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THE
BUILDING OF THE BRITISH ISLES.

THE
BUILDING OF THE BRITISH ISLES :

A STUDY
IN
GEOGRAPHICAL EVOLUTION.

BY
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OF GEOLOGY."

Illustrated by Maps and Woodcuts.



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1888.



Vidi ego quod fuerat quondam solidissima tellus
Esse fretum. Vidi factas ex æquore terras.

OVID, *Metam.* xv. 262.

PREFACE.

THE object of this volume is the geological history of the British Islands regarded from a geotectonic and geographic point of view, that is to say, it does not deal with the rock-groups of which our islands consist, so much as with the physical conditions under which they were formed, the rocks themselves being described only so far as is necessary for ascertaining whence their component materials were derived, in order to form some conception of the relative position of land and water during each of the successive periods of geological time.

The attempt made in a former volume on Historical Geology to give brief accounts of the physical and geographical changes which took place during each period, showed me that the subject required much more time and consideration than I was then able to bestow upon it. The restoration of the geography of any past period is a problem of great difficulty, and the more remote that period is from the present the greater does this difficulty become. Most of the restorations given in the work referred to were very incomplete, and in the present state of our knowledge many must remain so, but it seemed possible that a more detailed consideration of the geological data, and a fuller discussion of the inferences deducible from them, might yield better results, and might at any rate pave the way for attaining to more complete

and accurate conceptions of the successive geographical phases through which the British area has passed.

The pioneer in this branch of geological science was Mr. Godwin-Austen, whose masterly essays published in the "Quarterly Journal of the Geological Society," between 1856 and 1866, may still be read with advantage, for many of his conclusions have been confirmed by the information subsequently derived from deep borings in the eastern and midland counties.

Many geologists have dealt in more or less detail with the geographical conditions of particular epochs, but the first systematic treatise on the geography of successive geological periods was that by Professor Hull, published in 1882, and entitled, "Contributions to the Physical History of the British Isles." The larger part of Professor Hull's book, however, is devoted to the consideration of the Palæozoic periods and the origin of the Atlantic Ocean; the space allotted to the Neozoic periods being hardly proportionate to the knowledge that we really possess concerning them.

The aim and scope of the present volume are somewhat different from Professor Hull's, the successive periods of Neozoic time being treated at much greater length than those of Palæozoic time, partly because much more information is available, but chiefly because it is my object to trace out the succession of physical and geographical changes which have led up to the existing disposition of land and water in the north-western portion of Europe.

My thanks are due to many friends and correspondents for information and advice, especially to Dr. Callaway with regard to the Cambrian period, to Professor Hull respecting the Irish Devonians, to Professor A. H. Green, Mr. E. Wilson, and Mr. H. B. Woodward in connection with the Carboniferous, Permian, and Jurassic periods

respectively, and lastly to Mr. Whitaker for his kindness in reading the proofs of the Tertiary chapters, and for many suggestions thereon.

A. J. JUKES-BROWNE.

May, 1888.

N.B.—The reader is requested to make the alterations indicated in the list of errata.

*By A. J. JUKES-BROWNE, B.A., F.G.S.,
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ERRATA.

Page 118, line 24, *for* Dallaston, *read* Darlaston.

Page 162, line 21, *for* geoligial, *read* geological.

Page 187, line 5, *for* Plate VIII., *read* Plate IX.

Page 190, line 8, *for* Plate IX., *read* Plate X.

INTRODUCTION.

THE existing geographical and physical contours of the British Islands are the outcome of the long and varied geological history which this particular part of the world possesses. There are few other regions of the earth's surface which in so small an area exhibit so many different systems of rocks as are to be found in the British Islands. England alone includes portions of nearly all the rock-systems which are found on the continent of Europe.

Each of these rock-groups was formed during the maintenance of certain physical and geographical conditions, and the restoration of the particular conditions which prevailed during any one period will reveal one phase in the geographical evolution of Britain. Further, in the multiplicity of rock-groups we have proof that changes in the physical conditions of the area have been frequent, and it becomes evident that the history of this evolution is a long one; it is, in fact, a history of alternate upheaval and depression, of the repeated formation of islands and continents, and of their subsequent detrition and submergence. In this long succession of changes there have been many different arrangements of land and sea over the area where the British Isles now stand; every part of our country has been repeatedly depressed beneath the sea, though some parts have been submerged much more fre-

quently than others, and conversely every part of the area which is now covered by the environing seas has more than once been part of the dry land. Sometimes nearly the whole area has formed part of continental land, and at other times it has been almost entirely submerged beneath the sea.

But we can look back to an epoch in the geographical history of Britain when the foundations of our islands had been laid, and when the older and more mountainous parts of the country had been brought into the relative positions which they now occupy. We may, in fact, regard the Palæozoic districts of the British Islands as portions of ancient lands which have been broken up and reduced to their present dimensions during successive periods of erosion and denudation; these tracts and the vanished lands of which they formed part have yielded the materials that compose the more recent (Neozoic) strata, and there were at least three periods in these later times when Neozoic strata filled up the gaps between the older blocks of ground and welded the British Islands into a continental whole. Erosion and submergence, however, again began the work of destruction and separation, with the ultimate result of reducing them once more to the state of islands and of giving them the outlines which they now present.

Before proceeding to describe the successive phases of this process of geographical evolution, some consideration of the evidence on which we have to rely in trying to restore the geography of any period seems to be desirable. The greater part of the strata with which the geologist has to deal are marine deposits, and it is only rarely that actual proof of the former existence of land in any district is found in the intercalation of purely freshwater deposits. Occasionally we meet with estuarine beds which indicate the close proximity of land; and of more frequent occur-

rence are conglomerates and breccias recalling those which are formed along modern beaches. But in many cases the position of the land tracts during a given period can only be inferred from general considerations, such as the changes in the lithological characters of the sediments, the thinning or thickening of beds in certain directions, their entire absence in certain areas, their conformity or unconformity to the underlying rocks.

Shallow-water Beds.—In the first place, therefore, we must know what kinds of rock are likely to have been formed in shallow water. As a general rule, the coarser the grain of the rock the shallower was the water in which it was formed, and the nearer was the shore from whence the component materials were derived, or along which they were moved. Conglomerates consisting of stones which could only be moved by the beating of waves on a shore are, of course, decided evidence of the close neighbourhood of land to the spot where we now find them, and if they contain large angular or sub-angular boulders we may infer that they have been formed below a line of cliffs, and further, if such deposits form a mass of considerable thickness, it is probable that much of the material was brought down by floods and torrents from a range of hills above the coast-line.

We must remember, however, that such coarse deposits are not formed everywhere along a line of coast, and that sandstones may have been formed as close to a shore as conglomerates; nay, some sandstones have, doubtless, been formed above high water, and were originally sand-dunes, such as are common on our present coasts.

Sandstones formed from æolian drift, or blown sand, may generally be distinguished from water-borne sands by the character of their component quartz grains; those of the former being all much worn, rounded, and polished, while in the latter a large proportion of the grains are angular.

Professor Daubrée¹ and the late Mr. J. A. Phillips² have shown that the wearing down and rounding of angular quartz grains is an exceedingly slow operation, and that grain of quartz one-fiftieth of an inch in diameter requires an amount of abrasion equal to that which would result from its having travelled a distance of 3,000 miles in water before it becomes so rounded as to assume the form of a miniature pebble. In sand from the seashore of Cornwall Mr. Phillips found that the quartz grains between one-twentieth and one-fiftieth of an inch diameter were still angular, although they had been for years exposed to the beating of the waves. Only a few of the larger grains were partially rounded, and the same is the case with the sands of other shores.

The sands of the African and Arabian deserts, on the contrary, consist of completely rounded grains without any admixture of angular fragments, and the grains of blown sand from English dunes only differ in being rather less completely rounded. Most sandstones consist of more or less angular grains, but beds of consolidated æolian sand exist in some formations.

Pure quartzose sandstones of marine origin are always shallow-water deposits and are seldom found in deeper water than fifty or sixty fathoms, except where the bottom slopes very steeply from the coast; neither do they generally occur at a greater distance than twenty or thirty miles from land, except in shallow and land-surrounded seas like that which is sometimes called the German Ocean.

Outside a continent which has a fairly uniform coast-line trending for a long distance in one direction there is generally a regular succession of deposits from the coast-margin outwards, the coarseness of the materials decreasing with the distance from land, so that we pass from shingle or

¹ "Géologie Expérimentale," p. 256 *et seq.*

² "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 21.

coarse sand to fine sand, silt, clay, and calcareous mud. But along coasts which have many inlets or bays this order is not so well preserved, and fine silts or muds are sometimes formed quite close in shore; similar deposits of very fine grain occur also in the estuaries of large rivers.

In dealing, therefore, with clays and shales we must be guided largely by their fossil contents, and by the nature of the other beds with which they are associated, in deciding whether they are shallow or deep-water deposits. Black carbonaceous clays, for instance, containing much organic matter and associated with sandstones, would lead us to suspect the neighbourhood of a swampy shore or the estuary of a large river.

Limestones, again, though more often formed in comparatively deep water at a distance from land, are sometimes accumulated quite close to a coast-line, like the coral limestones of the present day. A pure limestone may be taken as a proof of clear water, and if there is reason to suppose that it was formed at no great distance from land, it may be assumed that no large rivers issued from the coast in question.

Every case in which limestones occur must be dealt with on its own merits, and no hasty conclusion as to the distance of land should be formed. There is, in fact, no rock-name that includes so many varieties as *limestone*, and the conditions under which a limestone may be formed are as numerous as are the varieties. That many of the limestones which occur among British rocks are shallow-water deposits is generally admitted; no one would claim a deep-water origin for a current-bedded oolitic limestone, or for the Llandovery limestones, which succeed sandstones and conglomerates, or for the Liassic limestones of Glamorganshire. The Carboniferous limestones of Northumberland and Scotland can hardly have been deep-water beds, and perhaps none of the Carboniferous limestone, even in

its more massive facies, was formed very far from land, though the water was doubtless clear and deep in those places where it attains great thickness.

Deep-water Beds.—It is now generally acknowledged that the great mass of the rocks which compose our modern continents are such as are now only formed within 200 or 300 miles of land, and very seldom include any deposits which resemble those now accumulating in the depths of the Atlantic and Pacific Oceans. There is only one formation in Britain which was undoubtedly accumulated in deep water at a great distance from land of a continental character, and that is the Chalk. When, therefore, we speak of deep-water beds, it must be remembered that comparatively deep water is meant, and not water of oceanic depth.

Massive compact limestones and calcareous clays or marls have generally been formed in water of considerable depth. Many bluish and greenish clays, shales and slates, especially such as do not contain many fossils, have doubtless been formed in deep water, and are comparable to the blue and green muds which are found over certain tracts of the sea bottom, between the shallow water and the deeper tracts of the ocean.

Variations in Thickness.—The evidence derivable from the thinning and thickening of deposits also merits some examination. If we consider the case of sediment which is being transported by the action of a current setting off a coast-line, there can be little doubt that the greatest amount of sediment would be thrown down at a certain distance from land, where the bottom began to shelve into deep water. Little could be deposited in the shallow water near shore, but would be carried to a greater or less distance in proportion to the depth of the water; and if the bottom shelved gradually the deposit might cover a considerable space, but as soon as fairly deep water was

reached most of the sediment would subside, and little would be left to travel farther. A deposit formed under these conditions would form a large lenticular mass which would thin out principally in two directions, viz., in the direction of open sea and in the direction of land. Subsidence would make no difference to this arrangement, but would only tend to increase the thickness of the deposit.

The deposit would also thin out laterally, away from the central axis of deposition, but a transverse section across the mass would exhibit a different appearance from a longitudinal section; in a longitudinal section the size and nature of the particles composing the deposit would be nearly the same throughout, while in a transverse section we should find a gradation from coarse sand to fine mud.

When, therefore, we are dealing with a deposit, or a group of beds, which is thinning out in a certain direction, no conclusion should be drawn without having regard to their lithological characters, and whether these change in that direction or not. Thus, if we start with a thick mass of shale or clay, the materials of which must have been derived from the land, and we find that this simply becomes thinner without change of character or replacement by other deposits, we can only infer that we are passing away from the source of supply, possibly toward what was deep water, but more probably in a lateral direction from the major axis of deposition. If, however, as it diminishes in thickness, it becomes decidedly more calcareous, assuming the character of a marl and including beds of limestone, we may assume that we are proceeding away from the contemporaneous land and toward what was then an area of clear and deep water. If, on the other hand, a thick argillaceous deposit is gradually replaced by beds of sandstone, and these by pebbly and conglomeratic beds, there can be no doubt that the position of the contemporaneous land

is indicated by the direction in which the coarser beds set in.

We may note here that the formation is likely to be thickest along the tract where shales and sandstones alternate with each other, and as sandstones are more rapidly accumulated than clays, the formation may thicken landwards by the intercalation of sandstones; so that if only this portion of a group of beds is preserved to us, the direction of the land will be indicated by the thickening of the sandstones and the thinning of the shales. Among the Palæozoic rocks this is sometimes the only kind of evidence we possess to guide us toward the position of the land areas.

The Evidence of Unconformities.—The existence of a widespread unconformity in any district, accompanied by the absence of certain groups of rocks which occur in neighbouring districts, raises the presumption that the first district was a land tract during the period which these rocks represent. Unconformities are therefore very important guides in the restoration of ancient geographies, because we may regard the eroded surface as the actual relic of an ancient land. It does not, of course, present all the physical features of that ancient land, because the surface has always been greatly modified as its successive levels came within the erosive powers of the sea under which it sank. Still we can often tell whether it was originally a high and hilly land, or whether it was of no great elevation.

In drawing inferences, however, from the absence of certain formations above a surface of unconformity, some caution must be exercised. If an unconformity occurs between two systems which are in geological sequence, such as the Ordovician and the Silurian, or between two parts of the same system, we must conclude that the older set of rocks was elevated during the epoch which is repre-

sented by the missing groups. And again, if a whole system of rocks be absent, we may reasonably suppose that the area in question was land throughout the whole of that particular period.

If, however, the gap is very great, and several systems of rocks are missing, we must not conclude that the area has been continually above water during the whole of the periods of time which are unrepresented. The area may have been submerged more than once in the interval, and may have received deposits belonging to more than one of the absent systems, but all remnants of these deposits may have been swept away during the erosion which accompanied and followed the last elevation. Thus the Trias rests in many places on Silurian or Devonian rocks, but it is probable that in most of these cases the older rocks had sunk beneath the Carboniferous sea, and had originally been covered with some portion at least of the Carboniferous system; the Dyassic or Permian period, which preceded the Carboniferous, was one of great disturbance and denudation, and large areas of Carboniferous strata were then broken up and removed, so that the absence of these strata at the localities in question was probably due to this erosion. Such an unconformity may then be evidence of land in Dyassic times, but affords no clue to the position of the land tracts in the Carboniferous period.

In cases of unconformity the rocks which rest directly upon the old land surface are generally conglomerates or pebbly sandstones, the materials of which have been derived from the rocks of which that land was composed. Such conglomerates often cover very large surfaces, but it is well to remember that such beds are not the invariable accompaniments of unconformity. Thus, where a tract of land has sunk slowly beneath the sea for a long period of time, so that the newer deposits have overlapped one

another against its sloping surface, the lower portion of the newer series may be margined by conglomerates, while the higher portion is not; the latter may consist of shales and sandstones, with perhaps barely a foot of pebbly material at their base. Instances of such overlap with an absence of conglomerates are common in the case of the Carboniferous system; where the Lower Carboniferous rocks lie unconformably on older strata, conglomerates and pebbly sandstones are always present, but where the Coal-Measures overlap the lower group and lie on older beds, they often rest directly on the surface of the latter without the intervention of any conglomerate, and with only a thin pebbly basement bed. So also in the east of England, where an ancient land surface is buried beneath the Cretaceous rocks, the Gault clay overlaps the sandstones and rests on the older rocks with a mere basement bed, which is generally only a foot in thickness.

When such cases occur we may perhaps infer that the extent and height of the land had been so reduced by continued submergence that the area remaining was small and of low elevation above the sea, so that the conditions were unfavourable for the formation of conglomeratic beds. In many cases the tract of land had doubtless been reduced to the condition of an island, an isthmus, or a low promontory.

The Difficulties of Geographical Restoration.—These arise chiefly from two causes—the imperfection of our knowledge and the imperfection of the geological record. The first is being gradually removed by the industry of geologists, but there are still many parts of the British Islands about the geological structure of which we really know very little, and there are many others about which more detailed information is much to be desired. Again, there are very large areas where the older rocks exist, but where they are buried and concealed from view by the newer for-

mations; thus we hardly know anything of the subterranean geology of the large areas which are covered by strata of Carboniferous age both in England and Ireland. Other areas again are concealed by the Neozoic strata, and we are only just beginning to obtain some knowledge of the underground limits of the older Neozoic rocks, by means of the deep borings which have been made from time to time in the eastern part of England.

The imperfection of the geological record is another great source of difficulty, and one which will never be altogether overcome. The rocks which remain to us as the records of any one period are but a remnant of the deposits which were formed during that period, and yet before we can attempt to restore the geography of that time we must replace in imagination the rocks which are lost, so as to form a conception of the space over which they originally extended. For some portions of the space this may be easily done, as in the case of conformable beds lying on each side of an anticlinal, but when the final limit of a formation toward a given direction is a fault or an abrupt boundary, without even an outlier beyond, we are left in complete uncertainty as to the original limits of those beds in that direction. Under such circumstances we are obliged to fall back on general considerations, such as the lithological changes seen in the exposed areas and the physical characters of the country beyond the present boundary of the formation; still it must be admitted that in many such cases any attempt at geographical restoration partakes more or less of the nature of guess-work.

I must, therefore, ask my readers to remember that some of the restorations attempted in the following chapters, especially those of the earlier periods of geological history, are built on slight foundations, and may have to be modified by the results of new discoveries. In some instances the facts which are known suggest different inferences to

different minds, and there are several cases in which different views are held with regard to a certain area having been above or below water during a certain period. In such cases I have carefully examined the different views which have been taken by those who have written on the subject, before selecting that which appeared to be the most probable interpretation of the facts.

CHAPTER I.

ARCHÆAN TIME.

BELOW the oldest rocks which contain definite organic remains there are in certain parts of the British Islands still older rocks, which are now generally known by the name of Archæan, as being the most ancient rock-masses that have yet been recognized in the earth's crust. They are also called Pre-Cambrian, for their infra-position to the Cambrian rocks is the real proof of their antiquity.

In England, the principal Archæan tracts occur in South Wales (Pembrokeshire), North Wales (Carnarvon and Anglesey), Shropshire (Wrekin and Caradoc range), Charnwood Forest, the Malvern Hills, and the Lizard peninsula. In Scotland, the Hebrides, as well as parts of Ross and Sutherland, consist of Archæan rocks. In Ireland, they occur in Donegal and Galway.

The Archæan rocks are all more or less metamorphic; some are distinctly crystalline and foliated, others are as clearly volcanic ashes and lavas, while some seem to be of sedimentary origin, such as the quartzites and limestones. The general opinion is that these Pre-Cambrian rocks are divisible into two great groups,¹ which may or may not belong to distinct systems. The older group consists chiefly of gneiss, which is often so granitoid as to resemble a true granite; the newer group is composed either of vol-

¹ Callaway, "Geol. Mag.," Dec. 3, vol. ii. p. 258.

canic rocks, felspathic lavas and ashes, or of hypocrySTALLINE rocks, including schists of many kinds, quartzites, dolomites, and altered grits.

Some geologists think that the upper group lies unconformably on the lower, and that they should be regarded as widely separated systems; others think that the apparent unconformity is only a local one connected with the volcanic origin of the newer group; while some—and particularly Dr. A. Geikie—regard the granitoidite as truly igneous rock of later date than the hypocrySTALLINE strata.

It is obvious that while such diverse opinions exist with regard to the relations of the Archæan rocks, little can be said concerning their probable origin and mode of formation, or concerning the physical conditions of the earth's surface at this early period of its history. Mr. J. E. Marr has even ventured to doubt whether any of the Archæan rocks were originally marine sediments; he points to the great amount of volcanic activity which is testified by the intrusive and eruptive rocks of the Welsh, Shropshire, and Charnwood districts, and he suggests that even some of the hornblendic and chloritic schistose rocks may only be metamorphosed tuffs. The limestones are thin, lenticular beds, and might, he thinks, have been formed in lakes, or by the calcareous springs which are common in volcanic districts.

From these and other facts he concludes that Archæan time was one of continued and universal vulcanicity, and that the amount of erosion and denudation which took place at its close was so violent, rapid, and extensive that great masses of rock, which had been metamorphosed at a considerable depth below the original Archæan land, were in many places brought to the surface; while the greater part of the unaltered surface rocks were swept away and re-deposited as Cambrian sediment.

Dr. Callaway's inquiries into the genesis of the gneissic rocks of the Malvern Hills, and Mr. Peach's experience of the Archæan rocks of Scotland, though not exactly corroborating Mr. Marr's views, are certainly not at variance with them. Dr. Callaway believes that the hornblende-gneiss of Malvern is a crushed and modified diorite; that the mica-schists have been similarly formed from felsite, and the mica-gneiss from granite;¹ while he considers some of the banded gneisses were produced by earth-pressures acting upon complex interveining of granite in diorite, resulting in a parallelism of the veins; so that he would regard many of the Archæan gneisses and schists as metamorphosed igneous rocks, and not as metamorphosed sedimentary rocks. Mr. Peach says:² "The gneisses all bear evidence of having been formed by the crushing and re-crystallization of igneous rocks, their schistosity being due to mechanical movement of the particles produced by differential pressure."

Without entirely acquiescing in Mr. Marr's hypothesis, there can be little doubt that a large portion of the British Archæan rocks are of igneous origin, and that only a small proportion are sedimentary, and that they were accumulated in a volcanic district which was eventually elevated into lofty mountain ranges.

¹ "Quart. Journ. Geol. Soc.," vol. xliii. p. 525.

² "Proc. Roy. Phys. Soc.," vol. ix. p. 23.

CHAPTER II.

CAMBRIAN PERIOD.

§ 1. Stratigraphical Evidence.

CAMBRIAN rocks rise to the surface in several parts of the British Islands, but they nowhere occupy any very large tract of country, so that we can only compare their isolated exposures, and cannot trace their stratigraphical variations from one district to another. In England and Wales there are five districts where rocks referable to the Cambrian system occur—South Wales, North Wales, Shropshire, Warwickshire, and the Malvern Hills.

Wherever the base of the system is exposed, the basement bed is found to be a conglomerate containing fragments of Archæan rocks, and resting unconformably on a very uneven surface of those rocks; the conglomerate being probably in process of formation at different levels throughout the whole of the period, and belonging, therefore, to different stages at different places.

The Lower Cambrian rocks are not known to exist east of the Longmynd, but Upper Cambrian shales have been found in Warwickshire, and may occur at intervals beneath many parts of our Midland and Eastern counties.

The stratigraphy of the Cambrian rocks is not yet completely understood; there are many unsolved difficulties connected with them, and any account of them must at present be regarded as provisional.

In Wales the normal succession of the Cambrian rocks is as follows:—

Tremadoc slates, 1,000 to 2,000 feet	} Upper Cambrian.
Lingula Flags, a group of sandy flagstones and slates, 2,000 to 5,000 feet	
Menevian slates, 200 to 750 feet	} Lower Cambrian.
Harlech Beds, red, green, and purple grits and slates, 3,000 to 9,000 feet	

The Harlech Beds of Merioneth are more than 8,000 feet thick, and the base is not there seen, but when they reappear on the west side of the Snowdon range, they are much thinner, and are probably not more than 3,000 feet thick, including the basal conglomerate of Llyn Padarn, which lies on the eastern flank of the main Archæan ridge. On the west side of this ridge the basal conglomerate is overlain by grits and slates, and, near Bangor, by sandstones and mudstones, which have been referred to the Harlech series, but it is quite possible that they are shore beds of Lingula Flag age. As they are directly succeeded by Arenig slates (Ordovician), it does not seem probable that the Lingula Flags should be entirely absent, for the lowest beds usually thin out before the higher. If, therefore, we regard the greater part of the Bangor Cambrians as Lingula Flags, it follows that in the space of about two miles the Harlech series has thinned from 3,000 feet to, perhaps, 100 feet of grit and conglomerate. This suggests that the surface of the Archæan rock formed a steep slope, inclining to the south-east, when the Cambrians were deposited against it.

In Shropshire the same thing seems to take place on a still larger and more surprising scale; for the rocks of the Longmynd, which are supposed to be of Lower Cambrian age, and which lithologically resemble the Llanberis grits and slates, have a great thickness (possibly 10,000 feet), and are faulted on each side against tracts of undoubted

Archæan rock. But the eastern or Caradoc Archæan ridge is flanked on the other side by a quartzite conglomerate, which is succeeded by sandstones of Middle or Upper Lingula Flag age; the Lower Cambrian being entirely absent. How can this sudden disappearance of so thick a mass of rock be accounted for? There seem to be only three possible ways of meeting the difficulty:—

(1) That the Longmyndian sediments were raised into a block of land about the epoch of the Menevian Beds, and that this block afterwards sank again to receive the upper half of the Lingula Flags and the Tremadoc Slates.

(2) That the Caer Caradoc range was the border of a mass of Archæan land, and formed a precipice or steep declivity about 10,000 feet high, so that it was not over-topped by the Cambrian Sea till the time of the Lingula Flags.

(3) That the faults on the east side of the Longmynd and Caradoc ranges are thrust planes, bringing together portions of districts which were originally many miles apart. But the faults appear to be of the normal kind, and there is no evidence of the great crushing which must accompany lateral thrust.

If none of these suggestions are considered satisfactory, it can only be argued that the Cambrian age of the Longmynd rocks is an assumption, and that the facts of the case show them to be physically more closely connected with the Archæan than with the Upper Cambrian. It is indeed quite possible that they are pre-Cambrian, and belong to the interval which is elsewhere represented by the gap between the Archæan and the Cambrian.

If, however, they should prove to be of Lower Cambrian age, we must select the first of the above hypotheses as the least unlikely, and must suppose that an upheaval took place in the middle of the Cambrian period, but that the land so formed was soon submerged again beneath the sea of the Lingula Flags.

In South Wales there are indications of a similarly rapid disappearance of Lower Cambrian sediments. Near St. Davids these beds are only 4,000 feet thick, which is about half their thickness in Merioneth. Whether they thin eastward in the trough between the two principal Archæan tracts is not yet known, but at Trefgarn on the south-east side of the eastern massif no Harlech Beds or Menevian are found, and the Upper Lingula Flags with a basal conglomerate appear to rest on the Archæan. It is true there are some signs of faulting, and Dr. Hicks believes the Lower beds are faulted out, but more evidence of this is required.

Dr. Callaway favours me with the following remarks on the lithological composition of the Lower Cambrian rocks: "These sediments show that the adjoining lands were partly built up of granitic, volcanic, and metamorphic rocks. The purple conglomerates and sandstones of the Longmyndian, reaching a thickness of several thousand feet, as well as the broad band of pale-green slates which skirts the eastern side of the Longmynd, are largely derived from the rhyolites of the Uriconian and indicate the proximity of an extensive land area. Rounded fragments of granitic and schistose rocks are not uncommon in the conglomerates, while the grains of quartz and felspar in the grits have probably the same origin. These grits grow less felsitic towards the south, and fragments of metamorphic rocks increase in number—indications which suggest the conclusion that the Malvern Hills are a worn fragment of a mass of land which made a conspicuous feature in the Longmyndian ocean.

"The rocks of North and South Wales afford similar evidence. The conglomerates of Moel Tryfaen and the sandstones further west contain a very large proportion of fragments of felsite similar to the Archæan rhyolite near Carnarvon, while the massive grits of the Merionethshire

anticline, though very quartzose, are partially constructed of felsite grains."

If we next consider the Upper Cambrian we find they also are thickest in Merioneth, being there no less than 7,000 feet thick. Near Llanberis, west of Snowdon, the Lingula Flags are only 2,300 feet, and there is little that can be called Tremadoc. Finally, near Bangor, the Lingula Flags are represented by sandstones and mudstones resting on the grits which overlie the basal conglomerate; even if the basement beds are also part of the same series (see *ante*, p. 17) the total thickness is not more than 1,000 feet, and there is no representative of the Tremadoc.

A similar change takes place southward; near St. Davids the Lingula Flags are not more than 2,000 feet thick, and consist largely of sandstones and flags, many of the beds showing ripple marks, and all attesting shore conditions. The Tremadoc slates are 1,000 feet thick.

At Malvern there is 500 feet of sandstone resting on Archæan, and overlain by 1,000 feet of shale belonging to the Dolgelly and Tremadoc groups, and in Shropshire there is a similar sequence. In Warwickshire, however, the series again thickens; there is a massive quartzite of uncertain age, but probably Upper Cambrian, overlain by 2,000 feet of Upper Cambrian shale.

The Cambrian rocks of Wales seem, therefore, to have been formed in a deep trough between lofty ridges formed of the Archæan rocks on the east and on the west, and possibly also to the south-east.

The only Irish rocks referable to the Cambrian system are those in Wicklow and Wexford.¹ Lithologically they are comparable to the Lower Cambrian of Wales and Shropshire, but as their base is not seen, we do not know on what they rest, and no definite fossils have yet been found in them.

¹ The Galway rocks, regarded as Cambrian by Mr. Kinahan, are more probably of Archæan age.

In Scotland we once more find rocks resting on undoubted Archæan and covered by Ordovician, but they are very different lithologically from the Cambrian of Wales. They consist entirely of red felspathic sandstones, with beds of breccia and conglomerate at the base, and are in places from 3,000 to 4,000 feet thick. This Torridon Sandstone is probably of early Cambrian age, and has evidently been formed against an Archæan coast-line. Its composition is thus described by Professor Bonney¹: "Its coarser basement beds are crowded with fragments of the underlying gneisses and schists, and since the epoch of their formation no important change has taken place in either the one or the other. The finer beds, though other materials occasionally occur, are largely, sometimes almost exclusively, composed of grains of quartz and of felspar identical in every respect with those of the underlying series. It may be a fact of some significance, for it agrees with what I have elsewhere noticed in very old fragmental rocks, that the felspar appears to have been broken off from the parent rock while still undecomposed, and in many cases is even now remarkably well preserved. It would seem, therefore, as if the denudation of the granitoid rock had been accomplished without material decomposition of its felspar; but I must not allow myself to digress into speculations on this interesting and suggestive fact."

The Torridon Sandstone has not, however, been entirely derived from the Archæan gneiss. Mr. B. N. Peach states that in some parts of Sutherland the basal conglomerate consists chiefly of stones derived from older sedimentary rocks, such as greywacke, quartzite, hardened shales, and cherty limestones, together with a few pebbles of slaggy diabase lava.

Professor Judd remarks²: "These rocks in their cha-

¹ Pres. Address to Geol. Sec. of Brit. Assoc., 1886.

² Pres. Address to Geol. Sec. of Brit. Assoc., 1885.

racters and their relations so greatly resemble the Sparagmite Formation of Scandinavia, that it is impossible to refrain from drawing comparisons between them. The Scandinavian formation, however, includes calcareous and slaty deposits, which are wanting in its Scottish analogue;” and he points out that as Upper Cambrian fossils have been found at the very top of the Sparagmite series, this fact lends support to the view that the Torridon Sandstones are of Lower Cambrian age.

§ 2. Geographical Restoration.

The relations which the Cambrian sediments bear to the underlying Archæan, both in this country and elsewhere, are so remarkable that we are driven to conclude that the physical conditions of the earth's surface at this early period of its history were very different from that which it subsequently acquired. At the commencement of what we call the Cambrian period, the surface of the earth seems to have been extraordinarily rugged and uneven, exhibiting a series of lofty mountain ridges separated by deep troughs and hollows, the bottoms of which were 10,000 or 12,000 feet below the summits of the ridges.

How such inequalities were formed is a difficult question to answer. Were they the result of the mode in which the Archæan rocks were originally formed, or were they partly the result of rain and rivers acting on a newly-formed crust? The conglomerates and coarse sandstones which are so frequent in the Lower Cambrian series, and the unweathered state of the felspar grains in the grits, are suggestive facts, and one cannot help thinking that these rocks must have been accumulated with much greater rapidity than could be effected by any modern process of formation. An obvious speculation suggests itself: Are we looking

upon the result of the first condensation of water upon the earth's surface, and was the Cambrian sea the first great body of water that ever lay over the European area? It must be admitted that there are some grounds for so thinking; there may have been lower levels and older oceans in other parts of the world, but so far as we know the Cambrian rocks are the oldest aqueous deposits in Europe, and the Caerfai beds of South Wales contain the oldest remains of invertebrate animals; moreover, though these animals are certainly the ancestors of modern marine species, the waters of the Cambrian sea may not have been salt; and we have no proof that these creatures had been differentiated into salt- and fresh-water forms until we reach the close of the Devonian period.

Dr. Hicks has discussed the general geographical conditions of the Cambrian period,¹ and he thinks that the higher parts of the pre-Cambrian land lay toward the north-east of Europe, and that the surface had a general slope from north-east to south-west, but was traversed by mountain ridges having a general E.N.E. and W.S.W. direction. If this were so, and subsidence took place, the part of the surface which faced south-west would first become covered by the sea. He infers from a consideration of the Cambrian series in various parts of Europe that the sea gradually spread further and further to the north-east, and that there was a difference in level of 15,000 feet between the low ground of the south-west and the high ground in Russia.

The late Professor Linnarsson, however, entirely differed from Dr. Hicks. He points out² that the Scandinavian succession goes nearly, if not quite, as low as that of South Wales, and further that, though the sandstones below the Scandinavian Menevian are not so thick as the British, this

¹ "Quart. Journ. Geol. Soc.," vol. xxxi., p. 552.

² "Geol. Mag.," 1876, p. 145.

may have been mainly due to a less rapid rate of deposition. "If Mr. Hicks' views of the physical geography of the Cambrian period were correct, there ought to be in the middle and upper portions of the Swedish series many signs of littoral conditions. . . . The facts, however, rather tend to show that most of the Swedish Cambrian rocks were deposited in a deeper sea and farther from land than the British."

The fact is that in Scandinavia, as in Britain, there are great variations in the thickness of the Lower Cambrian rocks; thus in Norway the lowermost sandstones are 2,000 feet thick, while in Sweden they are only 100 feet. Again, the Olenus beds in Norway contain sandstones and quartzites, but in Sweden they are wholly shales with bands of limestone. These facts point rather to the conclusion that the greatest mass of land lay to the north-west, for coarse sediments are likely to thicken in the direction of land and not away from it, as Dr. Hicks seems to suppose. The Russian succession is not antagonistic to this conclusion, for the whole Cambrian series is not 700 feet thick; the basal sandstones are 300 feet, and the overlying beds are such as would be formed at a distance from land, being blue clays surmounted by glauconitic shales and limestones like some of our Cretaceous beds.

All the available evidence certainly seems to favour the view taken by Professor Hull,¹ that the greater mass of dry land lay to the north-west of Europe, and occupied a large part of what is now the North Atlantic Ocean. There may have been smaller but still extensive tracts of land of the European area, as is plainly indicated in England and Bohemia; nay, it would appear that in Lower Cambrian times there was in Europe more land than sea, and that the subsequent changes throughout the Upper Cambrian and Ordovician periods tended to reverse this state of things

¹ "Physical History of the British Isles," p. 61.

by continued subsidence, which broadened the sea-spaces at the expense of the land.

In dealing specially with the geographical conditions of the British area, I have sought the assistance of Dr. Callaway, whose studies of the Cambrian rocks are well known, and he has kindly furnished me with an outline of such inferences as he thinks it is safe to draw in the present state of our knowledge. These are as follows:—

“The ideal reconstruction of the geography of any past epoch is always a rather speculative task, but it becomes especially difficult when we revert to a period so ancient as that of the Lower Cambrian or Longmyndian. We can learn little about tracts which are covered by post-Cambrian deposits, and the deep borings of the south-east of England give us no help. We can, however, determine the approximate position of some of the land masses which rose amidst the waves of the Longmyndian sea.

“The groups of volcanoes which in later Archæan times had spread out their lavas and ashes over so large a part of England and Wales were extinct at the commencement of the Cambrian period, but it would seem that several mountain chains, some of them crowned like the Andes or the Rocky Mountains by numerous volcanic cones, stood above the waves. Dry land probably extended over what are now the counties of Shropshire, Staffordshire, Leicestershire, Warwickshire, and Worcestershire, at least as far south as Malvern, but how far this land stretched to the north, east, and south, we have no means of knowing; it can only be said that analogy points to its having had a considerable north-east and south-west extension.

“The preponderance of coarse sandstones indicates a rapid submergence of the neighbouring land, and the basal conglomerates in Wales indicate the gradual advance of the waves over a sinking shore. The rapid thinning-out of the Cambrian strata toward the west suggests that in the

sea which now separates Wales from Ireland, land must then have predominated. Parts of Carnarvon and Anglesey are all that remain of the eastern side of this vanished country.

“Beyond this there may have been another sea or gulf if the rocks in the east of Ireland are rightly referred to the Cambrian; but it is a significant fact that no deposits of Cambrian age have been found in any part of central or northern Ireland, or in any part of Scotland, except, perhaps, in Ross and Sutherland. It is rather unlikely, if any considerable part of these areas had been under water in Cambrian times, that every remnant of the deposits then formed should have been since either swept away or covered in. The balance of probability, therefore, is in favour of the conclusion that land masses of considerable size lay to the north and west of what is now Great Britain, and formed a Cambrian Atlantis, of which a part of Norway, the Hebrides, Donegal, and the highlands of Connemara are the worn and inconspicuous remains.”

To these remarks it is only necessary to add that at the close of the Cambrian period the sea had gained very largely on the land, that the tract of land indicated as existing over central England was entirely submerged, and that the promontory or island between Wales and Ireland was probably reduced to very narrow limits, though parts of it seem still to have remained above the sea-level. The entire absence of Upper Cambrian rocks, so far as is yet known, in northern Ireland and northern Scotland, seems to justify the supposition that these areas remained in the condition of land throughout the Cambrian period. The Torridon sandstone may have been formed in a narrow gulf penetrating into this land, or else, as Sir A. Ramsay has suggested, in an inland freshwater lake.

CHAPTER III.

ORDOVICIAN PERIOD.

1. Stratigraphical Evidence.

ENGLAND.—The most southern area of Ordovician rock in England is a small tract on either side of Dodman Head on the east coast of Cornwall. The rocks exposed consist of brown grits, quartzites, slates, and ash-beds, with some conglomerates, and they contain fossils of Bala age, but as their base is not visible it is impossible to draw any certain inferences as to the neighbourhood of land. It is true that Mr. Godwin-Austen has called the conglomerates “shingle-beds,”¹ and infers that they were formed in close proximity to a coast-line, but Professor Sedgwick describes them as trappean and schistose conglomerates, and speaks of their passing into “schaalstein” and “trap shale” (*i.e.* volcanic ash), so that they hardly seem to warrant the inference drawn by Mr. Austen.

At Malvern there is a total absence of Ordovician strata, the Upper Cambrian shales being unconformably covered by Silurian, but as the former dip under the latter, it is possible that Ordovician rocks exist beneath the Silurian area to the westward, and it would not, therefore, be safe to infer that the Malvern area was land throughout Ordovician times, though it will be seen from the sequel that land did then exist over the centre of England, and it is

¹ “Quart. Journ. Geol. Soc.,” vol. xii. p. 44.

quite possible that the Malvern Hills were part of the southern border of this land.

The larger part, if not the whole, of Wales formed part of the Ordovician sea, and in this area the Cambrian sediments are succeeded by a thick series of comparatively deep-water rocks, though they certainly were not formed at any great distance from land. The succession consists of (1) the Arenig series—black slates and flags, from 3,000 to 4,000 feet thick, with the addition of much volcanic material in the north-west of Wales; (2) the Llandeilo series—another group of black slates and flags, with a thin limestone, in South Wales; (3) the Bala series—a more variable group, consisting of shales and sandstones, with two bands of limestone, the whole from 4,000 to 6,000 feet thick.

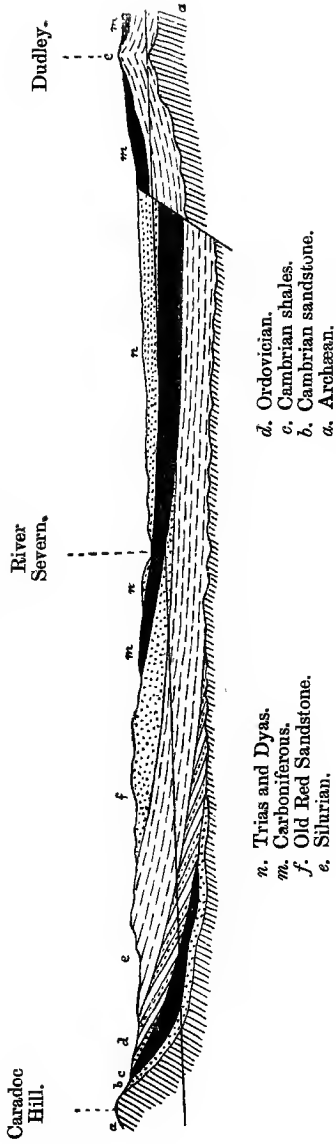
As these Ordovician strata occur in full force on both sides of the Pembrokeshire Archæan axis, it is probable that this was completely submerged and covered by these sediments.

In Shropshire the same complete series is found on the western side of the Longmynd ridge, but in the Caradoc district, on the eastern side of that ridge, the Arenig and Llandeilo series are absent, sandstones of Bala age, having a conglomerate at their base, resting on the local representative of the uppermost Cambrian.

Fig. 1 is an ideal section, drawn for the purpose of showing the possible underground geology of the midland counties, for it is absolutely necessary to form some conception of this before we can draw any inferences regarding the probable position and extent of the land area which seems to have existed over the centre of England in Ordovician times. From the section it is seen that the Caradoc sandstones are supposed to thin out beneath the Silurians against the pre-Cambrian rocks, and that there is reason to suppose that they were never deposited over that part of

Fig. 1. Diagrammatic Section through parts of Shropshire and Staffordshire.

Distance about 30 miles.



n. Trias and Dyas.
m. Carboniferous.
f. Old Red Sandstone.
e. Silurian.

d. Ordovician.
c. Cambrian shales.
b. Cambrian sandstone.
a. Archæan.

Staffordshire which is traversed by the section, nor over Warwickshire, where Coal-measures rest on Cambrian shales. We may assume, therefore, that this district was dry land during the whole of Ordovician time, that the Longmynd and Caradoc tracts formed part of the land area in Arenig and Llandeilo times, but were submerged toward the close of the period, and covered by the Caradoc sandstones and shales. The fact of quartz-felsite, like that of Charnwood, having been found below the Lias near Kettering, seems to indicate that this land tract had a still further eastward extension.

In Anglesey and Carnarvon the pre-Cambrian ridges which formed land throughout Cambrian times were still further submerged, and, perhaps, eventually were overtopped by the waves of the Ordovician sea. The exact age of the earliest fossiliferous deposits of Anglesey is not yet quite settled, but the probability is that the fossils in the lowest grits are not of earlier date than the Arenig, and Dr. Callaway thinks that at this time the northern and central parts of the island were still above water.

“The basement conglomerates contain not only boulders from the granitoidite, but also pieces of halleflinta, such as we find east of Llanfaelog, and numerous fragments of purple and green shale, very similar to types characteristic of the tract west of Malldraeth Marsh. . . . The western area furnishes similar evidence; the large angular fragments in the Tywyn conglomerate cannot have travelled far, and the pieces of altered shale in the Clymwr conglomerate must have been derived from the neighbouring land to the west.”¹ In other parts of the island beds of Bala age have been found, and these probably extended much farther west, and were, perhaps, continuous with beds of the same age in the west of Ireland.

In the Lake District we again find a thick series of

¹ Callaway in “Quart. Journ. Geol. Soc.,” vol. xl. p. 582.

muddy deposits representing the lower part of the Ordovician system—that part of the Skiddaw slates which underlies the grit-beds of Gatesgarth and Latterbarrow being 4,000 or 5,000 feet, and that above these grits being no less than 7,000 feet thick. These are succeeded by an immense series of lavas and ash-beds with interbedded slates (the Borrowdale series, estimated at 12,000 feet), above which are limestones and shales, which correspond to the upper part of the Bala group of Wales.

With regard to the Skiddaw series, Mr. J. C. Ward¹ remarks that the grits in the lower part of the series thicken to the westward, whence he infers that continental land lay in that direction. The water in which the material of the slates subsided was probably never very deep, and there must have been a long-continued depression of the area to allow of so thick an accumulation of sediment. Mr. Ward states that in the south-west of the district the volcanic forces came into play much earlier than they did to the north-east. It is also known that in some places the Limestone group rests unconformably on the volcanic series.

The following paragraphs are quoted from Mr. Ward's paper. The observed facts "all point to volcanic action commencing at the close of the so-called Skiddaw slate period beneath the waters of the sea, and the gradual passage from submarine volcanic conditions to those of terrestrial and wholly subaerial volcanoes.

"The centres of eruption are difficult to fix upon, as might be expected amongst volcanic remains of such antiquity. The boss of Castle Head, Keswick, almost certainly represents one such centre, and the best developments of lava flows are all found occurring within easy distance. . . . What the height of the old Cumbrian volcano or volcanoes may have been it is difficult to estimate, but volcanic de-

¹ "Geol. Mag.," 1879, p. 51.

posits were accumulated to a thickness, in parts, of at least 12,000 feet, and the highest beds known are unsucceeded by any conformable series of sedimentary rocks; hence we know not how much of the products of the old volcano has been lost, and for aught we know to the contrary, an Etna in size may once have stood where now are the resting-places of quiet lakes."

When volcanic activity had ceased, "a subsidence of the region ensued, accompanied doubtless by much waste of the volcanic material through the agency of atmospheric denudation. Subsidence, however, continued until the old volcano came within the planing power of marine coast-action, and at last there was probably but little of the old terrestrial volcano left above the level of the sea." As the waters gradually crept over the site of the volcanic disturbances the calcareous sediment which was being deposited on the surrounding sea-bottom gradually enveloped and covered the surface of the sinking volcanic area. That this sea covered the greater part of northern England is known from the existence of Ordovician rocks in Teesdale and near Ingleborough.

Scotland.—In the south of Scotland Ordovician rocks are known to occupy large areas, and they have been mapped by the Geological Survey, but little information has yet been published about them. There are, in fact, only two districts where the vertical succession has been ascertained, viz., Girvan in Ayrshire, and Moffat in Dumfries, and our knowledge of these is almost entirely due to the careful investigations of Professor Lapworth.

It so happens that though the same succession of fossils can be traced in each area, yet the characters and thicknesses of the beds containing them differ enormously, the Girvan strata being over 3,000 feet thick, while those of Moffat are only 150.

In the Girvan area there are shales of Arenig age, but

they are so entangled among igneous and metamorphic rocks that their stratigraphical relations have not yet been made out. Moreover, it appears certain that there is a marked unconformity between the igneous group, or Ballantrae rocks, and the succeeding deposits of Upper Llandeilo age. At the base of the latter is a coarse purple conglomerate containing fragments of the Ballantrae rocks, and we may therefore conclude that land existed in this area during the greater part of the Arenig and Llandeilo periods. Moreover, the base of the Bala series is a conglomerate 500 feet thick, which overlaps the Llandeilos on to the older rocks, so that some land was then still above the sea-level, but this was soon submerged, and the subsidence continued throughout the Bala period till a thickness of 3,300 feet of deposits had been laid down.

That the land thus indicated did not extend far in a due easterly direction seems probable from a consideration of the Moffat section; here no base is exposed, but the small thickness and uniform shaly character of the deposits, taken together with the rarity of any organic remains except graptolites, lead us to infer that these shales were formed at some distance from land and in comparatively still and deep water. It is possible that the land may have had a south-westerly prolongation into the north of Ireland, but the base of the Ordovician is not there seen, and consequently there is no actual evidence for this supposition.

