumatella, Cristatella (marine). (No fossil forms.)

Gymnolæmata.

a. **Cyclostomata.** CRISIA, DIASTOPORA, ENTALOPHORA, HORNERA, IDMONEA, LICHENOPORA, TUBULIPORA, *Fascicularia*, *Fenestella*, *Ptilodictya*, *Synocladia*.

b. **Ctenostomata.** Alcyonidium, Bowerbankia, Serialaria, Vesicularia (marine), Paludicella (freshwater). (No fossil forms.)

c. **Cheilostomata.** Bugula, Cellularia, Flustra, CELLEPORA, ESCHARA, HIPPOTHOA, LEPRALIA, LUNULITES, MEMBRANIPORA, RETEPORA, SALICORNARIA, *Vincularia*.

3. ENTOPROCTA.

Pedicellinea. Loxosoma, Pedicellina, Urnatella. (No fossil forms.)

B. *BRACHIOPODA.*

Tretenterata (or **Inarticulata**).	Crania, Discina, Lingula, *Lingulella, Obolella, Siphonotreta.*
Clistenterata (or **Articulata**).	Terebratula (Lamp-shell), Rhynchonella, Terebratella, Thecidium, Waldheimia, *Athyris, Atrypa, Chonetes, Leptæna, Magas, Orthis, Pentamerus, Productus, Spirifera, Strophomena, Terebrirostris.*

2. MOLLUSCA.

Lamellibranchiata (or **Pelecypoda**).	Ostrea (Oyster), Pecten (Scallop), Avicula, Lima, *Gryphæa, Inoceramus, Pterinea, Posidonomya.* Mytilus (Mussel), Cardium (Cockle), Arca, Cyprina, Leda, Mya, Nucula, Pholadomya, Tellina, Trigonia, Unio, *Anthracosia, Radiolites* (= *Hippurites*).
Scaphopoda.	Dentalium.
Polyplacophora.	Chiton, *Helminthochiton.*
Heteropoda.	Atlanta, *Bellerophon, Porcellia.*
Gasteropoda.	
a. **Pulmogasteropoda.**	Helix (Snail), Limax (Slug), Bulimus, Limnæa, Physa, Planorbis, Pupa.
b. **Branchiogasteropoda.**	Buccinum (Whelk), Cypræa, Natica, Patella, Pleurotomaria, Turritella, Voluta, *Euomphalus, Holopella, Murchisonia.*
Pteropoda.	Hyalæa, *Conularia, Tentaculites, Theca.*
Cephalopoda.	
a. **Dibranchiata.**	Argonauta (Paper-nautilus), Sepia (Cuttle-fish), *Spirula, Belemnites, Belosepia, Geoteuthis.*
b. **Tetrabranchiata.**	Nautilus, *Ammonites, Ancyloceras,* **Ceratites, Clymenia, Goniatites, Lituites, Orthoceras, Turrilites.* [*Aptychus* (or *Trigonellites*), regarded as the operculum of *Ammonites.*]

VI. *PHARYNGOPNEUSTAL SERIES.*

Hemichordata (or **Enteropneusta**).	Balanoglossus. (No fossil forms.)
Urochordata (or **Tunicata**).	Ascidium (Sea-squirt), Appendicularia, Botryllus, Leptoclinum. (Recently found in the Pliocene deposits of St. Erth.)

VERTEBRATA.

I. *ICHTHYOPSIDA.*

1. PISCES.

A. *HYPICHTHYES.*

Cephalochordata (or Pharyngobranchii). Amphioxus (Lancelet). (No fossil forms.)

B. *MYZICHTHYES.*

Marsipobranchii. Myxine (Hag-fish), Petromyzon (Lamprey), *Conodonts?*

C. *CHONDRICHTHYES.*

Chimæroidei. Chimæra (King of the Herrings), *CALLORHYNCHUS, *Edaphodon*, *Elasmodus*, *Ischyodus*, **Rhynchodus.*

Selachii. (Sharks) Cestracion, CARCHARIAS, CARCHARODON, LAMNA, *Asteracanthus*, *Hybodus*, *Onchus*, *Otodus.* (Rays) ÆTOBATIS, MYLIOBATIS.