With regard to the northern part of Scotland, it is only quite recently that its structure has been properly understood. Messrs. Lapworth and Callaway were the first to establish the true upward succession, and to show that it was in many places inverted by the complete overthrow of the strata. Their work has been continued by the officers of the Geological Survey, and the succession in Durness and Eriboll is given as follows, in descending order:—

4. A great limestone series, believed to be over 1,400 feet thick.
3. Calcareous grits and mudstones, about 80 feet.
2. Fine-grained quartzites, with worm casts, 300 feet.
1. Coarse quartzites, with a thin conglomerate at the base, 200 feet.

Many fossils occur in the limestones, and so far as they are yet known it seems probable that the beds are of the same age as the *Orthoceras* limestone of Sweden and the Trenton limestone of Canada, viz., Upper Arenig or Lower Llandeilo.¹ If this is so, the basement beds can hardly be older than the Arenig of Wales. No break or overlap appears to exist in the series, but the group as a whole rests unconformably on the older rocks, lying partly on the Torridon sandstone, and partly on the Archæan gneiss.

The succession above mentioned plainly indicates the gradual subsidence of a land surface and its submergence beneath an increasing depth of water. Mr. B. N. Peach draws the following inferences from the characters of the rock:² "In the case of the basal quartzites, where we have a passage from a land surface to a sea-bed, there is little or no organic matter mixed with the coarse siliceous sand, which from its coarse texture, and the false-bedding of the layers, bears evidence of rapid accumulation. There would therefore be no food for the support of Annelides under these conditions. But with the slower accumulation of sediment indicated by the 'pipe-rock,' there was evidently time for the fertilization of the sand by the shower of minute pelagic organisms which is ever falling on the sea-floor, so that it could afford food for the burrowing annelids, whose casts now form the stony 'pipes.' . . . As the sea-floor gradually subsided, the shore-line was removed farther from the area of deposit, and hence during the deposition of the 'fucoid beds' only the finest sedi-

¹ See J. W. Salter, "Quart. Journ. Geol. Soc.," vol. xv. p. 381, and J. E. Marr, "Classif. of Cambrian and Silurian Rocks," 1883, Cambridge, p. 67.

² "Proc. Roy. Phys. Soc. of Edinburgh, 1886," vol. ix. pt. i. p. 4.

ment derived from the land was mingled with the calcareous and organic matter."

"After the deposition of the Serpulite grit hardly any sediment derived from the land entered into the composition of the overlying limestones, and eventually nothing seems to have fallen on the sea-floor but the remains of minute organisms, whose calcareous and siliceous skeletons slowly built up the great mass of limestone and chert so conspicuously displayed at Durness."

Ireland.—There are five principal districts in Ireland where Ordovician rocks occur: (1) Wicklow, Wexford, and Waterford; (2) Clare and Tipperary; (3) South Ulster—Down, Armagh, &c.; (4) North Ulster—Donegal and Londonderry; (5) Galway and Mayo. Between 1 and 3 are two small but important exposures, that on the Dublin coast at Portrairie, and the ridge known as the Chair of Kildare.

No Irish rocks have yet been identified by their fossils as contemporaneous with the Welsh Arenig. Wherever the base is seen in the east of Ireland, beds with Llandeilo fossils rest unconformably on metamorphic rocks, which are classed as Cambrian. Coast sections near Bannow and Greenore Point in Wexford expose the basement beds, which are purple conglomerates and sandstones overlain by black shales with Llandeilo fossils, a succession which recalls that of the Girvan district in Ayrshire. The Dark Shale series (Llandeilo) may have a thickness of 2,000 or 3,000 feet, and it is surmounted by an equal thickness of grey and greenish shales with interstratified igneous rocks, the slates containing fossils of Bala types.

The Portrairie section is remarkable for the resemblance of the rocks to the upper part of the Cumberland Ordovician system, *i.e.* the Coniston Limestone and the underlying Borrowdale group, with its lavas and ash-beds. There can be little doubt that this area was the centre of similar

volcanic disturbances, followed by similar conditions of sedimentation, as in the case of the Cumbrian district already described (p. 32). A third centre with a similar sequence is found in the Chair of Kildare on the same line of strike, and other tracts of Ordovician rocks occur still further south-west, in the mountains of Clare and Tipperary.

In South Ulster we have a continuation of the South Scottish Ordovicians, and the succession, so far as it is known, is similar; the base is not seen, but certain shales have yielded the graptolites of the Glenkiln group (Llandeilo), and others contain Bala fossils, while at Pomeroy, in Tyrone, there is a limestone from which many Bala fossils have been obtained.

In Mayo and Galway there are shales which are believed to be of Llandeilo age, and others which contain the characteristic fossils of the Bala rocks; they are estimated at several thousand feet, but the stratigraphy of this part of Ireland requires further investigation.

2. Geographical Restoration.

From the foregoing facts it would appear that the submergence which began in Cambrian times continued, during the formation of the Arenig series, over the whole of the western and northern portions of the British area, but that over a certain space in the centre of the sea which covered England there was an upward movement resulting in the appearance of an island composed of Archæan and Upper Cambrian rocks. In an east and west direction this island seems to have had a length of at least eighty miles, stretching from the Longmynd in Shropshire to Charnwood Forest in Leicestershire and the neighbourhood of Kettering, and possibly even further to the east. Of its northerly extension we can predicate nothing at present;

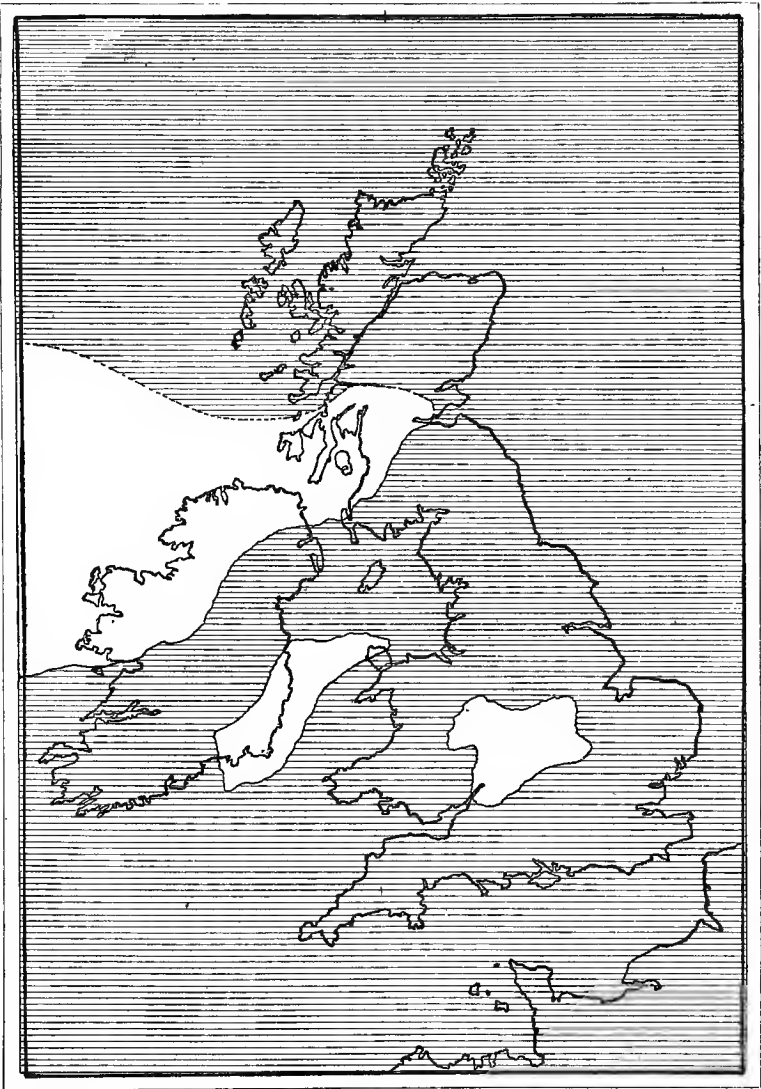


PLATE I. HYPOTHETICAL RESTORATION OF EARLY ORDOVICIAN GEOGRAPHY
(ARENIG EPOCH).

it is not at all unlikely to have stretched some distance to the north-east, but I have not ventured to indicate such an extension on the map. Southward it probably sent a promontory as far as Malvern, but its southern boundary is as uncertain as its northern limit.

West of this island there seems to have been another formed by the unsubmerged portion of the ridge spoken of in the last chapter as reaching across from Anglesey to the south-east of Ireland, but how much farther to the west and south it extended at this time we have no means of knowing, so that the tract shown on the map may be regarded as the minimum amount of land in this region.

It is difficult to say how much of Ireland may have been land in Arenig times, because we do not yet know whether any Arenig beds exist in that country or not, but they certainly seem to be absent in Wicklow and Wexford, and they have not been identified elsewhere. If the metamorphic rocks of Mayo and Galway are Archæan, and the Llandeilo shales rest upon them with an entire absence of Cambrian and Arenig beds, we may suppose that this part of the Archæan surface was not submerged till after the beginning of the Ordovician period. How far this land extended eastward in Upper Cambrian and Arenig times is a point of very great interest when viewed in connection with the great differences which exist between the Arenig rocks of England and those of northern Scotland.

The similarity of the Durness and Trenton limestones and the American aspect of the fauna found in the former have suggested to Mr. Peach that "some old shore-line or shallow sea must have stretched across the North Atlantic or Arctic Oceans, along which the forms migrated from one province to the other, and that some barrier must have cut off this area from that of Wales and central Europe."¹ He might have supported this suggestion by a reference to

¹ "Address to the Roy. Phys. Soc., Edinburgh, 1886," p. 7.

the opinion expressed by Sir R. Murchison, that a large part of the Arctic region was land in Lower Silurian times, because no rocks of that age had been discovered there. Nor have any been found since this opinion was expressed, though (Upper) Silurian rocks cover large areas in the north-western part of the Arctic Archipelago.

It seems probable, therefore, that the great northern continent of early Cambrian times was partially broken up by the submergence which ensued, and that an open sea extending from North America to Scotland and Scandinavia was established for the first time at the beginning of the Ordovician period; that this sea divided the Cambrian continent into two parts, the larger part lying over Greenland and the northern regions, while a smaller mass lay to the south, and stretched eastward through the north of Ireland and into the south of Scotland, so as to separate the northern sea from that which lay over the European area. The thick conglomerates of Llandeilo and Bala age which occur in the Girvan district may indicate a part of its southern border, but of its northern shore we have absolutely no evidence at present. Mr. J. E. Marr takes a somewhat similar view,¹ and has suggested the existence of a ridge of pre-Cambrian land across the centre of Scotland in Arenig times, separating the sea in which the *Orthoceras* and Durness limestones were formed from that of the Girvan area. It is possible, therefore, that the land barrier had a still further eastward extension, but until more is known of the geology of the central Highlands this must remain uncertain, and the form given to the land in the accompanying map is of course merely a suggestion based upon the preceding considerations. The map is in fact only a pictorial representation of the theory suggested by the facts which are known to us, and may require considerable modification as our knowledge increases, and the same may

¹ "Classif. of Camb. and Sil. Rocks," p. 68.

be said of the succeeding restorations of Palæozoic geographies, so little do we really know of these rocks and their extension beneath the British Islands.

During the deposition of the Llandeilo and Bala rocks depression continued, and the whole of the British area seems to have been submerged, with the exception of a portion of the central English island; the dimensions of this island were of course considerably diminished, as testified by the extension of the Caradoc sandstones to the east of the Longmynd, but these do not extend into Staffordshire or Warwickshire. Llandeilo and Bala rocks seem to have been laid down over the whole of Ireland, and if any part of the land barrier above mentioned remained above water it must have been outside the present limits of Ireland.

Numerous volcanic islands, however, came into existence during this period, and portions of the lava-streams which they emitted are interbedded with the sedimentary rocks of Llandeilo and Bala age. In Llandeilo times a line of such islands seems to have stretched across Ireland and the north of England in a south-west and north-east direction, while in Bala times great eruptions took place from a group of volcanoes in Wales and the east of Ireland.

The period was brought to a close by an upheaval which brought up the submerged ground, but gave it a different outline and extension from that which it possessed in Arenig times.

CHAPTER IV.

SILURIAN PERIOD.

1. Stratigraphical Evidence.

COMMENCING with what is usually regarded as the typical Silurian district, it may be stated that the Silurian rocks form a continuous escarpment through Shropshire and the east of Wales, and that they rise to the surface at intervals in the counties of Gloucester, Monmouth, Hereford, and Stafford.

The lowest beds in this district are sandstones, shales, and conglomerates; this (Llandovery) division is thickest in the western part of the area, and is there divisible into two groups, with a combined thickness of nearly 2,000 feet, but the upper stage frequently overlaps the lower, and it is the only one found in the more eastern outcrops, where they include beds of conglomerate; these basal conglomerates vary much in thickness, and sometimes overlap the Ordovician strata, as in the Longmynd and Malvern areas, where they rest upon the Cambrian rocks.

The Llandovery sandstones are succeeded by a great series of dark grey shales, in which limestones are developed at intervals; some of these limestones attain a thickness of 100 feet, but they are all lenticular deposits, and it is often difficult to identify the beds seen in one detached area with those which occur in the others. Only three of these limestone bands have received distinctive names,

these being respectively, in upward succession, the Woolhope, the Wenlock, and the Aymestry limestones, but at Tortworth, May Hill, and Malvern, there is a fourth limestone between the Wenlock and the representative of the Aymestry, which might be regarded as a distinct horizon. This great shale and limestone series is from 2,000 to 3,000 feet thick.

The highest Silurian beds in this region consist of yellow sandstones and reddish shales, the latter passing up into red laminated micaceous sandstones and marls, some of which contain marine fossils; these beds form a passage from Silurian to Old Red Sandstone, and were evidently formed in shallower water than the dark mudstones and limestones of the Wenlock series.

As regards the eastward extension of the Silurian rocks very little is yet known; the most easterly outcrop is near Walsall and Barr in South Staffordshire, but Wenlock shales have been found below the cretaceous rocks in a deep boring at Ware, near Hertford, so it is probable that they have a wide subterranean extension beneath the south and east of England.

The subdivisions which have been established in the limited area where the Silurian rocks were first described, will not apply to the rocks of the same age outside that area. When traced in any westward direction, a great change takes place in the lithological character of the strata: all the limestones thin out and disappear, and the soft mudstones change into a series of hard shales, flags, and grits. In central and northern Wales these alternations of shales and sandstones attain a thickness of from 5,000 to 7,000 feet, and this change suggests the existence of a considerable mass of land to the westward.

The Silurian rocks of the Lake District are similar to those of North Wales—they have a conglomerate at the base which lies unconformably upon Ordovician rocks, and

to this succeeds an immense series of shales, grits, and flags, which are no less than 13,000 feet thick. Of this total only 250 feet belong to the lower or Valentian group, the great mass of the beds (11,000 feet) representing the Salopian shale and limestone group, while the upper 2,000 feet represent the red passage beds of the Welsh border. Although no Upper Silurian beds are found in Cumberland north of their Coniston and Windermere outcrop, yet they set in again on the north side of the Solway, and, as the late Mr. J. C. Ward writes,¹ "there is every reason to believe that the whole series once extended over the now exposed volcanic rocks, for there is nothing in the deposits themselves to indicate a land margin near their present outcrop. Such a thickness of beds as that just described implies a continued subsidence of the sea-bed throughout the whole period of deposition."

The prevalence of sandstones and flagstones, however, shows that the water was never very deep or very far from land, and we are guided to the direction in which some of this land lay by considering the lithological changes which the lowest group exhibits when traced in different directions. In Westmoreland it consists entirely of shale, with a local conglomerate at the base; to the south-east, near Settle, it is represented by a band of calcareous mudstone resting on a few inches of grey shale, while to the north and north-west it thickens into a great series of shales and sandstones, which are spread over large areas in the Southern Uplands of Scotland.

In the Moffat district (Dumfries) the Birkhill and Gala groups must be several thousand feet thick, and consist largely of hard sandy and micaceous flagstones, but without any actual shore-beds or conglomerates. In Ayrshire, however, near Girvan, they include thick beds of conglomerate; the basal bed of this district is a boulder conglome-

¹ "Geol. Mag.," 1879, Dec. 2, vol. vi. p. 55.

rate about seventy-five feet thick, consisting of rounded pebbles and boulders in a matrix of purple sand, and it passes up into soft sandstones 250 feet thick. In another locality these beds are absent, and rocks belonging to a higher horizon rest unconformably on the Ordovician; again there is a basal conglomerate about fifty feet thick and greenish in tint, "the main mass of this conglomerate is made up of well-rounded boulders varying from one inch to a foot and a half in diameter; they consist of pieces of granite, porphyry, felstone, greywacke, shale, Lydian-stone, quartz, and jasper, embedded in a coarse sandy matrix of a dark-green colour, and excessively indurated."¹ Higher still is a band of quartz conglomerate succeeded by a series of shales, grits, and flagstones, and the total thickness of the Valentian here is estimated at about 1,800 feet (exclusive of the *Cyrtograpsus* shale).

It is clear, therefore, that land existed in this Girvan district at the commencement of Silurian time, and that in passing southward and eastward we recede from this land; the mass of the land must consequently have lain to the north and north-west.

The higher Silurian groups are represented in the south of Scotland by the Hawick and Riccarton Beds, with their equivalents, the Bargany and Stratton groups, in Ayrshire, and finally, in Lanark and Edinburgh there is a series of brown and grey beds with Wenlock and Ludlow fossils, which are from 3,000 to 4,000 feet thick, and pass up into the Lower Old Red Sandstone. We may conclude, therefore, that a thick mass of Silurian strata once extended over the whole area of the Southern Uplands, and passed beneath the Lowlands of central Scotland. No Silurian rocks, however, emerge from beneath the Old Red Sandstone on the northern border of the Lowlands, where this sandstone rests unconformably on the Highland gneissic series; neither

¹ Lapworth, "Quart. Journ. Geol. Soc.," vol. xxxviii, p. 638.

is any area of Silurian rock known to exist in northern Scotland. So far, therefore, as we can judge from present evidence, the Silurian rocks probably die out beneath the Lower Old Red on the south side of the great boundary fault.

Passing now to Ireland, we find a significant absence of Silurian rocks in the south-east of that country. The Ordovician rocks of Dublin, Wicklow, and Wexford are flanked by Upper Old Red Sandstone and Carboniferous rocks—a sequence suggestive of these districts having been land throughout the periods of the Silurian and Lower Old Red Sandstone. Rocks representing the Llandovery group occur at several localities in eastern and central Ireland, as in County Down, at Portraine in Dublin, and at the Chair of Kildare, but the only complete sections of Silurian rocks are found on the extreme western shores. In Galway and Mayo there is striking evidence of great physical changes having taken place in the interval between the formation of the Ordovician and Silurian rocks of Ireland. Here the basement beds with Llandovery fossils rest on the edges of upturned and metamorphosed Ordovician strata, so that great terrestrial disturbances must have taken place, resulting in the compression, metamorphism, and upheaval of the older series before the deposition of the Silurian deposits, for the conglomerates contain fragments of these underlying metamorphosed Ordovicians.

We may reasonably infer that the existence of the continental land which was postulated as existing to the north-west of Ireland in Ordovician times had much to do with the location of this pressure and metamorphism, and that the terrestrial forces finally expended themselves in an elevation and extension of the land which had previously existed, bringing its boundaries farther south and within the limits of what is now Irish soil. During subsequent subsidence the coast-line again receded northward, and the

Silurian conglomerates were deposited along its shores, while the sand and mud that was worn from the detrition of the land was carried eastward and spread over the bottom of the neighbouring sea.

Silurian rocks occur also in Kerry, and include representatives of nearly the whole system, but the actual base is not seen, while their upper limit is difficult to fix, as they pass into a series of slates and grits which are lithologically similar to the beds below, but do not contain fossils.

2. Geographical Restoration.

We have seen that nearly everywhere, but especially in the north-west of Ireland, there was great disturbance and upheaval at the commencement of the Silurian period; that this was followed by a gradual subsidence, during which the materials gained from the land tracts were quietly spread over the sea-bottom; and that, finally, over the English and Scottish areas, the incoming of sandstones and the narrowing of the areas of deposition bespeak a rapid elevation.

It will be best to consider the geographical conditions which seem to have existed at the beginning of the period, for we cannot say how much of the land areas remained during the subsequent submergence.

The largest land tract seems to have been to the north and north-west of the British Isles, and there is reason to think that a continent of some size occupied a large part of what is now the North Atlantic Ocean. No Silurian rocks having been found in the northern parts of Scotland, it is probable that in early Silurian times the coast-line of this continent ran through the north-west of Ireland and the centre of Scotland. The Ayrshire conglomerates were probably formed round an island, or possibly off

a promontory jutting out from a main line of coast, but I have not ventured to insert either on the map (Pl. I.), as so little is known of their lateral extent, and as yet they have only been proved to occur over a small area. To the east there was open sea, and the close correspondence between the Scottish and Swedish zones of life leads us to infer that the sea-bed was continuous from one region to the other.

It is possible, however, that an island of considerable size lay between Ireland and Wales, and included certain areas which now form portions of these countries. The lateral change which takes place in the character of the Silurian strata as they pass westward from Shropshire, and the thickening of the sandstones to the north-west, are facts which indicate land in that direction. From the quantity of felspar grains that enter into the composition of the Denbigh grits, Sir A. Ramsay has inferred "that part of the mountain region of North Wales between Conway and Cader Idris then formed land (very different from its present form), which in some degree contributed locally to make these strata by the waste of the felspathic lavas and ashes that form such a distinguishing feature of the Lower Silurian rocks."¹ If, however, the Ordovician tracts of eastern Ireland were united to those of Wales, and formed a continuous mass of land during part and, perhaps, the whole of the Silurian period, there is no necessity to suppose that the felspathic material was derived from the Snowdon region in particular, since felspathic lavas occur also in Wicklow and Wexford, and were doubtless exposed at many places over the intervening tract of land. Northward this land may have extended as far as the Isle of Man, and the conglomerates which occur in the Sedburgh and Settle districts suggest the presence of islands at its north-eastern end, but there can be little

¹ "Geology of North Wales," second edition, p. 285.

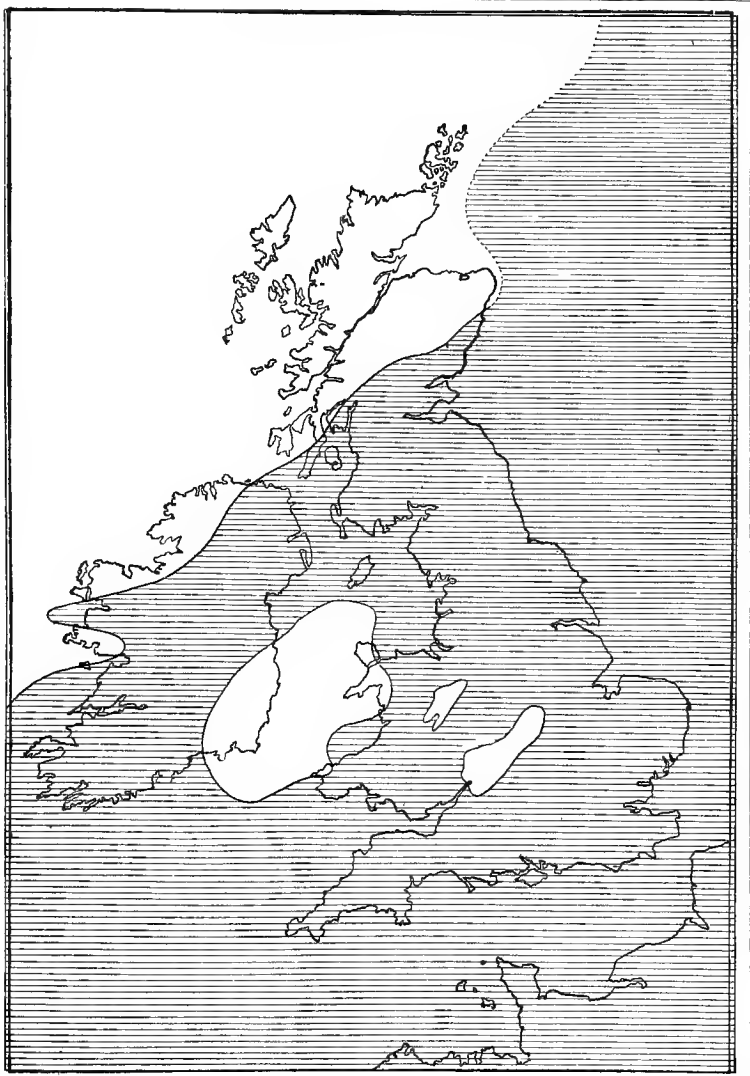


PLATE II. HYPOTHETICAL RESTORATION OF SILURIAN GEOGRAPHY
(LLANDOVERY OR VALENTIAN EPOCH).

doubt that they were soon deeply submerged and covered by the Silurian sediments.

The evidence for the existence of this Hiberno-Cambrian island is not at present very strong, but it furnishes us with a means of accounting for the great thickness of the Silurian deposits on its eastern side, for if we suppose that the tidal currents came from the south-westward, a reference to the map (Pl. I.) will show that they would naturally sweep the débris gained from the erosion of its southern and western shores round to the more sheltered side, and that great banks of sand and mud would be likely to accumulate along the eastern shore and beyond the north-eastern extremity; the sea itself may originally have been of considerable depth, and the continued submergence would prevent it from being entirely silted up.

There is better evidence for the existence of two smaller tracts of land to the eastward, which may have been separate islands, or may have been promontories from a larger tract lying to the north-east of them. One of these was formed by the rocks of the Longmynd and Shelve district; the Llandovery conglomerate wraps round the edges of this tract, which doubtless had a farther extension to the north-east in Silurian times beyond the range of the Wrekin. The coasts of this island were probably rather steep, and the sea, on the eastern side at any rate, was deep, or limestones would not have been formed in such near proximity.

The other island was probably rather larger, and was the remnant of that which seems to have existed over the midland area in Ordovician times, but only the higher ridges between Malvern and Charnwood Forest were left, and it is impossible to say whether these remained above water throughout the Silurian period.

It is probable, indeed, that both this and the Longmynd island were surrounded by coral reefs which were built up

around them as they sank beneath the Silurian sea, till after existing for a time in the condition of atolls, they were eventually submerged and buried under the higher Silurian shales and mudstones.

It is just possible that another island existed to the south-west of England, and included part of Cornwall, for no rocks of true Silurian age have yet been found in that county, and it is believed that the oldest Devonians rest on the Ordovician rocks of Mevagissey and Veryan Bay. Further examination of this district is required, however, before any definite conclusions can be drawn.

Basal Silurians exist in Brittany, but nothing comparable to our Wenlock and Ludlow series is found there, and French geologists believe that during the latter part of the Silurian period the Armorican and Cotentin region formed an island the limits of which were very nearly those which are now presented by the pre-Devonian rocks of this district.¹

¹ Lapparent, "Traité de Géologie," second edition, p. 781.

CHAPTER V.

OLD RED SANDSTONE AND DEVONIAN.

THERE is much uncertainty about the classification and correlation of the rocks which intervene between the Silurian and the Carboniferous systems, and this uncertainty mainly arises from the fact that there is no locality in Britain where an unbroken series of these intervening rocks can be studied. In several areas the Silurian is seen to pass upward into a series of red and purple sandstones (Old Red Sandstone), but in every case there is a break before the Carboniferous series is reached. Again, there is one area (North Devon) where Carboniferous rocks rest conformably on a series of strata containing a peculiar fauna which stamps them as of intermediate age between Silurian and Carboniferous, but the base of these (Devonian) rocks is not seen, so that we do not know what they rest upon, and it is possible that a considerable thickness of rocks intervenes between the Lower Devonian Sandstones and the Silurians of Upper Ludlow type, if such beds exist beneath North Devon.

The Old Red Sandstone is divided into a Lower and an Upper Series, with a gap between them. The greater part of the Devonian system was doubtless deposited during the period which this gap represents, though its lowest portion may have been coeval with part of the Lower Old Red, and its uppermost portion is generally acknowledged as the equivalent of the Upper Old Red.

Since, however, we cannot be sure that the strata which conformably succeed the Silurian are represented to any great extent in the Lower Devonian group, and as it is possible the mass of them may be older, the safest plan will be to treat the rock-groups above mentioned as three separate series, viz.: (1) Lower Old Red Sandstone, and its homotaxial equivalents in Scotland and Ireland; (2) Devonian rocks; (3) Upper Old Red Sandstone. This is the plan adopted by Mr. H. B. Woodward in his new edition of the "Geology of England and Wales."

1. Stratigraphical Evidence.

1. *Lower Old Red Series.*—In England this series is only found on the borders of Wales, in the counties of Brecknock, Monmouth, Hereford, and Shropshire, where it covers a considerable area. The rocks consist of sandstones, flagstones, and marls, the sandstones generally red, the marls red, grey, or green, and including lenticular masses or nodules of limestone, which are locally known as "cornstones;" hence the whole series is sometimes called the "Cornstone Series," and its thickness is supposed to be from 2,000 to 2,500 feet. It is succeeded by the Middle Old Red Sandstone, or "Brownstone Series," but Mr. Symonds believes that there is a break in the succession at the summit of the Cornstone group.¹

The limits of this group are not yet accurately known, but its western outcrop is believed to extend from the head-waters of the river Usk in Brecknock to Much Wenlock in Shropshire, and as it also flanks the Silurians of Woolhope and Malvern, &c., it would appear to lie in a broad synclinal which has a general north-east to south-west strike. The area becomes narrower towards the north-

¹ "Records of the Rocks," p. 234.

east, and though it is doubtless continued for some distance under the Shropshire Coalfield, it probably "noses out" beneath the northern boundary of that county.

What its original limits were is a much more difficult question, but it undoubtedly spread some distance westward over the Silurian rocks of Brecknock, Radnor, and Shropshire; northwards it may have stretched through parts of Denbigh, Cheshire, and Derbyshire, for fragments of the Tilestones which occur at the base of the Cornstone group have been found in the basal Carboniferous sandstone of Flint. Eastward, or rather north-eastward, it probably did not extend far, for if (as we suppose) there was land in that direction during Silurian times, the area of this land is likely to have been much larger during the time of the Lower Old Red, which was one of upheaval. South-eastward, near Berkeley in Gloucestershire, it is either absent or very thin, but southward there are probably large tracts of rock which were continuous with the Cornstone series, though these are concealed beneath the Devonian and Carboniferous rocks. In Cornwall, however, the Lower Devonians extend downward into a series of grits and slates estimated to be 10,000 feet thick, and these may be older than any in North Devon.

In Scotland there are four distinct areas of Old Red Sandstone: (1) in Berwickshire and the Cheviot Hills; (2) below and on either side of the great central coalfields; (3) in the north-east, over the Orkneys, Caithness, and parts of Sutherland and Ross; (4) a small area in Argyleshire. In all these there is the same general succession, viz., a great series of red and purple conglomerates and sandstones, with dark grey flags and shales, and interbedded sheets of felsite and porphyrite. These beds in every case either pass down into Silurian rocks (as in the Pentland Hills), or rest unconformably upon rocks that are older than the Silurian. Above them there is always

an unconformity, and they are succeeded by other red sandstones and conglomerates which have been termed the Upper Old Red. Neither series contains any marine fossils, but fish have been found abundantly in both.

The Old Red Sandstone of Scotland has excited the admiration and kindled the enthusiasm of many Scotch geologists. Its immense thickness, the varied colours of its component strata, its peculiar scenery, and the extraordinary forms of its entombed fossils, have furnished themes for all who have studied this unique formation. Immortalized by the pen of Hugh Miller, the wonders of the Old Red Sandstone are familiar to all, while its history in connection with the scenery of Scotland has been recorded in the graphic and artistic descriptions of Archibald Geikie.

Both writers have been struck by its massive thickness, and by the proofs of its having once extended far beyond its present limits over the gneissic districts of Scotland. Miller thought that it must originally have covered the whole Highland region "from Ben Lomond to the Maidenpaps of Caithness;"¹ and though Dr. Geikie does not accept this view, and believes that the areas in which it occurs were always distinct and separate, yet he is forced to admit that the Highland tracts which were not so covered must have been comparatively small. Thus, after describing the vast natural pyramids of Morven and the Maidenpap, which form such conspicuous landmarks in Caithness, and the chain of rounded, craggy, conical hills between Golspie and Helmsdale, he says²: "It is impossible to look at these brown hills without being convinced that they remain as a mere fragment of a great sheet of conglomerate and sandstone which stretched away westward across the abraded platform of schists forming the

¹ "The Old Red Sandstone," second edition, p. 53.

² "Scenery of Scotland," second edition, p. 139 *et seq.*

interior of Sutherland. But as if to make this point quite certain, in the very heart of the county, the two solitary conical mountains of Ben Griam, 1,936 feet, which rise so conspicuously above the worn platform of old crystalline rocks, are cakes of conglomerate formed out of the detritus of the schists on which they lie. . . . The same deposit (*i.e.* Old Red conglomerate) runs southward from Sutherland along the eastern coast of Ross and the shores of the Moray Firth. It stretches up the valley of the Great Glen and rises in Mealfourvonie to a height of 2,284 feet. Thence it sweeps eastward along the seaboard of the counties of Inverness, Nairn, Elgin, Banff, and Aberdeen, and detached portions are found thirty or forty miles in the interior. . . . The highest of them is that which runs up the valley of the River Avon above Tomintoul, where it reaches a height of upwards of 1,300 feet above the sea. The coarseness of the conglomerate at this locality is remarkable; huge blocks of the schists and other crystalline rocks of the district piled up in the conglomerate there, bear emphatic witness to the abrasion of the Highlands during, as well as before, the time of the Old Red Sandstone."

"Along the southern border of the Highlands the evidence is less obtrusive, but perhaps no less definite. From sea to sea the Highland mountains are there flanked by the Old Red Sandstone in low rolling plains that creep up to the base of the hills, but sometimes, as in the case of the Braes of Doune, rising into long heathery heights, that form a kind of outer rampart to the main mass of the Highlands. Even from a distance the stratification of the conglomerates and sandstones of these uplands can be easily traced, the beds presenting their denuded truncated ends toward the mountains, to which they evidently at one time were prolonged, and from the waste of which they were formed. If we prolong with the eye the lines of

these truncated strata, we see that they probably once stretched far away into the interior of the Highlands."

On the south side of the central Lowland tract the belt of Lower Old Red is partly overlapped by the Upper division, but from Girvan to the Pentland Hills it is faulted against the older rocks, and there can be no doubt that its original limit lay far to the south of its present boundary.

In the north of Ireland there are two areas which exhibit a set of rocks which are similar to the Lower Old Red of Scotland,—one of these is a tract about thirty miles long by ten wide, lying between Lough Erne and Pomeroy in Tyrone; the other is a very small tract on the north coast of Donegal.

In the south of Ireland there is some uncertainty about the stratigraphical relations of the rocks which lie between the Silurian and the Carboniferous systems. Such rocks are only found in Kerry and Cork, and are known as the Glengariff Grits; they consist of hard green and purple sandstones, with purple slates and some beds of conglomerate. In the Dingle promontory these beds conformably succeed the Silurian, and are covered unconformably by the conglomerates of the (so-called) Upper Old Red Sandstone. Further south, however, near Killarney, the upper conglomerates are absent; the highest Glengariff slates are succeeded by the sandstones of the Lower Carboniferous series. At Glengariff the Carboniferous slate has grey grits and slates at its base (Coomhola grits), which seem to rest conformably on the Glengariff slate and grit series. Still further south, near Toe Head, the yellow sandstones again come in between the Glengariff and the Carboniferous slates.

Professor Hull believes that the Carboniferous conglomerates are overlapped southward by higher beds, and that these come to rest upon the Glengariff grits at Killarney

and Kenmare; he thinks the apparent conformity is deceptive, and that there is everywhere a great break between the Glengariff series and the Carboniferous beds. It is certainly very difficult to reconcile the Dingle and Glengariff sections on any other view, for there is no reason to believe that there are any beds at Glengariff which are unrepresented at Dingle, but rather that there are beds below the Carboniferous shale east of Dingle which are absent in the Glengariff country, so that, as Professor Hull argues, the greater break is actually where there is least actual evidence of it. The Glengariff grits occupy a large surface area in the south of Kerry, and extend eastward through the central part of Cork. They are believed to underlie the whole of South Cork and the greater part of Kerry, but their northern limit is unknown, and is probably concealed under the Carboniferous beds of North Cork and Limerick.

2. *Devonian System.*—The rocks of this system are only found in the south of England, and they are only exposed to view in the counties of Somerset, Devon, and Cornwall.

The rocks of North Devon and Somerset are divided into three groups, which, as at present defined, consist respectively of the following strata: (1) hard purple and grey grits at the base, with grey slates and thin grits above; (2) sandstones succeeded by a series of thin-bedded limestones, grits, and slates—above these are thick green and grey slates; (3) purple slates succeeded by red, brown, and grey sandstones.

In South Devon and Cornwall the rocks are so contorted and faulted that it is difficult to determine the real sequence, but it is known that there are (1) red sandstones and slates with Lower Devonian fossils, (2) a great series of slates and limestones (with interbedded volcanic rocks), which represent the Middle Devonian, and (3) a slate and sandstone group resembling that in North Devon.

In North Devon no base is seen; in Cornwall there are beds which may be older than any in North Devon, but it is not known whether they rest on rocks of Silurian age, or lie unconformably on the Ordovicians of Mevagissey.

In comparing the rock-series of North and South Devon, we may notice the prevalence of sandstones in the northern area, especially in the lower half of the system, showing the neighbourhood of land; the same conclusion may be drawn from a comparison of the limestones, which are much thicker and more fossiliferous in South Devon, indicating a greater depth of water in that direction.

As regards the original extension of these Devonian rocks there can be little doubt that it was chiefly in an easterly direction, and that the sea in which the Middle Devonians were formed shallowed toward the west and south. Rocks belonging to the Middle Devonian have been found in deep borings below London, and at Turnford in Essex; they occur also in Belgium and the north-east of France, so that it is highly probable that they were continuous over the whole area now occupied by the English Channel and the southern counties of England. In Normandy there is an absence of Middle and Upper Devonian, though there are thick deposits of Lower Devonian age.

3. *Upper Old Red Sandstone*.—The precise relations of the strata which have been grouped as Old Red Sandstone in Brecon, Hereford, and Salop remains to be ascertained. Above the Cornstone group there are signs of unconformity according to the Rev. W. S. Symonds, and the succeeding beds are brown sandstones with red marls and shales. These are sometimes called Middle Old Red Sandstone, and it is possible that they represent some of the marine Devonian beds; they are probably from 3,000 to 4,000 feet thick, and are certainly older and distinct from the true Upper Old Red Sandstone of South Wales and Ireland.

The Upper Old Red Sandstone proper borders the Carboniferous areas of Gloucester, Monmouth, and Glamorgan, and stretches westward into Carmarthen and Pembroke, overlapping both the underlying groups and the Silurian rocks, till it rests directly on the Ordovician between Carmarthen and Narberth. The beds consist of red and white conglomerates at the base, succeeded by red marls, above which are red and yellow sandstones with fish and plant remains. It has been supposed that these strata are of lacustrine origin, but no freshwater mollusca have yet been found in them, while *Serpulæ* and the Pteropod *Conularia* are said to occur in them, so that there seems much more reason to regard them as marine. Southward they are found in the Mendip Hills, and they were doubtless continuous with the Pickwell Down Sandstones of North Devon and the Cockington Beds of South Devon. To the northward they are found in the Clee Hills of Shropshire, but as they do not recur beneath the Carboniferous rocks of the neighbouring coalfields, that seems to have been nearly the limit of their original northward extension.

They may be represented in Anglesey, where there are 600 feet of red sandstone and conglomerate below the Carboniferous Limestone, but neither here nor in Denbigh and Flint is there any definite band of shale between the sandstones and the limestones, so that it seems more probable that the former are shore beds of the age of the limestone, and therefore newer than the true Upper Old Red Sandstone.

The same is the case in the north of England and in the south of Scotland, where there is always a group of red sandstones at the base of the Carboniferous system, and in Scotland these are sometimes 2,000 feet thick, but they occasionally contain beds of red limestone with Carboniferous fossils.

In the east of Scotland, however, there are older beds

which may be more truly called Upper Old Red, since they contain fish-remains of the Old Red Sandstone type, and they resemble the upper sandstones of Wales and Ireland. In Fife and Forfar these consist of red conglomerates and sandstones, surmounted by yellow sandstones and shales, which are sometimes called the Dura Den beds, from a locality near Cupar, whence many fine specimens of fish have been obtained. Similar sandstones occur in Elgin on the Moray Firth.

In Ireland the Upper Old Red Sandstone is confined to the southern part of the country. It sets in below the Carboniferous limestone and shale of Kilkenny and Waterford. Where best developed it is 3,200 feet thick, and consists of a basement conglomerate overlain by red and purple sandstones and red shales, above which are yellow and greenish sandstones with olive green shales. These last are known as the Kiltorcan Beds, and they contain the freshwater mollusc *Anodon Jukesii*, together with numerous plants, fish, and large Crustacea, and the beds are believed to be lacustrine.

Beds of the same age and of similar aspect are seen at various localities in Tipperary, Limerick, Cork, and Kerry, so that they are believed to underlie nearly the whole of the south of Ireland, but they are absent over certain tracts in the west of Kerry, as mentioned on a previous page (p. 54). In the Dingle promontory there are thick red conglomerates, estimated to be more than 2,000 feet, succeeded toward Tralee by 1,500 feet of the Yellow Sandstone group; in Clare and Limerick they are very much thinner, and they are believed to die out along a line drawn from Galway Bay to Queen's County, and thence southward through Kilkenny.

2. Geographical Restoration.

During this period great geographical changes took place; the greater part of Britain was elevated into dry land, and formed part of a continent which must have had a considerable extension to the north and west of our islands. The sea which covered so large a part of the British area in Silurian times was now contracted into a much smaller space, and only lay over the southern part of England, whence it stretched eastward through the north of France and Belgium. Westward it seems to have extended into Ireland (if the Glengariff grits are marine beds), but can only have covered a comparatively small area in the extreme south-western part of the country.

An arm of the sea is represented on the map (Pl. II.) as covering the area occupied by the Old Red Sandstone of Wales and Shropshire, for Professor Hull's opinion—that this was formed in a bay or estuary which opened out of the Devonian sea—seems more probable than the view advocated by Sir A. Ramsay and Dr. Geikie, who regard it as a purely lacustrine deposit.

Sir A. Ramsay points to the prevalent red colour of the rocks, but red rocks can be formed in seas as well as lakes. The organic remains are few; there are fish and large Crustacea, such as occur in the Scottish Old Red Sandstone, but these may have been able to exist both in salt and fresh water, like many fish at the present day. The marine shell *Lingula cornea* is said to occur in some of the Cornstone beds, and this would certainly prove the beds containing it to have been formed in salt water. Lastly, we may observe that there is no physical evidence to support the supposition of a land barrier to the south.

At the same time it is true that the Cornstone and Tilestone series hardly present the usual characteristics of an estuarine deposit, and the inlet may have been a long bay

rather than an estuary. The nature of the deposits would depend entirely on the character of the rocks which form the neighbouring land, and it is evident that this land must have consisted largely of granitoid, felspathic, and quartziferous rocks, and though some of the material doubtless came from the western side, yet it seems probable that the larger proportion came from the eastern. We have seen that land-tracts formed in part of such rocks lay over central England in Silurian times, and the Devonian upheaval doubtless greatly extended their boundaries, especially toward the east and the north.

We have no evidence as to the direction of the inlet further northward, but it probably narrowed, and may have received the waters of a river that drained the land to the north and east. In the north-west of England and in the Isle of Man there is a great unconformity between the older Palæozoic rocks and the Carboniferous, so that it is inferred that all the north of England was land.

Parts of Scotland were also dry land, and the earth-movements in this region seem to have resulted in the formation of several mountain ranges having a north-east and south-west direction, between which ranges were low-lying tracts that were at first inlets of the sea, but by the continued elevation of the land were apparently converted into large inland lakes.

Dr. Arch. Geikie considers that the four areas of Old Red Sandstone, mentioned on p. 51, were distinct and separate basins of deposit, at any rate during the earlier half of the period;¹ that they were also disconnected from the sea, and formed large inland lakes. He has, therefore,

¹ The great thickness of material in them would be more easily understood if they lay between lofty mountain ranges, for they find a parallel in the Siwalik group of India, and the manner of their formation is illustrated by deposits in the upper basin of the Indus. See Drew in "Quart. Journ. Geol. Soc.," vol. xxix. p. 441.

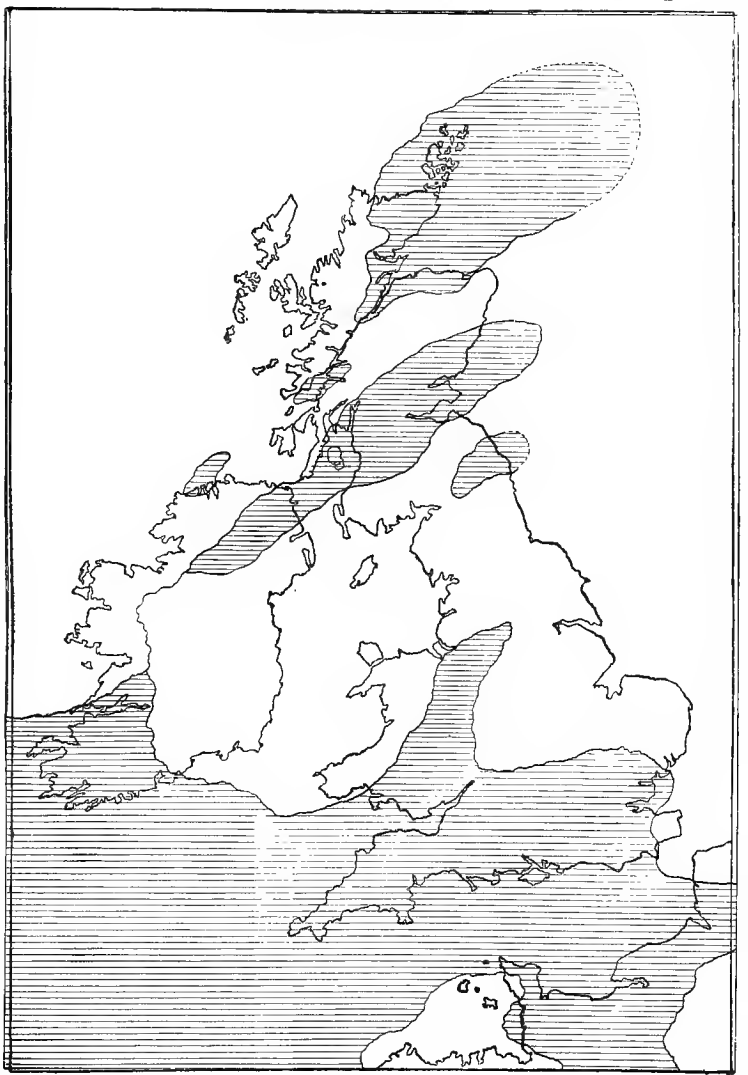


PLATE III. SUPPOSED GEOGRAPHY OF LOWER DEVONIAN AND LOWER
OLD RED SANDSTONE TIME.

proposed separate names for these basins, calling the south-eastern area Lake Cheviot, the central one Lake Caledonia, the small western basin Lake of Lorne, and the northern basin Lake Orcadie.

From the proofs which have been adduced of the original wide extension of the Old Red Sandstone (p. 52), it might be thought that the three principal basins could hardly have been separate lakes, but must have been inlets proceeding from one large inland sea, the greater part of which lay to the east of Scotland; and, indeed, so far as the stratigraphical evidence goes this would be the most natural conclusion, for the lithological differences between the strata of the several basins are hardly greater than the differences which exist between the Lanark and Forfar types in the same Caledonian basin. The palæontological differences are, however, very much greater, the piscine fauna of the Forfar and Caithness flags being so distinct that Sir R. Murchison thought they could not be of the same age, and was led to suggest that the Caithness flags formed a middle group distinct from the Lower Old Red, and of younger date than the flags of Arbroath in Forfar. Dr. Geikie has shown that this is improbable, and that the discrepancy is not complete, and that the general succession of beds in the two areas is very similar. "The admitted palæontological distinctions are probably not greater than the striking lithological differences between the strata of the two regions would account for, or than the contrast between the ichthyic faunas of contiguous water-basins at the present time."¹ The difference is, however, sufficiently remarkable, for out of eighteen genera with sixty species from Caithness, and ten genera with seventeen species from Arbroath, only four genera and one or two species are common to the two areas. So great a difference, though it may perhaps be lessened by future

¹ "Textbook of Geology," first edition, p. 715.

discoveries in Forfar, affords good ground for concluding that there was no direct communication between the waters of the two lakes.

There is less evidence for regarding the Cheviot basin as distinct from the Caledonian, as no fish have yet been found in the Cheviot district, and we do not know how far the Lower Old Red originally stretched over the southern uplands; much of it was removed before and during the formation of the Upper Old Red, the latter in all probability deriving much of its material from the destruction of the older series. The Lower Old Red partakes in the plication of the Silurian and Ordovician rocks of southern Scotland, and it may for ought we know have been co-extensive with them over the whole region. On the other hand, it should be noted that the Lower Old Red of the Cheviot district rests unconformably on the Silurian, which is an unusual relation, and suggests that the Cheviot basin was formed at a somewhat later date than the Caledonian basin by a local depression of the land surface. This, however, is not incompatible with its having then been an inlet or extension of the Caledonian Lake, but I have not ventured to express this view on the map, which is a rendering of Dr. Geikie's opinion.

The greater part of Ireland likewise seems to have been land enclosing lake basins, and was doubtless at this time connected with England and Scotland, so that the whole formed one mass of land, and was part of a large continent that extended far westward into the place now occupied by the North Atlantic. The tract of Old Red Sandstone in Tyrone being in alignment with that of the central Scottish basin, Professor Hull has suggested that the Lake Caledonia extended thus far into Ireland, and I have adopted this view in the restoration of Old Red Sandstone geography (Pl. III.). The other small tract of Old Red recently discovered in Donegal may have been formed in a

separate basin, which has been named Lake Fanad by Professor Hull.

We may now glance at the succession of events in the south of England. Here, in the sea which occupied the space between the northern part of France and the Bristol channel, there had been continuous deposition of sediment throughout the Devonian period. After the first elevation at the close of Silurian times, this southern area does not seem to have been affected by the upheaval which was in progress to the northward, and indeed it may have occupied a trough of compensating depression. The western part of it was raised into land, however, after the formation of the Glengariff Grits, all the south of Ireland probably being land during the formation of the Middle Devonian rocks.

According to Professor Gosselet, the Devonians of the Boulonnais and the Ardennes were deposited in a narrow strait connecting the wider seas of the Westphalian and the Anglo-French areas.¹ Along the northern side of the Devonian tract from Boulogne to Namur the Lower Devonian is absent, and the base of the Eifelien division consists of conglomerate and sandstone. It is highly probable that the land thus indicated was connected with that which lay over the centre and east of England.

Parts of Brittany and Normandy seem also to have been land, and Professor de Lapparent thinks that they formed an island, the limits of which were very nearly the same as those of the present massif of Cambrian and Ordovician rocks. Inlets of the Lower Devonian sea penetrated the district near Brest, in Basse Loire, on the frontiers of Maine and from the Normandy side; but whether it sank beneath the sea of the Middle and Upper Devonian epochs is not known, as the strata of these stages occur only to the south in Basse Loire.

¹ "Esquisse géologique du nord de la France," p. 60; but the evidence for the southern shore of this strait is inconclusive.

In the tracts which were covered by the sea there was continuous deposition throughout the period, but in the lacustrine areas it appears to have ceased altogether for a time; there is a great gap between the Lower and Upper Old Red Sandstone, and we have no records of the intervening time. But this very absence of deposits is in itself evidence of the conditions which prevailed—the lakes must have been dried up and converted into land surfaces, probably in consequence of the continued elevation of the country, and the deepening of the river channels which would result from this elevation.

We may, therefore, conclude that the general succession of events in the northern areas was as follows: at the beginning of the period the upheaval of the ridges which subsequently became mountain ranges contracted the sea-space into gulfs, which were gradually shallowed by the material poured into them from the land on either side, and by the continued upheaval of the country, till they were entirely isolated from the sea, and were converted into large freshwater lakes, comparable to those of modern North America, and tenanted by a great variety of curious fish. Lake Caledonia must, indeed, have greatly resembled Lake Michigan, which has a length of 345 miles, and an extreme width of only 84 miles. Now the Scottish portion of Lake Caledonia has a length of 160 miles; and if, as Professor Hull supposes, it stretched continuously into North Ireland, we must add another 80 miles to its western extension, giving a total of 240 miles, while how far it extended to the east of Scotland we have no means of knowing, but it may well have been 300 miles in length, and its extreme width was perhaps not more than 80 or 90 miles. The greater part of Lake Orcadie lay outside the present limits of Scotland, and in that part of the continent which stretched toward Scandinavia, so that we can form no idea of its size. The other lakes seem to have been

small in comparison, though Lake Cheviot may have been 40 or 50 miles long.

During the existence of these lakes volcanic activity was rife, and immense sheets of lava were poured over the country and interbedded with the lacustrine deposits, and all this time it is probable that the lake bottoms were not very far above the sea.

Along the southern border of the central basin there is, in fact, evidence that there must have been some alternating movements of depression, or such differential movements between the lake-basin and the dividing ridges of land that the area of the former was sometimes invaded by the sea. Thus, near Lesmahago, a few hundred feet above the base of the red beds, there are shales containing marine fossils of Silurian species, and again, near Carmichael in Lanark, 5,000 feet above the base, there is a band of shale which has yielded a *Graptolite*, an *Orthoceras*, and a *Beyrichia*—forms which must have continued to exist in the neighbouring sea, and which prove that the Silurian fauna was still prevalent in that sea. This shale band, intercalated between thick masses of red sandstones, shales, and conglomerates, which are supposed to be of lacustrine origin, is a proof that the lake-basins were at first isolated from the sea by the ridging up of land-barriers, rather than by any general elevation of the country.

During the formation of the higher beds, however, we may suppose that a general elevation took place, and that the lakes came to have excurrent as well as incurrent rivers, till in course of time, as the excurrent streams cut their channels deeper and deeper, the waters of the lakes were partially or completely drained off, just as the great Tertiary lakes of North America were drained by the excavation of the Colorado cañon. The country would then present the aspect of a high and dry upland, formed of lofty hill ranges separated by immense sandy plains, the

sites of the desiccated lakes ; through these plains ran the rivers in deep and narrow channels, while on the mountain slopes piles of débris were prepared by the agencies of disintegration and detrition. It is, indeed, not unlikely that much of the material forming the conglomerates of the Lower Carboniferous series was originally prepared by sub-aerial agencies, and was only rearranged by the waters of the later epoch.

A reverse movement at length set in toward the end of what must be called the Devonian period ; portions of the old lake-basins were again filled with water, the area of which widened and deepened as the land sank ; torrents washed in the detritus of the land, and the material thus collected became the conglomerates and sandstones of the Upper Old Red and Lower Carboniferous series.

This depression led to the formation of a large lacustrine area in the south-west of Ireland, spreading over the tracts now known as the counties of Clare, Limerick, Kerry, Cork, Waterford, Tipperary, and Kilkenny. Its northern shore appears to have been somewhere along the parallel of Galway Bay ; the Granitic and Ordovician rocks of Wicklow, Carlow, and Wexford formed its eastern boundary, while how far it extended to the south and west we have no means of knowing, except that in the Dingle and Kenmare districts we appear to be approaching its western shores. From Dingle to Thomastown in Kilkenny is a distance of 135 miles, and from Galway Bay to the Old Head of Kinsale is 108 miles ; this would form a fine sheet of water, but even if it stretched another 100 miles to the southward, it would only have been about half the size of the modern Lake Superior.

In this lake were laid down the strata described on p. 58, and at the epoch of the Kiltorcan beds, with their abundant remains of plants, it is evident that its shores were bordered by tracts of fertile land, on which grew the

Lepidodendra, *Cyclostigmæ*, and the splendid ferns known as *Palæopteris hibernica*, the fronds of which are nearly two feet in breadth. Eventually here and elsewhere the continued depression of the land brought the level of the lake waters down to that of the Carboniferous sea, which was gradually extending itself over the lower parts of the great Devonian continent.

This view of the relations of the so-called Upper Old Red to the Carboniferous system has been well expressed by Mr. B. N. Peach.¹ "As the land in the northern areas gradually sank, the lacustrine and littoral deposits were succeeded conformably by estuarine and marine strata of Lower Carboniferous age, and a much newer facies of fish fauna followed the Old Red types. . . . This remarkable palæontological break in a conformable series of strata can be satisfactorily explained if we regard the Upper Old Red fishes as the survivors of an older fauna still confined to land-locked basins, while the Carboniferous forms suddenly gained access to the Scottish area from the open sea, where they had developed at a much more rapid rate than their less favoured relatives."

Whether the Welsh gulf continued open throughout the whole period we are not at present in a position to say; possibly it was at times completely silted up and converted into a low-lying tract of land, but it was under water again during the formation of the Upper Old Red Sandstone, and its limits were then greatly extended in an east and west direction. The sea then probably stretched westward for some distance toward Ireland, and was only separated by narrow barriers from the lacustrine waters of that area. When at length these barriers were submerged, and the sea spread over all the lower parts of the great Devonian continent, it ushered in a new fauna, and with this we com-

¹ "Proc. Roy. Phys. Soc. of Edinburgh," vol. ix. p. 13.

mence a new period of geological time. The history of this depression belongs to the next chapter, but it has this connection with the geography of Devonian times, that the relative height of different portions of the Devonian continent may be indicated by the relative age of the Carboniferous beds which lie upon them.

CHAPTER VI.

CARBONIFEROUS PERIOD.

1. *Stratigraphical Evidence.*

CARBONIFEROUS rocks occupy large areas in the British Isles and they are known to have a wide subterranean extension (see "Historical Geology," p. 181). They exhibit three principal facies, which may be called (1) the southern or Culm-measure type, (2) the central or Pennine type, (3) the northern or Scottish type.

The southern type is found in Devonshire and in the south-west of Ireland; it consists mainly of black and grey shales (cleaved into slates in Ireland), the limestones being very thin and insignificant. The lower part consists of green and grey shales with bands of sandstone (Baggy and Pilton Beds), the middle of black shales and thin limestones (Lower Culm-measures), the upper of hard grey grits with bands of shale (Middle and Upper Culm-measures).

The central type is more varied and consists of a series which is divisible into four groups as follow:—

4. The Coal-measures (shales, sandstones, and coals).
3. The Millstone Grit (sandstones and shales).
2. The Upper or Yoredale Limestones and shales.
1. The Lower Limestones, with shale and sandstone at the base.

Nos. 1 and 2 are known as the Lower Carboniferous series, and sometimes attain a thickness of 8,000 feet.

Nos. 3 and 4 are the Upper Carboniferous series, and are as much as 12,000 feet thick in some parts of Lancashire and Yorkshire. This type prevails over the larger part of England and Ireland.

The northern type is differently divided in Northumberland and Scotland, but the following classification would apply to both areas:—

Upper.	{	The Coal-measures (2,000 to 3,000 feet).
	{	The Millstone Grit (100 to 600 feet).
Lower.	{	A limestone group with shales and coals (1,500 to 3,000).
		A carbonaceous shale group (800 to 2,500).
		A sandstone group with basal conglomerates (1,000 to 3,000 feet).

Certain areas in the north of Ireland exhibit beds of a similar type.

The records of the Carboniferous period being thus more complete than those of earlier times, and the rocks being more fully exposed and more easily classified, we possess more certain grounds on which to reconstruct the geography of the British area, at any rate during the early stages of the period.

It is clear that the period was ushered in by the partial submergence of the great continent which included so large a part of Britain in the preceding (Devonian) period. The movement of depression seems to have been very different from the movement which raised that continent; the upheaval was effected by a force which acted rather horizontally than vertically, forcing up the earth's crust by lateral compression into a series of mighty ridges and furrows. The Carboniferous submergence was apparently an even and uniform downward movement gradually bringing the lower portions of the pre-existent land beneath the level of the sea.

The only district which presents evidence of differential movement is that of the Old Red Sandstone tract of Shropshire, for though the Upper Old Red exists there, the Lower Carboniferous beds are absent, and the several stages of the Upper Carboniferous rest unconformably on the Old Red Sandstone and Silurian rocks; whence we may infer that though this was low ground at the close of Devonian time, it was not submerged beneath the Lower Carboniferous sea, but was undergoing elevation which kept it above water till late in the Carboniferous period.

In dealing with the evidence derivable from the lithological changes in the Lower Carboniferous rocks, I propose to follow a different method from that adopted in previous chapters. Although there can be no doubt that the greater part of England and Ireland was submerged during the formation of the Carboniferous Limestone, I think there are grounds for believing that a large island of irregular shape existed over the area now covered by St. George's Channel, and that it stretched northward into Scotland, and eastward through the centre of Wales and the midland counties of England. Instead therefore of discussing the conclusions to be deduced from a study of the English, Scotch, and Irish rocks respectively, I propose to adopt a more synthetic method, and, taking the existence of this island as a theorem, to state the facts which may be regarded as strong evidence, even if they do not amount to proof of the proposition.

It will be convenient to start with Shropshire, as the evidence for the existence of land in that county has just been alluded to; it is corroborated by the rapid northerly thinning of the Carboniferous Limestone series in Gloucester and Monmouth; near Bristol this series has a total thickness of about 2,600 feet, including the lower and upper shales; near Chepstow it is about 1,500 feet thick, and in the Forest of Dean it is only 840 feet, having lost 1,760 feet

in a distance of twenty to twenty-five miles; if its attenuation continued at the same rate it must have died out some ten miles north of the Forest of Dean coalfield, *i.e.* a little to the south of the 52nd parallel of latitude, and as a matter of fact it appears to be absent at Newent. The same northerly thinning occurs throughout the South Wales coal-basin, the Limestone series on its southern border being variously stated as from 1,000 to 2,000 feet thick, while along the northern border it is not more than 500 or 600 feet thick, and near Haverfordwest it appears to die out altogether, and to be overlapped by the Coal-measures. These facts may be taken as indicating the existence of land a few miles north of the present boundary of the limestone.¹

From Pembrokeshire we pass across to the coast of Wexford in Ireland, and as we find very similar conditions existing there, it is exceedingly probable that the coast-line we are following was continuous from Pembroke to Wexford. Carboniferous rocks occur round Wexford Harbour, and extend south-westward in a narrow strip between areas of Cambrian rocks, and are found again on either side of the entrance to Waterford Harbour. Mr. Kinahan states that the dark shales and limestones which are found along the southern margin graduate into red shales, sandstones, and conglomerates along their northern margins, and that "these rocks seem to have accumulated in a narrow bay which shallowed out eastward."²

That the Cambrian, Ordovician, and Granitic areas of Wexford, Carlow, and Wicklow were land at the time

¹ That the thinning of the limestone was in the direction of land, and not away from it, is shown by the simultaneous thinning of the Millstone grit and the overlap of the Coal-measures. We know also that the Carboniferous limestone was often formed in close proximity to shore-lines.

² "Geology of Ireland," G. H. Kinahan, p. 78.

when the lower beds of the Carboniferous limestone were formed is shown by the overlap of this limestone on to the granite of Carlow, and it is probable that this land being steep and mountainous was not wholly submerged till the close of the Carboniferous period, and perhaps not even then. This lower limestone continues to border the older rocks through Kildare, but in County Dublin it appears to be overlapped by shales belonging to the Calp and Upper Limestone series.

The limestones between Howth, Swords, and Rush are believed to belong to the Lower Limestone, but they show unmistakable evidence of the close neighbourhood of land. The Hill of Howth was clearly an island in this Lower Limestone sea, and part of a shore conglomerate still exists there. Between Rush and Skerries the limestones include thick beds of conglomerate containing pebbles derived from the neighbouring Ordovician rocks; there is some doubt whether these limestones belong to the Lower or Upper division,¹ but there is no doubt that farther north-west, near the Naul, the Upper Limestone rests against the Ordovician shore, and that it is moreover overlapped by the succeeding (Yoredale) shale group. At one place there are boulder beds, consisting of blocks from the Ordovician rocks cemented together by grey Carboniferous Limestone, and Professor Jukes observes:² "This is evidently a portion of the very beach or margin of the Carboniferous sea in which the fallen blocks and shingle from the wasting land above were enveloped in the calcareous deposits of the Carboniferous period."

The facts described in the memoir referred to seem explicable only on the supposition that the beds were deposited in a bay which had land to the south, east, and north

¹ See "Mem. Geol. Survey (Ireland), Expl. of Sheets 102 and 112," pp. 65, 66.

² Op. cit., pp. 59, 60.

of it. The older beds are only found in the central part of the area, and the water was not clear enough for the formation of limestone during the whole time, the higher beds being chiefly dark earthy shales, which overlap the limestones on to the sinking land both northward and southward, as doubtless they also did to the eastward. The great development of shales in this district may have been caused, as Jukes suggested, either by the influx of a river which had previously some other debouchure, or by the sea having reached some tracts of earthy Ordovician shale which had previously been above its level (*op. cit.*, p. 23).

North of the area just described, and around the town of Drogheda, is another tract of Lower Carboniferous strata lying in a hollow between ridges of Ordovician rocks. The Lower Limestone is only found to the westward, and disappears about two miles east of Slane, owing "to the conformable overlap of the higher beds of the formation on to the Silurian (*i.e.* Ordovician) rocks, over which they were deposited along a gradually shelving shore."¹ This tract was probably, therefore, another bay narrowing eastward.

The tract of Carboniferous beds between Ardee and Kingscourt exhibits a complete section of the Lower series, and these beds doubtless extended originally all over the Ordovician tracts of Cavan, Monaghan, and Louth. There are also outlying tracts near Dundalk and Carlingford, but these seem to belong to the Upper Limestone series, and it is not unlikely that a large part of County Down was a promontory of land jutting westward into the sea of the Carboniferous Limestone. In the north-east of County Down, at Holywood and Castle Espie, there are limestones associated with red shales and sandstones, which are probably shore-beds of Upper Limestone age.

¹ "Mem. Geol. Surv. (Ireland), Expl. Sh. 91 and 92," p. 35.

We have now traced indications of the existence of a coast-line all the way from Wexford and Waterford to the north of County Down, and here we are, doubtless, not far from its northern limit, for there can be little doubt that there was a connection between the Irish and Scotch waters at this period. The rocks of County Down are evidently a continuation of the Silurian and Ordovician tracts of southern Scotland, and it is highly probable that in early Carboniferous times they formed one continuous mass of land, and it is not at all improbable that this land included the northern part of the Isle of Man. It is true that there is carboniferous limestone at the southern end of the Isle of Man, but there is no proof that it ever extended far to the north, and the red sandstones and cornstones of Peel may be shore-beds of the Limestone sea, like the red sandstones of Scotland.

That this was the case on the northern border of the land area we are now considering is the decided opinion of the Geological Surveyors of Lanarkshire. Describing the basal conglomerates of this district, they say: "These conglomerates continue to fringe the Carboniferous area, while the strata above pass quite away. Hence, in this continuous band of conglomerate, one portion is on the horizon of a low part of the Calciferous Sandstone series, while another portion is on the horizon of the Carboniferous Limestone series. It thus brings before us evidence of shore conditions during a protracted submergence of this area in Lower Carboniferous times."¹ It must be remembered, also, that what is here called the Calciferous Sandstone is now regarded as contemporaneous with the lower part of the English Carboniferous Limestone.

Returning to the Isle of Man, the existence of the Limestone series there is no proof that there was open sea to the

¹ "Mem. Geol. Surv. of Scot., Expl. Sh. 15," p. 30.

westward. It is, of course, possible that there was communication by way of a narrow strait between the Carlingford area and that of the Isle of Man, but the evidence on the Irish side is in favour of there having been a continuous mass of land over the western part of the Irish Sea, and the Manx rocks are just as likely to have been formed in a bay on the eastern side of this land, seeing that there were several such bays on the western side.

Exactly the same reasoning applies to the Carboniferous rocks of Anglesey. The succession here is very similar to that of the Isle of Man—a basal conglomerate, succeeded by red sandstones and cornstones from 200 to 300 feet thick, overlain by limestones only 450 feet thick, and covered directly by the Millstone Grit. These small thicknesses suggest the neighbourhood of land, and that this lay to the west is shown by the fact of the Limestone series rapidly thickening to the east, and attaining some 2,000 feet in the north of Flint. It is quite possible, therefore, that the western part of Anglesey was land, and that the Carboniferous beds were deposited in a bay or inlet which penetrated into this land, and narrowed south-westward.

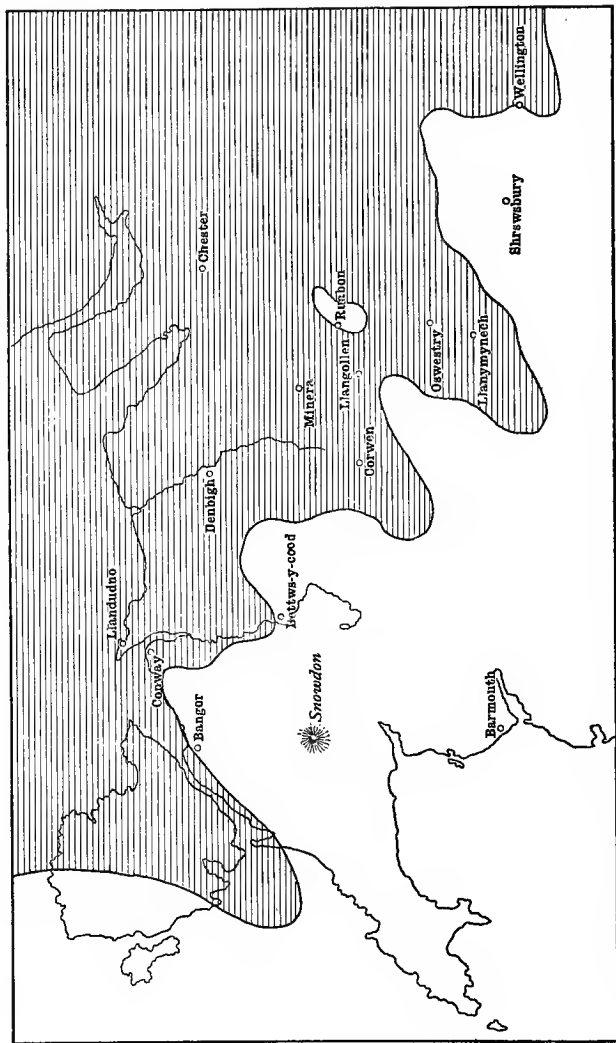
Patches of limestone skirt the coasts of North Wales and border the Silurian rocks along the Vale of Clwyd; here and in North Flint its thickness is about 1,500 feet, and it keeps this thickness for some distance southward, being still 1,200 feet thick at the north-west end of the Eglwyseg escarpment near Llangollen, where it rests on 300 feet of yellow sandstone and conglomerate. Thence, however, it thins very rapidly to the south-east, being only 600 feet thick at Trevor, and under 200 feet at Fron-y-Cysyllte on the south side of the Dee; thus, in a distance of four miles, the red sandstones and about 1,000 feet of the limestone have thinned out against a slope of Silurian rock, a fact which suggests the existence of an island in the sea of the Lower Limestone near Ruabon and Chirk.

Mr. G. H. Morton¹ has shown that in this district the Limestone is divisible into four stages, and that at Fron only the highest, and 28 feet of the third remain. Near Chirk the latter have thinned out, and only the uppermost grey beds (137 feet thick) are found. That this thinning indicates an island is proved by the white beds coming in again below the grey at Craig Sychdin, seven miles south of Fron, and these continue to form a base as far as Crickheath Hill, when shales belonging to the second stage appear, and at Llanymynech the total thickness of the limestone has increased again to 450 feet. Here the escarpment terminates; and when Carboniferous strata set in again five miles to the south-east, Coal-measures rest on Silurian, so that the limestones had thinned out in the interval.

With regard to the westerly extension of the Limestone we are furnished with valuable testimony in the shape of an outlier, faulted down against Silurian shales, near Corwen, and no less than twelve miles W.S.W. of the Eglwyseg escarpment. Moreover, the thickness here is still considerable, probably about 750 feet, so that the limestone must have extended some distance farther to the west and south of Corwen. It is hardly likely, however, to have reached so far as the Arenig mountains, though it may have run up the valley of the Dee as far as Bala; the northern flank of the Berwyn mountains probably formed its southern boundary, these mountains forming a promontory which stretched north-eastward towards Llangollen and Chirk, and separated what may be called the Corwen bay from the Llanymynech bay (see map, fig. 2).

The absence of the limestone over the Shrewsbury district indicates another extension of the land area between Llanymynech and Wellington, where the border of the

¹ "The Carboniferous Limestone and Cefn-y-Fedw Sandstone," 1879.



Walker & Boutall, sc.

Fig. 2. Map of North Wales, showing the relative positions of land and sea during the formation of the Carboniferous Limestone.

limestone is again found. On the east side of the Wrekin the basement beds consist of lava and volcanic ash, which seem to have been the products of subaerial eruptions from volcanoes situated on the border of the land; on these lies a thin representative of the Carboniferous Limestone comprising 20 to 40 feet of limestone, overlain by about the same thickness of shale and sandstone. The south end of this outcrop is cut off by a fault, beyond which the limestone is absent, and the Millstone Grit conglomerate rests on the Silurian. It would appear, therefore, that the greater part of Shropshire was land with open sea to the north and north-west.

We have now returned to the county from which we started, and the logical conclusion to be drawn from the facts which have been described is that the whole area inside the localities mentioned was a continuous mass of land (see map, Plate IV.).

It only remains to give the evidence for the easterly extension of this land, and this was clearly given by Jukes so long ago as 1853 in his "Memoir on the South Staffordshire Coalfield." He there describes the great unconformity between the Coal-measures and the older rocks in South Staffordshire and Warwickshire, these older rocks being Silurian in the one case and Cambrian in the other. The natural inference to be drawn from the facts cannot be stated better than in Jukes' own words: "It is highly probable that all this tract of country, together with much of the adjacent district from Montgomeryshire to Leicestershire, became dry land after the close of the Silurian period, rising perhaps very slowly, and undergoing a very gradual and long-continued process of degradation as it passed through the destructive plane of the sea-level; and that it remained above the waters during great part of the period marked by the formation of the (Upper) Old Red Sandstone and Mountain Limestone, and that

accordingly those two rocks were never deposited upon it." ¹

On the north-east side of the Leicestershire coalfield the Millstone Grit and Carboniferous Limestone are again found; and south-eastward, near Northampton, the Limestone was found in one deep boring, and Lower Carboniferous shales and sandstones in another; but at Orton (twelve miles to the north-east) a thin representative of the Trias rests directly on a quartz-felsite resembling some of the Charnwood rocks.

Whether the land we have traced terminated in Leicestershire, or widened out again eastward and formed part of a larger land mass in that direction, there is at present no evidence which will enable us to decide; but, as it evidently became very narrow in Leicestershire, we have thought it safer to show land on the map only so far as there is evidence for it, and therefore to suppose that it was surrounded by the sea in Lower Carboniferous times.

We have now to consider whether any other tracts are likely to have existed as islands at this time, and the first tract that claims attention is that known as the Lake District. That this was an island at the commencement of the Limestone epoch is tolerably certain, as testified by the conglomerates and sandstones which form the base of the Limestone series; but the question—How long did it remain unsubmerged?—is a very difficult one to answer. It has been discussed by the Rev. J. C. Ward,² who comes to the conclusion that only a very small area north of the Keswick Valley could have been above water, since the Mell Fell conglomerate runs up to a height of 1,760 feet. Curiously enough, this conglomerate consists chiefly of Upper Silurian detritus, and not of stones derived from the Ordovician rocks against which it rests. Mr. Ward

¹ "Geology of the South Staff. Coalfield," first edition, p. 253.

² "Geol. Mag.," Dec. 2, vol. vi. (1879), p. 58.

thinks it was formed in a narrow channel or strait which separated a smaller northern island from a larger southern one, and that the pebbles were drifted by a current from the south, and accumulated chiefly at the eastern end of the supposed channel, where their further northward progress was impeded.

Mr. J. G. Goodchild, however, informs me that he differs from Mr. Ward's view, and believes the pebbles were derived from northern sources. The Silurian rocks of Westmoreland are strongly cleaved, and though a few of the Mell Fell stones are undistinguished from Westmoreland rocks, yet many pebbles of uncleaved mudstones occur, together with other rock-fragments which are unlike any in the Lake District, but can be matched with rocks in the south of Scotland. A further proof of a northerly current is found in the fact that the conglomerates of Tebay (further south-east) contain stones and boulders that have certainly come from the Lake District, and their percentage increases up to a certain point as the beds are traced southward. Again, along the Pennine escarpment the basement beds contain stones derived from the Lower Old Red Sandstone of the Cheviot district, and these must also have come from the north.

Mr. Goodchild concludes, therefore, that the drift of the pebbles was from the northward, and, as regards the submergence of the land, he holds that there was a ridge of high ground extending across the Pennine and Lake Districts, which formed an island at the time when the conglomerates and sandstones were being deposited, but that it was rapidly submerged and entirely covered by the sea before the epoch of the Yoredale Beds. The position of the ridge can be determined by drawing a line round the points where the Lower Carboniferous Beds are thinnest. Thus the beds below the Yoredale series, along the Pennine range, are found to be thinnest in Teesdale (400 feet) and

near Milburn, where they are 700 feet; northward they rapidly thicken to over 2,000 feet, and southward they increase to 1,800, and then to 2,500 at the head of the Eden Valley. Along the border of the Lake District the thickness of the same beds varies from 400 to 800 feet, except at Mell Fell, where the basal conglomerates seem to fill an old hollow; north-west of Appleby they are about 900 feet, but south-eastward they gradually increase to 2,500 feet.¹

Another ridge which was gradually submerged in Lower Carboniferous times seems to have lain under Ingleborough, and probably extended thence to the north-east. The total thickness of the sub-Yoredale Beds near Ingleborough is about 650 feet, of which 150 may be assigned to the basal conglomerate; while, to the north, the thickness near Sedburgh is 2,400, and to the west and south-west it is over 3,000 feet.

With regard to the southern uplands of Scotland, it has already been suggested that the western part of this region was in connection with the Hiberno-Cambrian land, and we have also seen that it probably supplied rock-fragments to the conglomerates in the north of England; but the great valley through which the river Nith now runs seems to have existed before the Carboniferous period, and to have been occupied by a long gulf or inlet of the Carboniferous Limestone sea, as testified by the fossils which occur in the bands of limestone associated with the red sandstones and shales of the Thornhill basin. The similarity of these deposits to those of Ayrshire makes it probable that they were continuous, and that the inlet was soon converted into a strait which separated the upland region into two parts.

The central uplands then became an island, and the red sandstones and conglomerates which form the base of the

¹ For all these particulars I am indebted to Mr. Goodchild.

Carboniferous system can be traced all round it. They sweep over the high ground on the borders of Berwick and Haddington, and seem to have covered the whole of the Lammermuir Hills, but the central uplands of Lanark, Peebles, and Selkirk may have remained above water during the greater part of the period. There is, indeed, no evidence that they were ever submerged. The Calcareous sandstones are clearly shore-beds deposited on an uneven and irregular surface, and it would be very unsafe to assume that those at the higher levels must have been succeeded by the whole series of Carboniferous rocks which are found to the north or south of such tracks. It is probable that the sandstones represent higher and higher parts of the series as they near the higher ground, and that the conglomerates which fringe the Carboniferous rocks were formed on the slope of a sinking coast-line. There is, indeed, positive evidence in the south of Edinburgh that the whole of the beds below the Limestone group have thinned out, for south of Magbiebill an outlier of the limestone rests directly on the Lower Old Red Sandstone. Here, therefore, more than half the thickness of the Scotch Carboniferous system has died out against the slope of the southern uplands, so that it becomes highly probable that this hill region was above water till the close of the Limestone epoch, and if the Millstone Grit was formed during a slight upheaval, as many think, the land area would then have been somewhat enlarged.

It may be advisable to point out that the existence of the great boundary fault does not invalidate the above conclusion. If this were a post-Carboniferous dislocation it might be said that the ground on the upcast side was so much lower in Carboniferous time that it might have been covered by the limestones; as a fact, however, the limestones and coal-measures are not broken by the fault, and in the south of Edinburgh it seems to have given rise to a steep bank

or cliff, against which the limestones and their associated strata were laid down.¹

Lastly, can we gather any evidence regarding the northern limits of the Carboniferous sea and the probability of continental land existing in that direction? There is, in the first place, good reason to believe that land existed outside the north-west portion of Ireland: in Galway and Mayo the Carboniferous limestones are everywhere bordered by conglomerates, and it is stated that these are on the horizon of the Upper Limestones; that near Oughterard the conglomerates and sandstones graduate eastward through shales into limestones along the line of strike, and that in other localities the limestones themselves contain pebbles up to the size of a bean.

The northern part of Donegal seems to have formed part of this land, for the Carboniferous rocks occurring in South Donegal and North Tyrone seem to pass northward into shales and sandstones.

On the west coast of Scotland, in the district of Morvern (Argyleshire), there is a small tract of Carboniferous sandstone let down by faults among the older rocks. This is believed to be of Coal-measure age, and was probably laid down in a gulf which penetrated the northern mass of land between Donegal and the Highlands of Scotland; we may suppose, therefore, that a similar gulf existed in Lower Carboniferous times, but a smaller and less extensive one.²

There is every reason to suppose that the Highlands were land throughout the Carboniferous period. I am informed by Mr. H. M. Cadell that the oil-shales of the Lothians are mostly replaced by grits and sandstones in the north of Fife, and that everything indicates an approach to land in that direction. Indeed, the persistent recurrence

¹ "Mem. Geol. Surv. Scotland, Expl. of Sheet 24," p. 17.

² By mistake it has been carried too far north in the map, Plate IV.

of shallow and fresh-water conditions throughout the Scottish Carboniferous series proves the neighbourhood of land, and leads to the conclusion that the area of the Devonian Lake Caledonia was converted at this period into a land-locked gulf which stretched north-eastward into continental land, and was only connected with the more open sea by narrow channels between the mainland and the islands above indicated. We may reasonably suppose that many rivers emptied themselves into this gulf, especially at its north-eastern end, and the nature of the deposits indicates that the subsidence was at times more than counterbalanced by the amount of material brought down by the rivers, so that the eastern part of the gulf was sometimes silted up and converted into tracts of low swampy land, enclosing large sheets of water, which were sometimes fresh, sometimes brackish, and only occasionally invaded by the sea.

2. Geographical Restoration.

The evidence for most of the coast-lines delineated on Plate IV. has been amply discussed, and it only remains to show reason for the lines to the east and south of England, and to give some account of the conjectured extent of the continent which lay to the north of the British Carboniferous sea.

The entire absence of Carboniferous rocks over the whole of the Scandinavian peninsula, except the extreme south of Sweden, renders it highly probable that this area formed part of the northern continent, and was united to the Scottish Highlands; the southern border of this land seems to have crossed the centre of Denmark, and a prolongation of this line would strike the coast of Yorkshire. Professor Hull suggests that it trended south-westward and joined that of the land which lay over the midland

counties of England, but there is really no evidence for this, and I think it is more likely to have had an outline such as that shown on the map, broken into a series of bays and estuaries, like that in which the Scotch measures seem to have been formed.

As there was evidently land to the north-west both of Scotland and Ireland, and as this was probably united to the Scoto-Scandinavian land, it is evident that the greater part of the North Atlantic must have been land at this time. When, moreover, we remember that no rocks of Carboniferous Limestone age have yet been found in any part of Iceland or Greenland, nor in any part of northern Canada, nor in the Arctic regions south of Grinnell Land (where it does occur), the facts seem to be greatly in favour of Professor Hull's view that at this period a large continent occupied the whole area of the North Atlantic, and extended from Finland on the east to the Rocky Mountains on the west. We cannot attempt to define its southern border across what is now the Atlantic Ocean; this, of course, must ever remain a matter of pure speculation, but it is puerile to make this a ground of objection to Professor Hull's hypothesis.¹ Those who have adopted the theory of the permanence of continents and of oceans throughout all geological time are naturally biassed against the existence of an Atlantic continent at any period, but those who think that continents may last long without being absolutely permanent see no reason why large parts of the Atlantic region should not have been land more than once in the course of geological time.

Professor Green has published a representation of Lower Carboniferous geography which differs in some important particulars from Professor Hull's, and from the restoration I have attempted in Plate IV. There are two

¹ "Physical History of the British Isles," 1880, p. 37, and "Trans. Roy. Dub. Soc.," ser. ii. vol. iii. p. 305.

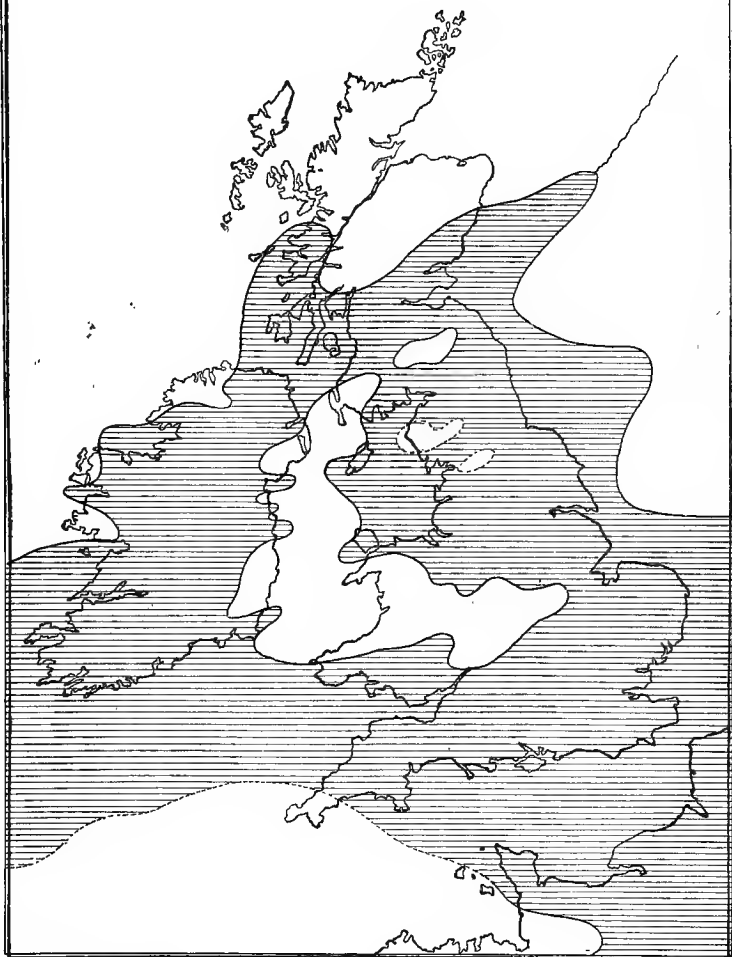


PLATE IV. GEOGRAPHY OF THE LOWER CARBONIFEROUS PERIOD
(LOWER SHALE AND LIMESTONE EPOCH).

features in his map¹ which do not seem to be in any way warranted by the facts. In the first place he unites the land which lay off the north-west of Ireland with that of the southern uplands of Scotland, and makes the Scottish Carboniferous basin open north-westwards into the Atlantic. Probably he would now be inclined to alter this part of his map, for there is certainly much more reason for connecting the North Irish land with that of the Scottish Highlands than with the southern uplands, and the probability of such a connection stands altogether apart from the question of continental land in the North Atlantic.

In the second place he shows continuous land, not only from the east across the centre of England, but from Wales south-westward to join a mass of land between Ireland and France, so that the sea which covered the south of England is depicted as having no connection whatever with that which covered Ireland and the north of England. Now this is hardly probable; that land may have existed to the south of Ireland I am prepared to admit, but there is no evidence for connecting it with the central barrier, while the close correspondence between the deposits of South Ireland and those of South Wales and Devon is quite against such a view and in favour of a continuous water-space between them. The preponderance of mechanical deposits, and the absence of any thick limestones in the Carboniferous series of Devonshire, points to deposition in a muddy sea which received the sediment brought down by large rivers draining continental land. This land could only have been to the west or south-west, and the overlap of the Culm-measures on to the Petherwyn Beds in Cornwall makes it probable that the shores of this land were not far distant, and may even have traversed part of Cornwall. More information, how-

¹ "Coal, its History and Uses," 1878, p. 38.

ever, is required before more than the general position of this land can be indicated. Thus until recently it was supposed that the Lower Carboniferous series was not represented in Brittany. Dr. Ch. Barrois,¹ however, has shown that certain slates and sandstones, which were previously regarded as Devonian, are really of Carboniferous age. They are based on conglomerates and volcanic rocks, and are overlapped southward by the Coal-measures, which rest on the Lower Devonian near Quimper. Land, therefore, existed in the south of Brittany during Lower Carboniferous time, but whether it was an island or a promontory from a western Atlantic continent we cannot yet decide.

The sea which lay over so large a part of what are now the British Isles stretched eastward through the north-east of France, Belgium, Germany, Poland, and Russia, covering, therefore, a large part of the present continent of Europe, and thence extending toward the North Pole by way of Bear Island and Spitzbergen, but it seems to have been bounded on the south by a more or less continuous belt of land through France, Switzerland, Bavaria, Bohemia, and Hungary.

Thus it seems clear that the sea in which our Carboniferous beds were deposited was not an open sea or ocean, but a land-locked sea, comparable, to some extent, with the Mediterranean of the present day; it was studded with islands of various sizes, its coast-line formed a series of gulfs and promontories, and it communicated with other seas by means of one or more narrow straits like the Straits of Gibraltar.

¹ "Bull. Soc. Géol. de France," ser. iii. t. xiv. pp. 661, 665.

3. Physical Conditions indicated by the Successive Deposits of the Period.

The Carboniferous rocks differ in certain respects from those of the preceding and succeeding systems, and they exhibit characters which can only have resulted from a general uniformity of physical conditions having prevailed over very large areas of the earth's surface. The same general succession of deposits is met with, not only over the whole of the British Islands, but over the greater part of Northern Europe and of central North America. Furthermore, the fauna and flora of the Carboniferous rocks are everywhere similar, and are everywhere persistent throughout a great thickness of strata. Of the marine fossils a few species are indeed confined to the lowermost beds, and a few to the highest marine beds—to beds, in fact, which were formed when the physical conditions were undergoing a change, and when the forms would necessarily be most liable to variation; a few other species—those, namely, which were the chief contributors to the formation of the limestones—are naturally most abundant in those limestone masses; but by far the larger number of species have a very great vertical range, many of them extending from top to bottom of the marine series, and even appearing in the essentially freshwater and estuarine strata above and below, wherever the temporary prevalence of marine conditions led to the formation of limestone.

As regards the process of sedimentation which went on in the central sea which covered the northern part of England, Professor Green has given an account, from which I extract the following:¹ “This Mediterranean sea had a fringe of shallow water around its margin, and deep depressions in its central portion. Round its edges deposits were

¹ “The Yorkshire Coalfield,” by Green and Russell, “Mem. Geol. Survey,” p. 24.

formed, mainly of mud and sand, though every now and then calcareous animals established themselves in sufficient numbers to give rise to beds of limestone. At a certain distance from the shore all the sediment sank down to the bottom, and beyond this limit the water was bright and clear, and the only deposit consisted of accumulations of the hard, calcareous parts of marine animals which are now pure limestone.

“In the deep hollows the deposits of limestone reached a great thickness; over the ridges which parted the hollows it was not so thick. This will explain how it is that the Carboniferous Limestone shows such great variations in thickness at different spots. The growth of the limestone gradually filled up the deeper parts of the sea, and at last the area became as shallow throughout as it had been originally only at its edges. The mixed deposits of sandstone, shale, and impure limestone, which had at first been confined to the neighbourhood of the shore, now extended themselves over nearly the whole marine tract, and the deposition of the Yoredale rocks began. . . .

“After a time a further important change took place. Either by the outlets becoming blocked up, or by the upheaval of a portion of the bottom, the land-locked area in which the lower marine portion of the Carboniferous rocks was deposited became cut off from communication with the open ocean . . . and converted into a fresh-water lake or a large estuary which received the waters of rivers flowing from the north, east, and south.¹ In this freshwater, or brackish area, the Millstone Grit and Coal-measures were deposited. When the water was at its shallowest, currents piled up banks of sand, or drifted coarse materials over the bottom, and shot them down into hollows,

¹ It would be better described as an immense delta or fenland, including many large lagoons and wide channels, surrounded by swamps which were never much above the level of the sea.

and thus formed lenticular beds of sandstone, or washed down and spread out pre-existing sandbanks, and gave rise to more regular sandstone beds. When the depth was greater, only fine mud was brought into the water, which settled down into more regularly bedded and uniform deposits of shale.

“The subsidence which allowed of the growth of the mechanically-formed deposits did not go on without interruption. Every now and then a pause occurred, and whenever this happened, the water became filled up, and there was a tendency to the formation of low, swampy flats.” He proceeds to point out that wherever a land surface was formed, vegetation quickly sprang up, and furnished the material for beds of coal. When these swampy flats were again submerged, fresh deposits of mud and sand covered the rich, carbonaceous soil, and entombed the trees and plants which grew in it.

Such, according to Professor Green, is a brief sketch of the submarine changes attendant upon the gradual deposition of the Carboniferous rocks of Yorkshire, and it is applicable to all other regions where a similar series of beds is found. As far as the earlier members of this series are concerned, there is nothing very remarkable in their mode of formation. They are simply masses of limestone, shale, and sandstone which can be paralleled by similar groups in other geological systems; but the upper members were accumulated under conditions which have been much less frequently repeated during geological time—conditions, indeed, which have never prevailed again in the European area to the same extent as they did in the Carboniferous period. It will, therefore, be worth while to describe these conditions a little more fully, and to see what conclusions may be drawn from them as to the general state of physical geography towards the close of this long period.

Professor Green elsewhere points out that the great series of beds which compose the divisions of the Millstone Grit, the Lower and the Middle Coal-measures, have so many common characteristics "that it is impossible to resist the conclusion that they were all three formed under substantially the same conditions, and that these conditions were altogether different from those which gave rise to the Carboniferous Limestone and the Yoredale rocks."¹ He thinks the change was caused by the blocking up of the communications between the inner and the outer sea, so that the former was converted into a large freshwater lake, but though this might account for the succession in the principal English and Scotch coalfields, it is far too local an explanation to account for the Irish, French, Belgian, and other European coal-measures.

In the first place let us consider the formation of the Millstone Grit, which consists principally of coarse sandstones, the grains of which are mostly angular and very little worn, and are sometimes of very large size. The sandstones are in fact coarser than those which occur in the Yoredale Beds below or in the Coal-measures above, and Professor Green remarks that the Upper Carboniferous series exhibits a gradational change in the texture of its sandstones from the Millstone Grit upwards. The Millstone Grits are not only coarse and massive, but are remarkably persistent over large areas. "In the Lower Coal-measures sandstones still play an important part; but as a rule they are neither so coarse nor so strong as those of the Millstone Grit, and they vary much more from place to place both in thickness and texture. Throughout a large portion of the Middle Coal-measures thick sandstone beds are conspicuous by their absence, and when such beds do occur, they are, with very few exceptions, fine in grain; they are also markedly local, and can seldom be traced

¹ "Coal, its History and Uses," 1878, p. 50.

continuously for more than a few miles" (op. cit., p. 60).

Now the persistence of the coarse-grain sandstones and the impersistence of the finer-grain beds is just the opposite of what might be expected, and is indicative of some special conditions during the formation of the Millstone Grit. Such widely-distributed and coarse-grained sandstones can hardly have been deposited during a continuance of the subsidence which led to the formation of the underlying shales and limestones; moreover, the thickness of the grits does not increase in the direction of the mainland, but is greatest in the south-western part of what may be called the central basin, where the Yoredale group is also the thickest.