D. *HERPETICHTHYES.*

Dipnoi. Lepidosiren, CERATODUS, *Dipterus*, *Phaneropleuron?*

E. *OSTEICHTHYES.*

Ganoidei. Polypterus, ACIPENSER (STURGEON), LEPIDOSTEUS, *Cephalaspis*, *Coccosteus*, *Cœlacanthus*, *Holoptychius*, *Lepidotus*, *Macropoma*, *Megalichthys*, *Palæoniscus*, *Pholidophorus*, *Pteraspis*, *Pterichthys*, *Pycnodus*, *Rhizodus.*

Teleostei. Salmo (Salmon), GADUS (COD-FISH), BERYX, ESOX, *Cimolichthys*, *Osmeroides*, *Thrissopater.*

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2. AMPHIBIA.

Urodela. (Newts and Salamanders) Amphiuma, Axolotl, Proteus, Siren, TRITON, **Palæosiren?* **Protriton.*

Anura. (Frogs and Toads) RANA, BUFO.

Peromela Cæcilia, Siphonops. (No fossil forms.)

Labyrinthodonta. *Anthracosaurus*, **Archægosaurus*, **Dendrerpeton*, *Labyrinthodon*, *Loxomma*, *Mastodonsaurus*, *Ophiderpeton.*

II. *SAUROPSIDA.*

1. REPTILIA.

Chelonia.	Chelone (Turtle), Emys, Testudo (Tortoise), Trionyx, *Pleurosternon.*
Plesiosauria.	**Elasmosaurus*, *Plesiosaurus*, *Pliosaurus.*
Lacertilia.	Lacerta (Lizard), *Macellodus*, *Mosasaurus*, *Proterosaurus*, *Saurillus*, *Telerpeton.*
Ophidia.	Crotalus (Rattlesnake), Python, Pelias, Tropidonotus, *Palæophis*, *Paleryx.*
Ichthyosauria.	*Ichthyosaurus*, **Eosaurus.*
Crocodilia.	Alligator, Crocodilus, *Goniopholis*, *Stagonolepis*, *Steneosaurus*, *Teleosaurus.*
Anomodontia.	
a. Placodontia.	**Placodus.*
b. Endothiodontia.	**Endothiodon.*
c. Cryptodontia.	**Oudenodon.*
d. Rhynchocephalia.	Sphenodon (Hatteria) *Hyperodapedon*, *Rhynchosaurus.*
e. Dicynodontia.	**Dicynodon.*
f. Theriodontia.	**Cynodracon*, **Cynosuchus*, **Gorgonops.*
Dinosauria (or Ornithoscelida).	*Ceteosaurus*, *Hylæosaurus*, *Hypsilophodon*, *Iguanodon*, *Megalosaurus*, *Thecodontosaurus.*
Pterosauria (or Ornithosauria).	*Dimorphodon*, *Pterodactylus*, *Rhamphorhynchus.*

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2. AVES.

Saururæ.	**Archæopteryx.*
Odontornithes.	
a. Odontolcæ.	**Hesperornis.*
b. Odontotormæ.	**Ichthyornis.*
Ratitæ.	Emeu, Rhea, *Struthio (Ostrich), *Apteryx, **Æpiornis*, *Dasornis*, **Dinornis*, *Gastornis*?
Carinatæ.	Passer (Sparrow), Anser (Goose), Larus (Gull), *Argillornis*, **Laornis*, *Lithornis*, **Palæotringa*, *Pelagornis*, *Odontopteryx.*

[Prof. A. Newton (Encyclop. Brit. ed. 9, vol. xviii. p. 44) disallows the existence of *Odontornithes* as a taxonomic group, and refers *Hesperornis* and *Ichthyornis*, with their several allies, to the *Ratitæ* and *Carinatæ* respectively.]

III. *MAMMALIA.*

1. HYPOTHERIA.

This division is proposed by Prof. Huxley for a hypothetical type of Mammal lower than anything at present known; but which it is anticipated will be met with in rocks of later Palæozoic age.

2. PROTOTHERIA (OR ORNITHODELPHIA).

Monotremata. Ornithorhynchus, *ECHIDNA.

3. METATHERIA (OR DIDELPHIA).

Marsupialia. Didelphys (Opossum), *MACROPUS (KANGAROO), *Amphitherium*, **Diprotodon*, *Microlestes*, **Nototherium*, *Phascolotherium*, *Plagiaulax*, *Spalacotherium*, **Tritylodon*?