The distribution of the grits, indeed, is such as to suggest that the materials were derived from the detrition of the land which formed the southern shore of this central basin, and the position of which has already been indicated. Thick lenticular masses of Millstone Grit occur both on the north and south sides of this land tract, the centre of one great mass being in Lancashire and that of another in the Bristol coalfield. From the Burnley coalfield, where the sandstones alone are over 2,000 feet thick, the grits thin away to the north-east through Yorkshire and Durham, and to the south-east through Derbyshire, but less rapidly to the south, being still thick and coarse in North Staffordshire, within thirty miles of the shore-line. Moreover, in the extreme north-east (Northumberland) their texture is so fine that they are actually less coarse than some of the Lower Carboniferous sandstones of that area; it is clear, therefore, that the material did not come from that direction. In the Bristol coalfield the Millstone Grit is 950 feet thick, and though the group thins in all directions, yet the coarse grits are conspicuous along the north side of the South Wales coalfield and in the Forest of

Dean, while in Gower and Devon they are represented by shales and fine-grained sandstones. In Ireland the Millstone Grit is seldom coarse-grained, but usually consists of flagstones which are never more than 650 feet thick. Such being the arrangement of these grits, it is difficult to see from what quarter they could have been derived, except from the central and eastern parts of the large island shown on Pl. IV., these parts being probably its highest and steepest districts.

Even then, however, we cannot understand the superposition of coarse sandstones upon a limestone and shale series without assuming that great changes took place in the physical geography of the area. During the formation of the lower limestones the brooks which drained this part of the land can hardly have carried any sediment to the sea, their waters must have been clear, and the rainfall must have been small; later on, however, they seem to have carried both mud and sand, and eventually their volume and velocity were so increased that they could transport coarse sand to very great distances. I see only one way in which such a change could be brought about, and that is by a general and considerable elevation of the area, raising the central parts of the island into those atmospheric regions where rain, frost, and wind are most vigorous and incessant in their action. The effects of upheaval in altering the character of the sediment deposited round the land would be greater in the case of a rocky island with steep slopes, which were prolonged beneath the surrounding sea, than on the mainland, where the mountain ranges would seldom be so close to the coast-line. In the latter case much of the sand would be deposited before the rivers reached the sea; but in the former the streams and torrents would not only be able to carry the sand to the sea, but the issuing currents would sweep it to some distance from the shore. Further, not only would the velocity

of the streams be increased with the increase of the rainfall, but as the area of the land enlarged and the depth of the sea became less, the sand would be carried farther and farther out over the sea-bottom, and would be arranged in sandbanks and shoals by the sea-currents. So far did this filling-up process go on, that parts of the sea-floor actually became shallow enough for the growth of terrestrial plants, and seams of coal occur in the highest part of the Millstone Grit of Lancashire.

There seems, therefore, good reason for supposing that the Millstone Grit marks a general and rather rapid upheaval of the whole British region, but it is quite certain that this movement exhausted itself before the commencement of the true Coal-measures, for these were undoubtedly formed during a gradual and general subsidence, and it is interesting to note how this subsidence is attended by a reverse change in the texture of the sandstones (see p. 92). As Professor Green remarks,¹ "The gradual subsidence and the ceaseless wear and tear of atmospheric denudation gradually lowered the elevated tracts, so that they were acted on less vigorously by subaerial agencies; at the same time the rivers, descending by gentler gradients, lost by degrees the power of moving coarse heavy detritus. So, with the lapse of years, the amount of sandy sediment gradually grew less and less, and sandstones formed a gradually decreasing item in the deposits in process of formation."

In spite of the submergence, however, large tracts of the sea-floor were repeatedly silted up and converted into marshy flats, for the best authorities are agreed that coal-seams are land-growths, though the tracts on which they were accumulated were evidently never raised much above the mean level of the sea. It is not improbable that the coal-seams mark pauses in the progress of the subsidence,

¹ "Coal, its History and Uses," p. 61.

while the occasional occurrence of a marine band indicates a time when the downward movement was more rapid than usual, causing the waters of the open sea to overflow the wide alluvial levels. Lastly, from the overlap of the Coal-measures, and from the wide extension which individual coal-seams attain in the Middle Coal-measures, we may infer that the area of the marshy flats on which the coal-plants flourished was being continually increased at the expense of the higher and drier inland districts which they surrounded.

We know what a wide extension the Coal-measures had over the British area, and that what are now separate basins or coalfields were originally connected and continuous areas. But this great development of Coal-measures is by no means peculiar to Britain; coalfields are found in many parts of the Continent, notably in France, Belgium, Germany, and Russia, everywhere presenting a similar aspect and a similar succession of measures, making it certain that they belonged to one natural province or geographical area.

We must conclude, therefore, that over a large part of what is now Europe there existed vast tracts of alluvial land but little above the sea-level, the conterminous deltas, in fact, of the rivers which drained the surrounding land, just as Holland is the conterminous delta of the Rhine, Meuse, and other rivers. It is as if an area as large, or larger, than that covered by the Mediterranean Sea, were slowly silted up and converted into one enormous swamp. To bring about such a result there must have been many rivers of large size emptying themselves into this sea, rivers comparable to the largest which now exist in the world, and for the supply of such rivers the surrounding continents must have possessed mountain ranges comparable to those of America and Central Europe, and must have been watered by a copious rainfall.

Again, although the area of deposition was constantly widened by subsidence, yet the detritus brought down from the higher to the lower levels was always sufficient to counterbalance this depression. Further, it would appear that all this material must have been obtained from the surface of the land, and transported by fluvial agencies, for there could have been very little coast-erosion round the borders of this land-locked sea.¹ Rain and frost must therefore have been constantly at work on the surface of these continents, disintegrating and dislodging the rocks of which they were composed, while the rivers would be chiefly employed in carrying off the detritus so prepared, for the continued depression would have diminished their erosive capacity by lowering the slope of their channels.

It is a geological axiom that deposition is a measure of detrition, and we may see, therefore, in this enormous mass of sediments a measure of the detrition which took place, and of the amount of material removed from those portions of the great Carboniferous continent which drained into that sea whose limits have been indicated above.

Now the time necessary for the progress and consummation of all these natural operations must have been enormous, and yet the geographical changes must have been so slight and so slowly accomplished throughout this great length of time that they did not materially alter the relative positions of land and sea, or interrupt the process of swamp formation; this, then, is the peculiar and remarkable point in Carboniferous history which I desire to impress upon the reader's mind, that it was a period of internal quiescence, a period in which terrestrial disturbances were at a minimum, and consequently when the surface agencies of change were able to continue their course of action to a greater extent than usual. Now their course of

¹ It is very probable that, as in the modern Mediterranean, the rise and fall of the tide in this sea was very small.

action is such, that if they were allowed full play, and were not checked or balanced by uplifting movements, every continent would gradually be reduced in height, and worn down to a level but little above that of the sea, while the surrounding waters would be choked and shallowed by the materials poured into them from the wasting land. It would appear, therefore, that the Carboniferous was a period when this theoretical result was more nearly approached than it ever has been before or since; when the continents were gradually lowered by the combined action of detrition and depression, the area of high ground being continually diminished, but the area of low-lying, swampy ground at or about the sea-level being continually increased, so that at the close of the period similar physical conditions as to climate, rainfall, surface slopes, soil and vegetation, seem to have prevailed throughout the greater part of the northern hemisphere.

Such a condition of affairs will account for the remarkable uniformity of life which prevailed throughout the Carboniferous period, a fact to which attention was called on p. 89. The geographical changes being so slight, and during the earlier portion of the period consisting chiefly in an extension of the marine areas at the expense of the land, we may suppose that the seas retained their same relative positions and connections throughout an enormous lapse of time, and that the denizens of these seas spreading far and wide through the broadening water-spaces found everywhere a similarity of conditions that enabled them to flourish and survive without change or variation. Later on, when the seas were shallowed by the continued deposition of material derived from the continents, and when the higher land was everywhere encircled by a wide belt of low-lying jungle and swampy ground, intersected by sluggish water-ways and lagoons, the conditions would be exactly those where nature would present a monotonous

and uniform aspect, and where the plants and animals which had established themselves would be likely to maintain their existence unchanged so long as the same conditions prevailed.

In this way it seems possible to explain the widespread uniformity of Carboniferous deposits and the remarkable persistence of Carboniferous forms of life,—phenomena which make this period a unique portion of geological time. It is as if we were contemplating the close of one great phase of the world's history, when the forces and causes which had hitherto been operative were exhausted and quiescent, when evolution was nearly at a standstill, and the world was allowed a grand pause before entering on the mighty changes which were to commence a new order of things, and to give such a powerful impulse to the development and differentiation of the earth's inhabitants.

There now remains for consideration only the epoch of the Upper Coal-measures, which exhibit certain important points of difference from the measures below. The shales and sandstones are generally of red, purple, brown, or green tints; the clays are often red, or mottled red and green; the coal-seams are thin and less numerous; the fossil remains are entirely freshwater, and there are occasional beds of limestone which are not made up of organic remains, but are either compact and creamy-looking when freshly broken, or are porous and spongy in texture. All these circumstances are indices of an important change in the conditions of deposit.

Red and mottled clays occur in other formations under conditions which show them to be lacustrine deposits. The colouring matter of the sandstones is ferric oxide, every grain being coated with a thin pellicle of such oxide, as if the colouring matter had been deposited upon every grain as it came to rest at the bottom of a stagnant body of water. Now such an amount of iron oxide is not

likely to accumulate in waters which opened into the sea, but might do so in lakes and swampy tracts which were not traversed by any strong currents, and were never invaded by the sea-waters.

Professor Green, indeed, thinks that these beds were formed in lakes which had no outlet at all, and the waters of which were gradually concentrated by evaporation. He points to the limestones as having characters which resemble those of limestones formed by precipitation from saturated solutions, and such saturation is certainly almost an impossibility in a lake with an outlet.

There is another fact which tells greatly in favour of this theory, namely, that the Upper Coal-measures are frequently found to lie unconformably on those below, and the Middle measures have sometimes suffered a considerable amount of erosion before the upper group was deposited on them. Such a relation implies terrestrial movement, and probably an elevation of those districts in which it is found, and when we consider the enormous extent of nearly level ground which must have existed in the time of the Middle Coal-measures, it is easy to see that very slight uplifts would be sufficient to convert large areas into shallow lake-basins.

Moreover, the known geographical distribution of these red Coal-measures has considerable significance. They occur in all the Midland coalfields, as well as in Lancashire, Yorkshire, Cumberland, and Scotland; but the so-called Upper Coal-measures of South Wales and Gloucestershire are not red, neither is there any such group in Ireland or in Devonshire. It may, of course, be said that the true Upper Coal-measures are absent by denudation in these last-mentioned districts, but in South Wales the Coal-measure series is thicker than in any other district, if the upper group is deducted; and the fact remains that the red measures are only known to occur in the country

which lies to the north and east of the island barrier. Now a reference to the map (Plate IV.) will show that this area over which the red rocks occur is exactly that which is most likely to have been converted into a lake or group of lakes by a very slight geographical change. The sea had probably always been shallow at the northern and eastern ends of the central island, and a union of these to the mainland would completely enclose the area in question, isolating it from the other areas of deposition, and converting it into such a shallow lacustrine basin as the facts seem to indicate. Such appears to have been the last stage in the Carboniferous geography of the British area.

CHAPTER VII.

DYASSIC OR PERMIAN PERIOD.

1. Stratigraphical Evidence.

EXCEPT in the north-east of England the Dyassic rocks occur only in fragmentary strips and patches along the borders of the Coal-measure basins. This disconnected mode of occurrence is partly due to the overstepping of the Trias, under which many areas of Dyas are buried and concealed, and partly of course to the removal of large portions by erosion. Their limitation, however, to certain districts and their entire absence in the south of England are facts due to the conditions under which they were originally deposited. The Dyassic beds exhibit two distinct lithological facies, which may be called the eastern and western types; the latter being the more local and abnormal, while the former is similar to that which prevails in Germany.

A. The rocks of the eastern type are supposed to underlie the greater part of East Yorkshire, Lincoln, and Nottingham, and their outcrop forms a continuous strip of ground, between the Carboniferous and Triassic strata, from the coast of Durham, southward by Auckland, Ripon, and Pontefract, to the neighbourhood of Nottingham.

The beds are thickest and most purely calcareous in Durham, where they consist almost entirely of dolomite or magnesian limestone. The basement beds are soft sand and calcareous shale of variable thickness; the limestones

above are 450 feet thick, and the highest beds (proved in the borings at Middlesbrough) include deposits of rock-salt and gypsum.

In South Yorkshire the main mass of limestone is 270 feet thick, and there are marls and limestones above to a thickness of 140 feet; but in Notts all the beds are greatly attenuated, the total thickness near Mansfield being probably about 200 feet, of which not more than 100 are limestone, and parts of this are really calciferous sandstones. Near Nottingham it is still less, and seems to be on the point of thinning out when it is overlapped by the Trias.

A boring near Newark and about fifteen miles east of the outcrop at Mansfield is important as throwing much light on the lithological changes of the formation. This section proves that while the limestones remain about the same, the formation thickens eastward by an increase of the marls and shales, the calcareous marls at the base having a thickness of 118 feet, as compared with fifteen or thirty feet in Notts. A boring through the Trias at Owthorpe, in the south of Notts, proved the Dyas to be wanting there, and passed directly into Coal-measures. These facts show that, in Notts at any rate, the Dyas thins rapidly both southward and westward, whence we may conclude that land lay in both these directions, an inference which is confirmed by the collection of pebbles found in the basal breccia, which comprises not only pebbles of Carboniferous limestone and fragments of sandstone and shale from the underlying Coal-measures, but pebbles of slate, quartz, and quartzite, which have probably been derived from the rocks of Charnwood Forest.

B. Passing now to the western districts, we may select that of the Cumberland Plain or Vale of Eden as the most complete and important. Here and elsewhere on the west side of the Pennine chain there is very little lime-

stone, and the rocks consist chiefly of red sandstones with occasional beds of calcareous breccia. Between Carlisle and Penrith there are two massive sandstones, the lower about 1,000 feet, and the upper about 1,500 feet thick, separated by a zone of red shales. Near Appleby the lower sandstone contains thick beds of breccia (locally called brockram), consisting of pebbles derived from the Carboniferous limestone, and the red shales have at their base bands of magnesian limestone and impure coal.

On the west side of the Lake District there is another strip of Dyas, but the lower (Penrith) sandstone is not present, and the basal beds at St. Bee's Head consist of magnesian limestone with fossils (11 feet thick) resting on a thin breccia of limestone fragments.

Northward, in Dumfries and Ayr, rocks similar to the Cumberland sandstones are found occupying several basin-like depressions, and resting partly on Carboniferous and partly on the older rocks. In Nithsdale and the valley of the Ayr sheets of porphyrite and volcanic ash are interstratified with the sandstones, and even the stumps of the volcanic vents from which these materials were ejected can be identified.

Returning to England, small detached patches of Dyassic deposits occur at intervals round the coalfields of Lancashire, Denbighshire, Shropshire, Staffordshire, Warwickshire, and Worcestershire. The Lancashire beds resemble those of Cumberland, consisting of a red sandstone overlain by red marls, shales, and limestones, with fossils of the Magnesian Limestone type.

Denbigh and North Staffordshire exhibit rather a different type, the beds being similar in both districts, and consisting of dark red and purple sandstones, with red marls and bands of cornstone; these beds are only slightly unconformable to the Upper Coal-measures.

In the Shrewsbury, Bridgenorth, and South Stafford-

shire districts there is a similar set of beds, divisible into three stages, the middle one (from 200 to 400 feet thick) consisting of breccia and conglomerate, sometimes calcareous, and sometimes chiefly composed of felspathic materials—large blocks of felstone, syenite, and volcanic tuff occurring with boulders of quartz rock, limestone, sandstone, and slate; all these have probably been derived from the Archæan, Cambrian, and Silurian rocks that underlie the Dyas and Trias of the Midland counties.

Further south still the Lower Sandstones disappear, and at Church Hill, in Worcestershire, the breccia lies directly on the Coal-measures, the fragments composing it being very large and angular, and identifiable with rocks of Cambrian and Silurian age lying to the north-west. Small outliers of similar breccia rest against the Silurian of the Abberley Hills, and the most southerly is that at Haffield, at the southern end of the Malvern range.

This incoming of breccias southward with a thinning out of the lower beds is unequivocal evidence of a close approach to the southerly limit of the area in which these deposits were formed, and the breccias are also a proof that the shores were steep and rocky.

The only other districts in England where rocks of this age occur are, (1) Warwickshire, where they consist of red sandstones and marls, with occasional beds of calcareous breccia and conglomerate, the whole supposed to be nearly 2,000 feet thick, and (2) Anglesey, where similar beds to a thickness of 400 feet overlie the Coal-measures.

In Ireland three small patches occur in Ulster, fossiliferous magnesian limestone existing at Cultra, on Belfast Lough, and at Tullyconnel in Tyrone, and Boulder beds, with a limestone breccia at the base, rest on the Carboniferous Limestone of Armagh. The blocks in the Boulder beds are chiefly grits and sandstones derived from the Silurian and Old Red Sandstone districts that lie to the north-west.

2. Geographical Restoration.

In Chapter VI. the Carboniferous period was described as one of quiescence, during which the forces of terrestrial disturbance were in abeyance; but, as a calm precedes a storm in the atmosphere around our earth, and a great stillness often forebodes an earthquake, so in the earth's history a period of quiet deposition and rock-making has often been followed by a period of disruption and rock-destruction. Certain it is that the calm of Carboniferous times was followed by an epoch of great disturbance in the European and Atlantic areas, causing movements which produced very great geographical changes in the northern hemisphere, and resulted in the breaking up of the Carboniferous continents, and in the upheaval of the ground which had been covered by the Carboniferous seas.

At the close of the Carboniferous period there seem to have been important upheavals of land on either side of the great Atlantic continent. The Alleghany Mountains in America date from this epoch, as do also the series of domes, ridges, and faulted upheavals which make up the Pennine chain or "backbone" of England. It appears certain that the principal earth-throes, those which produced the more important disturbances of the Carboniferous rocks in Britain, occurred during the unrepresented period of time which intervened between the Coal-measures and the Dyas. The stratigraphical relations of the latter to the former make it clear that the disturbances, which bent the Coal-measures into the basin-shaped forms they now present, took place before any Dyassic strata were deposited. These movements resulted in the development of a double system of anticlinal and synclinal axes, one set running north and south, the other nearly east and west. It is impossible to say whether this double system of axes was formed simultaneously, or whether one set was

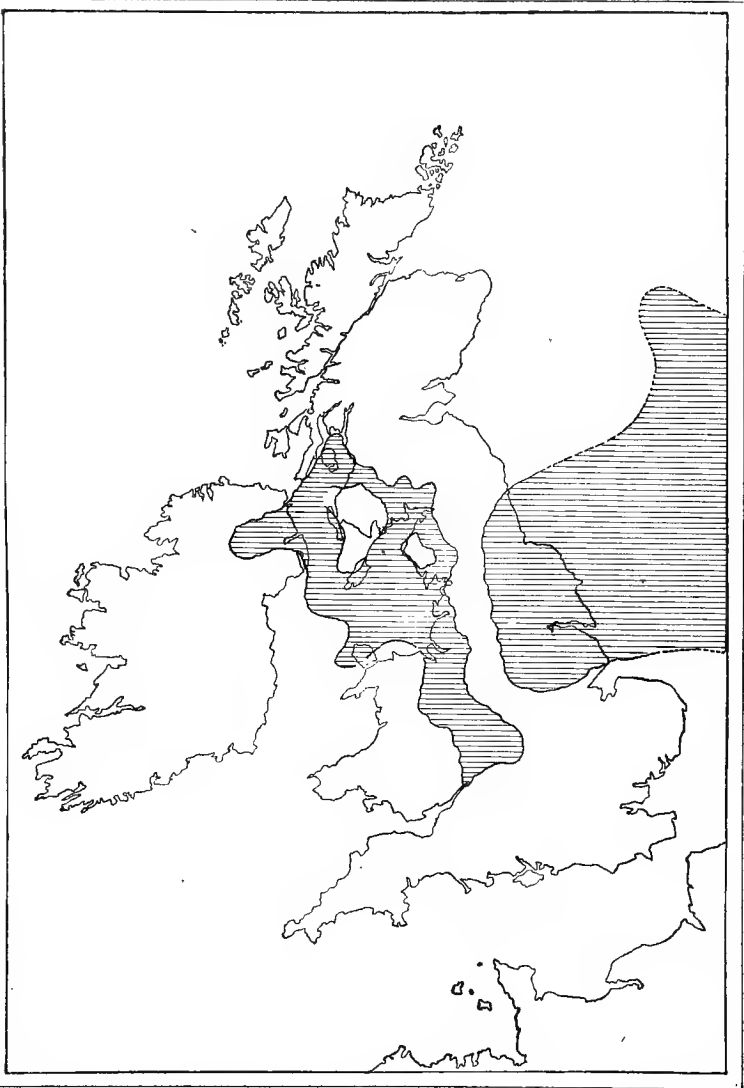


PLATE V. GEOGRAPHY OF THE DYAS OR PERMIAN PERIOD.

formed first and the second set by a separate and subsequent movement, but it is certain that the interference or combination of these axes has produced the broad basins in which the Coal-measures are now found.

The system of east and west flexures is particularly well marked in Ireland, the pre-Dyassic movements acting most forcibly over the northern and southern districts, and raising the whole central mass of country between them. In the south of England there is a set of ridges similar to those in the south of Ireland, passing from Devon and Somerset beneath the newer rocks of the southern counties into Belgium and the north of France. It is also very likely that the tract of Palæozoic rocks which underlies the east of England was elevated at this epoch.

Simultaneously with these upheavals it is very probable that the ancient Atlantic continent was broken up, submerged, and converted into an open ocean; the depression of this Atlantic area being in fact the proximate cause of the upheavals on either side. Such, according to Professor Hull, was the genesis of the North Atlantic Ocean,¹ and, apparently, it has never ceased to be an ocean from that time to the present day, though throughout the Mesozoic periods there was a large continuous tract of land to the west of England, of which Ireland, Wales, and Cornwall are now the sole remnants.

It may, in fact, be said that the rock-masses out of which Ireland, Scotland, and the greater part of England have been hewn, were now, for the first time, brought into connection as a compact mass of land. The greater part of this land region lay to the south and west, spreading from the north of France, through the south of England, to Wales and Ireland, and thence, by way of the Hebrides, to Scotland and the Border counties. It was not Britain,

¹ "Physical History of the British Isles," 1882, p. 44.

but a West-European continent, which presented a continuous front to the Atlantic, considerably to the west of what are now the shores of France and Ireland.

It is now time to seek for the boundaries of the seas and lakes in which the Dyassic sediments were deposited. The open Mediterranean sea of the Carboniferous period appears to have been converted into a large inland sea, like the Caspian of the present day, surrounded by a rocky and hilly continent, on which grew trees and plants of various kinds. Many of these plants are closely allied to those of the Carboniferous, but species belonging to the Yew and Fir tribes, which flourish on dry ground, preponderate over the reeds, ferns, and gigantic lycopodia which flourished in the Coal-measure swamps.

The western part of this inland sea stretched across the centre of what is now the North Sea, and covered a portion of north-eastern England, and its actual margin seems to have lain only a little to the west of the outcrop which now runs through the counties of York and Nottingham, curving round to the eastward beneath the south of Lincolnshire. If the Pennine range formed a continuous barrier in Dyassic times, its eastern slope must naturally have been the shore-line of the Magnesian Limestone sea, and such is now the prevalent opinion; but it is only fair to state that the geologist who first studied the uplifts of the Pennine range¹ came to the conclusion that they were post-Dyassic. Strong arguments were, however, subsequently adduced by other writers to show that he was mistaken, and it is perhaps desirable that the reasons for the view here adopted should be stated *seriatim*.²

1. The flexures of the South Yorkshire and Derby coal-fields are certainly pre-Dyassic, and as their major axes

¹ Hull, in "Quart. Journ. Geol. Soc.," vol. xxv. p. 171.

² See Wilson, "Geol. Mag.," ser. 2, vol. vi. p. 500, and Teall, vol. vii. p. 349.

are parallel to the central Pennine axis, we may safely assume that they were both formed at the same time.

2. After crossing the Millstone Grit area of central Yorkshire, the outcrop of the Dyas again passes on to Coal-measures in the south of Durham, showing that all the flexures between the two coal-basins were pre-Dyassic.

3. No Dyassic outliers occur at any distance west of the main escarpment, and no fragments of Magnesian Limestone have been found in the Triassic rocks, as might have been expected if that limestone had passed over the Pennine axis, and had been subjected to erosion in Triassic times.

4. On the other hand, fragments of Carboniferous Limestone are said to have been found both in the Dyassic breccias and in the Triassic sandstones, which would prove that this limestone had already been bared along the Pennine axis.

5. The Dyassic rocks on opposite sides of the Pennine range are very dissimilar, the thin local beds of magnesian limestone on the western side bearing no comparison with the massive dolomites of the eastern tract, while the red sandstones are essentially a feature of the western districts.

It might perhaps be doubted whether the range formed a complete barrier, and whether there was not communication between the two areas of deposition by means of a narrow strait across the centre of Yorkshire. The only piece of evidence in favour of such a communication is the occurrence of Magnesian Limestone fossils in the limestones of Lancashire and Ireland, but as both the eastern and western areas were uplifted portions of the Carboniferous sea, the same forms of life are likely to have remained in both, even if one was rapidly isolated by the upheaval of a barrier. On the whole, therefore, the

balance of evidence is against the existence of any connecting strait, and in favour of the view that the Pennine range then formed a continuous and lofty chain of hills reaching from Derbyshire to the Scottish border, so that the western Dyassic lake was entirely isolated from the waters of the inland sea to the east.

Neither can I see that there is any strong evidence for the existence of the east and west barrier-ridge through Cheshire, which is supposed by Professor Hull to have divided the western area into two distinct lakes. The differences between the Lancastrian and Salopian deposits are really unimportant, and are quite compatible with their having been formed in different parts of the same lake. The width of the ridge, as shown on Professor Hull's map,¹ is so small, that it is not likely to have been a permanent barrier, but it may have been a subaqueous ridge separating the lake into two basins, much as the Mediterranean is divided into two basins by the ridge between Sicily and Africa.

This lake then appears to have extended from Warwickshire and the Malvern Hills to the Firth of Clyde, a distance of 280 miles, with an extreme width of 100 miles, so that it was about the size of the modern Lake Huron. It spread over the counties of Warwick, Worcester, Stafford, Salop, Cheshire, and Lancashire, and over the eastern part of the Irish Sea. It encircled the Lake District, which must have risen as a rocky island out of its waters; it covered the valley of the Eden and Solway Firth, and arms of it ran up the valleys of the Nith and Annan, and probably for some distance up the Firth of Clyde, while westward a gulf extended into Ireland as far as Armagh and Dungannon in Tyrone. How far it reached westward and southward beyond Anglesey we have no means of

¹ "Physical History of the British Isles," pl. viii.

knowing, but there is no reason to suppose it extended far, for Wales and Ireland were doubtless connected by a tract of high mountainous land.

The slopes surrounding this lake seem in most places to have been steep, and the rivers running into it were consequently rapid, carrying down quantities of sand, and in some regions large stones and boulders, as in the breccias of the Midland counties. The size of the transported boulders in these breccias, their angularity, and the occasional striation of their surfaces, suggested to Professor Ramsay that they had been carried by floating ice. Many of the fragments can be identified with Welsh rocks, and it is highly probable that the Welsh mountains were then much more lofty than at present, and that snow may have accumulated on them in sufficient quantity to form glaciers. Some of these may have reached the level of the lake, and torrential streams bursting from others may have been equally active in carrying down the rock-fragments quarried from the frosty regions above.

On the northern borders of the lake volcanic forces came into play, and lava-flows with beds of volcanic ash were interbedded with the lacustrine sandstones (see p. 104).

From the thickness of the mechanical deposits in this north-western lake, and the rarity of magnesian limestones, we may infer that many streams and rivers ran into it, bringing a constant supply of fresh water and preventing the formation of chemical deposits. The north-eastern lake, on the other hand, seems to have suffered from evaporation and concentration; possibly, also, the waters poured into it contained a larger proportion of salts in solution. At any rate, there are good reasons for regarding the Dyassic dolomites as direct chemical deposits, although the process of precipitation cannot be imitated in our laboratories.

The analogy between the conditions of the modern Cas-

pian Sea and those which appear to have prevailed in the sea of the Magnesian Limestone has been pointed out by Sir A. Ramsay. Just as the Caspian is believed to have been originally connected with the Arctic Ocean, and as its fauna is really a marine assemblage, so also the inland sea which in Dyassic times stretched from England into Germany seems to have been isolated from the main oceans of the period, the introduction of new species and genera being thus prevented, so that the fauna was only a dwarfed and modified remnant of Carboniferous life.

Mr. E. Wilson suggests the following as the probable sequence of events in the north-eastern basin.¹ After indicating the formation of the basement sands, he says—“After a time the waters would become sufficiently saturated to cause dolomitic materials to be thrown down to some extent, which, commingled with the sand and mud, as also with the large supplies of ferrous carbonate likewise brought down by the rivers, would give rise to the blue-coloured plant-bearing dolomitic sandstones and shales of the Marl Slate series. During this stage, mechanical deposition predominated, on the whole, over chemical precipitation. . . . Somewhat suddenly (however) this state of things came to an end.² Chemical precipitation now began to predominate, and the formation of the white and yellow Dolomites commenced.” In the north this precipitation continued uninterrupted, but the intercalations of shale and marl in the southern part of the area point to the inflowing of large rivers from the land which then existed over the east of England. It was clearly these southern

¹ “The Permian Formation of N.E. England, Midland Nat.,” vol. iv.

² The change, as Mr. Wilson suggests, was probably due to progressive subsidence, which, by diminishing the altitude of the surrounding land, while increasing the area of evaporation, would tend to promote condensation of the lake-waters, and the consequent precipitation of mineral matter in solution.

rivers that brought down the argillaceous material of the Marl Slates and Middle Marls, derived doubtless from a wide surface of Coal-measures then undergoing destruction, while the streams from the west, being smaller but more rapid, may be credited with the introduction of the Yorkshire "quicksands."

CHAPTER VIII.

TRIASSIC PERIOD.

1. Stratigraphical Evidence.

THE lie of the Triassic rocks is different from that of any of the Palæozoic systems. In England their outcrop is nearly continuous from the southern to the northern coasts; in Gloucestershire it is very narrow, but it broadens out over the Midland counties, and stretches northward over tracts of considerable width on either side of the Pennine range. The one tract meets the sea in Durham, the other in Lancashire, but both must originally have extended much farther north, for detached areas of Trias occur in Cumberland and Dumfries, also in the north-east of Ireland, in the Inner Hebrides, and in the north-east of Scotland on the Moray Firth.

The Triassic strata are everywhere unconformable to the rocks on which they rest; they extend far and wide beyond the edges of the Dyassic beds, and run up many of our wider valleys as if the principal hill-ranges of England were then already in existence, as indeed they doubtless were. The Coal-measures and older Palæozoic rocks had been bent into troughs, basins, and ridges, and had suffered enormously from erosion and detrition before the Triassic beds were deposited upon them, so that in most parts of the country these beds rest upon a surface of erosion which had been previously formed across the tilted edges of the Palæozoic rocks.

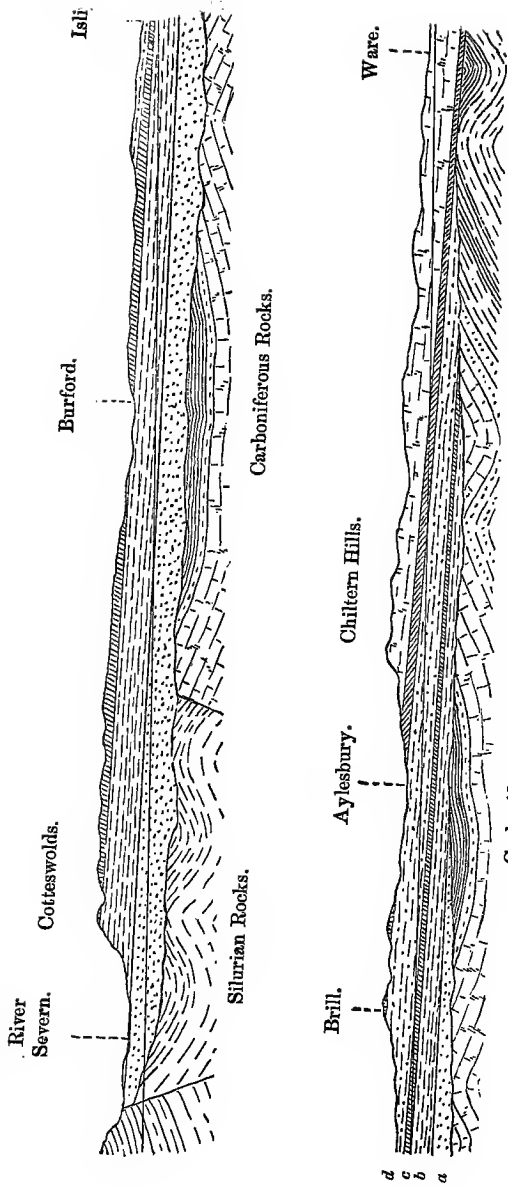


Fig. 3. Diagram-section to show the relations of the Paleozoic and Neozoic rocks under the Midland Counties.

- f. Chalk.
- e. Gault and Vectian Sands.
- d. Upper Jurassic.
- e. Middle Jurassic.
- b. Lias.
- a. Trias.

The manner in which the Trias, with the succeeding Jurassic and Cretaceous strata, rests upon a floor of Palæozoic rocks is shown in fig. 3. This is a section from the valley of the Severn near Gloucester, through the counties of Gloucester, Oxford, Buckingham, and Hertford, to the valley of the Lea at Ware. It does not pretend to be an accurate representation of the subterranean structure of the country in respect to details, for the Palæozoic rocks have only been touched at two places along the line of traverse, viz., at Burford and Ware. At the former place Coal-measures were found at a depth of 1,080 feet from the surface, the Trias being here only 424 feet thick, and belonging wholly to the Upper, or Keuper division; at Ware, Silurian rocks were found below the Gault, so that it is clear that the Trias and all the Jurassic strata must thin out against the slope of Palæozoic rocks indicated in the diagram, though how far eastward each division extends is not yet known. It should also be stated that the flexuring and faulting of the Palæozoic rocks represented in the diagram is quite theoretical, and is only intended to convey a general idea of the way in which these rocks are supposed to lie.

In Ireland the Trias occupies a similar position, resting on an uneven floor of Ordovician and Carboniferous rocks, and being covered conformably by Jurassic and Cretaceous strata. In Scotland also its stratigraphical relations are similar.

The British Trias is divisible into two series, the lower being usually called the Bunter, and the upper the Keuper, from their German correlatives. There is no representative of the marine member of the German Trias, and the British Trias is certainly not a marine formation.

The Bunter Beds occupy three distinct areas of deposition: one in Devonshire, which probably extends some way beneath Dorset and the English Channel; a larger one in

the Midland counties, and stretching thence through Cheshire into Lancashire; and a third on the eastern side of the Pennine chain in Nottingham, Lincoln, and York, but this seems to have been connected with the Midland area by a narrow neck between Nottingham and Derby. The Southern and Midland areas were separated by a broad ridge of Palæozoic rocks, which was not submerged till the epoch of the Keuper, or Upper Trias.

In Devonshire the Bunter consists of coarse breccias and sandstones, the blocks and stones in the former having been derived from the neighbouring Devonian and Carboniferous rocks. They have evidently been accumulated under the action of rapid currents, being obliquely and irregularly bedded, so that though their thickness appears to be about 1,000 feet, their real depth at any one place may not be more than 500 feet. Over these coarse-grained beds are some 400 feet of marls and sandstones, succeeded by 80 feet of pebble beds, which are sometimes compacted into a conglomerate.¹ In many places the pebbles consist of Devonian limestone and sandstone, like those found in the underlying breccias, but elsewhere, and especially at Budleigh Salterton, there are pebbles of sandstone and quartzite which are different from any Devonshire rocks, but some of which are identical in character and fossil contents with certain rocks occurring in Normandy and Brittany, viz., the Grés Armoricaïn and the Grés du May.

It has, therefore, been surmised that these pebbles were brought either from France or from land connecting France with Cornwall, and since destroyed. This inference, however, has been somewhat weakened by the finding of similar pebbles in the Trias of Staffordshire, and even if the

¹ These are placed by Mr. Ussber in his upper division of the Devonshire Trias; but as the whole series is continuous, I prefer to treat them with the lower beds, as being comparable to the Bunter pebble beds of the Midland counties.

pebbles did originally come from the southward, it is by no means certain that they were transported from their original source in Triassic times. On this point Mr. H. B. Woodward remarks: "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."¹

The Bunter of the Midland counties consists of bright red and yellow sandstones with a central zone of pebble beds, and it is a remarkable fact that these pebble beds are more constant and have a wider extension than the sandstones above and below. Each division varies much in thickness, but the whole attains a maximum thickness in Cheshire of 1,800 feet; it is nearly the same in Shropshire, but thins southward through Worcestershire, and dies out on the east side of the Abberley Hills. Thence the subterranean boundary of the Bunter probably passes eastward through Warwick to the neighbourhood of Rugby, and thence northward into Leicestershire. The lower sandstones thin out in Staffordshire along a line from Dallaston and Stafford to Wolverhampton; the upper sandstones die out a little further east and north-east, so that in Leicestershire and Derbyshire only the pebble beds remain. In the Nottingham district the Bunter division is never thick, the upper sandstones being absent, the lower sandstones being from 25 to 100 feet, and the pebble beds being about 300 feet thick near Nottingham; they can be traced as far as Doncaster, but the pebbles become fewer and smaller toward the north, and the rock seems to pass into an orange-coloured sandstone, which can be traced as far as Ripon. •

¹ "Geology of England and Wales," second edition, p. 239.

The same is the case with the pebble beds in Lancashire; near Liverpool they consist of reddish brown pebbly sandstones, and are more than 600 feet thick, but the pebbles are small and scattered, and the group is said to die out between Ormskirk and Preston. In Ireland (Antrim) certain red and yellow sandstones are referred to the Bunter division, but no beds of this age have been recognized in Scotland.

Observations on the lithological characters of these sandstones and pebble beds have disclosed several important facts. Certain beds of friable sandstone have been described by Dr. Sorby and Mr. J. A. Phillips, under the name of "Millet-seed beds," the grains of quartz and felspar of which they consist being so completely worn and rounded that the disintegrated sand flows through the fingers as easily as seed or shot. Such sandstones are frequent in the Lower Bunter, and occur also in the upper division. Ordinary sandstones consist of more or less angular grains (see p. 4), and Mr. Phillips, after having examined a number of modern sands, states that "none of them, excepting such as had long been subjected to the wearing effects of wind action, were found to resemble those of the Millet-seed sandstones in having all their grains reduced to a pebble-like form. Among these the grains of blown desert-sands most completely resemble those of millet-seed sandstones."¹ From these facts we may infer that such sandstones are of æolian formation, and that during the epoch of the Bunter Beds large desert tracts, with their usual accompaniment of blowing sands, existed in the British region.

The pebble beds have been studied by Professor Bonney and Mr. W. J. Harrison. The majority of the pebbles consist of vein-quartz or quartzite, and Professor Bonney finds that the quartzites differ from any English rock that

¹ "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 27.

he is acquainted with, but that they closely resemble the quartzites of the Highlands of Scotland, pebbles of which are common in the Old Red and Lower Carboniferous conglomerates of central and southern Scotland. He has also found pebbles of a quartz-felspar grit, which can only be compared with the harder parts of the Torridon sandstone, so that he thinks the currents which carried the pebbles came from the north.

Mr. Harrison, however, argues that the pebbles have been derived from the Palæozoic rocks which underlie the Trias in the Midland and Eastern counties. He points to the fact that the pebbles are largest in the Midlands, and decrease in size as the beds are traced northward, and he has also found quartzites which contain Devonian fossils similar to those in the Budleigh Salterton pebbles. These are undoubtedly strong arguments against the northern derivation of the pebbles, at any rate against the idea of their having all been transported from the north in Triassic times.

It is possible, however, that both observers may be right, and that the conflict of opinion may be more apparent than real. Professor Bonney rests his opinion chiefly upon the remarkable correspondence of the quartzites with certain rocks which only occur *in situ* in Scotland, but he admits that they are not likely to have been derived directly from these rocks in Triassic times. In point of fact, they may have had more than one resting-place before reaching their present location; some of them may have been primarily embedded in the Lower Old Red Sandstone, and may from this have been washed into the Upper Old Red and Carboniferous conglomerates. Now the latter are known to contain rocks of Scotch origin as far south as the Isle of Man, Westmoreland, and north-west Yorkshire. It is quite possible, therefore, that such pebbles may have been carried as far south as Derbyshire, and may, for ought we

know, be exposed beneath the Trias in the south of Derbyshire.¹ Quartz and quartzite are exactly the rocks which would survive long transportation and repeated transference from one formation to another, in which process the more destructible Scotch rocks would be destroyed.

We must therefore confess that our present knowledge does not enable us to arrive at any definite conclusion as to the exact position of the strata from which the pebbles of the Bunter conglomerates were derived. It is certain, however, that, whether they came from the north or the south, they can only have been distributed over the area they now occupy by the action of strong currents. What currents these can have been will be discussed in the sequel.

Coming next to the Keuper, or Upper Triassic beds, we find that these have a much wider extension than the Bunter beds. There is generally a certain amount of unconformity between the two divisions, the surface of the Bunter being often uneven and eroded, and the base of the Keuper in the Midland counties being always a breccia, pebble bed, or conglomerate. Over this base there are red, yellow, and white sandstones, and these are succeeded by flaggy sandstones and sandy marls passing up into red marls with beds of rock-salt and gypsum.

The Lower Keuper sandstones are generally soft and fine-grained, often micaceous and laminated, and frequently current-bedded. There are, however, some beds of coarser sandstone with worn and rounded grains, which may have been wind-borne sands. The red and brown flaggy sandstones, which are generally known as "the waterstones," exhibit clear signs of having been deposited in the shallow

¹ It is more likely perhaps that the exposures of the Carboniferous pebble beds lay more to the south-east, beneath Northampton and Huntingdon, as Lower Carboniferous sandstones occur beneath the Trias near Northampton.

waters of a lake. Ripple-marks, sun-cracks, rain-prints, worm-markings, and the footprints of reptiles are common on their surfaces.

The red and mottled marls are such as would be formed in the deeper parts of the lake, and they sometimes include beds of sandstone, which contain remains of plants, fish, and small crustacea (*Estheria*). The thick beds of rock-salt and gypsum which occur in the marls attest the saline nature of the lacustrine waters.

The Keuper deposits, like those of the Bunter, are thickest in Cheshire, where they are believed to be over 3,000 feet thick. Thence they seem to thin in every direction, but most rapidly to the south and south-east. In Worcestershire the Keuper is only about 900 feet thick, in Gloucester and North Somerset it is much less, and is in some places only represented by shore-beds consisting of sandstone and conglomerate, the pebbles and grains of which are held together by a dolomitic cement, whence it is known as the Dolomitic conglomerate. Elsewhere there are sandstones and marls from 200 to 400 feet thick, the latter containing bands of red and grey limestone, the material of which has clearly been derived from the Carboniferous Limestone. In West Somerset and Devon the marls and sandstones again thicken to nearly 1,500 feet.

If we proceed south-eastward from Cheshire, we find the Keuper beds diminished to less than 1,000 feet in South Staffordshire, and to about 700 feet in Warwickshire; while borings near Northampton disclose the very eastern limits of the formation, its thickness there varying from 24 to 82 feet. The Gayton boring is especially interesting, for beneath 60 feet of red Keuper marl and sandstone 12 feet of breccia was found, consisting of large blocks of carboniferous limestone and sandstone embedded in a sandy matrix. Under it was 9½ feet of marl and shale, which rested on an eroded surface of a limestone belonging

to the Lower Carboniferous series. Such a breccia can only have been formed in close proximity to a shore-line, and the blocks are probably the débris of a cliff that overhung the waters of the Keuper lake.

Southward the Keuper marls and sandstones are known to pass beneath Oxfordshire, where their thickness is about 400 feet, and it is highly probable that they stretch continuously through Berks and Hants, and beneath the English Channel into Normandy, where there is a small area of Trias, consisting of conglomerates, sandstones, and marls. In Jersey also there is a small patch of conglomerate which is believed to be Triassic.

Whether Trias exists beneath the London Basin is a moot point; because it is not yet settled whether the red sandstones and marls which have been found in the deep borings at Richmond, Crossness, and Kentish Town belong to this formation or to the Old Red Sandstone. The red and yellow sandstones of the Trias and the Upper Old Red are certainly very similar to one another, but it may be observed that no thick deposit of red marl, such as forms the mass of the Keuper, has been met with in these borings, although the red strata traversed at Richmond were over 200 feet thick, and those at Kentish Town 188 feet. Further, the Keuper Sandstone group generally maintains a uniform character over considerable areas, whereas the characters of the strata below London vary largely; at Richmond they are soft variegated sandstones and marls, at Crossness hard quartz sandstones with red and grey shales, and at Kentish Town variously coloured sandstones and clays, with a thin bed of conglomerate. These variations might of course be due to the proximity of a shore-line; but, considering all the circumstances, and especially the great distance of the sites south-east of any place where Trias is known to exist, I incline to the opinion of Professor Prestwich and others that these

strata belong to the Old Red Sandstone, and not to the Trias.

Northward the Keuper beds extend far beyond the limits of the Bunter. In Cumberland and the north-east of Ireland their characters are similar to those of the Midland counties, but on the west coast of Scotland the strata are rather different. Their thickness here varies considerably, but in Mull, Morvern, and parts of Ross it is about 1,000 feet, and the whole probably belongs to the Keuper. The lower part consists of coarse breccias, conglomerates, and sandstones, and the upper half exhibits a variable succession of red marls with bands of concretionary limestone and of hard white or greenish sandstone. The breccias and conglomerates were doubtless accumulated in the same manner as those of Devonshire, and the higher beds seem to have been deposited in the quiet waters of a lake.

2. Geographical Restoration.

The unconformity which exists between the Dyas and the Trias, wherever the latter rests on the former, points to a period of elevation and disturbance, which probably involved the total desiccation of the Dyassic seas and lakes, and the conversion of their floors into wide tracts of dry desert land. The only beds in England which appear to be of intermediate age are certain deposits of rock-salt, gypsum, and limestone, which have been found below the Trias in deep borings near Middlesbrough-on-Tees. The limestones contain Dyassic fossils, but lie between beds of rock-salt, the upper of which seems to be conformably overlain by Triassic sandstones; none of them appear along the outcrop, and they must, therefore, occupy a limited area. They may have been formed in one of the restricted lake-basins which doubtless existed during the gradual drying

up of the Magnesian Limestone sea. It is certain that the general elevation was accompanied by differential movements producing areas of comparative depression and elevation; thus a further uplift of the Pennine range took place, and the Dyassic beds on either side received a slight tilt, so that the lower beds of the Trias were laid down across their edges, and overstepped them on to the Carboniferous rocks. Consequently that beds of intermediate age should exist beneath the Trias to the eastward is only what might have been expected.¹

That the continued upheaval caused a great alteration in the physical conditions of the European region is evident from the great changes which took place in its inhabitants. The Dyassic forms of life, which were mostly survivals of Carboniferous forms, were completely exterminated and replaced by a different fauna and flora. Among plants new genera of ferns and conifers appeared, Cycads began to flourish, and *Eqwisetum* replaces the Carboniferous and Permian *Calamites*. The fish and reptiles which inhabited Triassic waters all, except *Palæoniscus*, belong to new and distinct genera; crocodiles and Dinosaurs now first appear, and before the end of the period a marsupial mammal made its way into the British area.

¹ Professor A. H. Green's review of Lebour's "Geology of Northumberland and Durham" (in "Nature," July 28, 1887) came to hand after this chapter was written. He takes exactly the same view of the Middlesbrough beds, and observes—"It seems likely that toward the end of the Permian period unequal subsidence produced hereabouts a depression in the bed of the water; that as now happens elsewhere under similar conditions, the Permian lake became largely laid dry, so that the water remained only in this and perhaps other similar basins; and that from the highly concentrated solutions which remained in these lakelets local deposits of a strongly chemical character were precipitated." To this I will only add that the "Gypseous Shales" of the Carlisle basin may belong to the same period of transition, and may have been formed in a similarly limited basin, for some geologists class them with the Trias and some with the Dyassic rocks.

During the formation of the Bunter deposits it seems probable that the whole European region, including the North Sea and Baltic areas, formed one large continent, in which there may have been both salt and freshwater lakes, but that all such water-spaces were then reduced to a minimum. We know, however, that there was a greater amount of elevation in the northern than in the southern part of the European region, and that in the Alpine area it was soon followed by submergence; a sea of considerable depth covered this area which is now so mountainous, and its waters at one time extended northward as far as Germany and the eastern borders of France. The Muschelkalk limestones thin out in the Vosges country, and are not found to the westward of a line between Luxembourg and the Côte d'Or. The north-east of France and the region of the Ardennes seem at this time to have constituted a tract of high and mountainous ground, which probably extended northward through Belgium¹ and the east of England, and thus separated the British from the Germanic area of deposit.

The formation of the Keuper deposits marks another change, and we may suppose that the depression of the Triassic continent, which is indicated by the extension of the Muschelkalk sea, was continued in such a manner that, though the sea was still excluded from the northern areas, the courses of the principal rivers which had previously

¹ Messrs. Cornet and Briart have attempted to estimate the height to which this land rose above the sea-level of the period, and place it at from 16,000 to 20,000 feet. They arrive at this result by a consideration of the complicated system of fractures and flexures in the axis of Artois (Belgium). They attribute these to a succession of movements, and describe the several stages in the process by which the present collocation of rock masses was in their opinion accomplished; but their views are somewhat cataclysmic, and they do not seem to have allowed sufficiently for the removal of material by detrition during the process of faulting, flexure, and elevation. ("Ann. Soc. Geol. Belg.," iv. p. 71.)

found their way into the southern sea were altered, and their waters deflected into the depressed areas, forming large inland seas or salt lakes. Professor Ramsay compares the geographical conditions of northern Europe during Triassic times to those of central Asia at the present time, where from the Caspian Sea for 3,000 miles to the eastward and far south toward the Himalayah there is a comparatively rainless district in which all the lakes are salt, except those which have an outlet to some lower lake.

Confining our view now to the area of the British Islands, we find in early Triassic times three separate areas of deposition (see p. 116): one in the south, where the Devon and Dorset Trias was formed; one in the north-west over the site of the western Dyas lake; and one in the north-east, which was probably a long and narrow tract bounded on each side by a range of mountains.

Let us first consider the conditions which prevailed in the southern area at this epoch. The deposits which form the lower part of the Trias in this district are such as might be accumulated in a lake that was bounded by high and rocky land; the succession of breccias, sandstones, and marls is strongly suggestive of deposition in water, and there can be little doubt that the lake-basin was bounded on the west and south by land of a rocky and mountainous character, which extended continuously from Devon and Cornwall into the north of France. On the east and north the lake was enclosed by a projecting mass of land which stretched from France and Belgium through the south-east of England, and was united to Wales by an extension of the Mendip Hills; but as the ground on the north was subsequently covered by the Keuper marls, we may infer that it was lower than that which lay to the west, south, and east.

The western coasts of the lake seem to have been especially steep and rocky, the mountains probably coming

close to its shore, just as the Maritime Alps border the shores of the Riviera. It seems, indeed, as if the conditions under which the lower breccias and pebbly sandstones of Devonshire were accumulated, must have been very similar to those which have long existed in the Riviera. Sir Charles Lyell describes some remarkable deposits near Nice;¹ there torrents from the Alps bring down vast quantities of detritus, fine in summer, coarse in winter, and this is poured into the Mediterranean, and deposited in slanting layers immediately outside the mouths of the torrents, the shore being so steep that depths of 2,000 and 3,000 feet are found within half a mile of the beach. An elevated delta of this kind can be studied in the valley of the Magnan (near Nice), where inclined beds of sand, marl, gravel, and conglomerate succeed one another in cliffs 200 to 600 feet high for a distance of nine miles; if their inclination were assumed to be a dip, this would give a thickness of many thousand feet, whereas their real thickness cannot be proved to be even one thousand.

Similar accumulations are probably frequent where the conditions are similar, and the aspect of the coarse sandstones of Teignmouth and Dawlish, with their angular fragments of local rocks, seem to be torrential deposits of this kind. The overlying marls may indicate submergence, or a rise in the level of the water from increased rainfall, which carried the coast-line farther west, and so allowed a finer sediment to rest upon the coarse shore-beds.

Whether the northern areas were at this time lake-basins, or low-lying terrestrial surfaces on to which material was swept by mountain torrents, is very uncertain. Professor Ramsay suggests a lacustrine origin for the whole of the British Trias, but Professor Bonney remarks² that "the number and size of the pebbles (in the Bunter)

¹ "Students' Elements of Geology," fourth edition, 1885, p. 20.

² "Geol. Mag.," Dec. 2, vol. vii. p. 407.

seem to point to the action of strong currents, such as would only occur in an open sea or in the delta of a large river. The average Staffordshire pebbles would require a current of about three miles an hour to sweep them along. Larger pebbles, up to six or eight inches in diameter, are by no means infrequent."

If we adopt the lake theory, we must suppose two long, narrow, and shallow sheets of water, each receiving the current of a rapid river at its northern end. To account for the character and limited extent of the Lower Bunter Sandstone, we must conclude that the rivers were at first only of sufficient volume and velocity to carry sand into the lakes, and that their sandy deltas gradually filled up the spaces which were then covered by water. The wider extension of the Pebble Beds would indicate a rise in the level of the lake-waters due to an increased winter rainfall; an increase which might be caused by continued elevation of the country. We must assume that the rivers then became equal to transporting pebbles over the same areas, and that a pebbly delta was superimposed upon the sandy one, gradually extending beyond the tracts covered by the lower sandstones, and round the southern termination of the Pennine range. The upper sandstones, if deposited in water, would indicate a decrease in the velocity of the streams, and a return to the former conditions, except that no such deposit was formed in the eastern tract.

This view of the manner in which the Bunter series was laid down is not altogether satisfactory. Professor Bonney says ' he has always felt it difficult to explain the great length of these Triassic tracts on the "filled-lake" theory, and to account for the entire absence of mud or shale. He thinks that the idea of subaerial river deltas, such as are found in some parts of India, Persia, and Abyssinia, offers a simpler explanation of some of the facts. On this theory,

¹ Address to Geol. Sect. of Brit. Assoc., 1886, p. 18.

the tracts now covered by the Bunter were flat lands on to which the torrents from the surrounding hills swept the detritus which they carried, at first dropping the pebbles in the mountain valleys, and only carrying sand on to the plains.

The final arrangement of this sand seems frequently to have been accomplished by the wind (see p. 119), and we may therefore suppose that during the greater part of the year the plains formed bare and arid deserts, over which hot winds whirled clouds of sand, and on which no living creature could find sustenance. Such conditions would account for the total absence of organic remains in the Lower Triassic sandstones of Britain. When the period of increased rainfall came on the torrents would carry the pebbles to greater distances, and there may have been a time when the streams were strong enough to sweep out all the detritus which had accumulated in the upper valleys, and to spread it over the lowlands in the shape of the pebble beds. Depression and decreasing rainfall would bring back the former conditions, and a partial recurrence of sandy deposits.

That the mountain torrents should only fill their channels in the winter or rainy season is not at all improbable, for this is the case with many watercourses in eastern Egypt and Abyssinia at the present day. In those countries immense quantities of débris are swept out of the hill-valleys by the heavy rains which occasionally occur in winter time, and are spread out over the plains and wider valleys which occur at lower levels, and which in the dry season form arid tracts of sandy and pebbly desert. It is probably to such regions that we must look for a type of the conditions which prevailed in Britain during the earlier part of the Triassic period.

When the depression which ushered in the conditions of the Keuper epoch took place, an inland sea of considerable

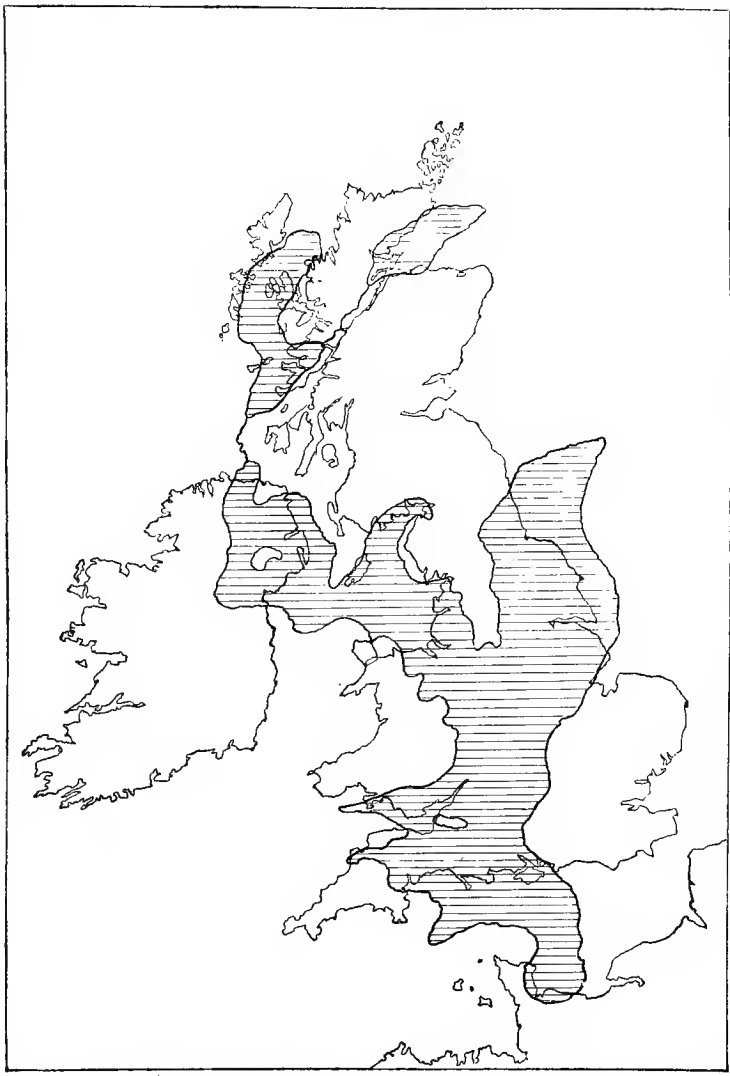


PLATE VI. GEOGRAPHY OF THE TRIASSIC PERIOD (KEUPER).

size and very irregular shape was formed. We cannot say exactly how this was, in the first instance, filled with water ; it does not seem to have had any previous connection with the open sea as the Dyassic lakes had, and as the modern Caspian has had ; it was probably a freshwater lake, which gradually became salt by the concentration of its waters, like the Salt lakes of North America. It may be that the outlet of the lake which previously existed in the south-west of England was blocked by volcanic disturbances and local upheaval, so that its waters gradually rose and overflowed the low barrier of Palæozoic rocks which separated them from the northern tracts. However this may be, it is certain that in Upper Triassic times there was a large space of water occupying the whole of central England, but divided by the Pennine chain into two long gulfs or arms, one of which spread to some distance east of Lincolnshire and Yorkshire (see Plate VI.), and the other extended into Cumberland and the north-east of Ireland. How much of the Irish Sea was covered by this arm it is very difficult to say, and the geography of this portion of the lake can only at present be guessed at.

Southward a gulf extended across what is now the English Channel, and terminated in Normandy, but the course that part of the shore-line which ran below the east of England is uncertain, because of the doubt existing with regard to the age of the red rocks beneath London (see p. 123), but the line on the map (Plate VI.) is drawn in accordance with the more probable view.

We may feel confident that there was still a large tract of land on the east side of the lake, comparable in many respects to that which lay to the westward ; we know that it was composed of Carboniferous, Devonian, and Silurian rocks similar to those of North Devon, Wales, and Shropshire, and we may reasonably assume that it was a hilly and rocky region such as Wales is now, and presented a

similarly irregular coast-line. Both the eastern and western land-tracts had long been exposed to the action of rain and rivers, and were doubtless sculptured into a network of ravines and valleys, which opened into wider valleys and plains at lower levels. That one such valley opened eastward along the site of the British Channel is evident from the manner in which the Keuper marls trend westward into that channel; this old valley in and south of Glamorganshire lay probably along the course of the Carboniferous Limestone, and led westward into the heart of the hilly region which then united Pembroke and Devonshire, and of which Lundy Island is the sole remaining fragment. Another smaller inlet, penetrating into the centre of Devonshire, seems to be indicated by the strip of Trias which extends westward from Crediton, and doubtless there were many other such inlets, bays, and estuaries, along the shores of the great Triassic lake.

Such was the lake in which the sandstones, marls, salt and gypsum beds of the Upper Trias were deposited. The climate of the country was probably warm and dry, and the saline waters of the lake were doubtless clear, and probably of that deep blue tint which such waters generally present. The ripple-marks, sun-cracks, and reptile-tracks so frequent on the surface of the sandstones, show that the volume of the lake-waters was subject to variations, and that there were times when tracts of sand were exposed and dried in the sun, and on these the strange reptiles of the period have left their footmarks. It was also principally during such times of partial desiccation that the beds of rock-salt and gypsum were deposited by precipitation from the saline waters.

That at least one island existed in the lake is proved by the relations of the Rhætic and Liassic beds to the Dolomitic conglomerate in the Mendip district, the newer beds overlapping the conglomerate along the flanks of these hills,

which were doubtless much steeper and higher than they are now.

It will be seen from the map (Plate VI.) that I have supposed the Scottish Triassic deposits to lie on the sites of two smaller and separate lacustrine areas. It might, of course, be argued that the western basin was only an arm of the Anglo-Hibernian lake, and that it was also connected with the north-eastern basin by a narrow channel along the site of the Great Glen; but the absence of rock-salt and gypsum in the Scotch Trias, and the presence of bivalve shells resembling *Cyrena* at Ardtornish, are facts which make it probable that the water of the Scotch lakes was fresh, and not salt, and consequently that the connection between them and the salt lake was by means of a river channel.

The absence of the Rhætic beds and the estuarine character of the Lower Lias in Sutherland are also facts which confirm the view that the Scotch lakes were at a somewhat higher level than the great salt lake; and the contrast between the marine and estuarine character of the Lower Lias of the two districts seems to indicate that the level of the eastern was higher than that of the western. Hence we seem justified in concluding that in Triassic times the eastern discharged itself into the western, and that the overflow of the latter was conducted by a river into the western arm of the great salt lake. We may, in fact, regard the Scotch lakes as the mountain-fed reservoirs of the Anglo-Hibernian lake.

CHAPTER IX.

JURASSIC PERIOD.

THE Jurassic strata, comprising the Lias and the Oolitic series, succeed the Triassic marls with complete conformity, the passage from one system to the other being through a group of grey marls, shales, and limestones, which are known as the Rhætic or Penarth Beds. The Jurassic system is divisible into three rock groups or series.

The Lower or Liassic series is essentially a clay formation, with occasional bands of limestone, sand, and ironstone of variable thickness.

The Middle Jurassic series consists mainly of limestones, with only subordinate bands of sand and clay.

The Upper Jurassic, again, is an argillaceous series, the limestones being discontinuous, and sometimes absent or replaced by clays.

The most persistent formations are the three great clays: the Lower Lias, the Oxford, and the Kimeridge Clays. These range all across England, and form broad tracts of low-lying land; while the intermediate limestones, where they are well developed, form long ridges, with escarpments facing the west or north-west, in consequence of the prevalent easterly dip.

§ 1. Stratigraphical Evidence.

Rhætic and Lias.—The Rhætic Beds, though in Britain they are quite a subordinate division, are of special interest,

because they mark the epoch when the great Triassic lake was first invaded by the sea. At, or near the base of the Rhætic shales, there is usually a layer of shaly sandstone, which contains phosphatic nodules and is crowded with the remains of fish and small reptiles, and sometimes there are several such layers. It would appear as if the sudden irruption of the sea-water was prejudicial to the inhabitants of the Triassic lake, so that most of them died, and their bones, scales, and teeth were drifted into layers on the sea-floor.

The Rhætic Beds have been found everywhere in England where the junction of the Trias and Lias is exposed, and they occur in the north-east of Ireland, but are not known in Scotland. It is true that on the western Scottish coasts the base of the Lias is nowhere clearly exposed, but Professor Judd thinks that no representative of the Rhætic shales exists there. These beds, therefore, so far as our present knowledge enables us to judge, were confined to the area of the Anglo-Hibernian lake. On the borders of this area, as on the Mendip Hills and in Glamorganshire, the shales and limestones are sometimes replaced by sands and sandstones.

The Lias has a wider extension; its thickness is often more than 1,000 feet, and it must have overlapped the Trias more or less in every direction, though the actual extent of the Lower Lias may not have been very much greater than that of the Trias, because the western coast of the Triassic lake was in many places very steep. The broad outcrop of the Lias stretches across England from Dorset to Yorkshire, and outlying tracts occur in Staffordshire, Shropshire, and Cumberland, and in the north-east of Ireland. They occur also on both sides of the Scottish Highlands.

The thick clays and shales of this series indicate a sea into which many rivers discharged a constant supply of

muddy material derived from the waste of the surrounding land. The shaly layers, which are familiar to us under the name of Lias, are evidently such as were formed in the more central and deeper parts of the sea, and there are only a few localities where littoral beds of this age have been preserved; but of these it is desirable to give some special account.

Shore-beds of Lower Liassic age are known in four districts, viz., the Mendip district, Glamorganshire, the Inner Hebrides, and eastern Sutherland. In the Mendip district, near Shepton-Mallet, the ordinary clays and thin limestones pass into massive white limestones, associated with conglomerates composed of Carboniferous Limestone and chert. Again, on the northern flank of the hills near Chewton-Mendip, and Harptree, there is a compact cherty deposit, containing Lower Lias fossils, and resting indifferently on Old Red Sandstone, Carboniferous Limestone, and Dolomitic Conglomerate.¹

Similar deposits occur in Glamorganshire, near Bridgend, Sutton, Brocastle, and Cowbridge, the basal beds being hard, cherty, conglomeratic limestones, and passing up into massive limestones full of fossils. The Sutton stone is a soft white limestone, and in it corals are particularly abundant.

In the west of Scotland the lower part of the Lias resembles that of South Wales, consisting of hard limestones alternating with calcareous and conglomeratic sandstones. Above these are shelly limestones and shales. On the east coast these beds are represented by estuarine deposits. At the base are coarse sandstones and conglomerates, with pebbles derived from the Lias, and these pass up into a series of sandstones and shales, with thin layers of clay and coal, the whole attaining a thickness of between 400 and 500 feet.

¹ Woodward, "Geology of England," second edition, p. 265.

It is rather remarkable that in three of these districts the shore-beds should be chiefly limestones, and we must infer that in these places, at least, very little detritus of any kind was carried in from the land at the beginning of the Liassic period. That this should be the case round the Mendip island is quite natural, but that limestones should be formed on the margin of the western inlet between Wales and Devon requires explanation; possibly this is to be found in the supposition that freshwater lakes existed in the country to the west, and that these for a time arrested and detained the mechanical detritus brought down by the rivers, leaving only the calcareous matter in solution to be carried on to the sea by the effluent stream. This, when added to the lime derived from the waste of the Carboniferous Limestone along the shore, was more than the sea-water could hold in solution, and the formation of limestones was the result. In the Scotch case, we may suppose that the Sutherland basin was the lake or lagoon which received the detritus, and thus allowed the formation of limestones in the western gulf.

The only shore-beds of Middle Liassic age preserved to us are those on the Scottish coast, where the Scalpa beds of Professor Judd,¹ in the islands of Scalpa, Skye, and Raasay, consist of calcareous sandstones, 200 feet thick, containing the fossils of the English Marlstone. In Mull they are represented by soft greenish sandstone with few fossils; and similar beds seem to have been formed in the eastern basin, blocks of them occurring in the Boulder clays of Elgin and Moray.

No marginal deposits of Upper Liassic age are known, but it may be noticed that round the Mendip Hills the water was very shallow throughout the Liassic period, the whole series being in some places represented by only

¹ "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 710.

30 feet of strata, in which beds of Lower, Middle, and Upper Lias can be distinguished. This is the case near Radstock, and it is quite possible that the Mendip ridge then extended much further eastward than it does now.

In Gloucestershire the total thickness of the Lias is little short of 1,000 feet, but at Burford in Oxfordshire it is only 650, the difference being due to the thinning of the Middle and Upper members. The formation probably continues to become thinner toward the east, but its limits in that direction are not yet known.

Middle Jurassic Series.—Between the Upper Lias clays and the limestones of the Inferior Oolite there are in the south-west of England certain sands which are grouped by some with the Lias and by others with the Oolite, but they are, in fact, passage beds from one series to the other. Above them come a variable series of limestones and marls, the former generally oolitic, and containing an abundance of fossils. These beds are divided into two groups—the Inferior Oolite and the Great Oolite—and in the south-west of England they are entirely of marine origin.

In Dorsetshire their combined thickness is over 700 feet, but they thin northward toward the Mendips, and near Frome they are not more than 100 feet thick. Here the Inferior Oolite overlaps the Lias, and rests on the older rocks, its base being sometimes conglomeratic.

North of the Mendips they thicken again, and reach a total of 460 feet near Cheltenham; but when followed eastward, they are found to thin very rapidly, the whole of the Inferior Oolite being represented in the valley of the Cherwell by 10 or 12 feet of brown sandstone, and the Great Oolites above are not more than 150 feet thick. There is at the same time evidence of the vicinity of land in this direction, not only from the sandy character of the Inferior Oolite, but from a thin zone of estuarine beds at the base of the Great Oolite. These are known as the Stones-

field Beds, and contain the remains of many plants and terrestrial animals.

In the continuation of the series to the north-east these estuarine beds thicken at the expense of the Great Oolite limestones, while other beds of a similar character replace part of the Inferior Oolite. Moreover, in Northampton, the two estuarine groups are separated by a plane of erosion or unconformity, and the whole series is in some places reduced to less than 100 feet, of which only 30 feet are marine limestones.

In Lincolnshire there is a greater thickness of marine limestones, a lenticular mass of limestone coming in between the two estuarine groups, but this becomes very thin in the north of that county, and in Yorkshire the estuarine beds thicken, so that they eventually form a thick series of deposits in which marine limestones are quite subordinate features. As this Yorkshire series is such a contrast to that of the south-western counties, a brief account of its component members may be given.

At the base of the section are marine sandstones and ironstones (about 50 feet thick). Above these is a group of estuarine sandstones and shales, with much carbonaceous matter and thin seams of impure coal; this group is 280 feet thick near Whitby, but thinner to the westward. Then comes a band of calcareous sandstone, which contains marine fossils, and appears to be the attenuated representative of the Lincolnshire Limestone; but above this is another mass of estuarine deposits, from 50 to 100 feet thick, containing several workable seams of coal. This group is succeeded by the Scarborough Limestone, a lenticular mass, which is thin on the coast, but thickens to the west and north-west. Above this limestone is a third set of estuarine shales and sandstones, from 120 to 220 feet thick, which are generally supposed to represent the Great Oolite, as they are covered by the Cornbrash, and there is

no other bed containing the marine fossils of the Great Oolite except the Cornbrash. Thus, out of a total thickness of about 650 feet, no less than 550 are estuarine beds—a fact which proves the Yorkshire basin to have been in close proximity to land of a continental character, and to have received the deposits of a large river, the mouth of which lay apparently to the north-east of the Yorkshire coast.

Of the western extension of the Middle Jurassic strata we have absolutely no evidence beyond the fact that all the marine limestones thicken in that direction—a fact which may be held to prove that their present outcrops are far removed from their original western limits; and since the series seems to have overlapped the Lias in other directions, we may assume that it did also to the west. Regarding their eastern extension, important evidence has recently been obtained from a boring at Richmond, in which sandy clays and limestones with Great Oolite fossils (87 feet thick) were found below the Cretaceous strata, and resting directly on red (Devonian?) rocks. At Meux's brewery in London similar beds occurred in the same position, the rocks below being undoubtedly Devonian. It is clear, therefore, that between Oxford and Richmond the Great Oolite overlaps the Inferior Oolite and the whole of the Liassic series, so as to lie directly on the surface of the old rocks which formed the eastern land of the period.

These Oolites have not been proved to exist beneath any of the south-eastern counties, but as they have a wide distribution over northern and central France, there can be little doubt that they are continuous beneath the Channel and the southern part of England.

The northern extension of this series is proved by thick deposits along the western coasts of Scotland, where the succession of marine and estuarine beds is very instructive. In Skye and Raasay the Inferior Oolite is represented by

shales, sandstones, and limestones of marine origin, and 380 feet thick, but including 60 feet of white sandstone, with bands of shale containing plant remains. But of the Great Oolite there is no marine representative, its place being taken by a remarkable formation which is evidently part of the delta of a large river; the mass of this consists of grey and white sandstones often current-bedded and ripple-marked, but both above and below these are groups of black shale and limestones, in which freshwater shells are abundant, together with the remains of reptiles, turtles, and fish. Professor Judd remarks upon the striking resemblance which these beds present to the Purbeck series of Dorset. Similar beds occur on the east coast of Sutherland, where the highest member of the series is a coal-seam $3\frac{1}{2}$ feet thick, resting on black shales with plants and crushed freshwater shells. From these facts it is clear that at this epoch the Scottish gulf was entirely silted up, and converted into swampy land, like that composing the delta of any large modern river.

Upper Jurassic Series.—Like the Lias this is essentially an argillaceous series, but it includes large lenticular and episodal developments of limestone and calcareous sand. The succession is most complete in the south of England, where it consists of the following members in descending order:—

5. Purbeck beds, estuarine and freshwater.
4. Portland limestone and sands.
3. Kimeridge clay.
2. Corallian limestone and sands.
1. Oxford clay.

The Oxford Clay is generally more or less sandy at its base, but the mass of the formation consists of dark grey or blue clay with layers of calcareous nodules. In the south of England it is from 300 to 600 feet thick, and it maintains the same character and average thickness to the north

of Lincolnshire, but then becomes thinner, and in Yorkshire it is only from 100 to 150 feet thick, the lower part (30 to 80 feet) consisting of sandstones and sandy limestones (Kellaways Rock).

The beds known as Coral Rag and Calcareous Grit are a variable set of oolitic and coralline limestones and calcareous sandstones, which are only developed in the southern counties and in Yorkshire, being absent, or represented by clays with thin layers of limestone, in the counties of Bucks, Beds, Hunts, Cambridge, and Lincoln. At Upware near Ely, however, there are the remains of a small isolated coral-reef, part of the mass consisting of coral-rock, and part of soft coral-sand limestone.

The Kimeridge Clay consists of dark clays and carbonaceous shales, which are continuous across England. They are thickest in the southern counties, 700 to 800 feet in Dorset, and over 1,000 in the sub-Wealden boring (Sussex). Toward the Midland counties they become thinner, being only 500 at Swindon, and apparently not more than 100 feet at Headington, near Oxford. Northward, however, they thicken again, but cannot be estimated, because of the overlap of the Cretaceous rocks. In Lincolnshire the group is at least 500 feet thick, and is about the same at Speeton in Yorkshire.

The Portland Beds of Dorset consist in the lower part of calcareous sands and marls (about 80 feet), and in the upper of shelly, chalky, and oolitic limestones (80 to 90 feet). A similar succession is found in the Vale of Wardour, but at Swindon the limestones are partly replaced by sands, with large calcareous concretions, and are separated into two stages by a surface of erosion, the uppermost beds being partly marine and partly freshwater, with a Purbeck facies.¹ The lower sands and marls are still 76 feet thick,

¹ See J. F. Blake in "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 203, and "Historical Geology," Bohn's Series, p. 348.

but it is clear from this remarkable section that the upper beds here were formed in much shallower water, and that the area was rapidly converted into an estuary, or fresh-water lake. When next seen in Oxford and Bucks other changes are found to take place; the lower sands thin out gradually from 70 feet at Shotover to 6 near Aylesbury, and the upper beds consist of limestone and fine silty sand in alternate layers (25 feet), passing up into a set of marly shales and limestones of freshwater origin (15 feet); these last, though homotaxially the equivalents of the Purbeck beds, are probably, in reality, of Upper Portland age. Beds of this character occur within a few miles of Leighton Buzzard, and may originally have stretched a little further north-east, as Portlandian fossils occur in the Cretaceous sands of Bedfordshire; but no Portlandian strata are again found till we reach Yorkshire, where black shales of this age overlie the Kimeridge Clay at Speeton.

As regards their south-eastern extension, sands and sandstone (about 80 feet thick) occurred at this horizon in the Sussex boring, and they are found in the north of France, so that they are doubtless continuous beneath the Channel, but they do not appear at the western outcrop of the series in Normandy.

Before noticing the Purbeck Beds we may glance at the correlatives of the marine Upper Jurassic series in Scotland. On the west coast the Oxford Clay only is seen, but in Sutherland a more complete series is found: the Oxford Clay is over 300 feet thick, and is marine throughout; it is succeeded by a zone of white cherty sandstone, with the fossils of the Lower Calcareous Grit overlain by a mass of estuarine sandstones with layers of lignite; these are 400 feet thick, and are surmounted by marine beds with Coral Rag fossils. The Kimeridge Clay is also represented by a thick and variable series of beds, chiefly estuarine sandstones in the lower part, with marine shales and limestones (500 feet

thick) in the upper part, the highest beds being light-coloured sandstones without any fossils. Near the Ord of Caithness thick beds of breccia occur amongst the shales of the Kimeridge Clay, and their formation is explained by Professor Judd as follows:—"The alternation of the brecciated beds with the finely laminated and quietly deposited strata and the confused arrangement of the blocks in the former, their admixture with trunks of trees, stems of cycads, and other plant remains, seem to indicate that the quiet deposition of the semi-estuarine beds was interrupted by the occasional occurrence, in the rivers just alluded to, of floods of the most violent character. These appear to have swept angular masses, just separated from their parent rock by frosts or landslips, subangular masses which had lain for a time in the course of the streams, and the rounded pebbles of the river-beds, along with trunks of trees torn from their banks, all in wild confusion out to sea, where they were mingled with the sea-derived materials of the shell-banks and shoals."

The Purbeck Beds exist only in the south of England; they consist of limestones, shales, marls, and black earths in thin layers, which exhibit alternations of terrestrial, freshwater, and marine conditions. Near Swanage, in Dorset, they are 400 feet thick, but they thin rapidly both to the west and north. In the Vale of Wardour only the lower and middle portions remain, and these are only 70 feet thick as compared with 300 feet at Swanage; at this rate of thinning they would not extend more than ten or twelve miles farther north beneath the Cretaceous rocks, but there is great uncertainty with regard to their northern limit. The freshwater beds of Swindon have been called Purbeck, but it is very doubtful whether these were ever actually continuous with those of the Vale of Wardour.

¹ "Quart. Journ. Geol. Soc.," vol. xxix. p. 195.

True Purbecks occur in Sussex near Battle, where their thickness is estimated at 400 feet, so that we may suppose them to be continuous from Dorset eastward through Hants and Sussex, but they probably die out in Kent, and are not known in the north of France.

In the Lower Purbecks of Dorset dirt-beds or carbonaceous soils are a conspicuous feature, and the presence of rooted stumps of cycadean and coniferous trees proves them to be actually terrestrial surfaces. At the base of the Middle Purbecks is a carbonaceous shale from which twenty-four species of small marsupial mammals, together with the bones of several crocodiles and lizards have been obtained. It has been pointed out by Professor E. Forbes¹ and Mr. C. J. A. Meyer,² that the changes from freshwater to marine deposits are abrupt, and that there is no real intermingling of marine and freshwater fossils in the same stratum, but a gradual return from brackish to freshwater conditions; these facts seeming to indicate lacustrine areas which were subject to occasional and sudden inroads of the sea, and, therefore, in all probability, lakes or lagoons in a silted-up bay or gulf. There is little evidence of direct fluviatile action; drift wood or plant remains are rarely found except in direct connection with terrestrial surfaces. One of the limestones, containing freshwater shells and nodules of chert, resembles those of the Tertiary lacustrine strata of central France. Lastly, the limestones of the Upper Purbecks being chiefly composed of the shells of the freshwater mollusc *Paludina*, are such as would be formed in quiet lacustrine waters.

The Purbecks of Sussex are a much less variable group, and were apparently formed in somewhat deeper water; they do not include any dirt-beds, but consist chiefly of shales, with two groups of hard grey thin-bedded lime-

¹ "Brit. Assoc. Rep.," Sect. C., 1850.

² "Quart. Journ. Geol. Soc.," vol. xxviii. p. 245.

stones. *Paludinae* are rare, and the principal fossils are freshwater bivalves and cyprids in the shales; marine shells are still less frequent.

§ 2. Physical History and Geography.

1. *Lower Jurassic Time.*—The physical geography of the Rhætic and Liassic epochs was a simple and direct modification of that which prevailed during the preceding Triassic period. No local elevations and subsidences took place in the British area, for the Rhætic and Liassic beds occupy the same basins of deposit as those which hold the Keuper marls; the great lakes or inland seas in which the latter were accumulated became by submergence the seas and bays in which the shales and limestones of the Lias were laid down.

This submergence set in doubtless toward the end of the Triassic period, and affected the whole of the Triassic north-European continent; the epoch of the *Avicula contorta* zone marks the time when the depression had proceeded so far as to submerge the lowest tract of land which lay between the great salt lakes and the wide-spreading southern ocean. It is very probable that at this time the level of the water in the salt lakes had been greatly reduced by evaporation, and was perhaps several hundred feet below that of the sea outside, and that when the dividing barrier was submerged, the sea waters would rapidly invade the lake basins and fill them up to a common level.

Let us consider the nearly parallel case of the Caspian Sea at the present day; the level of this sea is 85 feet below that of the Black Sea, and it is surrounded by extensive low-lying areas which were formerly covered by its waters before the sea shrank to its present dimensions; if therefore the waters of the Black Sea were admitted to the Caspian through the depression of the present barriers,

they would quickly spread over a large area in Central Asia which is now for the most part a dry and sandy desert. I do not mean to infer that anything like a cataclysmal influx of water would take place; the first inroad would doubtless occur during the prevalence of a strong west wind,¹ and would be only a temporary invasion, but as submergence went on, such invasions would be of frequent occurrence, till at length a permanent connection was established.

Two important results would follow from such a change: (1) large numbers of the creatures living in the Caspian would be immediately killed unless they could support the changed conditions of water and food; if destroyed, their remains would doubtless be laid out, and stratified, as it were, on the bottom of the sea, thus forming *bone-beds*. (2) The climate and appearance of the surrounding country would be gradually altered; evaporation from the newly-created sea would give rise to the formation of clouds; these would fall again as rain on the neighbouring hills; rills and rivers would come into existence, and the ordinary processes would be set in action; the country would be irrigated and fertilized, and the products of erosion would be washed into the widening sea. A scene of death and decay, desert wastes and slowly shrinking lakes would be converted into a sea full of active creatures, bordered by a region where the splash of waters and the hum of insects were unceasing sounds.

Such must have been the change which ensued when the Rhætic waters filled the basins of the Triassic lakes. The bone-beds testify to the suddenness of the invasion and the inability of the Triassic fish and reptiles to survive the change.

The fauna of the succeeding shales and limestones suggests

¹ If there were tides in the Black Sea, it would occur when there was an unusually high tide.

the inference that the mixture of sea and salt-lake water was not at first favourable to molluscan life; the assemblage of species is a small one, and consists almost entirely of bivalves, their shells having that dwarfed appearance which is generally the case with those living in unfavourable habitats. No Cephalopoda, Gasteropoda, Brachiopoda, Echinoderms, or Corals occur, but all these come in with the Lower Lias, proving that the waters were at first shallow and unfit to support these creatures, but that further submergence opened up free communication with the outside sea, bringing in a greater depth of water, and all the conditions favourable to the increase of molluscan life. The Liassic sea, indeed, with its large and active reptiles, its numerous fishes, and other inhabitants, must have presented a great contrast to the heavy and nearly lifeless waters of the salt Triassic lakes.

The plants and insects of the Rhætic and Lias also testify to the alteration of the climate, the humidity of the air, and the general fertility of the surrounding region. It is remarkable, however, that the insects are chiefly of a small size, and not such as might be expected to occur in association with the semi-tropical assemblage of marine creatures, but are rather such as would inhabit temperate climes at the present day. On this point Sir A. Ramsay has some interesting remarks. During the Triassic and Liassic periods, he says, it is not improbable to suppose that the mountains of Wales were at least double their present height, and were, therefore, 5,000 to 6,000 feet high, so that if a tropical or warm temperate fauna existed along the coast, a cold temperate land-fauna might exist among the hills. Now Professor Edward Forbes, while dredging along the coast of Lycia (Asia Minor), "observed that during the rainy season, the surface of the water was often partially covered with quantities of dead insects, washed into the sea from the neighbouring land. By far

the greater number of these insects were not derived from the hot low-coast territories, but were borne to the sea from the more distant and lofty mountain lands (7,000 to 10,000 feet high), by sudden floods which are then of frequent occurrence." They also, in accordance with the elevated regions from whence they came, bore the characters of temperate and cold climates; and Sir A. Ramsay thinks it probable "that the insect remains described by Mr. Brodie were washed from the mountain country we have described into the surrounding seas, and there entombed amid creatures of a tropical character."¹

The geography of the British region, so far as concerned the relative positions of land and water, was similar to that of the Triassic period. The waters of the Liassic sea covered the whole area of the Triassic lake, and extended some little way beyond its margins. From the southerly extension of the Lias through France it would seem that the southern sea gained access to the British area through that country, and if this were so we can understand how the Jurassic fauna and flora came to have their semi-tropical character. With continental land extending far to the east and west through the northern temperate zone, but not reaching far into the Arctic Circle,² and with an open sea spreading from tropical climes to its southern shores, we have exactly the conditions which would carry a high temperature and tropical productions far into the temperate zone.

As to the western shore of the British sea we can only say that it lay considerably to the westward of the present boundary of the Trias, though probably not far beyond

¹ "Mem. Geol. Survey," vol. i. p. 325.

² There are Jurassic deposits in East Greenland, Spitzbergen, Northern and Eastern Russia, and the fossils they contain make it improbable that there was any accumulation of ice round the North Pole at this time.

the original limits of the latter; that on the sites of the English and Bristol Channels there were gulfs which narrowed westward, and that the Mendip Hills seem to have formed an island, parts of which remained above the level of the sea throughout the whole epoch, whence we may conclude that the slopes of the hills were then very steep, and that their higher parts rose to a height of 800 or 900 feet above the level of the Rhætic waters.

From Swansea Bay the coast probably ran through Glamorgan and Monmouth to the Malvern Hills, and thence trended north-westward through Shropshire and Denbighshire, and across the Irish sea to the west coast of Ireland. As to the space now occupied by the Irish Channel no evidence is forthcoming, but if a gulf then existed on its site, it probably opened northward, and narrowed southward. From Ireland the sea extended over the site of the western Scottish lake, and thence probably up the great glen to the north-eastern basin; here the estuarine beds of the Lower Lias mark the debouchure of a large river, but the overlying marine beds show that as the submergence proceeded the sea gained on the land, while the sandy beds of the Middle Lias prove that the narrow water spaces were soon silted up.

With regard to the eastern limits of the Liassic sea we know that it encroached considerably upon the eastern land, for near Northampton, where the Trias is only from 50 to 100 feet thick, the Lias is over 700 feet, and this thickness must carry it some 30 or 40 miles further east, unless the slope of the eastern land became very steep. Further south it probably thins out beneath the Chiltern Hills (see fig. 3), and thence we may suppose that its boundary curves round to the south-east below Berkshire, Surrey, and Sussex, and crossing the English Channel enters France a little to the north of Abbeville.¹ North-

¹ De Lapparent, "Traité de la Géologie," second edition, p. 912.

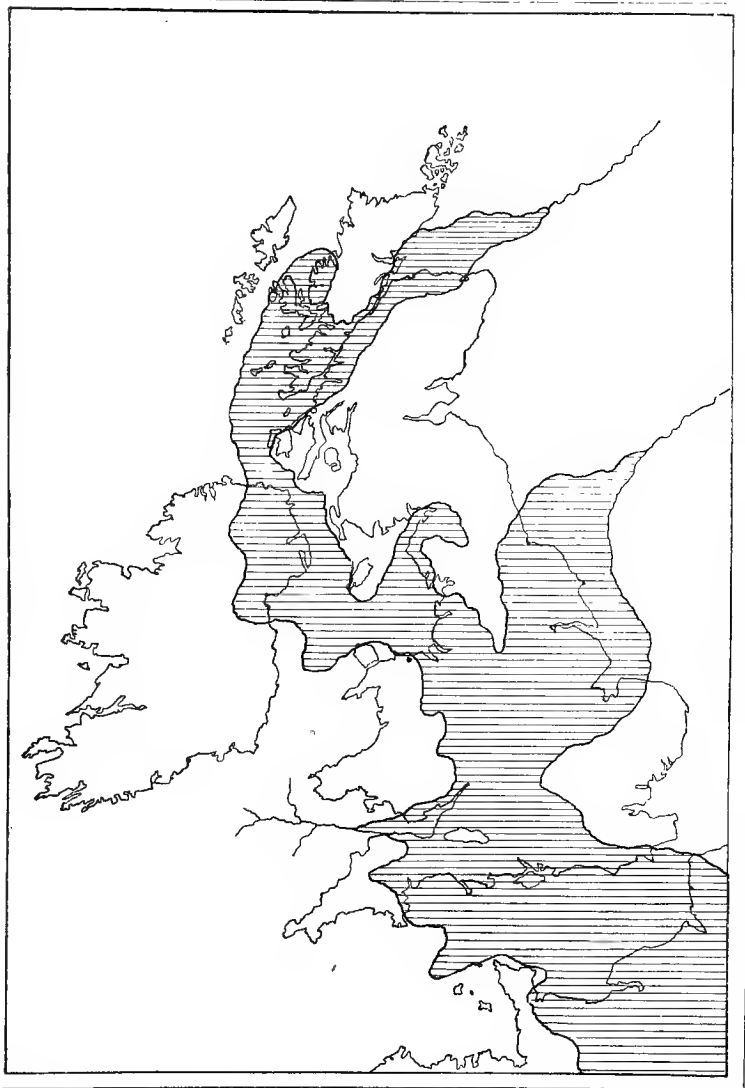


PLATE VII. GEOGRAPHY OF THE LIAS AND INFERIOR OOLITE.

eastward there was a broad gulf over the eastern arm of the Triassic lake, but there is no reason to suppose that the land connecting Scotland and Scandinavia was submerged at this time.

The view of Liassic geography above given differs from what has been previously suggested¹ in the restriction of the north-eastern part of the sea, and in connecting the Sutherland basin with the western gulf instead of with the eastern. Professor Hull in his restoration of Jurassic geography² has depicted an extension of the sea round the east of Scotland and entering the Sutherland basin from the east, but he informs me that this map is intended to represent the epoch of the Oxford Clay, and, as we have no actual evidence for any such continuous extension either of the Keuper or the Lias, we can only consider the probabilities which are suggested by the characters of the beds above and below the Lias. Now there is nothing in the British Trias to show that it was ever connected with that of Germany, and I have adopted the view that even the Keuper was formed in a restricted basin bordered on the east by a continuous barrier of high ground (see Plate VI.), which rose from beneath the eastern lip of the Northumberland coalfield, just as the Pennine Range does from its western lip. If this were so, then it is not likely that the Liassic sea encroached farther on to the land in a north-easterly direction than it did eastward beneath England. Again, if we consider the strata which overlie the Lias, we find estuarine conditions prevailing in Yorkshire (see p. 139), and proving the vicinity of land to the east and north-east at that time; hence it is not likely that the land lay very much farther off during the formation of the underlying Lias.

The deposition of so great a thickness of dark-coloured clay and shale in Liassic times is another point that calls

¹ "Historical Geology," p. 359.

² "Physical History of the British Isles," pl. x.

for explanation, and it may be fairly assumed that this material was mainly supplied by the destruction of the Coal-measure shales. Large tracts of Coal-measures must have existed at this time both in Ireland and Scotland, and the rivers flowing off these tracts would pour little else than black mud into the surrounding sea, while the waves would eat deep into such portions as came within their reach during the gradual submergence.

Middle Jurassic Time.—The change from Liassic shales to Oolitic limestones and marls is a rapid one, and is accompanied by a great change in the fauna, for though many Liassic species range into the passage beds (Midford Sands), yet very few survived till the era of the Inferior Oolite. These facts imply that a considerable and rapid change took place in the physical conditions of the period, but what this change was is not quite so easy to determine. At first sight nothing seems easier to explain than such a change; a clay succeeded by a limestone seems to point to a general depression, whereby the extent of the sea was enlarged, and its depth increased; but it is an error to suppose that all limestones are deep-water formations,¹ and oolitic limestones in particular are generally of shallow-water origin. Moreover, the Stonesfield Beds, with their proofs of shallow water and the vicinity of land, occur in the middle of this Oolitic series, the whole of which becomes more and more estuarine in its character as it is followed to the north-east. These facts prove conclusively that the water was not on the whole so deep as it had been in Liassic times. Lastly, in Oxfordshire the Upper Lias and Inferior Oolite seem to thin out beneath the Great Oolite, and there are also signs of erosion between the Inferior Oolite and the Lias; these facts imply an elevation of the sea-floor and not subsidence, for in the latter case the Inferior Oolite would overlap the Lias.

¹ See "Physical Geology," Part I., ch. xii.

It by no means follows, however, that this elevation was uniform and equable over the whole area. We notice, in fact, a decided tendency to the formation of separate basins of deposition, and to the upheaval of certain submarine ridges having a general east and west direction across England. Thus we can hardly understand the continuance of shallow water over the Mendip district without supposing a local upheaval, and it is not unlikely that there is an eastward extension of this axis in the form of a ridge separating the southern basin from that of Gloucestershire. A second ridge stretched across North Oxfordshire and Northampton, the evidence given on p. 138 proving that over these counties there was a broad space of shallow water separating the deeper basin of the Cotteswold area from the equally deep north-eastern basin.

This ridging up of the Liassic sea-floor, and the consequent formation of three separate submarine basins like those which exist in the modern Mediterranean, must have produced very material changes in the physical conditions of the Jurassic sea, and was probably one reason why the waters of the southern basins became so rapidly clear enough for the growth of reef-building corals; the muddy material would be all thrown down in the northern basins, that of Yorkshire on the one hand and of the Irish sea on the other, the submarine ridge preventing the currents from carrying much of it over the central and southern counties.

It is clear, however, that this was not the only cause for the cessation of the shaly and muddy sediment, and it is probable that the supply of such sediment was diminished by a slight elevation of the country from which it was obtained. Assuming that the supply was chiefly derived from the erosion of the Coal-measure shales (as previously suggested), it is certain that the amount of such material carried off a given area by one system of rivers must have become less and less as the rivers cut their way through

the Coal-measures into the sandstones, limestones, and older rocks beneath ; a slight elevation would quicken this process of erosion, and the natural result would be that the rivers would carry less mud, but more sand in suspension, and more calcareous matter in solution. In the combined effect of the two causes above indicated we seem to have a complete explanation of the rapid change from the physical conditions of the Lias to those of the Oolitic sea.

In the epoch of the Great Oolite there appears to have been a certain amount of subsidence in the southern districts, for we know that this stage overlapped the Lias in the latitude of London (see p. 140), and also in the north-east of France ; this overlap may, however, have been partly due to erosion of the coast by the waves ; there is no proof that the northern area was affected by the subsidence, and it was evidently insufficient to cause any material alteration of the geographical conditions.

Throughout this Oolitic epoch the clear water and warm temperature of the southern sea were favourable to the growth of coral-reefs, and it is well known that the Oolitic limestones are to a large extent formed from the materials derived from the waste of such reefs and from the shells of the marine creatures which swarmed in their neighbourhood. As in similar situations at the present time, Echinoderms, Brachiopoda, Pelecypoda, and Gasteropoda were especially abundant.

The fauna and flora of the land were in keeping with those of the sea. Ferns, Cycads, and Equisetums abounded on the borders of the rivers, and were mingled with Coniferous trees on the higher slopes ; huge Dinosaurian Reptiles, that walked or hopped on their hind legs like kangaroos, and small insectivorous Marsupials were the chief vertebrate inhabitants of the dry land, but Crocodiles swarmed in the rivers, and bat-like Pterodactyles flitted through the air.