4. EUTHERIA (OR MONODELPHIA).

Edentata. Bradypus (Sloth), Myrmecophaga (Ant-eater), DASYPUS (ARMADILLO), **Glyptodon*, **Megatherium*, **Mylodon*.

Sirenia. Halicore (Dugong), *MANATUS (MANATEE), *RHYTINA, **Felsinotherium*, *Halitherium*.

Cetacea. BALÆNA (WHALE), MESOPLODON, PHOCÆNA (PORPOISE), *Balænodon*, *Choneziphius*, *Squalodon*.

Insectivora. ERINACEUS (HEDGEHOG), SOREX (SHREW), TALPA (MOLE), MYOGALE (=*Palæospalax*), *Stereognathus*.

Cheiroptera. VESPERTILIO (BAT), Pteropus (Flying-fox), RHINOLOPHUS.

Dermoptera. Galeopithecus (Flying-lemur). (No fossil forms.)

Rodentia. ARVICOLA (VOLE), CASTOR (BEAVER), LEPUS (HARE), MUS (MOUSE), *Trogontherium*.

Ungulata.

a. **Subungulata.**

1. **Hyracoidea.** Hyrax.
2. **Condylarthra.** **Periptychus*, **Phenacodus*.
3. **Proboscidea.** ELEPHAS, **Dinotherium*, *Mastodon*.
4. **Amblypoda.** *Coryphodon*, **Dinoceras*, **Elachoceras*, **Loxolophodon*, **Uintatherium*.
5. **Toxodontia.** **Toxodon*, **Typotherium*.

b. **Ungulata vera.**

6. **Perissodactyla.** EQUUS (HORSE), RHINOCEROS, TAPIR, **Anchitherium*, *Hipparion*, *Hyracotherium*, *Palæotherium*.
7. **Artiodactyla.** Bos (OX), CERVUS (DEER), HIPPOPOTAMUS, SUS (PIG), *Anoplotherium*, *Dichodon*, *Hyopotamus*.

Carnivora.	
a. **Fissipedia.**	FELIS (TIGER), CANIS, HYÆNA, URSUS, *Hyænodon*, *Machærodus*, **Miacis*, **Nimravus*, **Oxyæna*.
b. **Pinnipedia.**	PHOCA (SEAL), TRICHECHUS (WALRUS).
Primates.	
a. **Lemuridæ.**	Lemur, Galago, *Adapis*, **Necrolemur*.
b. **Arctopithecini.**	(Marmosets) Hapale, Midas. (No fossil forms.)
c. **Platyrrhini.**	(American Monkeys) Ateles, Cebus, *MYCETES.
d. **Catarrhini.**	(Old World Monkeys and Apes) Cercopithecus, Colobus, Cynocephalus, MACACUS, *SEMNOPITHECUS, *PLIOPITHECUS; Gorilla, Hylobates, Simia (Ourang), Troglodytes (Chimpanzee), **Dryopithecus*.
e. **Anthropidæ.**	HOMO (MAN).

INDEX.

[The figures within brackets refer to dates of birth and death.]

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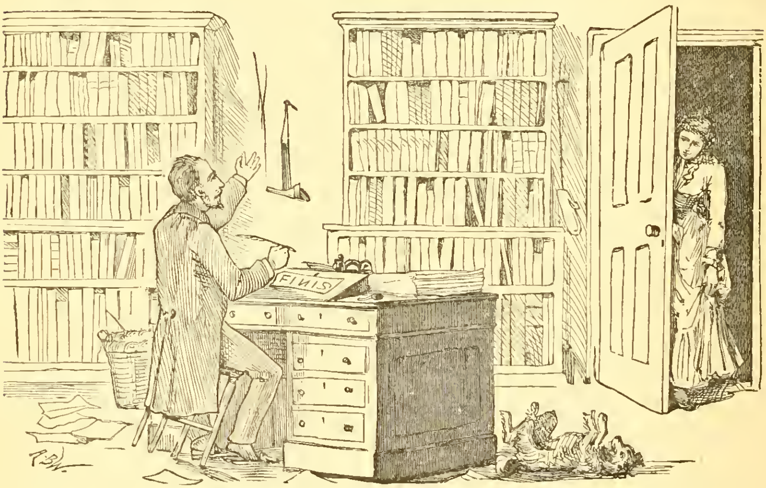

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MAP
GEOLOGY OF ENGLAND & WALES