The nearest approach in modern times to such a scene as Britain must have displayed in the Middle Jurassic period is to be found in Australia and its neighbouring islands. There many of the Jurassic types still survive. The indigenous Mammalia are all Marsupials; the plants include Ferns, Cycads, and Araucarian pines. Coral-reefs fringe the shore, and in the waters are Cestraciont Fish, and many of the same Molluscan genera as are found in the Oolites, viz., *Phasianella*, *Stomatia*, *Trigonia*, *Corbis*, and *Terebratula*, with others that have a wider distribution. There are, however, no survivors of the Jurassic Reptiles, or of the Ammonites and Belemnites which swarmed in the older seas.

Upper Jurassic Time.—During this part of the Jurassic period a considerable subsidence took place, and this was followed by a still greater and more continued upheaval, which eventually raised the greater portion of the British area into dry land, and brought the Jurassic period to a close.

Once more we have a complete change in the character of the sediment, and as the phenomena exhibited are exactly in reverse order to those of the change from Lias to Oolites, we may assume that they were caused by movements of precisely an opposite kind, and that the epoch of the Oxford Clay was produced by a general and equable subsidence of the whole region from the very south of England to the extreme north of Scotland.

In this case the sands and sand-rock of the Kellaways Beds are the strata formed at the commencement of the change, and constitute the zone of passage. The sandy nature of the Kellaways rock precludes us from supposing it to have been a deep-water deposit, but its fauna indicates that deep water was not far off, for in these beds a large number of new Ammonites suddenly make their appearance, and most of them continue in the Oxford clay. If further

testimony to the shallowness of the Great Oolite waters were needed, the scarcity of Ammonites in the rocks of that group would supply it, only three species being known to occur in the Forest Marble and Cornbrash. The change from Cornbrash to Kellaways is particularly striking in Yorkshire, where the latter contains no fewer than forty-one species of Ammonites, and only one is common to the two deposits; twenty of these species pass up into the Oxford clay. Mr. Hudleston, who has made such a careful study of the Yorkshire Oolites,¹ remarks: "Probably this great sandbank was deposited during a submergence of this region far more continuous in time and extended in space than those more partial depressions which during the period of the Lower Oolites (Middle Jurassic) had in this region intercalated the spoils of the sea with those of the estuary and the marsh. This more continuous descent seems at length to have removed or lowered barriers which had hitherto kept out the waters of a sea swarming with strange Cephalopoda."

One of these barriers was undoubtedly that tract or promontory of land which occupied the North Sea, and stretched from Belgium into the eastern part of the British area throughout the Liassic and Middle Jurassic periods. The southern part of this ridge began to be submerged during the formation of the Great Oolite, and though the Oxford clay is not found beneath London, it occurs below Chatham in Kent, and its absence further north is doubtless due to the great denudation which took place in Cretaceous times. We may therefore assume that a large part of the eastern land was completely submerged during the formation of the Oxford clay, and that by the close of this epoch a continuous deposit of the clay was spread over the whole of the eastern and midland portion of the British area, and

¹ "Proc. Geol. Assoc.," vols. iv. and v., and "Quart. Journ. Geol. Soc.," vol. xxxiii, p. 272.

that even the Scottish coast-lines were carried back so far that the same clay was spread over areas where only estuarine deposits had previously been laid down (see p. 143); but whether there was continuous sea outside the east of Scotland, as Professor Hull thinks, is quite uncertain. In this great deposit of dark blue clay we seem to have a repetition of Liassic conditions, and it is highly probable that the source of supply was the same—namely, the Coal-measures which once covered so large a portion of Wales, Ireland, and North Britain.

The episode of the Corallian Beds marks a time when from some cause the deposition of mud ceased over certain parts of the sea-bottom, and the water became clear enough for the growth of coral-reefs with their accompaniments of calcareous sands, marls, and oolitic limestones. This episode may have been caused either by the temporary diversion of the mud-bearing currents, or by the diminution of the supply, in the manner already explained when treating of the change from Lias to Oolites. The latter is, perhaps, the most probable cause, and we may regard the Corallian stage as indicating a pause in the movement of subsidence during which less muddy material was carried down by the rivers. The succession of beds in Sutherland lends some confirmation to this view; there as elsewhere the Oxfordian clays and shales tell of submergence, but the overlying sandstones (see p. 143) show that the currents were able to carry sand further out from the shore, and over the deep sea mud, as they might do if the land was stationary for a time, and just as an extension of sand over mud is believed to be now taking place in the English Channel.¹ In the succeeding series of alternating marine and estuarine beds we trace the progress of a further subsidence. It would appear, therefore, that the intercalation of white sandstones in the shallow waters of the Scottish area, and

¹ See Godwin-Austen, "Quart. Journ. Geol. Soc.," vol. vi. p. 82.

of corallian limestones in the deeper water of the English sea, were due to one and the same cause.

During the formation of the Kimeridge Clay the subsidence reached its farthest extent, and eventually a reverse movement set in, the supply of mud grew scantier, and the bluish argillaceous sands which underlie the Portland stone were doubtless formed during upheaval. Finally, a large part of the sea-bottom was raised into dry land, and the sea was contracted into two separate branches or gulfs, the separation of which seems to have resulted from the upheaval of a tract across the centre of England—a tract which had formed a submarine ridge ever since the time of the Lias. The existence of this ridge was mentioned on p. 139, and the influence it had on deposition can be seen from the following table of thicknesses, which shows that the amount of sediment laid down over it was about 1,000 feet less than the accumulation in the basin to the south, and 450 feet less than that in the area to the northward:—

	Wiltshire.	Oxford and Bucks.	Lincolnshire.
Portland Beds . . .	100 . . .	50 . . .	absent?
Kimeridge Clay . . .	500 . . .	150 . . .	500
Corallian	200 . . .	absent . . .	absent.
Oxford Clay	500 . . .	300 . . .	350
Lower Oolites	350 . . .	100 . . .	200
	Foot 1,650	600	1,050

This central tract now became an isthmus, uniting the eastern and western Palæozoic areas to one another, and probably also to the southern end of the Pennine chain. The emergence of this isthmus began in Portland times, the sea of the Portland Limestone lying wholly to the south of the latitude of Bedford, and opening southward through France, while a northern gulf extending from Germany reached into Yorkshire and Lincolnshire (see Plate VIII.).

Once more, therefore, we find limestone in the south of England and shale in the north, and in this case it is clear that the formation of limestone was possible because of the intervening barrier which prevented the influx of the northern mud-bearing currents.

We have now brought the history of the British Jurassic sea to a close, and have arrived at the epoch of the great Purbeck-Wealden continent; but before we can with any confidence restore the physical geography of the Purbeck and Wealden times, we must pause to ask what systems of river-drainage would be likely to come into existence under the circumstances of the Portlandian upheaval. In the first place, the uprise of the central barrier which caused the restriction of the north-eastern part of the Jurassic sea, must have similarly affected the north-western branch of the sea, and if we consider that this had probably been a land-locked gulf throughout the Jurassic period, we are inevitably led to conclude that the Portlandian upheaval must have converted it into a large inland lake.

In the absence of any Jurassic deposits of later date than the Oxford Clay over this area there is, of course, no positive evidence for the existence of such a lake, but the probability of its having existed may be increased by another process of inductive reasoning. If there were no such catchment basin on the site of the gulf, this must have formed a wide valley traversed by a river which would receive many large tributaries from the mountains on either side, and, flowing southward across what is now the Irish Sea, would necessarily be a very large and powerful stream, carrying down a great quantity of detritus. If it continued its course over the newly-emerged bed of the Jurassic sea in spite of the local upheaval across England,¹

¹ There is no reason to suppose that the Irish Channel was then in existence any more than the English Channel was, nor is it probable that there was any opening westward into the Atlantic.

it must have emptied itself into one of the two marine gulfs, and must have formed a great delta, so that we should have expected the occurrence of a thick mass of estuarine Portland-Purbeck deposits either in one basin or the other, but there is no sign of such a formation ever having existed in either.

If, however, a large lake existed on the site of the Irish Sea, as indicated in Plate VIII., the detritus brought down by the mountain streams would find a resting place, and the excurrent river would be as clear as the Rhone when it leaves the Lake of Geneva. Such a river, flowing southwards and not receiving any important affluents, might enter the southern gulf without giving rise to any extensive estuarine or deltaic deposits, or leaving any larger record of its existence than such a channel and break in the marine sequence as is found at Swindon. The Swindon section seems to indicate the presence of a river of some size, and if the north-western river did have the course above suggested this may have been its debouchure.

Besides this river the only other streams, so far as we can see, that could enter the southern or Purbeck basin would be those draining the country to the west and south. Now in Portland times the influence of these rivers does not seem to have been great, and possibly they then carried more material in solution than in mechanical suspension. Even the subsequently-formed Purbeck beds of Dorset are less fluviatile than lacustrine in character, and Mr. Meyer has indeed argued for their purely lacustrine origin. He goes so far as to speak of the Purbeck basin being "probably from its commencement rather that of a lake, a series of lagoons, or even of an inland sea, than of an estuary in the ordinary meaning of the word."¹ This

¹ "Quart. Journ. Geol. Soc.," vol. xxviii. p. 245.

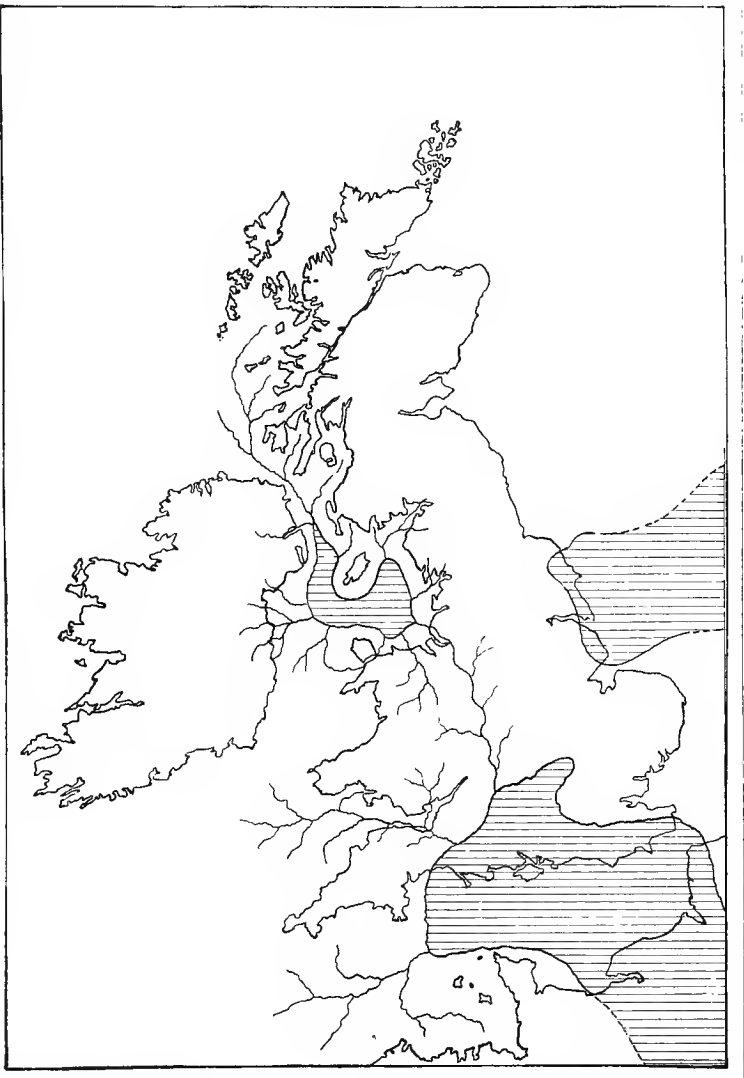


PLATE VIII. GEOGRAPHY OF THE PORTLANDIAN EPOCH.

The lake and river system are hypothetical.



perhaps is pushing the inference too far, and the conditions of the Purbeck basin seem to me more correctly described as those of a silted-up gulf or bay, portions of which became freshwater lakes or meres, such as formerly existed in the Fenland of Norfolk and Cambridge. It is true that the conditions of sedimentation in the Purbeck bay were evidently different from those in the great bay of the Fenland; the latter has been filled up chiefly by tidal silt, and the areas of freshwater deposits are very small, while in the former the lacustrine areas were large, and silt-bearing currents were absent, so that even the marine deposits were calcareous. Still, there is much analogy between the cases, and I therefore agree with the wording of Mr. Meyer's conclusion that it was "by the co-existence within a comparatively wide area of a fauna suited respectively to freshwater and brackish-water conditions, and by the interchange of such conditions over portions of the same area, supplemented by the occasional intrusion of the ocean, that I would account for the alternation of freshwater, marine, and brackish-water fossils in the Purbeck strata; for neither the conditions of their accumulation nor the life-conditions of their fauna appear to be sufficiently in accordance with an estuarine position" (loc. cit., p. 246).

On this view, too, the stratigraphical relations of the so-called Purbeck beds of Oxford and Bucks admit of easy explanation; for if our view of Portlandian geography is correct, it is exactly in this Midland district where we should expect to meet with evidence of the early prevalence of such conditions, and to find freshwater strata of an earlier date than that of the Dorsetshire Purbecks. There we find beds with Portlandian fossils passing up into purely lacustrine strata, which were evidently deposited in the quiet waters of a lake that was never invaded by strong currents either of fresh or salt water. We may

conclude, therefore, that it was a large lake or mere which occupied an area of newly-emerged and low-lying ground, and that its level was maintained by the local rainfall, not by the influx of a large river.

My attention has been directed to an essay by Professor Hébert,¹ in which he discusses the physical history of the Jurassic period in France. He divides it into two portions—a period of depression and a period of upheaval. He considers that the former only lasted till the time of the Great Oolite, and that the Jurassic sea then attained its greatest superficial extension. Instead of admitting a further submergence at the time of the Oxford Clay, he attributes its absence over the exposed Great Oolite area to non-deposition, and thinks the Oxfordian sea was limited to the Parisian gulf, the sea-space becoming smaller and smaller during succeeding epochs, till it was finally upraised in Purbeck times.

To most English geologists this must seem a very crude and antiquated view, but I am surprised to find that Professor Gosselet and other French geologists hold similar opinions, and interpret the geological record of other systems on the same principles. (See Gosselet's "Esquisse Géol. du Nord de la France.")

¹ "Les Mers Anciennes et leur Rivages dans le Bassin de Paris. Part I. Terrain Jurassique." 1857.

CHAPTER X.

THE CRETACEOUS PERIOD.

IN the south of England, where the highest Jurassic beds are fully developed, there is a complete sequence through the freshwater Purbeck and Wealden groups to marine deposits of Cretaceous age; but elsewhere throughout Britain and the north of France the marine deposits of the two systems are separated by a marked break and unconformity, representing the interval during which the older rocks were upheaved and remained in the condition of dry land.

In the south of France this gap is filled by a complete series of marine deposits, which are known as the *Neocomien* and *Urgonien* groups, and these, therefore, are the marine equivalents of our Wealden series. In Yorkshire and Lincolnshire also the freshwater series is partially represented by marine deposits, some of which are probably as old as the upper part of the French and Swiss Neocomian, but there is still an unconformity at their base. The following is a tabular view of the members of the Cretaceous system in the south and north of England respectively, with the names of their French equivalents; the two lower stages of the English succession being grouped as the Lower Cretaceous series, and the four upper constituting the Upper Cretaceous series.

Isle of Wight.	Yorkshire.	France.
6. Upper Chalk.	Upper Chalk.	Senonien.
5. Middle Chalk.	Middle Chalk.	Turonien.
4. Lower Chalk.	Lower Chalk.	Cenomaniensien.
3. Upper Greensand and Gault. }	Red Chalk.	Albien.
2. Lower Greensand, or Vectian. }	Speeton Clay, upper 270 feet. }	Aptien.
1. Wealden. }	Speeton Clay, lower 230 feet. }	Urgonien. Neocomien.

§ 1. Stratigraphical Evidence.

Lower Cretaceous.—The Wealden Beds are restricted to a comparatively small area in the south of England, and do not extend far beyond the limits of the Purbeck Beds. They occupy the country known as the Weald of Kent and Sussex, and pass beneath the chalk hills which surround this district, but they do not extend far to the north, for the deep borings at Chatham, Erith, and Richmond proved their absence at those places. Eastward they reach below the Straits of Dover into the Boulonnais, and westward they spread beneath Hampshire and the Isle of Wight into Dorsetshire, but have not been traced beyond Osmington and Ridgeway. Southward they do not seem to have reached so far as the present shores of France, for they do not appear below the Aptien at the northern end of the Pay du Bray inlier in Normandy.

The Wealden Beds consist of thick lenticular alternations of sand and clay, the sands being thickest in the lower part and the clays in the upper part, so that they are usually divided into (1) the Hastings Sand, and (2) the Weald Clay. In the lowest beds (Ashdown Sand) layers of lignite are not unfrequent; the Wadhurst clay also contains lignite as well as nodules of clay ironstone. In the sands

near Cuckfield and Lindfield there are thin layers of conglomerate, the pebbles in which are largely derived from Palæozoic rocks, and were probably brought down by streams draining off the land to the north; and this is interesting as showing that streams had already cut down through the Upper Jurassic clays to the Palæozoic rocks of that region. The Weald Clay consists of clays and shales with local beds of sandstone and many layers of shelly limestone, the latter consisting of *Paludina* shells, and resembling the Upper Purbeck limestones.

The Wealden Beds are about 1,800 feet thick in the west of Sussex, and they attain a still greater thickness near Swanage in Dorset; but when followed westward they are found to thin out rapidly, being only 172 feet thick in Man-of-War Cove. In Dorset, moreover, the series is not divisible into a lower sandy and an upper clayey portion, the sands and clays alternating throughout, but the highest beds are always shales with limestone bands.

The fossils of the Wealden are entirely freshwater and terrestrial, plant remains, minute Crustacea, freshwater mollusca, fish and reptile bones occurring throughout; and there is no admixture of marine species, except at the very top of the series in the Isle of Wight.

Wealden Beds occur in the Vale of Wardour, but are not seen again in Wiltshire. In Oxfordshire there are some freshwater deposits overlying the so-called Purbeck Beds, but there is a decided unconformity between them, and just as the one group in all probability antedated the true Purbeck Beds, so it is thought that the newer group is of posterior date to the true Wealden series.

In Yorkshire and Lincolnshire there are contemporary beds of marine origin. In Yorkshire these are blue clays with a basement bed containing rolled fossils derived from Jurassic rocks; in Lincolnshire they are partly clays and partly sandstones, with a similar nodule-bed at the base;

and in Norfolk there are clays and soft sands which may be of the same age; but how far they may originally have extended southwards we do not know.

The Vectian¹ group is most completely and clearly exposed in the Isle of Wight, where it is divisible into three portions: (1) Atherfield Beds, 150 feet, chiefly clays; (2) Walpen Sands, 400 feet; (3) Shanklin Sands, 256 feet. They are entirely marine, and the deposits of a shallow sea, rather deep and muddy at first, but becoming shallower afterwards. The basement bed of the Atherfield Clay is a seam of coarse grit containing small pebbles, with the teeth and bones of fishes; of this Mr. Meyer remarks, "it is just such an accumulation of sediment as would result from the dispersion of shore deposits over the floor of a moderately deep lake. The fish-bones are those possibly of inhabitants of the Wealden waters, and their presence at the junction of the two formations may be due to the suddenness of their destruction by the change from fresh to salt water."²

The Atherfield Clay is the deposit of a deepish gulf or estuary, but the Walpen Sands are current-formed beds in shallower water, and this fluviate action is very evident

¹ *Vectian*.—This group is usually known as the Lower Greensand, although it has long been admitted that this is an awkward and inconvenient appellation. So long ago as 1827 Fitton protested against its use; in 1845 he suggested the name *Vectine* in its stead, and in 1885 I proposed that of *Vectian*, which is only Fitton's term in another form. The fact that Phillips applied this name to the Upper Eocene Tertiaries cannot be held as any objection, for Fitton has undoubtedly a prior claim to it, and since the Fluvio-marine series is now known as the Oligocene, no one is likely to revive Phillips' use of Vectian. The term Upper Greensand is equally indefensible, for the beds so designated are not a separate group, and should be united with the Gault under a new name. In the following pages I shall use the name Vectian for all strata that are equivalent to the beds between the Wealden and the Gault, such as the upper part of the Speeton Clay, which no one likes to call Lower Greensand, and which it is incorrect to call Neocomian.

² "Quart. Journ. Geol. Soc.," vol. xxviii. p. 248.

at Punfield on the Dorset coast, where the beds include layers of lignite and shales with *Cyrena*. In this direction, too, the whole group thins out rapidly, and is not more than 100 feet thick at Worbarrow Bay.

The Vectian beds seem, indeed, to have their maximum thickness (800 feet) below Hampshire, for at the west end of the Wealden area, near Godalming and Petersfield, the whole group is not more than 450 feet thick, and it continues to diminish eastward, being about 320 feet at Sevenoaks, 250 at Sandgate and Folkestone, and only 31 beneath Dover. The same diminution can be traced along the foot of the South Downs, its thickness at Eastbourne being only 70 feet, and in each case it is the highest beds which remain; the same is the case at Chatham, where a boring has proved 41 feet of the upper sands resting on Oxford Clay.

It is clear, therefore, that the Vectian beds of the Weald thin to north-east, east, and south-east; that they should thin east and north-east is not surprising, for we know that land lay in that direction, but that they thin to the south-east is important as showing that the water was shallow near Eastbourne, and therefore that part of the southern shore-line was probably not far off that place.

How far the Atherfield Clay and Walpen Sands extend through the north of Hampshire has not yet been ascertained, but they probably thin out northward and westward in the same way as they do northward and eastward in Kent, for when the Vectian emerges from beneath the Gault in Wiltshire only the representative of the Shanklin Sands remains. In Wilts and Berks this upper member consists of brown ferruginous sands, with occasional beds of conglomerate, which contain a curious mixture of pebbles—rounded pebbles of quartz, banded slate, and cherty limestone, similar to those which occur in the Portland Beds, and which may have been derived from the destruction of

these beds, as the rest of the pebbles have come from the neighbouring Jurassic rocks, namely, the Coral Rag and Kimeridge Clay. It does not seem likely that the pebbles of Palæozoic rocks were derived directly from such rocks, because the localities are so far distant from any outcrops of Palæozoic rock that are likely to have been exposed at that time, unless they came from a buried continuation of the Mendip range; neither is it easy to see how they can have been derived from the Trias, for the strata containing them are shore-beds formed in close proximity to the actual land margin.

These pebble beds extend as far as Baldon, south of Oxford, but near Garsington and Shotover a very different set of beds come in, the characters of which more resemble those of the Walpen Sands at Punfield; they consist of variously coloured sands and clays, with beds of iron-ochre and fuller's earth, and they contain freshwater shells (*Cyrena*, *Unio*, and *Paludina*), with pieces of coniferous wood. These beds extend in outliers by Brill and Quainton to Whitchurch; and south of this line, near Thame and Hartwell, there are other beds in which marine fossils have been found. The actual relations of these two sets of beds have not yet been ascertained, but it may be remarked that no intercalation of beds with marine and freshwater fossils has yet been observed, and that the marine beds are generally in close proximity to the Gault. It is possible, therefore, that the freshwater beds are lacustrine and lagoon deposits of a slightly earlier date, and were formed in a low-lying tract of land which was afterwards invaded by the sea. This supposition finds some confirmation in Professor Morris's observation, that at the base of the marine sands near Hartwell there are derived blocks of brown sandstone containing freshwater fossils.¹

¹ See "Geol. Mag.," vol. iv. p. 458.

The Upper Vectian sands next appear near Leighton and Woburn, where they are 200 feet thick, and consist chiefly of yellow and white sands, but have near the base a remarkable seam of phosphate nodules, with fossils and pebbles derived chiefly from Upper Jurassic strata; there are pebbles of quartz and chert like those of the Berkshire beds, as well as fragments of an older Cretaceous rock. The sands above are current-bedded, and the inclination of the layers is generally south or south-eastward, showing that the prevalent currents came from the north. Similar beds with layers of nodules stretch through Bedford and Cambridge as far as Ely.

With regard to the subterranean extension of these sands, it is known that they do not stretch far to the eastward. In Cambridgeshire they are present at Shelford and Sawston, but appear to be absent at Saffron Walden in the north of Essex.¹ In Hertfordshire they occur below Hitchin, but are absent at Cheshunt and Ware. At Richmond there are ten feet of calcareous sandstone, with a pebble bed at its base, which consists of material derived from Palæozoic and Jurassic rocks; this is probably of Vectian age, but no such beds occur under London. It is clear, therefore, that the sands thin out against the slope of the Palæozoic rocks which underlie the east of England, see fig. 3, p. 115.

In Norfolk other beds begin to set in, the descending succession being (3) ferruginous sandstone or Carstone, (2) blue clay, (1) soft yellow and white sand. In Lincolnshire the clay is thicker, and in Yorkshire the whole is represented by clays, which rest on still older Cretaceous clays (see p. 164). The Lower Vectian consists of clays with *Pecten cinctus* and *Meyeria ornata* (120 feet), and the Upper

¹ A boring here was carried through blue clays below the Chalk for about 550 feet without any record of sand, and without finding any water. (See "Mem. Geol. Survey," Expl. Sheet 47, p. 79.)

of blue and black clays (150 feet). These were formed in much deeper water, and include representatives of the lowest Vectian beds, as well as the higher, many of the fossils being similar to those found in the Atherfield Clay. The Yorkshire succession, however, has much more resemblance to that of Hanover than to that of southern England or France, and there can be little doubt but that they were formed in a Germanic sea or gulf, which constituted a separate marine province.

Upper Cretaceous.—The lowest stage of this series consists of a variable group of clays, marls, sands, and siliceous rocks which are known as the Gault and Upper Greensand. It used to be thought that the argillaceous deposits were always older than the arenaceous, but it is probable that they are to a large extent replacive and coeval.

As a matter of fact, in East Kent the formation consists entirely of clay, more or less marly at the top, and including a thin bed of dark glauconitic sand. To the westward other beds of sand and siliceous stone come in, and in the Isle of Wight it is lithologically divisible into three portions, the lowest being blue clay (100 feet), the central consisting of sandy micaceous marl (55 feet), and the upper of yellow and grey sands, with layers of cherty stone (100 feet). Still further west the clays entirely disappear, being probably overlapped by the higher beds, which consist of grey and yellow sands, argillaceous below and glauconitic near the top, with a total thickness of 150 to 130 feet. These form the mass of the Blackdown Hills, and cap the Trias of Haldon Hill south of Exeter.

A similar group of beds doubtless swept northwards across the centre of England, but only the eastern part remains, all the western part between the Welsh hills and the Cretaceous escarpment having been removed by the erosion of subsequent periods; we cannot, therefore, trace the passage from Gault to Greensand across the Midland

counties, but the oblique section along the line of the out-crop reveals a still more remarkable lithological change. The Gault in the south of Bedfordshire consists of clay and micaceous marl, and is about 230 feet thick; thence to the north-east it gradually diminishes in thickness, the whole formation at Stoke Ferry in Norfolk being only 60 feet thick, and consisting of marly clay. Farther north, at Roydon, it is only 20 feet, and includes layers of chalky limestone and of red marl. At Dersingham there is only 7 feet of grey, yellow, and red marl, and this appears to pass into the red limestone of Hunstanton.¹

In Lincolnshire and South Yorkshire there is a similar red rock at the base of the Chalk, but as it is followed through Yorkshire considerable changes take place; at the north-west extremity of the Wolds it is very thin, but is still an essentially calcareous rock; to the east and north-east it thickens rapidly, becoming at the same time much more argillaceous, till at Speeton it is 30 feet thick, and Mr. W. Hill informs me that the material of the lower 8 or 10 feet contains nearly equal quantities of insoluble siliceous matter and carbonate of lime.

The clays of the Lower Gault seem to have been deposited in a shallow sea of 50 to 70 fathoms deep, which is about the depth of the sea between England and Ireland, while the fossils of the Upper Gault indicate a depth of 100 fathoms and upward.² The Gault and Greensand of the Isle of Wight and the Midland counties was probably all deposited in a sea of less than 100 fathoms, and the depth of the water became less toward the west, where the deposits exhibit abundant evidence of current action and the vicinity of land. In the sands of Haldon Hill Dr. Sorby found that only a proportion of one-tenth of the

¹ See "Quart. Journ. Geol. Soc.," vol. xliii. p. 550 *et seq.*

² See Price on the "Depth of the Gault Sea, Proc. Geol. Assoc.," vol. iv. p. 269.

quartz grains were well rounded and worn, while in those of the Isle of Wight the proportion is probably greater.

The Gault of Norfolk is a deposit formed in deeper water than that of Folkestone, and has a greater resemblance to the Chalk Marl than to the Gault clays of the southern counties; that it was formed at a distance from any land whence detritus was carried seaward is proved by the microscopical investigations of Mr. W. Hill. He has shown that the amount of inorganic matter, such as recognizable particles of quartz felspar and mica, decreases as the gault is traced northward, while in the Norfolk marls the proportion of organic material (Foraminifera and shell fragments) becomes very large; and it is doubtless to this gradual elimination of the transported sediment, and the consequent concentration of the calcareous matter, that the thinning out of the Gault is due.¹

Just as the upward succession at Folkestone, from the blue pyritous clay of the Lower Gault to the grey marly clays of the Upper Gault, indicates the deepening of the sea in which they were deposited, so the lateral passage from the argillaceous Gault of Bedford and Cambridge to the marls and limestones of West Norfolk points to an increasing depth of water and distance from land.

Borings in the east of England prove that the Gault underlies the whole of it, and rests on the surface of Palæozoic rock which was left uncovered by the Vectian Sands. It thins, however, to the north and north-east, and at Holkham in Norfolk there is only 10 feet of clay overlain by 8 feet of red marly chalk, a section which may be compared with that of Roydon.

Nothing comparable to the Gault occurs either in Ireland or Scotland, the basement bed being a glauconitic sand containing *Pecten asper* and *Ammonites varians*, fossils

¹ "Quart. Journ. Geol. Soc.," vol. xliii. p. 580.

which only occur together in the Chloritic Marl and in the sands just beneath it in Dorset. We may conclude, therefore, that the sea did not reach Ireland till this horizon was reached, and it is possible that the Irish *Pecten asper* zone is really the time equivalent of part of our Chalk Marl, the fauna of this zone being a shore-fauna which advanced as the shore receded. Consequently it may have prevailed at a western locality after the sediments containing it to the eastward had been covered by a considerable depth of the succeeding Chalk Marl.

In this connection the Cenomanien deposits of Sarthe in Brittany are instructive, for here the Chalk Marl (Craie de Rouen) passes westward into a sandstone containing some of the same fossils, but mixed with a shallow-water fauna which includes *Pecten asper*.¹

From the Greensand to the Chalk Marl of England the transition is always rapid and sometimes sudden. There is evidence of strong current action at this epoch, consequent probably on the submergence of certain barriers, and these currents seem to have swept away portions of the deposits which then formed the sea-bottom, sifting the soft marls and sands, washing out such fossils as were hardened by the deposition of phosphate of lime, and incorporating them in the basement bed of the new formation. This bed is generally known as the Chloritic Marl, and it frequently lies on a plane of contemporaneous erosion. In the south of England it contains fossils derived from the *Pecten asper* zone, but in Bedford and Cambridge the derived fossils have been obtained from the Gault, and the bed is sometimes called the Cambridge Greensand.

The Cambridge Greensand has also yielded a number of rock-fragments which have evidently been brought from

¹ A. Guillier, "Géologie de la Sarthe," Paris, 1886, p. 213.

distant sources. These include blocks of granite, hyperite, basalt, porphyrite, and felsite, with fragments of hard Palæozoic rocks and of quartzite schists and gneiss. Some of them resemble Scotch and Norwegian rocks, but are just as likely to have come from the north of Ireland. From their number and general angularity it is believed that these fragments were transported by floating ice in the same way as similar blocks are now carried southward by floating icebergs, and dropped on to the bottom of the Atlantic at the present day. Their presence may at any rate be regarded as indicating the influx of cold currents from more northern shores.

The Chalk Marl is an impure chalk, containing in the southern counties from 16 to 24 per cent. of fine sand and silt, with small particles of glauconite. It was formed in deeper water than the Gault, and attains its greatest thickness in and east of Berkshire, thinning both to the north and to the south-west; but as in the case of the Gault, the thinning to the south-west is accompanied by an increase in the proportion and size of the quartz grains, while toward the north-east there is a diminution in the number of recognizable quartz particles and of other inorganic materials, with an increase of minute shell-fragments, and of other calcareous materials.¹

The outcrop of the Chalk Marl along the base of the main escarpment from Dorset to Norfolk presents us with a transverse section of a large lenticular mass of slowly accumulated material, having its maximum thickness over a tract which lay at some distance from the land, and yet was not beyond the reach of currents bearing a certain amount of finely-divided inorganic detritus, and from this region of maximum development we can trace it into the purely calcareous deposit of a deeper sea on the one hand,

¹ See W. Hill in "Quart. Journ. Geol. Soc.," vol. xliii. p. 582.

and into shallow-water beds, with a minimum of calcareous matter, on the other.

The Totternhoe Stone seems to indicate a temporary increase in the strength of the prevalent currents, enabling them to carry coarser particles to a greater distance. This bed attains its maximum thickness in the counties of Bedford and Cambridge, thinning out to the north and south.

Upward through the Lower Chalk there is the same transition to a more purely calcareous deposit that we found taking place horizontally in the case of the Chalk Marl. Deposition was now more uniform, the thickness of the beds above the Totternhoe Stone varying less than those below. At the summit of the Lower Chalk, however, there is evidence of another physical change in the occurrence of one or two layers of grey shaly marl. This horizon is continuous from the Isle of Wight to Suffolk; it is obscure in Norfolk, but occurs again throughout Lincolnshire and Yorkshire. There is nothing more remarkable in the stratigraphy of the Chalk than the wide extension of these shaly marls, but they contain little that throws light on the circumstances which led to their formation.

We might suppose that the shale was due to elevation of the sea-floor and a consequent shallowing of the water, but if this were so we should expect the incoming of a shallow-water fauna, whereas the fauna of the marls is a very small assemblage, and is similar to that of the Chalk below. It seems more probable that the sea was at this time invaded by a flow of cold water from the north in a broad and steady current, which was strong enough to prevent the deposition of much chalky matter, but too far from land to carry much sediment with it. This hypothesis of a northern under-current will also account for the sudden disappearance of the creatures which lived in the

Lower Chalk sea. They may have been driven away by the coldness of the water, for few of the Mollusca or Echinoderms range up into the Middle Chalk above.

In Ireland the *Pecten asper* sand is succeeded by yellowish calcareous sandstones with nodules of chert, and varying from five to thirty feet in thickness. These sandstones are probably of the age of our Grey Chalk, the beds below being the equivalent of our Chalk Marl (see *ante*, p. 173).

The Middle Chalk has at its base a hard nodular rock, which passes up into firm rocky chalk that consists largely of broken and triturated fragments of *Inoceramus* shells, with many cells of Foraminifera. Higher up the chalk is softer and whiter, and microscopical examination shows that the shell-fragments become fewer, and the Foraminifera become less robust, having smaller and thinner shells; the mass of the rock consisting of a fine amorphous calcareous sediment. Toward the top of this division there is something like a reverse change, the Foraminifera becoming more abundant, and at the same time rather more robust.¹

This soft white chalk is evidently the deposit of a deep sea at a considerable distance from land, but it contains thin interstratified seams of marly shale, and it is important to observe that the argillaceous element in these seams increases northwards, till in Lincolnshire and Yorkshire they are veritable clays, dark grey or black, and yet only a few inches thick. Again, therefore, we seem to have evidence of the occasional influx of currents from the north.

The Middle Chalk is surmounted throughout the greater part of England by one or more beds of hard cream-coloured limestone, which is known as the Chalk Rock, and has every

¹ For these particulars I am indebted to my friend, W. Hill, F.G.S., whose microscopical studies have greatly added to our knowledge of the minute structure of the Chalk, and who has found that the successive zones exhibit constant lithological differences.

appearance of having been formed in much shallower water. Fossils are often abundant, Gasteropoda are not uncommon, and include such genera as *Turbo*, *Cerithium*, *Avellana*, *Aporrhais*, *Natica*, *Crepidula*, and *Emarginula*, the modern representatives of which do not live in deep water, some not ranging below 100 fathoms, and none lower than 150 fathoms. Moreover, some of the species are indistinguishable from those of the Chalk Marl nearly 400 feet below. The rock also contains numerous grains of glauconite, and includes layers of large green-coated nodules.

This sudden recurrence of peculiarities which characterize the Chalk Marl and Totternhoe Stone, associated with a fauna of similar character, compels us to conclude that the sea had again become shallower by the rise of a part of its floor; there is, however, no sign of strong current-action or of the proximity of land. The compact rock and its contents seem to have accumulated slowly in very quiet water under conditions which permitted a large number of marine animals to migrate eastwards, and repopulate the bed of the sea.

This rock continues with little change as far westward as the Chalk extends in England, but in Ireland there is nothing which exactly corresponds to it, or to any part of the Middle Chalk. Some of the fossils of this division occur, however, in certain glauconitic sands and marls which lie between the Cenomanien sandstones and base of the Upper Chalk; they vary from six to sixteen feet thick, they contain large grains and occasionally pebbles of quartz, and have evidently been formed in shallow water not far from land.

The Scotch deposits are still more abnormal, for the beds corresponding to the Irish Cenomanien are succeeded by white sandstones from 30 to 100 feet thick, without fossils, but including a seam of coal, and thus evidently formed in close proximity to land.

Above the Chalk rock of England there are a set of rough nodular and shelly beds of a yellowish tint, in which Echinoderms of the genus *Micraster* are extraordinarily abundant, and these pass up into soft white chalk with numerous layers of flints. Still higher is a considerable thickness of chalk without flints, surmounted by other beds in which they abound. The thickness of this Upper Chalk increases from west to east, its total thickness near Dorchester being estimated by Dr. Barrois at 500 feet, while in the Isle of Wight it is about 700, and in Norfolk probably 900 feet; even here, however, the actual summit is not reached, the very highest or Maestricht chalk not occurring in England.

In Ireland the base of the Upper Chalk is a hard limestone full of green grains and quartz pebbles, but holding Echinoderms of Upper Chalk species. It appears, in fact, to be the condensed equivalent of the two lowest zones of the English Senonien, which are 250 feet thick in the south of England, whereas the Irish bed is less than three feet. Above there is hard white chalk which, however, is less than 100 feet thick, though it must represent some 600 feet of the English Chalk. The same hard white limestone is found at a few places on the west coast of Scotland, in Mull and Argyleshire.

§ 2. Geographical Restoration.

Lower Cretaceous Time.—We have seen that at the close of the Jurassic period the area of deposition was limited to a region south of the latitude of Devizes and Chatham. Everywhere to the north of this line there is a gap and unconformity between the Jurassic and Cretaceous rocks; and we may conclude that the greater part of the British area was then in the condition of dry land. The areas occupied by the Palæozoic rocks formed hilly and mountainous

ground as they do now, and between these districts over the Midland counties of England, and over the space now occupied by the Irish Sea, and thence by the North Channel round the west of Scotland, spread a fertile lowland district formed of the newly emerged Jurassic strata.

In the Wealden area an extensive series of freshwater deposits was in process of formation, a series which is generally spoken of as the delta of a great river, and is usually compared with the deltas of rivers like the Nile and Mississippi, which empty themselves into the sea. It does not seem likely, however, that the area occupied by the Wealden beds was the head of a marine gulf or bay, for it is difficult to see in which direction it could have communicated with the open sea; the absence of Neocomian deposits over Belgium and the north of France points to the existence of land on the east, and there is no reason to suppose that the Palæozoic areas of Devon and Cornwall were then separated from those of north-western France by anything deeper than the valley of a river. Moreover, the delta of a large river entering the sea is generally, if not invariably, composed of alternating estuarine and freshwater beds, whereas the Wealden series is entirely of freshwater origin; hence many have regarded the formation as a purely lacustrine one.

Such a fluvio-lacustrine origin has especially been advocated by Mr. C. J. A. Meyer, who remarks,¹ that although there is considerable variation in the characters of the Wealden deposits, "yet one might venture to say that nine-tenths of the whole was quietly accumulated. The fine-grained sandstones and quartzose grits of the lower beds, the stiff red clays of the middle, and thinly foliated 'marls with *Cypris*' of the Upper Wealden might all be of lacustrine origin, and yet include both tree stems and the bones of reptiles. There is indeed in these again, as in

¹ "Quart. Journ. Geol. Soc.," vol. xxviii., p. 247.

some portions of the Purbeck series, a strong resemblance to the Tertiary lacustrine beds of central France."

From the nature and fossil contents of the lower and middle beds, he infers that the waters were at first shallow and frequently disturbed by the currents of inflowing rivers; "the finely laminated strata of the Upper Wealden, on the contrary, are such as belong to deeper waters, and rarely, if ever, show traces of disturbance." These considerations lead us to conclude that during the earlier part of the Wealden epoch the country was still rising, and that the Wealden rivers then attained their maximum velocity and carrying power; for a time perhaps the land was stationary, but subsidence quickly ensued, diminishing the river-action, increasing the area of the Wealden lake, and adding depth to its central waters.

The history of the Purbeck-Wealden episode may therefore be summed up as follows: The Purbeck series was formed during upheaval in lagoons that were gradually cut off from the retreating sea; the Lower Wealden beds were formed in a freshwater lake on the site of the old lagoons, and the level of its waters was maintained by the influx of one or more powerful rivers; the Upper Wealden was formed during a subsidence which widened the area of the lake, and eventually depressed it beneath the waters of the returning sea.

The next point which calls for consideration is the drainage system of the Wealden land, and whether it is possible to ascertain the direction from which the principal river or rivers ran into the lake. It must be remembered that in passing from the Purbeck to the Wealden we find evidence of rapidly increasing fluvial action, as if some large river had suddenly invaded the lake, or as if rivers which had previously carried little but matter in solution now became loaded with a quantity of detritus in suspension. Possibly both operations really took place. It has

been pointed out (p. 160) that in Purbeck times the valleys of the English and Bristol Channels were in all probability occupied by rivers of considerable size, but that on the first emergence of the land the amount of mechanically-transported detritus which they carried seaward seems to have been very small. Not only was the land at a comparatively low elevation, for we must remember that during the Jurassic period the height of the Welsh hills must have been diminished by the accumulation of at least 2,000 feet of strata round their flanks; but it is also very likely that small lakes existed in their upper reaches, which would intercept and retain the detritus carried by the stream, just as the mud of the Rhone is deposited in the Lake of Geneva. As, however, elevation proceeded and the land rose higher above the sea, rainfall would be increased, erosion would be accelerated, the load carried by the streams would be larger, and the volume and velocity of the currents would be greater, any lakes that existed would be rapidly filled up; under such conditions a large quantity of detritus would be carried to the mouth of the rivers and poured into the Wealden basin. This will sufficiently account for the differences observable in passing from the Purbeck to the Wealden beds.

If, however, these western rivers were the only streams that ran into the lake, we should expect the sandstones to diminish eastward, but this is not the case, the Lower Wealden of Sussex being more sandy than that of Dorset; and these Sussex sands must, I think, have been brought by minor streams which drained the land on the north side of the lake—a supposition which finds confirmation in the pebble bed of Lindfield (p. 165). It is also possible that a stream may have entered the eastern end of the lake, for, as we shall presently see, its outlet is not likely to have been in that direction.

We must not forget the possibility of a great river

coming in from the north-west, as Dr. A. Geikie briefly suggests;¹ that such a river must have traversed the north-western plains on their upheaval from the Jurassic sea was pointed out in the last chapter, and it was supposed that a lake then existed on the site of the Irish Sea, and received the detritus brought down by this stream. It was suggested that it continued a south-easterly course over the Jurassic clays, and discharged a large volume of water, but a small amount of sediment, into the Purbeck gulf. In Wealden time it may have carried a larger quantity of sediment, though we can hardly attribute the sands of the Lower Wealden to the influx of such a river, for after so long a course over a low-lying clayey country its current would not be likely to carry anything coarser than mud, unless it was joined by powerful tributaries from Wales.

We may therefore conclude that the principal rivers flowing into the Wealden lake came from the west and north-west, draining the large tract of country which then connected Brittany and Cornwall with Ireland. Other streams of smaller volume, but carrying much detritus, flowed in on the north and north-east. To the position of the outlet we are guided chiefly by the disposition of the overlying beds, and the tract over which they are most deeply accumulated being on a line from the Isle of Wight through the Paris basin, we may consequently assume that the excurrent river ran from a south-eastern prolongation of the lake, and, passing across France, fell into a gulf of the Neocomian sea that stretched northward as far as Vassy-sur-Marne.

Next let us endeavour to estimate the area over which the Wealden deposits originally extended, which is of course nearly the same thing as estimating the size of the lake itself. We know that these strata extend from the centre of Dorset to the Boulonnais, a distance of nearly

¹ "Textbook of Geology," first edition, p. 817.

200 miles. The rapid thinning out of the beds in Dorset shows that they did not reach much farther due east, but it is very likely that the lake was prolonged some distance to the south-east along the axis of the Channel valley, and there can be little doubt that its waters covered a large part of the area which now lies between England and France. It is not assuming much, therefore, if we suppose that the Wealden beds spread as far south of our present coast-line as they do to the north of that line. Now from the coast of Dorset they are known to reach inland for thirty miles, and in Hampshire a line joining the Vale of Wardour with the North Downs is forty miles north of the south coast of the Isle of Wight. If, then, we assign the beds an original length of 200 miles and an average breadth of seventy miles, we obtain an area of 14,000 square miles for their original superficial extent. The area may have been somewhat larger, because we do not yet know anything of their extreme southern or northern limits, but, on the other hand, there is reason to think that the eastern end of the lake was not so wide as the western. See map, fig. 4.

The Wealden Beds have often been spoken of as if they were one massive and continuous delta, and as if a calculation of the area over which they were spread out would give us the superficial area of this delta—a misconception which has probably arisen from the idea that the beds were formed in the estuary of a great river. If, however, as is most probable, they were formed in a lake, it is obvious that a massive formation might be accumulated in the lake-basin while only small portions of that basin were filled up by the deltas of the inflowing rivers, so as to be raised above the level of the waters, and it is clear that we can form no idea of the size of these deltas from a calculation of the area of the lake-basin itself. Nay, further, would not the size of these deltas be mainly

dependent on the movements of the land as influencing rainfall, erosion, and transportation of material?

From the considerations already stated, it is probable that the actual deltas would attain their maximum development in early Wealden times, while the land was rising or stationary, and it is even possible that at one time a large portion of the lacustrine area may have been silted up, and the whole made very shallow; but when the land began to subside erosion and transportation would be checked, though the volume of water filling the river-channels might still be large; the level of the lake-waters would probably rise, and the surface extent of the deltas would be greatly reduced, if they were not submerged altogether. Toward the close of the lake's existence this seems to have been the case, the shaly clays of the Upper Wealden indicating quiet deposition in the still waters of a lake that was being gradually lowered toward the level of the sea.

As already stated, the deposition of the Wealden Beds was contemporaneous with the formation of the marine Neocomian strata of France and Germany. The Germanic sea was extending itself eastward, and a gulf connected with it lay over the east of Yorkshire and Lincolnshire. At the same time the southern sea was gradually creeping up the valley of the river which ran from the Wealden lake, and the distance between the lake and the sea was gradually lessened, till at length the last barrier was broken through, and the Wealden lake became the Vectian gulf or estuary. The change from the lacustrine shales of the Wealden to the marine clay of the Lower Vectian is a sudden one, and in this respect is like the change from the Triassic marls to the Rhætic beds; but the actual conditions of the two cases were very different, the area of the Wealden lake was very much smaller, and its conversion into a gulf was not accompanied by the tremendous climatal change which took place in the earlier time, when the

Triassic deserts were converted into fertile and forest-clad districts. The land of Vectian time was doubtless similar in climate and aspect to that of Wealden time, and the plants and creatures which inhabited the country were the direct descendants of those that lived in the Purbeck and Wealden periods.

The geography of the British area had now become similar to what it was at the close of the Portlandian epoch. There were two gulfs, one on the south, in which the Atherfield Clay and Walpen Sands were accumulated, and one to the north-east, in which the middle part of the Speeton Clay was contemporaneously deposited. For a certain time after the first invasion of the Wealden lake the land seems to have been nearly stationary, so that this basin was gradually silted up, and shallow-water conditions prevailed till further subsidence took place. Thus in Oxfordshire and in Normandy (Pay du Bray), outside the limits of the marine Lower Vectian Beds, we find freshwater deposits similar to those of the Wealden, but probably of Vectian age.

Marine erosion, however, was active, and, aided by further subsidence, the sea spread farther and farther over the ground which separated the two gulfs, till at length the waves effected a junction across the lowest part of the intervening isthmus and invaded the lacustrine area, which seems at this time to have existed on the isthmus, and in which the Shotover Sands were formed. The communication thus established became a narrow strait or channel, through which a strong current ran from the northern to the southern sea (see p. 169). This channel doubtless increased in width, but there is no evidence that the sea had encroached very far either on the eastern or western land before the formation of the Gault, which overlaps the Vectian sands in both directions. Its western coast evidently consisted of Upper Jurassic rocks, and it is probable that

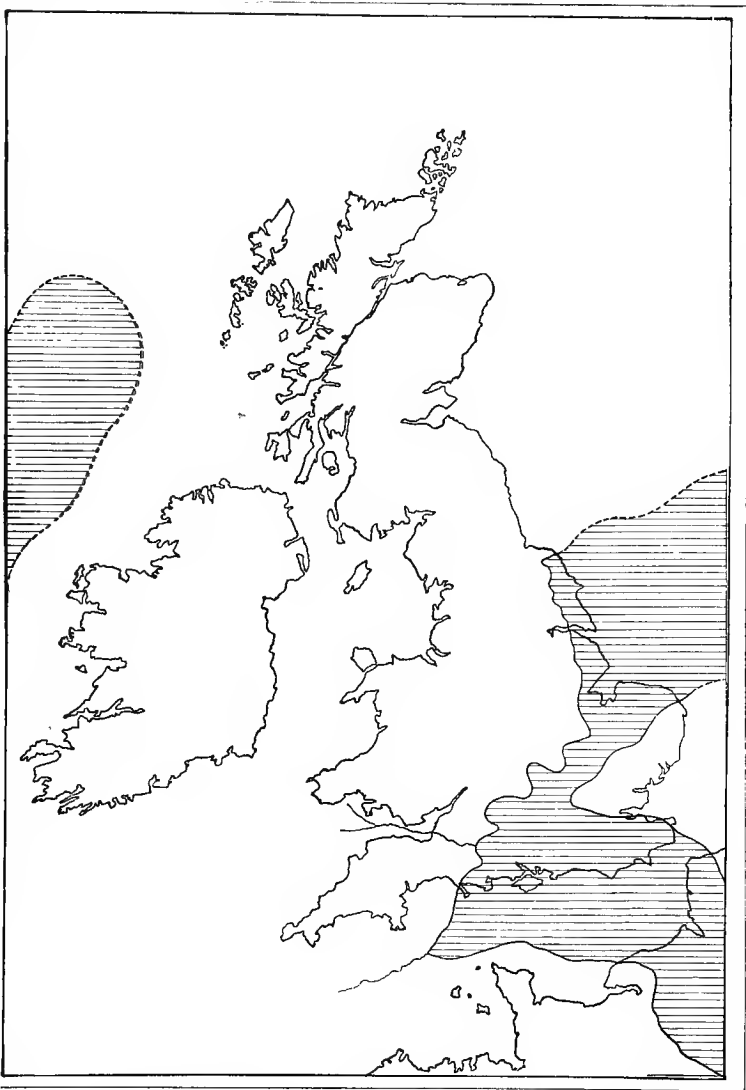


PLATE IX. GEOGRAPHY OF THE LATER PART OF THE VECTIAN EPOCH
(APTIEN STAGE).

the actual shore did not lie very far beyond the present limits of the Vectian sands, but ran in a N.N.E. direction from near the position of Oxford through Northampton, Rutland, and Lincoln. This phase of Cretaceous geography is represented in Plate VIII.

Upper Cretaceous Time.—We have now to chronicle the phases of the great subsidence which commenced at the epoch of the Gault, and continued throughout the remainder of the Cretaceous period, until a thickness of some 1,300 feet of sediment had been accumulated over the Lower Greensand. The thickness of the Upper Cretaceous sediments, however, as compared with those of the lower division, is no criterion of the relative duration of the two eras, for the coarser sediments of the earlier portion of the period must have been deposited far more rapidly than the fine materials of the later era. Some idea of the time occupied in the formation of the Chalk may be gained if we remember that the accumulation of the Atlantic ooze—the modern analogue of the Chalk—is a process so slow, that it is doubtful whether a foot's thickness of it is deposited in a century; at this rate 1,000 feet of chalk would require 100,000 years for its formation, and if we assume that chalk was accumulated twice as rapidly as the Atlantic ooze is supposed to be, the figures (50,000 years) still represent an enormous length of time.

Considering the depth of Gault clay which overlies the eastern Palæozoic area, and the manner in which the Gault and Greensand overstep the members of the Jurassic system westward, it is evident that the eastern part of the British region subsided much more rapidly than the western, so that the Jurassic strata were bent down, as it were, beneath the advancing Cretaceous sediments. The waves of the Cretaceous sea cut obliquely across the older strata, forming a plane of marine denudation which was carried rapidly westward, and had a gentle slope or inclination eastward.

The first result of the great subsidence was the submergence of the promontory which existed on the site of our eastern counties, and the outspread of the Gault muds over the whole of south-eastern England; at the same time the western shore of the Cretaceous sea was carried back to Devonshire, and doubtless also to the borders of Wales, though subsequent detrition has destroyed all evidence of the shore-line north of Devon. From the present disposition of the Cretaceous strata, however, we can hardly avoid the conclusion that the whole of central England was once more converted into a sea-bottom, on which sandy and glauconitic deposits were laid down, just as such deposits are now formed along the borders of our great oceans at a certain depth and distance from shore. Such deposits everywhere underlie the Chalk, but we cannot regard them all as of the same absolute age, because they were formed in a sea which was continually spreading further and further to the west and the north, so that the conditions which prevailed in England at the epoch of the Gault and Upper Greensand did not reach Ireland till the time of the Lower Chalk, and no true chalk was formed in that area till the time of our Upper Chalk.

At the close of the English Greensand stage, when the Warminster beds were being deposited, the whole of south-eastern and central England was covered by a shallow sea, nowhere apparently more than 100 or 150 fathoms deep, and gradually shallowing westward. In the south-west it stretched to the borders of Dartmoor, and it washed the foot of the North Devon and Quantock Hills; the valley of the Bristol Channel was a deep inlet, and thence the shore-line swept northward below the hills of Glamorgan, Monmouth, and Hereford. The height attained by the Greensand in the Blackdown Hills is not more than 600 feet, and these are on the same line of longitude as the

eastern escarpment of the South Welsh coal-basin. It may be that the south of England has been affected by subsequent subsidence to a greater extent than Wales, but the difference can hardly be more than 300 feet, so that we might guess the level to which Greensand formerly reached in Monmouthshire to be about 900 feet.

But in speculating on the possible course of this coast-line further north, and on the probable limits of the sea in which the Upper Greensand was formed, we must remember that the Lower Greensand or Vectian sea seems to have extended much farther west in the south of England than it did over the Midland counties (see p. 186), that its shore-line had a general north-easterly direction, and that, consequently, for a certain length of time, the shore of the Upper Cretaceous sea would have a parallel direction. We may assume that the recession of this coast-line proceeded at nearly the same rate so long as it lay along the strike of the Jurassic strata, but the superficial extent of these strata being so much greater in the Midlands than in Dorset or Somerset, it is probable that when the sea reached the borders of Devon its shore between latitude 52° and 53° did not lie farther west than the line of the Warwick and Leicester coalfields; and again, when the south-western shore was carried back to the Palæozoic rocks, the waves may still have been attacking the mass of Triassic marls and sandstones which must then have enveloped the coalfields of Stafford and Shropshire.

These Triassic beds would form a tract of land uniting the Longmynd district to the Carboniferous region of Derbyshire, and constituting a barrier that would for some time resist the advance of the Cretaceous sea. We have some reason, therefore, for supposing that from the hills of Monmouth the shore of the Upper Greensand sea trended north-eastward to Derbyshire, and passed up the eastern side of the Pennine range, without gaining access to

the basin of the Irish Sea. If the prevalent current set from the south-west, this curve of the shore would tend to give it an easterly course, so that it may have passed seaward and eastward from over the north of Warwick, which will account for the great eastward extension of the Gault, and also for its absence north of latitude $52^{\circ} 50'$.

The geography above suggested and represented in the map, Plate IX., assumes that the Pennine hills were not submerged, and, as this is an important point, we may consider it a little more closely. We know that the relations of the Jurassic and Cretaceous strata in the north-east of England are similar to those of their south-western equivalents; it is clear that the Upper Cretaceous sea, aided by subsidence, marched across the Jurassic ground and formed a plane of erosion that sloped gradually up to the Palæozoic hills. Now at Garraby, which is nearly the most westerly point of the Yorkshire Wolds, the Red Chalk, or homotaxial equivalent of the Gault, rests directly on the Lias at an elevation of about 600 feet; a few miles further west it must have lain on the Trias, and thence the sea-floor probably passed with a gentle slope to the foot of the Pennine hills. How far the Red Chalk extended in a westerly direction we cannot say, but sooner or later it probably passed into a more littoral deposit; comparatively deep water (100 to 150 fathoms) may, however, have continued to within a short distance of the shore-line, and the Pennine hills probably rose up from the sea with a steep slope, as the Riviera does from the Gulf of Genoa. Thus, if the base of the Chalk reached to what would now be a level of 900 feet over the edge of the Triassic boundary, and we suppose the water there to have been 600 feet deep, it would not have overtopped the Pennine hills, which even now rise in many places to heights of over 2,000 feet, and in the Cretaceous period the watershed must have been much higher than it is now. Hence I do

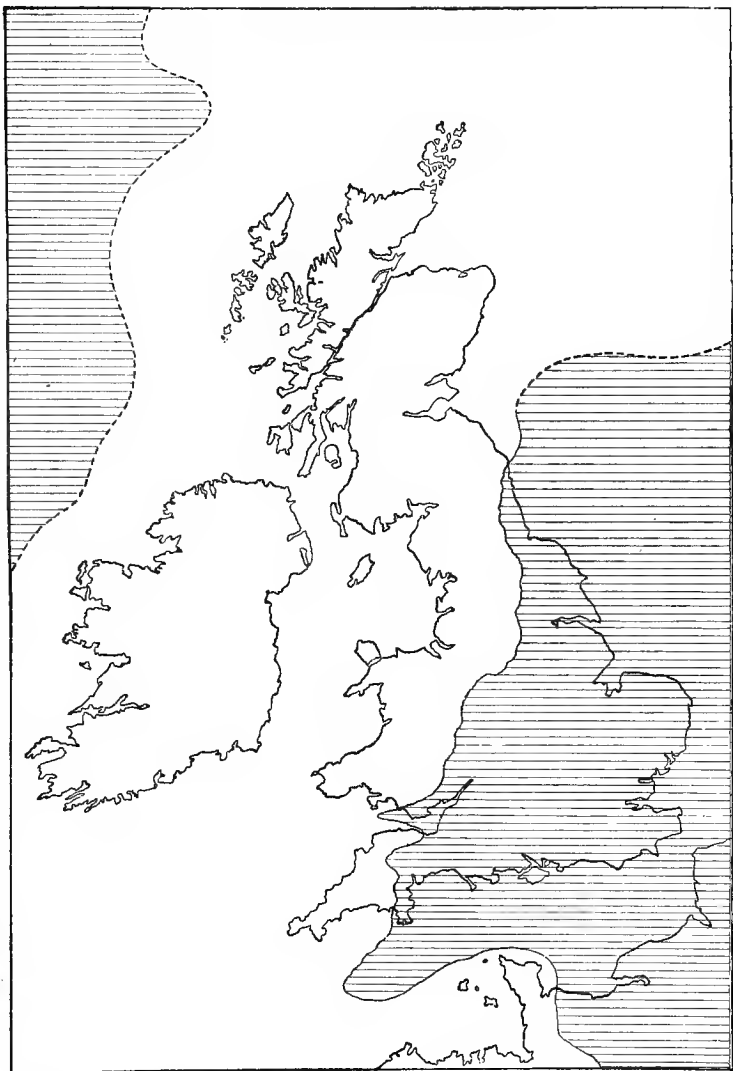


PLATE X. CRETACEOUS GEOGRAPHY (SHOWING THE PROBABLE COAST-LINE DURING THE FORMATION OF THE UPPER GREENSAND).

not think that this range was submerged till the time of the Middle or Upper Chalk.

The remarkable change, however, which takes place in the character of the Red Chalk when followed along the northern face of the Yorkshire Wolds, and its partially argillaceous condition at Speeton (see p. 171), are facts which suggest that currents carrying fine silt came from a north-easterly direction, and that their influence was felt as far south as the north-east of Yorkshire. This consideration leads us to infer that continental land existed at some distance north and north-east of the present outcrop—a land which doubtless included Scotland and Scandinavia, and would effectually shut out the Arctic currents; it is at the same time quite possible that its highest mountains were snow-clad, and they may even have nourished glaciers which reached far down the valleys toward the shores of the great European Ocean.

There would at length come a time when the barriers which limited the Greensand sea were breached and overtopped, when Wales was nearly isolated, and the hills of Devon and Cornwall converted into islands; the sea then spread to the north-west, over the areas of the older Mesozoic rocks, to the north of Ireland and the west coast of Scotland. The facts observed in connection with the Chloritic Marl and Cambridge Greensand seem to tally with what we might expect to be the results of such a change. The currents would be altered, and it is probable that strong currents would set either toward or out of the straits between Wales and Derbyshire, and to the scour of such currents the evidences of erosion at this epoch may be due.

It is very difficult to say how far west this subsidence carried the Cretaceous sea, or to what extent Ireland and the north of England were submerged during the formation of the Lower and Middle Chalk in southern England; for

though a thickness of over 400 feet of chalk was accumulated in the south and east of England during this time, it is probable that these were the areas of greatest depression, and that the western and northern portions of the British region did not sink to the same vertical extent. We cannot judge of the levels reached by the Cretaceous sea from the present relative levels of the Cretaceous strata in Antrim and Mull, because these areas have undergone an extensive local depression in Tertiary times, after the outpouring of the great lava-streams under which the Mesozoic strata are buried. We may be sure that in Pre-Tertiary times the relative level of these districts was many hundred feet higher than that at which they now lie, while the height attained by the base of the Greensand in Morvern (Argyleshire) shows that the Cretaceous sea must have covered considerable areas in western Scotland, and makes it probable that all the lowland district was submerged so as to form a strait or channel between the Highlands and the southern uplands. The latter, with the Cheviot Hills and the higher parts of Cumberland, Westmoreland, and Yorkshire, must have formed a group of islands; and it is not unlikely that Ireland presented a similar appearance, glauconitic deposits like those of Antrim being deposited in the comparatively shallow waters between the islands of the Irish archipelago. On this point we shall never obtain definite information, but the very existence of such deposits in Ireland and of chalk over so large a part of England, makes it certain that no large areas of land then existed, that the Cretaceous sea became more and more oceanic, and that the British region had never been so deeply submerged since the commencement of Neozoic time.

The subsidence had, however, by no means attained its maximum extent, for at the epoch of the Chalk Rock the downward movement seems to have been arrested; and if

the inferences drawn from the facts previously recorded (p. 177) are correct, there was actually an uplift raising the sea-floor in England till the water above it was not more than 100 or 150 fathoms deep. There is no clear evidence of any such oscillation in the Irish succession, but the white sandstones of Morvern (see p. 177) do lend some support to the view that the formation of the Upper Chalk was preceded by a movement of elevation, so that beds of estuarine origin, with the remains of something like a terrestrial surface, are here intercalated between marine deposits.

The subsequent subsidence must have been more rapid and still more extensive than that which had previously taken place, but we still find deposition prevailing more in the east than the west, and it was not until 250 feet of chalk had been accumulated over the Chalk Rock in the east of England that true chalk began to be formed in Ireland, and even then it was deposited so slowly that only 90 feet seem to have been accumulated in the time that 600 or 700 feet were formed in England; we may, therefore, conclude that the western region was never so deeply submerged as the eastern.

During the formation of this chalk it would seem that little of England or Wales could have remained above the level of the sea, for we must remember that such chalk is a deep-sea deposit, and is not now formed in water of less than 400 or 500 fathoms. If we suppose that at the epoch of the Chalk Marl central Wales was already so submerged that the sea-level stood at the 1,000 feet contour, that during the subsequent subsidence 500 feet of chalk were deposited around it, and that the highest bed of this chalk had 400 fathoms (2,400 feet) of water over it, it is clear that all the present surface of Wales would be under water; and even if we allow for subsequent detrition by supposing that from 800 to 1,000 feet of rock has been

removed since the Cretaceous period, there is very little of the territory which, with the addition of this thickness (*viz.*, 1,000 feet on the mountains), would overtop a line drawn 3,900 feet above the present sea-level. From this rough calculation, therefore, we may infer that if any land rose above the waves of the Upper Chalk sea on the site of modern Wales, it merely consisted of a small area overlying the present Snowdonian range.

The islands of the Irish archipelago were reduced to smaller and smaller dimensions, and it is probable that chalk once covered the greater part of the country, but whether the whole of it was ever submerged we have no means of ascertaining; and the same may be said of the south of Scotland. With regard to the Highlands, from the position of the Chalk in Morvern, and from the beds of flints associated with the Tertiary lavas, we may infer that it originally covered all the lower parts of Argyle and Inverness. Flints abound, and fragments of chalk are not uncommon in the Glacial deposits of the eastern coast, proving that "the Chalk must once have been in place at no great distance, if, indeed, it did not actually cover part of Aberdeenshire and the neighbouring counties."¹ We shall not, therefore, be assuming more than the facts warrant if we conclude that the central Highlands formed an island in the sea of the Upper Chalk.

How far this sea extended northward it is hard to guess, but some speculations have been hazarded even on this point. It is certain that the greater part of western and southern Europe was covered by an ocean which seems to have had a wide latitudinal extension, and may have been continuous from the southern part of North America, across the Atlantic, and through Europe into Asia. If this was the general trend and extent of the Cretaceous ocean, we may reasonably suppose the larger

¹ A. Geikie, "Scenery of Scotland," 1887, p. 125.

land areas of that period to have had a similar trend, at any rate in the northern hemisphere, and to have spread from east to west rather than from north to south like our present continents. It is probable, therefore, as Professor Prestwich suggested,¹ that a great northern continent stretched across what is now the shallower part of the North Atlantic Ocean, between Norway and Greenland, forming a barrier which excluded the colder waters of the Arctic seas, and allowed the Cretaceous ocean to have the full benefit of the warmer currents from the south.

¹ Pres. Address to the Geol. Soc., 1871; "Quart. Journ. Geol. Soc.," vol. xxvii. p. lxviii.

CHAPTER XI.

HANTONIAN PERIOD.

HAVING elsewhere stated my conviction that the Lyellian divisions of Tertiary time cannot be regarded as systems or groups of equivalent geological value to those which are recognized as divisions of Secondary time,¹ I need only here explain that no more than two such Tertiary systems can be admitted; for the first of them, including the Eocene and Oligocene series, the name *Hantonian* has been proposed, and for the second, which includes the Miocene, Pliocene, and Pleistocene series, the name *Icenian* has been suggested. The same nomenclature will be used in the present volume; and it may be observed that the importance of the break between the Oligocene and the Miocene has recently been recognized by M. de Lapparent.²

The simplest division of the British Eocene series into groups of fairly equivalent value is as follows³:—

Upper	{	Hordwell Sands and Barton Clay.
	{	Bracklesham and Bournemouth Beds.
Lower	{	Lower Bagshot Sands and London Clay.
	{	Reading Beds and Thanet Sands.

¹ "Geol. Mag.," 1885, p. 293, and "Historical Geology," 1886, p. 36.

² "Manual of Geology," 1886, second edition, pp. 1120, 1164.

³ This chapter was written before Professor Prestwich read his paper "On the Correlation of the Eocene Strata" ("Geol. Soc. Proc.," Dec. 21, 1887), in which he proposes the same division of the Eocene series.

The Oligocene series may also be simply divided into :—

Upper { Hempstead Beds,
 { Bembridge Beds.
Lower—Headon Beds.

The Hantonian strata of north-western Europe occur in several broad basins or trough-shaped areas separated by parallel anticlines or regions of elevation. The most northern of these is that which we know as the "London basin," but which is really only part of a large trough-shaped area extending from Belgium across the North Sea, and terminating in Wiltshire; the second is known as the Hampshire basin, and a third as the Paris basin.

A study of all these areas is necessary for a proper comprehension of the geographical changes which took place during the period, and the stratigraphy of the Paris basin is especially important from the fact of that area lying nearer to the southern shore of the Hantonian sea.

§ 1. Stratigraphical Evidence.

Eocene.—The gap between the Chalk and the Tertiaries is not bridged over by beds of passage in any part of England, but in Belgium and Denmark there are deposits which show that the Cretaceous period was brought to a close by a general upheaval of western Europe—a change which led to the expulsion of the Cretaceous fauna from the European area, and the introduction of a very different shallow-water assemblage, which we call the Eocene fauna because it contains the ancestors of our modern shallow-water European species.

In England, therefore, there is a considerable break between the Cretaceous and Hantonian systems, but the upheaval which caused this break seems to have been such a gradual and uniform movement that it did not lead to

any widespread unconformity, producing rather what may be called a physical and palæontological hiatus, which is intensified by the contrast between the characters of the Chalk and the London Tertiaries. There is, however, a certain amount of unconformity, arising probably from unequal uplift and erosion during the unrepresented time, for, as Dr. Ch. Barrois has pointed out,¹ "the centre of the Tertiary basin of London does not correspond with the centre of the Cretaceous basin of London. Norfolk, the deepest part of the Cretaceous sea, would still have been a depressed region after the Cretaceous if an upheaval of this area or a greater depression of the southern part of the basin had not modified this state of things before the deposition of the Thanet Beds."

A consideration of the variations in the thickness of the Chalk, as proved by deep borings in the London basin, shows that the Chalk is thinnest beneath or near London, and that it thickens in every direction from that centre, as if the original uplift had produced a low and broad dome which had its centre on the Surrey side of the Thames, and was quite independent of the subsequent upheaval which produced the axis of the Weald. Thus the Chalk is thinnest at Streatham (623 feet); beneath London, and thence northward as far as Loughton, it varies between 645 and 656 feet; further north it thickens to 680 at Cheshunt, and north-eastward to over 700 feet at Wickham Bishop and to 890 at Harwich; from London eastward it thickens to 682 at Chatham, and is over 734 at Chartham, near Canterbury; westward it is rather thicker at Richmond (671 feet) than below London, and at Bushey, to the north-west, it is about 700 feet.² South-west, at East Horsley, between Leatherhead and Guildford, it is 817 feet, and on the

¹ "Recherches sur le Terr. Cret. Sup.," 1876, p. 179.

² This thickness is obtained by adding the difference between the level of the ground at the well and the height of the Tertiary outcrop

south of the Weald, near Brighton, it is as much as 958 feet.

I agree with Dr. Barrois in thinking that the highest zones of the Chalk do not exist beneath the London area, but entirely differ from his view that their absence is due to original non-deposition. I see no reason to doubt that such an oceanic deposit as the uppermost Chalk extended continuously from Kent to Norfolk, and that its present absence near London is the result of pre-Tertiary erosion.

The lowest Eocene group, the Lower London Tertiaries, as they are sometimes called, is a somewhat complex one. The lowest member (Thanet Beds) is in East Kent about 80 feet thick, and consists chiefly of sandy marl or clay passing up into grey sand, with layers of calcareous sandstone; westward these beds are replaced by sharp grey or buff sand, which is 40 feet thick near Woolwich, but thins westward through Surrey, and has not been traced continuously further than Leatherhead. Beneath the London Clay they extend as far as Chertsey, and thence the boundary appears to run north-east along a line by Hampstead, Enfield, Epping, and Braintree, to beyond Sudbury. The Thanet Sands are therefore limited to the eastern part of the London basin.

The next subdivision is known as the Woolwich and Reading Beds, and is a very variable set of deposits, but has a much wider extension, for it occurs throughout the London and Hampshire basins, and seems to have been continuous originally across the intervening chalk ridges of Hampshire. These beds exhibit three distinct types or facies, and the geographical position and extent of these types is of course an important consideration.

1. The first and most widely distributed type is that of the Reading Beds, which prevail throughout the central to the thickness of chalk pierced by the boring. For this and other information on these borings I am indebted to Mr. Whitaker.

and western parts of the Hampshire basin, and through the western and northern parts of the London basin. They consist of clays and sands, which are generally bright-coloured and sometimes contain marine fossils at the base, but in the higher beds plant-remains are the only fossils; layers of pebbly sand, often compacted into conglomerate, are of frequent occurrence, the pebbles being always of flint.

2. The second type is that of the Woolwich Beds, which consist of dull or dark-coloured sands and clays, containing estuarine and freshwater fossils; pebble beds of variable thickness also occur in them. This type only occurs over a certain area from Guildford in Surrey to Milton in Kent, and again at Newhaven on the southern side of the Wealden anticline; but it would be rash to assume that it originally extended completely across the Wealden district.

3. The third type is purely marine, and consists of light grey and greenish sands, with very few pebbles; it is only fossiliferous in East Kent, but probably passes westward beneath the Woolwich type.

The first type can be traced into the second along the southern edge of the London basin, and the change consists chiefly in the thinning-out of the mottled plastic clays, and the setting-in above them of a bluish-grey laminated clay, which contains freshwater and estuarine mollusca as well as plant remains. Mr. Gardner has pointed out that the floras of these two clays differ—that of the upper clay resembling the London Clay flora more than that of the lower clays—and in his opinion the Reading Beds are a distinct group, older than the Woolwich Beds, and formed in an independent area of deposition. Mr. Whitaker and Professor Prestwich, however, do not agree with this view, and believe the two groups dove-tail into each other.

The pebble beds which form such a marked feature in the district to the south-east of London lie principally above the main mass of the Woolwich clays and sands. Eastward they appear to pass into marine sands with a pebbly base, and they have been described by Mr. Whitaker under the name of the Oldhaven and Blackheath Beds. He has also shown that during their formation erosion took place on an extensive scale, and that these pebble beds sometimes cut through the whole of the underlying Woolwich Beds, so as to rest upon the Thanet Sands. Moreover, it seems probable that they extended beyond the limits of these sands to the southward, overlapping them and resting directly on the Chalk, just as the Woolwich Beds do to the westward.¹

The very existence of such accumulations of flint pebbles to a thickness of 40 or 50 feet in some places would lead us to infer that they have been derived directly from the Chalk, and consequently that part of the Chalk area lying to the south of the London basin was then exposed to erosion.

The London Clay and the so-called Lower Bagshot Beds may be considered together, for there is much reason to think that they are parallel formations, and that the sands replace the clays towards the west and south-west. The London Clay is a marine deposit, formed during subsidence in the deeper part of a shallow sea. Its basement bed is always sandy and pebbly, but the mass of the overlying deposit in the eastern districts is clay. It would appear, however, that the lower and middle parts of this clay were formed in deeper water than the upper, or Sheppey Beds, which only yield fossils of terrestrial origin, transported by rivers, namely, the fruits, seeds, and leaves of plants in great abundance, together with occasional bones of snakes, birds, and other terrestrial animals. The Lower

¹ See "Quart. Journ. Geol. Soc.," vol. xxii. p. 419.

Bagshot Beds are chiefly sands with intercalated layers of clay. There is generally a complete passage by gradually increasing sandiness, or by such alternations from one formation to the other. In these beds plant remains are the only fossils found.

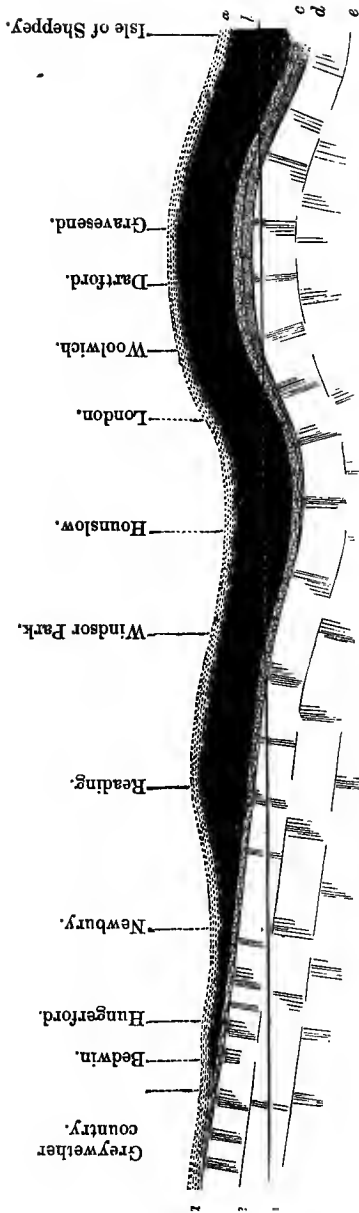
The London Clay attains its greatest thickness (480 feet) in Essex and Kent, where the Lower Bagshots are thin, and it must have spread over a large area to the north as well as to the south of its present limits, for a boring so far north as Yarmouth passed through 310 feet of it; originally, therefore, it must have covered the greater part, if not the whole, of Norfolk, and doubtless extended far beyond the present line of the chalk escarpment in Suffolk, Herts, Bucks, and Oxford. When traced westward through the London basin the clay becomes gradually thinner. Thus, in the Bagshot and Aldershot country it is only about 330 feet thick, but the beds grouped as Lower Bagshot are here from 120 to 150 feet thick, so that the total still reaches 480 feet. Moreover, at Ramsdell, near Basingstoke, there is a mass of brown clay 30 feet thick in what are called Lower Bagshot Beds, but the only reason for not calling this London Clay is the presence of sand below it.

When traced westward from the longitude of Reading and Basingstoke, the whole of the Lower Eocene undergoes such a rapid change and thinning out that we seem to be approaching a shore-line in that direction, and we certainly find the limit of the area in which the London Clay was formed.

Writing on the "Western End of the London Basin" in 1862,¹ Mr. Whitaker showed that near Marlborough the London Clay is reduced to a thickness of 15 feet, but is covered by a certain thickness—perhaps 40 or 50 feet—of "Lower Bagshot" Beds; still further west the basement

¹ "Quart. Journ. Geol. Soc.," vol. xviii. p. 259.

Fig. 5. Diagrammatic section, showing the westerly thinning of the Lower Eocene Beds in the London Basin. Distance nearly 120 miles. (Drawn by Mr. Whitaker, and reproduced by permission of the Council of the Geological Society.)



Vertical scale, 1,600 feet to an inch. Horizontal scale, 20 miles to an inch.

a == Bagshot Beds.

b == London Clay.

c == Woolwich and Reading Beds.

d == Thanet Sands.

e == Chalk.

ss == Sea-level.

The section shows the manner in which the Bagshot Beds cover the London Clay, but the upper line does not represent the present surface of the ground. The unconformity between the Chalk and the Tertiary is not taken into account. The distance of the contact of Chalk and Eocene above or below the sea-level has been drawn as it now is.

bed only of the London Clay remains, and this is directly covered by sands and pipeclays of the Bagshot type. The only conclusion Mr. Whitaker draws from this is that the London Clay has thinned out; but it seems to me that the persistence of the basement bed of the London Clay below the Bagshot Beds means something more, and proves that sands replace the brown clays—in other words, that the Lower Bagshot Beds belong to the London Clay group, and not to that of the Bracklesham Beds.

Fig. 5, which is reproduced from Mr. Whitaker's diagram, shows the rapid thinning out of the London Clay west of Reading, and the superposition of the "Lower Bagshot" on the Reading Beds. As the latter are also very thin here, he thinks that the Lower Bagshot Beds eventually overlapped them to the westward, so as to rest directly on the Chalk—a conclusion which is confirmed by the abundance of "greywethers" on the Chalk Downs in that direction, and by the presence of large rounded flints as well as small pebbles in the "basement bed," which is common to the sands and the London Clay.

With regard to the southern extension of the London Clay group, there is every reason to suppose that it spread completely through Hampshire into the southern basin. At Southampton and at Whitecliff Bay the London Clay is just over 300 feet, and the "Lower Bagshot" is about 50 or 60 feet; but at Alum Bay the former is only 200, and the latter increases to 248. Noting this replacement, and the fact that the plant remains of the Lower Bagshot Beds are more nearly related to those of the London Clay than to the flora of the overlying Bournemouth Beds, Mr. J. S. Gardner suggested in 1882 that the Lower Bagshots should be separated from the latter, and grouped with the London Clay.¹ In Dorset the London Clay is very thin,

¹ "Geol. Mag.," 1882, p. 470. Professor Prestwich has adopted a similar line of argument in his recent communication to the Geological

but beds of the Bagshot type are in great force at Studland Bay and Corfe.

Layers of pipeclay containing plant remains are present in the Lower Bagshot Beds, but are thicker in Dorset than they are in the London basin. As such clays have generally originated from the decomposition of granitic rocks, and as such rocks occur to the westward, in Devon and Cornwall, we may take it as very probable that the materials both of the clays and sands came from the south-west.

The geographical changes which seem to have taken place during the Eocene period cannot be properly understood without a study of the deposits in the Paris basin. In this area the Lower Eocenes are but feebly developed. The Sands of St. Omer and Douai, which correspond to our Thanet Sands, do not extend into the Paris basin, and as there is no equivalent of our London Clay, the whole series is represented near Paris by beds which are similar to our Woolwich and Reading group. For the following details of the succession at Vaugirard, I am indebted to Mr. J. S. Gardner:—

	Feet.
Base of Calcaire Grossier	—
Lower Eocene. { Blue clays and sands, with lignite	20
{ Mottled plastic clay	13
{ White marl with freshwater fossils	16
Calcaire pisolithique (Cretaceous)	10

Here the lignitic group is directly succeeded by the representative of the Bracklesham, but elsewhere there are sands (Sables de Cuise) which contain marine fossils, and are probably about the age of the Lower Bagshot Beds. Moreover, an outlier of London Clay occurs at Dieppe, so

Society, and has proposed that the Lower Bagshot should henceforth be called the London Sands, but it may be questioned whether it would not be better to retain the name of Bagshot for the lower, and to change the designation of the middle and upper beds.

that we may assume this clay extended across the Channel and into northern France.

The Bracklesham and Bournemouth Beds form a well-marked group, which is most fully developed in the Hampshire basin. At Bracklesham in Sussex they are wholly marine, consisting chiefly of clays and green glauconitic sands, which yield a large molluscan fauna of a much more tropical aspect than that of the London Clay. *Nummulites* appear for the first time, and are very abundant in some of the beds, while *Alveolina* and other Foraminifera enter largely into the composition of certain layers of calcareous sandstone. At Whitecliff Bay the lower part has a more estuarine aspect, and at Alum Bay nearly the whole is estuarine and lignitic. At Bournemouth the greater part is fluviatile and freshwater, the lower beds containing a large and varied assemblage of plant remains.

Still further east, in Devon, there is a tract of lacustrine beds which appears to be of the same age (Bovey Beds).

This series is represented in the London basin by the Middle and Upper Bagshot Beds, which both contain marine fossils of the Bracklesham type, but are lithologically more like the upper part of the Bournemouth series. They only occur over small areas, and their combined thickness is seldom over 200 feet, which is small as compared with that of the group in Hampshire, where the total thickness is over 600 feet.

Moreover, it is clear that this northerly attenuation is due to the vicinity of a shore-line. In the middle group the fossils only occur at certain horizons, and at certain localities they are by no means abundant or general; the green earths are not always glauconitic, the colouring matter being frequently carbonaceous, and removable by combustion or elutriation.¹ Freshwater diatoms have been recently found

¹ Rev. A. Irving, "Geol. Mag.," 1883, p. 404, and "Quart. Journ. Geol. Soc.," vol. xliii. p. 379.

by Mr. Irving both in the Lower and Middle Bagshots, as well as ferruginous concretions that retain impressions of vegetable structures, as in the case of bog-iron ores of the present day.¹ Lastly, pebbles in thin layers, and in the form of pebbly sands, are frequent throughout the Bagshot series, but especially in the middle and in the lower part of the upper group.

All these facts afford strong evidence that considerable changes in the relative levels of land and sea were going on in the London basin. Mr. Irving believes that the Lower Bagshots thin out to the north and north-west, allowing the middle group to rest on an eroded surface of the London Clay.²

In Hampshire the Bracklesham Beds are succeeded by the Barton Clay, which is nearly 300 feet thick, and is rich in marine fossils. The fauna, however, differs considerably from that of the Bracklesham, and recalls that of the London Clay, many of the species being closely allied to those of the Lower Eocene, as if they had been perpetuated in some neighbouring province, and their slightly modified descendants had returned to the British Sea as soon as conditions had again become favourable; this immigration of new species, taken together with the disappearance of the larger and more tropical-looking members of the Bracklesham fauna, is a certain indication of some important physical or geographical change.

The succeeding Hordwell Sands seem to have been formed in gradually shallowing water, for they contain a mixture of marine and estuarine species at the top, and

¹ "Quart. Journ. Geol. Soc.," vol. xliii. pp. 378, 381.

² This opinion is now apparently shared by Professor Prestwich, whose paper on the correlation of the Eocene strata was read as this volume was passing through the press. He includes the Lower Bagshot Beds in the Lower Eocene, and remarks that this series both in England and Belgium is separated from the overlying beds by a well-marked line of erosion. (See "Proc. Geol. Soc.," Dec. 21, 1887.)

pass up into the brackish and freshwater beds of the overlying Oligocene series.

Whether the Barton Beds ever reached northward into the area of the London basin we cannot tell, because of the uncertainty that hangs over the correlation of the Bagshot Beds ; it seems probable, however, that the Barton Clay was a formation of much more limited extent than the London Clay.

In the Paris basin the Bracklesham Beds are represented by the Calcaire Grossier, a limestone group about 100 feet thick, and containing numerous fossils. At the base there is a layer of pebbles overlain by glauconitic sands and limestones, and these by shelly and foraminiferal limestones, which must have formed in clear water at a considerable distance from land. The thickness of the group is only about 100 feet, but they evidently correspond to the whole of the Bracklesham and Bournemouth Beds, for such limestones would be accumulated much more slowly than deposits near the mouth of a large river. The Calcaire Grossier is succeeded by sands and sandstones, with marine fossils of Bartonian type.

The French series, therefore, differs from ours chiefly in the absence of the two great clay formations, the London and Barton Clays, which are such conspicuous members of our series. The former is consequently much thinner than ours, and all the beds, except the Calcaire Grossier, would seem to have been formed near a shore-line. The Calcaire Grossier stands out among these shallow-water beds, and marks the occurrence of an extensive subsidence, while its fauna proves that this subsidence opened the way for the immigration of a new and more tropical or southern fauna.

The only other region it is necessary to notice is that of northern Ireland and western Scotland, where a very different set of rocks was being accumulated. These dis-

tricts were the scene of tremendous volcanic eruptions, at first from lofty volcanic cones, and subsequently, in all probability, from huge gaping fissures, which now appear as lava-filled dykes. The lavas ejected from these sources form extensive sheets, which are spread out one over the other, till in some places they still form a pile over 3,000 feet in depth.

At certain localities, in Antrim and in Mull, fluviatile deposits are intercalated between some of these lava-flows, and consist of gravels, sandstones, and carbonaceous shales; the shales containing leaves of plants which prove to be of Lower Eocene age, according to Mr. J. S. Gardner.¹ The gravels consist chiefly of rolled flints and fragments of lava, with some pebbles of grey quartzite. In Mull the river-bed containing these deposits can be traced for a distance of nine miles, and the width of its valley seems to have been between a mile and a mile and a half when it was invaded and filled with the lava-flow which now covers it. This stream seems to have come from the north-west, and "a restoration of the contours about the river-gravels shows high ground to the south and east, coinciding with the boundaries of the traps, with the river channel roughly following the present outcrop of the Palæozoic rocks in the Ross. A spur of gneiss from Benmore, represented by the gneiss of Gribun, Erisgeir, and Inch Kenneth, directed its course westward, and there is but slight trace of it along the shore of Torosay."²

Another buried valley lies below the Scur of Eigg, the dark pitchstone of the Scur resting upon a thick bed of gravel, which fills a hollow or trench excavated in the underlying basalts, and amongst the gravel are fragments and branches of coniferous trees. This interesting relic of an Eocene river was first described by Dr. A.

¹ "Quart. Journ. Geol. Soc.," vol. xliii. p. 270.

² Gardner, loc. cit., p. 286.

Geikie,¹ and in his words, "the hollow in which the shingle lies is evidently the channel of an ancient stream which had eroded the older basalts. At the time when this stream was flowing the island of Eigg must have been joined to some higher land, probably to the west or north-west, for the stream brought down with it blocks of hard Cambrian sandstone—a rock not found in Eigg, but abundant on the opposite island of Rum." Dr. Geikie has also shown that the thickness of rock removed from some of the Highland valleys since the volcanic eruptions has been more than 3,000 feet, and that the valley in which Loch Lomond is situated could not then have existed. From this we may judge how much the general surface of the country has been lowered since Eocene times; and the large quantity of flints in the gravels proves that large tracts of the surrounding country consisted of chalk. It is, in fact, probable (as stated in the last chapter, p. 194) that at this time the whole of the central Highland region was fringed with a broad, undulating mantle of chalk, and that the valleys which now trench the gneissic rocks of this region were first marked out by the Eocene streams which coursed over the surface of these chalk plains.

Oligocene.—Deposits of this age occur only in one part of England, namely, Hampshire and the Isle of Wight, and only the central portion of this series now remains, so that no discussion of comparative stratigraphy is required except in connection with the French and Belgian series. The English deposits were evidently formed in the delta of a large river which drained a western continent, and they are often called the Fluvio-marine series.

The Headon group is truly fluvio-marine, having at the base freshwater clays and limestones, in the middle estuarine and marine beds, and at the top estuarine and fresh-

¹ "Quart. Journ. Geol. Soc.," vol. xxvii. p. 309, and "Scenery of Scotland," second edition, p. 152.

water beds. The total thickness at each end of the Isle of Wight is nearly the same (180 feet), but the central marine beds thicken eastward at the expense of the others, and are about 100 feet thick in Whitecliff Bay. The marine band is also largely developed, and still more fossiliferous, near Brockenhurst in Hampshire, so that the deepest part of the estuary seems to have lain to the north and east of the Isle of Wight.

The succeeding Osborne and Bembridge Beds are a variable series of freshwater deposits with one or more layers of estuarine oyster-beds. The Lower Bembridge or Osborne Beds appear to be of lacustrine origin; at Headon Hill they have at the base a limestone full of siliceous concretions, and a similar limestone, associated with calcareous sandstones and ragstones full of freshwater shells, occurs at the eastern end of the island; the upper beds are red, blue, and green clays, with intercalations of yellow and white sands in the eastern area. These beds were formerly estimated at 60 to 80 feet thick, but have recently been proved to be double that thickness.

The Bembridge Limestone is a remarkable horizon. At the west end of the island it is a single band of tufaceous and concretionary limestone about 15 feet thick, the lower part of which contains freshwater shells, while in the upper part land shells and eggs of the larger snails are found. Toward the east it is split up into several layers of compact creamy limestone, which contain a mixture of land and freshwater shells, and at Whitecliff Bay it is immediately overlain by a marl which is full of oyster-shells. These facts indicate the existence of a large shallow freshwater lake or "broad" on the borders of the estuary, and the gradual deposition in this lake of so much calcareous matter that parts of it were completely dried up. Moreover, the number of the large tropical land snails is so great that, as Mr. Gardner observes, their presence in such

quantity necessarily implies that there was a large and varied flora in the jungles surrounding the lacustrine area. Eventually, however, a submergence took place which brought in the brackish waters of the adjacent estuary and converted the greater part of the area into an oyster-bed, for in Whitecliff Bay such a bed overlies the limestone. The higher Bembridge beds are marls containing *Cyrenæ*, *Melania*, and other shells which lived in fresh and brackish water; and these marls are thicker in the eastern part of the island.

The base of the Hempstead group is taken at a band of black carbonaceous clay, which contains freshwater fossils and plant remains and seems to be the relic of an actual terrestrial surface. At Hempstead it is succeeded by about 140 feet of variously coloured clays and shales, with freshwater and estuarine fossils, passing up into green and brown clays with some purely marine fossils.

Mr. Clement Reid has recently discovered that the Hempstead Beds have a much wider extension in the central and eastern parts of the island than was previously supposed, and moreover that they are thicker to the east of the Medina river than they are at Hempstead. Thus the lower beds, which at Hempstead are only 140 feet thick, are at Wooton 180, and include a group of soft sands about 50 feet thick.¹

Passing over to France, a somewhat similar series is found in the Paris basin. A lower group answering to our Headon Beds commences with a freshwater limestone (Calcaire de St. Ouen), above which are marine sands and marls succeeded by gypsum with freshwater marls. The next group consists of greenish marls with marine fossils succeeded by thick sands and sandstones (Grès de Fontainebleau), and these correspond to our Bembridge and Hempstead Beds. The highest member is a freshwater

¹ "Geol. Mag.," 1887, p. 510.

limestone (Calcaire de la Beauce), which is believed to be newer than our highest Hempstead clays; it appears to be of lacustrine origin, and it covers a large area between the basins of the Seine and the Loire. The whole series extends westward into Normandy, and it is interesting to find an outlier of them in the Cotentin, due south of the Isle of Wight; the Oligocene beds are here only 36 feet thick, but are believed by M. Dollfuss to include representatives of the whole Parisian series.

In Belgium there appears to be a break and unconformity between the Eocene and Oligocene series, and the latter present quite a different facies from the contemporaneous sediments of the Anglo-Parisian basin. They are divisible into two groups only—the Tongrien and the Rupelien. The lower is about 100 feet thick, consisting chiefly of sands with marine fossils, but including some fluviatile beds. The higher (Rupelien) group is said to overlap the lower beds and to contain fossils derived from their erosion; it consists of marine sands and clays, the highest of which (Argile de Boom) is nearly 200 feet thick at Rupel and somewhat resembles the London Clay.

§ 2. Geographical Restoration.

Eocene Time.—The gradual upheaval of the British area, which took place at the close of the Cretaceous epoch, continued until the greater part of our islands were raised above the level of the sea, and they once more became part of a continent which stretched far westward and southward of their present limits. In imagining the aspect of this land we must remember that a large part of it was the upraised bottom of the Cretaceous ocean, and though, doubtless, portions of the Chalk were removed by erosion during upheaval, especially those which bordered the rising

coast-lines of Wales and other hilly districts, yet we must suppose that the great sheets of Chalk which occupied the intervening tracts suffered but little, and formed broad plains uniting Wales to the Pennine range and Ireland to England and Scotland.

The materials of which the Eocene and Oligocene strata consist are such as are derivable from the Chalk and from the granitic and Palæozoic rocks of the western districts. It would seem, indeed, that they were derived from these sources only, for not a chip or pebble of any Jurassic rock has been found in them; and there is therefore every reason to suppose that the Jurassic, and probably the Lower Cretaceous strata also, were deeply buried throughout the duration of the Hantonian period.

As regards the general elevation of the country above the sea at this epoch, if we bear in mind that the deepest part of the Cretaceous sea lay over eastern England, and the probability that Ireland was never so deeply submerged as England, we may conclude that the elevation which raised the eastern part of England into land must have carried Ireland and West Scotland to a much higher level above the sea than that at which they now stand. It is quite possible that there was a difference of 500 fathoms in the depth of the Cretaceous sea along the eastern and western parallels of the British area, and if the subsequent upheaval was approximately uniform, the upper surface of the Irish Chalk would on these assumptions have been raised to a level of 3,000 feet above the sea when the Chalk of eastern England was raised to the sea-level. Moreover, it is a remarkable fact that our islands are shown by the Admiralty charts to stand upon a submarine plateau, the border of which runs outside the coasts of France, Ireland, and the Hebrides; on this plateau the soundings are everywhere under 100 fathoms (600 feet), but from its surface the sea-bottom slopes steeply down

to depths of 1,300 and 1,500 fathoms (9,000 feet), as if its edge had for a long time formed the coast-line of western Europe.

Whether the west-European plateau was first upraised in Eocene or in Triassic time must remain doubtful, but it is highly probable that the coast-line of the Eocene land lay along the slope of this plateau, and that the land then stood at a much higher relative level than it does now; that is to say, the horizon of the Eocene Atlantic cut the Eocene land at a level which is now at least six hundred, and possibly several thousand feet below the present sea-level. This high relative level seems to have been maintained throughout the whole period, and it is possible that the western and north-western districts hardly participated in the oscillatory movements which took place in the eastern areas of sedimentation, but, being continuously exposed to detrition, underwent more or less continuous elevation throughout the whole period. There is no doubt that these districts were at this time subjected to an immense amount of erosion and detrition, and though denudation can hardly be the primary cause of elevation, it is certainly calculated to accelerate it by removing material and thus diminishing the weight to be lifted. Such a connection between denudation and elevation has been pointed out by several writers, notably Dr. Ch. Ricketts¹ and Capt. C. E. Dutton.²

The similarity between the Lower Eocene floras of Ireland, Scotland, Iceland, and Greenland is so great, and the climate which they indicate is so temperate, as to make it highly probable that these four countries formed at this time a continuous tract of land. There is still a submarine ridge connecting Scotland and Greenland over

¹ "Geol. Mag.," 1883, p. 10.

² "Nature," 1879, vol. xix. p. 251.

which the soundings are seldom more than 500 fathoms, and are more often between 300 and 400; this, then, may indicate the site of the connecting land which existed throughout Eocene, Oligocene, and Miocene times. To effect such a union now would require an elevation of about 3,000 feet, and it seems reasonable therefore to regard this as a rough measure of the difference in altitude between the base-levels of modern and Eocene Scotland. If to this we add the present heights of Scottish mountains, and allow 1,000 feet as the amount by which they have been lowered since the commencement of Tertiary time, we have a total of over 8,000 feet for the height of many of these mountains in the Eocene period.

Volcanic activity is so often an accompaniment of elevation that we are not surprised to find that it was rife throughout the whole of this region, and that great outpourings of basaltic lava occurred not only in Ireland and Scotland, but in the Faroe Islands on the line of connection above-mentioned, as well as in Iceland and Greenland. The denuded stumps of some of the great volcanoes which existed at this time are found in Skye, Mull, Rum, St. Kilda, and Ardnamurchan. The volcanoes of Skye and Mull appear to have been on a grander scale than the modern volcanoes of Italy; Professor Judd estimates that the base of the Mull volcano must have been at least forty miles in circumference, and as Etna, from a base of only thirty miles in circumference, rises to a height of 10,900 feet above the sea, he argues that if there was a similar relation between the base and the altitude of the Eocene volcano, the latter must have had an elevation of at least 14,500 feet. Checking this by another calculation, founded on the inclination of the lava-beds, he finds that it could not have been less than 10,000 feet high.

The existence of valleys, watercourses, and river-beds among these Eocene lavas proves the country to have been

watered by a copious rainfall; the contents of the gravel beds prove that rapid erosion was in progress; while the plant remains show that the lower slopes of the volcanoes and of the surrounding land were clothed with an abundant vegetation. We must, therefore, picture a country in which all the terrestrial agents of change were in full activity, a country where fire and water frequently contended for the mastery, where wide districts were from time to time devastated by burning streams of lava, but were soon restored to fertility by cooling showers and by the irrigation of a thousand streams that sprang from the slopes of cloud-capped mountains.

Coming now to the area within which sedimentation was taking place, it is evident from a comparison of the English and Belgian strata that Belgium came within the influence of the Eocene sea before England did, and that a depressive movement allowed the sea to advance westward and to occupy portions of Kent, Surrey, Essex, and Suffolk, at the time of the Thanet Sands. The area which these sands seem originally to have covered is indicated in Plate XI. by the finer blue lines, and this tract appears to have been part of a large bay which extended from the northern sea into the Anglo-French land region.

From the nature of the beds in East Kent—the abundance of glauconite grains, the admixture of calcareous matter, and the presence of such shells as *Pholadomya*—we may infer that the sea was moderately deep in that district; while the replacement of these beds by sharp quartzitic sands to the westward proves the water to have become shallower in that direction. From the purely marine character of the beds we may conclude that the sediment was carried by marine currents circulating round the bay in the same manner as such currents now circulate in the North Sea. From the absence of pebble beds we are justified in supposing the shores to have been low,

and it is more likely that they were bordered by sand dunes than by chalk cliffs.

Passing now to the Reading Beds, we find evidence in their wider extension of a further and more general subsidence, which carried the sea over the whole of the London basin, and southward over Hampshire into the southern basin. In the shallow gulf thus formed were deposited the marine basal beds of the Reading group, in which large oysters are the most abundant shell, but there is no evidence that these beds ever extended over the area of the Weald, and very good reason to think that they did not.

That the rise of the Wealden dome began in early Eocene times is by no means a new idea. It was suggested as long ago as 1852, by Professor Prestwich, in his paper on the Thanet Sands,¹ though some of the data from which he inferred its existence would not now be accepted; in 1866 Mr. Whitaker² remarked upon the southerly overlap of the Woolwich and Blackheath Beds, and at a later date³ we find him inferring from this "that the planing down of the chalk which once spread over the Wealden area began in Lower Eocene times, and that the pebble beds of Bromley, Blackheath, &c., are one of the direct results of that denudation."

The very limitation of the Thanet Sands to the northern side of the Wealden area seems to indicate the existence of land, or at any rate of a large shoal, over that area during their formation, and it is not at all improbable that the depression of the Anglo-Belgian basin was contemporaneous with an uplift of the region which is now the axis of the Weald and Artois. If this were so, and if the force of the uplift was concentrated more especially on

¹ "Quart. Journ. Geol. Soc.," vol. viii, p. 256.

² *Ibid.*, vol. xxii, p. 420.

³ "Mem. Geol. Survey," 1872, vol. iv, p. 241.

the Wealden area, producing the first outline of the oval or boat-shaped periclinal of this area, it is easy to understand the relations of the several members of the Lower London Tertiaries; at first the shores would be low and cliff-less, but the general submergence at the time of the Woolwich and Reading Beds would convert the Wealden dome into an island, and the erosion of the waves along its margin would lead to the development of cliffs, at the foot of which shingle beaches would naturally be formed.

In this conclusion, and except as to the precise epoch when the pebbles were first quarried from the chalk, I am, indeed, only following Professor Prestwich's original view, which is expressed as follows:¹—"From the foregoing considerations it is probable that there was some extent of dry land, possibly an island, somewhere intermediate between a line drawn, on the north, from Farnham toward Canterbury, and on the south from Winchester to Newhaven, and extending eastward into the north of France; and that the long-continued wear on its coast accumulated on its shores extensive banks of pebbles, whilst the finer sediment produced at the same time, in conjunction with the débris brought down by operation of streams, formed at a distance from the land the strata of this oldest Eocene epoch."

Let us next consider the evidence of the plastic clays of the Reading group, and the physical conditions which their characters appear to indicate. It is the general opinion that they are of freshwater origin. Their association with plant beds, and their actual intercalation between freshwater deposits near Paris, are strong pieces of evidence in favour of this view; but if they are freshwater beds, it is difficult to see how they can have been

¹ "Quart. Journ. Geol. Soc.," vol. viii. p. 259. He then thought the pebble beds were formed during the deposition of the Thanet Sands, and were afterwards redistributed.

formed in anything but a large lake or series of lakes. No one, perhaps, has studied them more carefully than Professor Prestwich, and in 1854 he referred their formation to river-action on a large scale, and looked to the granitic districts of the south-west for the supply of the argillaceous material.¹ Mr. Gardner also speaks of them as fluviatile; but considering the area over which they are known to extend in unbroken continuity, they can hardly be called fluviatile deposits in the ordinary sense of the term. That the lakes were shallow and prolonged into extensive arms and inlets is very probable, and they were doubtless fed by streams which had little velocity, but meandered quietly over the plains of chalk that surrounded the lacustrine areas, so that parts of the water-covered tract might be regarded as expansions of the river valleys, and in that sense fluviatile.

If this is a correct idea of the conditions under which the Reading Beds and Plastic Clays were formed, it is clear that some barrier must have been raised which prevented the access of the sea that had at first occupied a portion of the lacustrine area, for there cannot have been much difference of level between the marine and the lacustrine waters. It is not difficult, however, to understand the construction of such a barrier if the existence of land over the Wealden area is granted, for this would itself form a portion of the barrier, and the erosion of its shores would afford a supply of flint pebbles and sand which the set of the currents might carry northward and pile up in the form of shingle banks and sand dunes across the shallow waters of the London area. Seaboard lakes and alluvial levels, shut in and protected from the inroads of the sea by such banks, are of common occurrence; and it is a curious coincidence that pebble beds should exist at various horizons in the Woolwich and Reading Beds, and

¹ "Quart. Journ. Geol. Soc.," vol. x. p. 136.

should be thickest across the middle part of the London basin. The Hertfordshire conglomerate or pudding-stone is a relic of one of these beds; another is to be seen at Lewisham, and the Blackheath Beds form an enormous mass of shingle at a higher horizon.

If these pebbles had been brought by a large river from the west or south-west, we should expect to find them thickening in those directions; but such is not the case, they actually thin out westward as well as eastward, and appear to be local deposits confined to the northern side of the Wealden anticline. Mr. Whitaker has remarked that the pebbles in the Blackheath Beds are always well worn and rounded, and he infers that they were not formed as a beach against a shore-line, for in such beaches there are generally a certain number of subangular pebbles, but he thinks they have been carried out some distance from the actual shore, and only brought to rest after a long exposure to the wearing action of waves and currents. This is exactly what would happen under the geographical conditions I have supposed. It is, however, quite possible that many of the pebbles were rounded in the channels of small rivers draining the Chalk island of the Weald before they were brought down to the shores of that island.

The freshwater beds of the Woolwich group, again, were clearly formed in the estuaries and deltas of small rivers, and there is no reason whatever for supposing that these rivers came from the west, but much reason to think that they drained a tract of land over the Wealden area.¹ They only occur over a limited space on the northern and southern sides of this area, and they are just such deposits as might be formed in lagoons and in the estuaries of rivers which drained into a land-locked bay. Moreover, Professor Prestwich states that the prevailing dip of the

¹ See Prestwich, "Quart. Journ. Geol. Soc.," vol. x. p. 135.

layers of false stratification in the Kentish and Surrey beds is northward, or from the direction of the presumed island, at angles varying from 10 to 35 degrees.

Throughout the time of their accumulation, and of the overlying Oldhaven Beds, there is little evidence of any general subsidence; the probability is that the land was practically stationary, but that the coast-lines were being constantly altered by the action of tides, currents, and winds, just as the eastern and southern shores of England have been altered within historic times by the same agencies, one tract of coast being worn away and cut back, while at other localities the materials so obtained were piled across the mouths of rivers and in front of low-lying shores.

This stationary period was succeeded by one of decided and continuous subsidence, and the basement bed of the London Clay represents the final distribution of the sand dunes and shingle banks beneath the waters of the advancing sea, these barriers being destroyed, and the whole lacustrine area behind them being at once covered by the sea of the London Clay.

This submergence in all probability carried the Wealden island far below the sea-level, for there seems no good reason to doubt that the London Clay extended across the whole of south-eastern England, and over the north-western part of France, at least as far as the latitude of Dieppe.¹ How far westward the coast-line was carried at

¹ The sands on the North Downs, supposed by Mr. A. Irving to be Upper Bagshot, are probably post-Eocene. How far the Ypresien clay of Belgium reached southwards is uncertain. Professor Gosselet indeed thinks it did not pass into France, and in his map ("Esquisse Géol. du Nord de la France," Pl. XII. A), shows a broad tract of land extending from the Boulonnais to the Ardennes at this epoch; but in this, as in other cases, his restoration seems to have been constructed on the assumption that the present boundaries of the beds are nearly coincident with their original limits, very insufficient allowance being made for subsequent denudation.

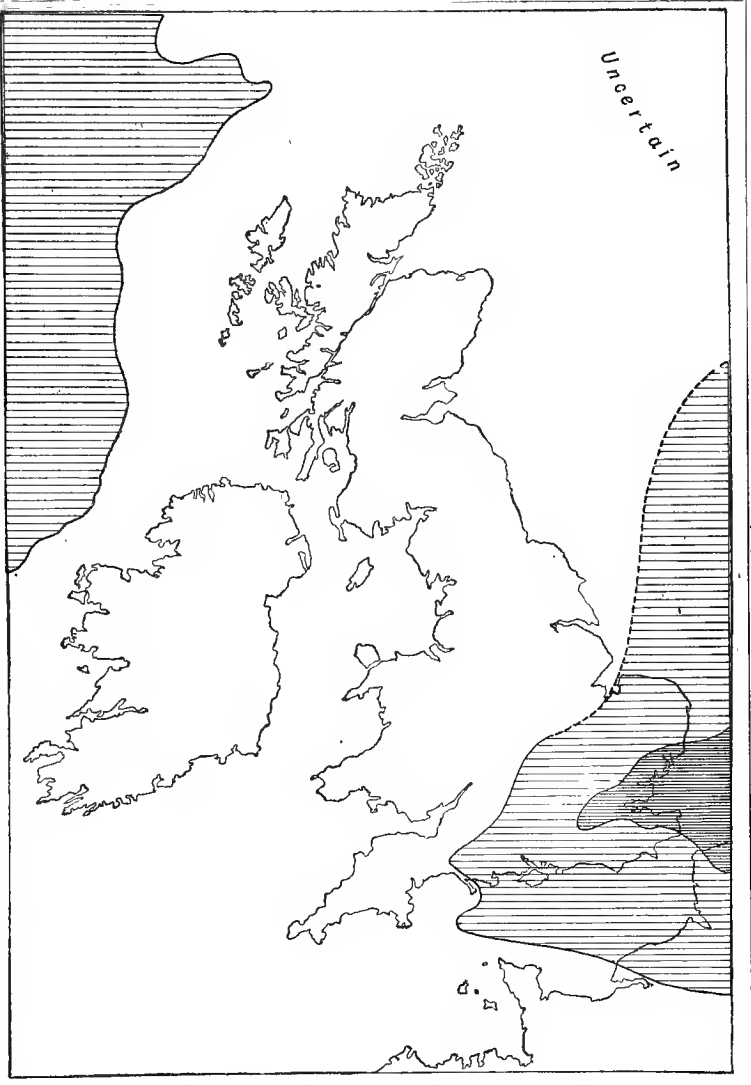


PLATE XI. GEOGRAPHY OF THE LOWER EOCENE PERIOD.

The closer lines represent the sea of the Thanet Beds, and the wider lines that of the London Clay.

this time is a very difficult point to determine. We know, however, that in Wiltshire the London Clay thins out and is replaced by sands (see Fig. 5), so that probably the sea did not extend very far west of Marlborough, perhaps no farther than the present position of the Chalk escarpment; thence it must have trended south-west to the western border of Dorset, and north-east outside the present limits of the Chalk, to the western border of Norfolk. The great plain of the Fenland was then, of course, covered by a continuous sheet of chalk, and there is no reason to suppose that the Eocene strata overlapped this either westward or northward. The probable limits of the sea at this time are indicated on Plate XI.

The London Clay is a purely marine deposit, and does not exhibit any traces of fluviatile action till we reach its highest beds, but the material of which it consists is usually supposed to have been brought down by some large river. Sir Charles Lyell thought that this river might have drained a continent that lay to the west or south-west of Britain, and Mr. J. S. Gardner¹ has accepted this view, though he does not urge any positive evidence in support of it. The London Clay does not assume a more estuarine facies either to the west or the south-west, but seems merely to thin out and to be partially replaced by sands. When we remember, indeed, that the locality which has yielded the most distinct evidence of fluviatile action lies to the east of London, there seems to be rather a greater probability that the river which carried the fruits to Sheppey came from an eastern quarter and drained some portion of the European continent.

Here, however, we must ask whether the phenomena of the London Clay really require the agency of a single large river, and whether they cannot be equally well accounted for on the supposition that several, if not many, rivers

¹ "Proc. Geol. Assoc.," vol. vi. p. 92.

emptied themselves into the sea and contributed to its formation. Is not the London Clay just such a lenticular mass of mud as would be formed in the central and deeper part of a rather shallow sea, into which many rivers poured their load of sediment? Mr. G. F. Harris, who has studied the Belgian strata, informs me that there is no evidence of fluviatile deposits on a large scale in Belgium, or of the influx of any large river from the east, but that the Belgian geologists attribute the fluviatile and estuarine portions of their Lower Eocene deposits to the influence of small streams from the eastward. In the same way the river by whose current the Sheppey fruits were carried may have come from the land which lay over France to the south,¹ but there is no reason to suppose that its volume was greater than that of the Thames. We must remember also that these Sheppey clays may be contemporaneous rather with the Lower Bagshot Beds than with the London Clay of the west. They may have been formed at a time when much of the shallow sea-bed had again been converted into a region of lakes, lagoons, and estuaries, partly by the process of silting up, and partly perhaps by an actual uplift of the northern part of the English area of sedimentation.

It is certain that great geographical changes took place during the formation of the Lower and Middle Bagshot Beds, but until the stratigraphy of this part of the Eocene series is more completely worked out, it would be rash to speak at all confidently with regard to the results of these changes. There is, however, much reason to believe that the tract which had hitherto been the principal area of deposition was raised, and that large parts of it became dry land, while the Paris basin was correspondingly depressed, and the Hampshire basin became an

¹ This was Professor Prestwich's view in 1854 (see "Quart. Journ. Geol. Soc.," vol. x. p. 448), where he gives very good reasons for it.

estuary into which rivers from the west emptied themselves.¹

In the first place, the Lower and Middle Bagshots of the London basin are certainly not the deposits of an open sea. All who have recently studied these beds agree in regarding the Lower Bagshot Beds as of freshwater origin and either fluviatile or lacustrine deposits, and Mr. Irving considers the middle group to be lagoon deposits in the close neighbourhood of land, the waters of which were kept in a partially saline condition by occasional intrusions of the sea, and by percolation through fringing shingle banks.² It is clear there was land to the north and west of this area and open water to the south, but it is probable that the ridge of the Wealden anticline was again above the sea-level and contributed a share of the flint pebbles that occur in the Middle and Upper Bagshot Beds.

Secondly, there are clear proofs in the strata of the Hampshire basin that this area was a gulf which received the waters and the sediment of one or more rivers; rivers which had doubtless contributed their quota of sediment to the London Clay. The changes of level which closed the episode of this clay formation converted the head of the southern gulf into a broad alluvial plain through which the rivers slowly made their way to the sea and probably opened out at intervals into lagoon or lake-like expansions. Thus Mr. Gardner is of opinion that the most western beds of Corfe, Studland, and Alum Bay were accumulated in a wide valley or shallow lake, and he remarks that "the complexity of the stratification suggests that two rivers united in this valley, and shows plainly that the waters must, in any case, have been rapid at times, and subject to periodical fluctuations of volume." He infers also, "from the absence of lignites in some parts of the series, that

¹ Gardner, "Proc. Geol. Assoc.," vol. vi. p. 95.

² "Quart. Journ. Geol. Soc.," vol. xliii. p. 389.

there were, in the upper parts of the river, lakes such as those of Bovey Tracey, which intercepted drifting timber; its abundance in other beds marking the time when these had been filled in." After the completion of the geographical changes which took place during the formation of the Lower Bagshot Beds, it is evident that the whole area underwent a gradual subsidence which allowed the sea to regain a part of its lost domain. To quote again from Mr. Gardner: "In the Bournemouth Beds we have deposits of the same river, but in a more open and level valley, and in closer proximity to the sea. In all the lower or freshwater series we have no sign of the presence of sea water, and when we do find it in the higher beds to the east, it is not that the river deposits encroached there on the sea, but that the land gradually sank, and allowed the sea to cover them."

"It is of great interest to trace through these beds the change from a comparatively upland flora to a valley, and then to a swamp flora; to follow out the lowering of the land until it became sea; to trace the sea, first trickling in, as it were, and forming lagoons, then overwhelming the mud deposits formed by these lagoons, with shingle and sand; to realize, in fact, the actual shore-line, now marked by river deposits, full of plant remains on one side, and a sea fauna with sharks' teeth on the other.

"The series of marine beds from Bournemouth to Highcliff, which belong to the Bracklesham Beds, are the shore deposits of the southern sea. The Bracklesham series proper show a gradually deepening sea; for, while the beds of sand which are prevalent in the lower stages show shallow water, the clay beds above them were formed in a deeper sea, and contain deeper water mollusca. In comparing the marine fauna with that of the London Clay, its very much more tropical character is apparent. Many southern types of mollusca abound in it which are scarcely repre-

sented in the London Clay. Their aspect is completely different, and though separated geologically by but a short interval of time, hardly any species are common to both, while the lithological characters of the formation are widely and persistently dissimilar. If we examine, on the other hand, the terrestrial fauna and flora of these and the intervening strata, we see that no increase of temperature or change had taken place in the climate, and that the land was still inhabited by similar groups of reptiles and plants. It is, therefore, plain that the sea alone had changed, and become much warmer, for depressions had enabled the southern sea, then occupying part of France, to advance and to overlap to a small extent the older deposits." ¹

Let us now turn to France and learn how this southern sea came to reach so far northward. Professor Prestwich and Mr. Gardner agree in thinking that the northern sea of Lower Eocene times lay to the east and north-east of our islands, and that the greater part of northern and central France was land, this land being continuous across the space between Brittany and Cornwall; so that the northern sea was entirely cut off from communication with the warmer seas of more southern regions. The Lower Eocenes of the Paris basin were formed in shallow bays and lagoons on the northern border of this land, and their fauna and flora are consequently those of the northern province.

To the south of this Eocene France lay a wide and deep sea which covered the greater part of southern Europe, spread over the northern borders of Africa, and extended far into the western part of Asia; this sea was, in fact, a greater Mediterranean, and in it were formed the Nummulitic limestones which occupy such large areas in the regions above mentioned.

From the superposition of marine limestones upon the

¹ "Proc. Geol. Assoc.," vol. vi. pp. 95, 96.

lignitic series of the Paris basin, and the sudden appearance in them and in their English equivalents of tropical forms of mollusca, we may infer that a subsidence took place which submerged part of the intervening land and allowed the waters of the great Eocene Mediterranean to occupy a portion of the low-lying tract on the northern side of the barrier. The temperature was raised by this influx of warm water, and a sub-tropical fauna and flora were established on the shores of Britain.

In Mr. Gardner's opinion, however, this southern sea never reached far into Britain. He thinks that its shore must have lain across the north of Hants and Sussex, while the area of the London basin was at this time part of a tract of land which stretched eastward and formed a barrier that prevented any commingling of the northern and southern seas. In other words, he holds that the depression of France coincided with a ridging up of land over England and Belgium, so that the waters of the two seas were still kept apart. He bases this opinion on the distinctness of the Lower Bracklesham fauna, and in a letter to the author has expressed himself as follows:—"I have carefully separated out the Lower Bracklesham forms, and find an utter absence of any approaching to the London Clay types. I am sure that the waters they lived in were perfectly isolated from any of our older Eocene seas." He therefore concludes that some barrier must have existed to keep out the northern forms, for otherwise there would have been a greater or less mingling of the faunas, and he supposes this barrier to have been submerged in Barton Clay times, when London Clay types again make their appearance in Hampshire, and are mingled with the remnant of the southern fauna. Mr. Gardner informs me that the tropical forms of the Lower Bracklesham fauna disappear, a certain number, *e.g.*, the great *Bulla*, *Cypræa*, and corals, dropping out rather suddenly,

others more gradually, while London Clay types modified by time come in more and more.

It is certainly difficult to explain the peculiarities of the Bracklesham and Parisian faunas on the supposition that there was a complete and open communication between the southern and northern seas, but on the other hand it is not easy to indicate the exact location of the isthmus which may be supposed to have separated them. The Bruxellian deposits of Belgium, however, seem to throw some light on the subject; the majority of the Bruxellian species are Bracklesham and Calcaire Grossier types, but with these are associated a certain number of species which are peculiar to the "Sables de Cuise," and have not yet been found in the Calcaire Grossier of Paris;¹ so that there appears to be in Belgium just that very comingling of the north and south faunas which does not occur in England. It would seem, therefore, that there was a direct communication between the French and Belgian areas of deposition, and it is indeed certain that such a connection existed during the formation of one zone (*z. de Nummulites lævigata*) at any rate; for fragments of hard sandstone with the fossils of this zone are scattered at intervals over the axis of Artois, and most abundantly over a tract to the south of Lille by Douai, Cambrai, and St. Quentin, lying, like our Sarsen stones, sometimes on the Lower Eocene sands, and sometimes on the Chalk, or still older rocks.

Since, then, this zone extended completely across the ridge, it is quite possible that the lower Bruxellian beds did also, for the sandstone fragments have been preserved in consequence of their hardness, and the fact of their presence is no proof that the older beds did not have the same extension. Professor Gosselet, therefore, is not warranted in assuming, as he seems to have done in pre-

¹ "Géologie de la Belgique," vol. i. p. 227.

paring his map of the Parisian epoch,¹ that no communication existed between the two basins except at the time of the *Numm. lævigata* zone.

Whatever conclusion may eventually be formed as to the emergence or submergence of the axis of Artois during the time of the Calcaire Grossier, it is very probable that it and the Wealden area were upheaved at the close of this epoch.²

Such a view is confirmed to a certain extent by the close correspondence which exists between the succession of the higher Eocenes in the basins of London and Flanders; the "sables chamois" of the latter answer to our Upper Bagshot Sands, and M. Ortlieb³ thinks that these sands were formed against the slopes of rising ground at the time when the Upper Eocenes were being accumulated in the Paris basin. The abundance of flint pebbles in the Upper Bagshots also proves that Chalk was somewhere exposed to erosion.

It is possible, however, that the elevation was greatest over the area of the Ardennes on the one hand, and over the Wealden dome on the other, so that for a time the two seas only communicated along the tract indicated by Professor Gosselet.

However this may be, it is certain that central France was raised above water at this time, and that the southern sea was forced to retreat, so that the Anglo-French area again became subsidiary to the northern province; many of the southern species of molluscs would be killed off by the consequent refrigeration of the water, and their places would be taken by northern species, and this seems almost

¹ "Esquisse Géol. du Nord de France," p. 321, and Pl. XIII. A.

² Both Professor Hébert and Dr. Ch. Barrois are of this opinion; see "Recherches sur les Terr. Cret. Sup.," by the latter, p. 178.

³ "Ann. Soc. Géol. du Nord," t. ii. p. 201; see also Barrois, t. iii. p. 84.

sufficient to account for the difference between the faunas of the Bracklesham and Barton Beds.

Oligocene Time.—At the commencement of the Oligocene period the geography of Britain can hardly have differed much from that of the later Eocene time. England, Scotland, and Ireland still formed one united mass of land, which was joined to France across what is now the western opening of the English Channel, so that the Atlantic had no communication with the area of the German Ocean. The waters of the latter extended south-eastward through Holland and over part of Belgium, but did not cover the south of Belgium nor the south-east of England.

In the Anglo-French area the passage beds between the Eocene and Oligocene show that the water in which they were deposited became rapidly shallow, and the strong unconformity between the two formations in Belgium proves that this shallowing was mainly due to a general upheaval of the whole of western Europe.¹ By this uplift the sea spaces were contracted, and land connections were formed with the African continent; Europe was invaded by a number of new terrestrial animals, and thus the Oligocene is marked by the introduction of a new and peculiar mammalian fauna, while the mollusca are obviously the descendants of the species which inhabited the northern province at the close of the Eocene period.

Let us now endeavour to restore the geographical outlines of southern Britain at this period. We may conclude that the western part of the country, including the land which then lay to the south of Ireland and united Cornwall to Brittany, was a region of hills and mountains, among which at least one large river had its origin. This river emptied itself into an estuary which lay at the north-

¹ The principal upheaval of the Pyrenees is believed to have taken place at this time.

western extremity of the sea or gulf which stretched from the Paris basin into Hampshire (see map, Plate XII.).

The Hcadon Beds present us with a section through part of the delta of this river. The alternation of marine, brackish, and freshwater beds, is due, partly, to the process of subsidence and silting up, partly, perhaps, to change in the course of the river channel, but the northerly and easterly increase of the marine strata (Brockenhurst Beds) and the southerly increase of the freshwater limestones are facts which prove the deepest part of the estuary to have lain to the north-east of the Isle of Wight, and to have trended from south-west to north-east through Hampshire into Wilts or Somerset, in which direction the embouchure of the great river probably lay.

The muddy flats of this estuary swarmed with *Cerithiadae*, *Cyrenidae*, &c., while the pools of the delta were peopled by species of *Planorbis*, *Limnæa*, *Paludina*, &c., the dead shells of which were swept down into the lower reaches of the river; crocodiles, gavials, and turtles abounded in its waters as in those of modern tropical rivers, and its banks seem to have been clothed with a luxuriant vegetation of reeds, ferns, and palms.

The southern shore of the estuary lay probably at no great distance from the Isle of Wight, and thence the coast must have curved southward to Normandy, possibly receiving the waters of another river from the south-west, and from a direction parallel to that of the English Channel. The southern shore-line of the Anglo-Parisian sea ran somewhere along the northern side of the watershed between the Seine and the Loire, while the northern shore must have skirted the southern slope of the Wealden area.

Similar conditions seem to have prevailed during the formation of the Bembridge Beds, but Mr. Gardner thinks that in these beds we have evidence, not only of a diminution in the volume of the river, accompanied by a general

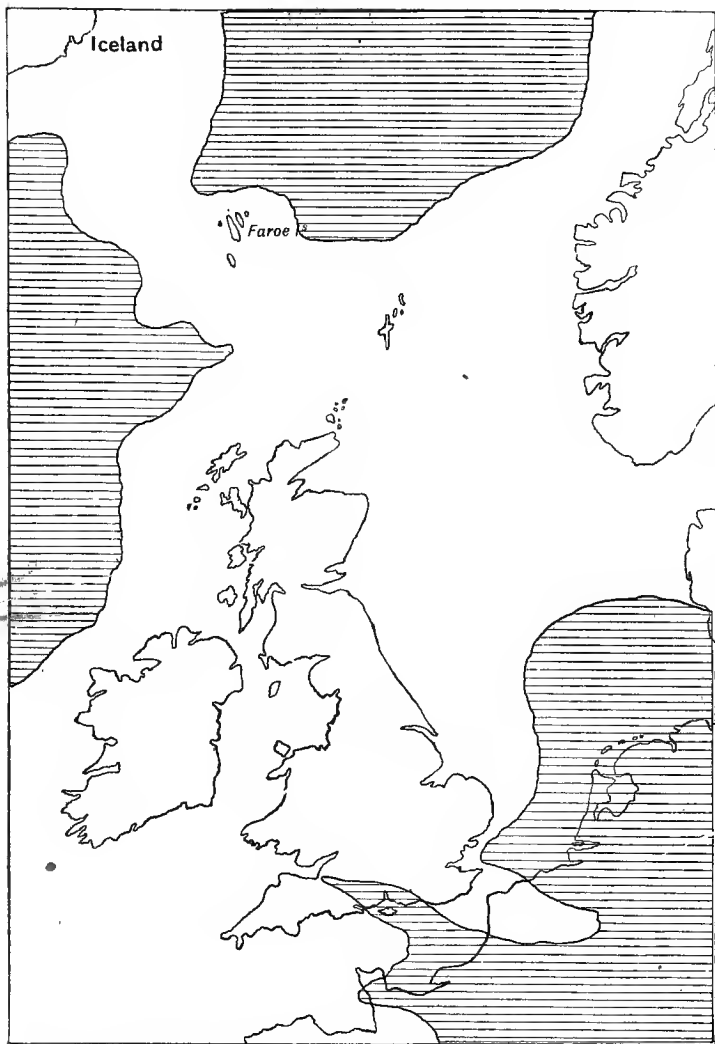


PLATE XII. GEOGRAPHY OF THE OLIGOCENE EPOCH.

silting up of the estuary and an increase in the area of the delta, but also of a gradual lowering of the temperature; till at length, in the time of the Hempstead Beds, the vegetation ceased to have any specially tropical characters, and the former estuary was converted into a swampy tract covered with a growth of the rushes and water-plants that belong to temperate climates.¹

With respect to the highest member of the Hempstead group, Mr. Gardner remarks that the assemblage of marine mollusca which it contains presents such a paucity of species, and these so stunted in growth, as to suggest that the sea which they inhabited had contracted to the dimensions of a mere salt or brackish-water lake, without any communication with the open sea then lying over Belgium; at the same time, it is clear that at this period the depth of the water in the Isle of Wight area was increased, not diminished, and this must have been due either to subsidence or to an influx of river-water into the lake.

When we consider that the whole of the British Oligocene series consists of shallow-water deposits, it is evident that a certain amount of subsidence must have taken place during the period in order to allow of the accumulation of such a thickness of beds (600 feet). That such subsidence took place is proved also by the Belgian succession, and by the comparatively deep-water character of the *Argile de Boom*, which is generally regarded as the equivalent of our Hempstead Beds. It is probable, however, that this subsidence was more or less localized to the basins of deposition, and it may have been contemporaneous with and complementary to a rise of the Wealden axis.

The records of the Hampshire delta are here abruptly broken off, and we have no means of ascertaining the last phases of its history; we can only guess from the analogy

¹ "Proc. Geol. Assoc.," vol. vi. p. 98.

of the French deposits that there was a gradual upheaval of the whole area, and that the depressions of this terrestrial surface were occupied by large lakes. Whether any such lakes existed on British ground we do not know, but many were scattered through the centre of Europe, in France, Switzerland, Germany, and Austria.

CHAPTER XII.

ICENIAN PERIOD.

THE reasons for grouping the Miocene, Pliocene, and Pleistocene deposits into one system have been given elsewhere.¹ Their geographical extension is entirely different from that of the older (Hantonian) Tertiaries; the later Miocene and the older Pliocene deposits of the continent are so intimately connected that it is often difficult to separate one from the other, while the close relations of the Pliocene and Pleistocene are universally admitted. As, however, the treatment of the Pleistocene epoch involves a consideration of the Ice Age and the many debatable questions connected with the Glacial deposits, it will be more convenient to consider the geographical changes which took place during the Miocene and Pliocene epochs first, and to discuss the complicated phenomena of the Pleistocene in a separate chapter.

§ 1. Stratigraphical Evidence.

Miocene Epoch.—Throughout both the Oligocene and Miocene epochs the greater part of Britain remained in the condition of dry land, and no actual Miocene deposits have been found either in Britain or in the north-eastern part of France. They occur in southern and western France, and patches of them exist as far north as the Cotentin in Normandy. Lately, also, it has been decided that certain

¹ "Historical Geology," by the author, pp. 36 and 486.

deposits in Belgium are of Miocene age—these are the sands of Antwerp and the Bolderberg, which rest unconformably upon the Oligocene (Rupelian) clay, and have a pebbly basement bed which contains flints and rolled septaria; the lower part of these sands is very dark and argillaceous, and contains many shells in the position of life; the higher sands are less argillaceous, but still dark coloured from the presence of glauconite; and the whole group was formerly termed the “black crag.”

There is some reason for thinking that similar deposits originally extended across the North Sea into the east of England, for the pebble beds at the base of the Suffolk Crag contain nodules of greenish or reddish-brown sandstone, which enclose casts of some of the “black crag” fossils.¹ Professor Ray Lankester has also recorded teeth of a Mastodon whale and shark (*Carcharodon*) in the same matrix, and he is of opinion that many of the mammalian bones found in these nodule beds have been derived from strata of Miocene age, of which no other traces now remain.

Pliocene Epoch.—The Pliocene series is divisible into an older and a newer group, and the British beds of this age may be classified as follows:—

Newer.	{	Forest Bed Group.
		Norwich and Red Crag.
Older.	{	St. Erth Beds.
		Coralline Crag.
		Lenham Sands.

The oldest Pliocene deposits in England are certain ferruginous sands which at Lenham and other places on the North Downs in Kent and Surrey are at or above the level of 600 feet. They were first described by Professor Prestwich in 1857,² and correctly referred by him to the Pliocene, but

¹ Ray Lankester, “Quart. Journ. Geol. Soc.,” vol. xxvi. p. 493.

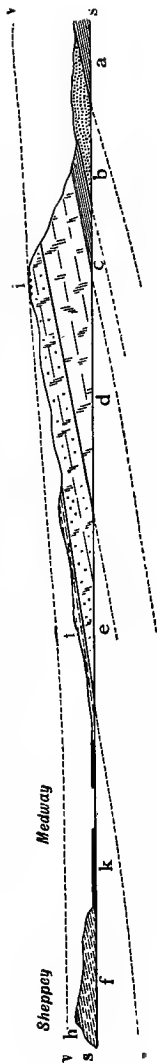
² “Quart. Journ. Geol. Soc.,” vol. xiv. p. 322.

the imperfect nature of the fossils then found, and the apparent presence of some Eocene species, led others to regard them as Lower Eocene. In 1886, however, Mr. Clement Reid was able to settle the question by obtaining fresh specimens, which proved the beds to be of older Pliocene age. The sands often contain flint pebbles, and include layers of loamy clay and seams of fossiliferous ironstone, and though their aspect is not that of deep-water deposits, yet the perfect and unworn condition of the shells shows that they are not shore deposits, and the fauna seems to indicate a depth of at least 20 fathoms.

The Lenham Sands occur at intervals along the Downs from the heights above Folkestone to Chipstead, near Croydon,¹ but though they are now found along this narrow tract, it is evident that they are the remnants of a formation which was once far to the north, and also some distance to the south of this line. It would appear, in fact, that though the upheaval of the Wealden area commenced in Eocene times, and though this district was exposed to erosion throughout the times of the Upper Eocene, Oligocene, and Miocene, yet that the great plane of denudation out of which the present surface of the Weald is carved was formed by the waters of the early Pliocene sea. Consequently, if we would restore the surface over which the Lenham Sands were laid down, we must imagine a sea-floor stretching northward from the summit of the Chalk escarpment at a high level above the Isle of Sheppey and the estuary of the Thames. Fig. 6 is an attempt to restore this horizon, and, allowing for some subsequent elevation over the Wealden area, to show the position which the base of the Lenham Sands would now occupy if they had not been so largely removed by subsequent erosion. Over

¹ At present, however, fossils have only been found at Lenham, and it is open to doubt whether the Chipstead sands, and those of Headley still further west, are precisely of the same age.

Fig. 6. Section through the Isle of Sheppey and the North Downs near Lenham.



Horizontal scale, three miles to an inch. Vertical scale, about nine times the horizontal (i.e. 1,760 feet to an inch).

- | | | |
|---------------------------------|---|----------------------------|
| <i>k.</i> Alluvium. | <i>f.</i> London Clay and Lower Tertiaries. | <i>c.</i> Gault. |
| <i>i.</i> Lenham Crag. | <i>e.</i> Upper Chalk. | <i>b.</i> Lower Greensand. |
| <i>h.</i> Bagshot Sand. | <i>d.</i> Middle and Lower Chalk. | <i>a.</i> Weald Clay. |
| <i>s. s.</i> Present sea level. | <i>v. v.</i> The surface on which the Lenham Crag was originally deposited. | |

The vertical scale being exaggerated, the dip of the strata is made steeper than it really is, and the slope of the line representing the floor of the Lenham Crag sea is also increased.

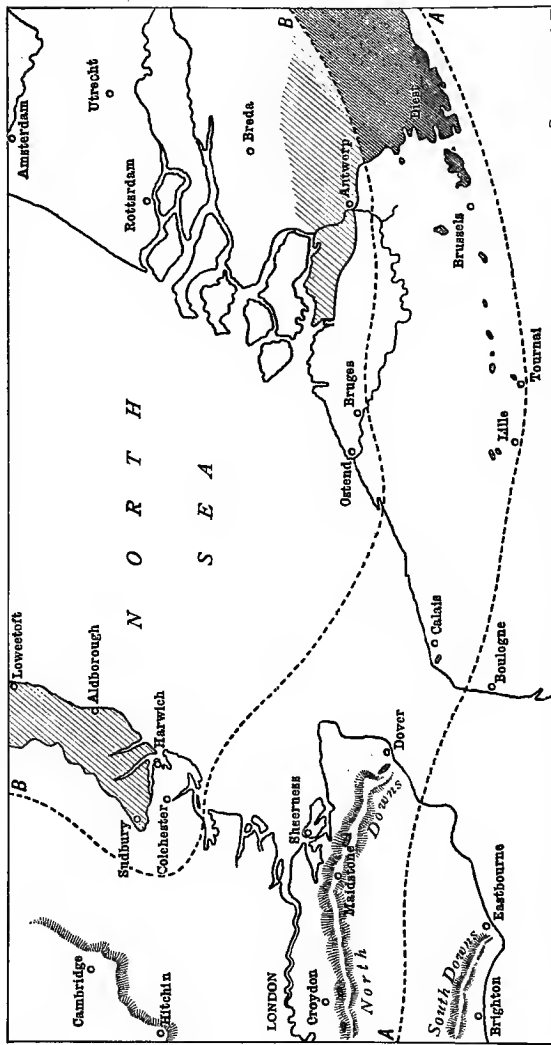
Sheppey and Essex they doubtless rested on some member of the Bagshot group, and thence their base-line passed across the outcrops of the Lower Eocene and Cretaceous strata till it rested on the Wealden beds over the central axis of the Wealden area (see fig. 6).

Outliers of similar ferruginous sands occur also at intervals in France and in southern Belgium, the level of their base-line sinking lower and lower to the eastward. Thus, at Cape Blanc-Nez, they are about 500 feet above the sea; at Cassel, near Ypres, their level is 470 feet; above Renaix it is 445; at Gramont 380; on the heights above Brussels it is only 245, and near Diest, though the level varies considerably, their base nowhere rises above a height of 200 feet.¹ Northward the base-line sinks still more rapidly, and is less than 20 feet above the sea near Anvers (Antwerp). Yet throughout this range the sands are similar in constitution and contents, proving that the present differences of level are due to subsequent differential movement of the land. Around Diest and Tessengerloo they cover a large area, and attain a thickness of nearly 100 feet; at Antwerp they contain many fossils, and form the zone of *Isocardia cor*, passing beneath newer Pliocene beds. Northwards, as they pass beneath Holland, their thickness increases, for at Utrecht a deep boring passed through the overlying beds and 410 feet of Diestien Sand without reaching their base, though carried to a depth of 1,208 feet. The range of these beds in Belgium and the north of France is shown in fig. 7, the eastern portion of which is reduced from Vandebroek's map.

Returning to England, fine yellow sands, sandstones, and sandy marls of somewhat similar character form the lower division of what is known as the Coralline Crag in Suffolk, and as nearly all the Lenham species occur also in

¹ Vandebroek, "Bull. Soc. Belge Géol.," &c., tome i. p. 51, and map.

Fig. 7. Map showing the southern limits of Older and Newer Crags.



Walker & Bondall sc.

The darker shading indicates existing areas and scattered outliers of Older Crag, and the line A the probable limit of their original area. The lighter shading represents the surface areas of Newer Crag, and the line B the probable original limits of that Crag.

these sands, it is probable that they are nearly of the same age, though possibly deposited in somewhat deeper water. At their base is a pebble bed which contains the "box-stones" already referred to, as well as rolled bones of various mammalia, pebbles of flint and sandstone, blocks of septaria from the London Clay, and at Sutton a large boulder of dark red felstone. The overlying sands and marls are from 20 to 50 feet thick; they contain numerous shells and Bryozoa, some in the position of life and growth, others drifted and mingled with layers of comminuted shells.

According to D'Orbigny the conditions essential to the growth of Bryozoa are a considerable depth of water, clear water, and the existence of strong currents; the modern species of *Lepralia*, for instance, of which many occur in the Crag, are generally found between 40 and 150 fathoms.¹ Of the Corals one species lives now at depths of 10 to 60 fathoms, and the descendant of another (*Flabellum Woodii*) has only been found at depths of over 300 fathoms. The Foraminifera, according to Messrs. Jones, Parker, and Brady, agree best with the assemblage found between 50 and 70 fathoms off the Scilly Isles.

The sandy beds are overlain by the peculiar rock which has given the name of Coralline Crag to the group; this is a soft, porous, yellow calcareous rock, which is almost entirely composed of comminuted shells and Bryozoa; it is from 30 to 40 feet thick, and the irregular bedding and oblique lamination which it exhibits are proofs of the action of strong currents in drifting, sifting, and reconstructing the layers of which it is composed. Mr. Prestwich concludes, therefore, that this rock indicates shallower water than that in which the sandy marls below were deposited, and infers that during its formation the sea-floor was raised

¹ Prestwich, "Quart. Journ. Geol. Soc.," vol. xxvii. p. 129.

by a movement of elevation and exposed to the action of tidal currents.

The beds known as Coralline Crag are now limited to a small area in Suffolk around and between the estuaries of the Deben and the Alde, but they are evidently mere remnants of a formation which had once a far wider extension.

The St. Erth Beds, which occur at a height of about 100 feet near Hayle in Cornwall, are regarded by Mr. C. Reid as approximately of the same age as the Coralline Crag. They consist of fine clays and sands, in which many fossils have been found, none of the shells having a northern range, while some of them are southern species which have not been found elsewhere in Britain.

Newer Pliocene.—Coming now to the Newer Pliocene series, we may consider the Red and the Norwich Crag together, as they are generally believed to be contemporaneous deposits. The Red Crag of Suffolk rests either on the London Clay or on an eroded surface of the Coralline Crag, and it is surmised that the latter had been raised into the condition of an actual land-surface and again submerged before the deposition of the Red Crag upon it. The Norwich Crag rests chiefly upon the Chalk.

These newer crags underlie nearly the whole of eastern Suffolk and Norfolk, extending westward as far as Sudbury in the former, and to Cringleford, near Norwich, in the latter county. They, in turn, suffered much from erosion at a later period, and we may assume that their original boundary lay considerably to the west of their present limits; the probable position of this boundary and, inferentially, of the sea in which they were deposited, is indicated by the line *BB*, in fig. 7, p. 240.

The Red Crag is divisible into two zones or stages: (1) a lower set of shelly and current-bedded sands, largely composed of the detritus of the Coralline Crag; (2) an upper set of horizontally stratified sands and clays (the

Chillesford Beds); and it is believed that these Chillesford Beds pass into the upper portion of the Norwich Crag. Generally speaking, the Suffolk type is the more purely marine deposit, and the Norwich Crag a more littoral one.

The Sutton section described by Mr. Prestwich¹ is interesting as affording definite evidence of subsidence during the formation of the Red Crag. This crag is here banked up round an island of Coralline Crag, and two distinct shelves or beaches are found, the upper one cutting into the cliff at a height of 9 or 10 feet above the lower one; each beach has a basal bed of pebbles and phosphatic nodules with large blocks of Coralline Crag derived from the cliff above. A basement bed of this kind, but without the blocks of Coralline Crag, is everywhere found at the bottom of the Red Crag, and yields chalk flints (some very little worn), septaria from the London Clay, (Tertiary) sandstones, Cretaceous chert, and fragments of red granite.

The shelly sands above are from 10 to 30 feet thick, and they have evidently been accumulated in shallow water, the materials being largely derived from the erosion of the older Tertiary deposits and heaped up by currents into shoals and sandbanks, which have been shifted and reconstructed many times before they came to rest in their present position.

"The Norwich Crag," says Professor Prestwich, "which occupies the contiguous area, and lies on the same level, seems to have been divided from the more open sea of the Red Crag by a barrier of Coralline Crag, behind which were sandy bays into which flowed a river or rivers, bringing down land and freshwater shells, and probably the mammalian remains, from land to the north-west and

¹ "Quart. Journ. Geol. Soc.," vol. xxvii. p. 340.

west. There is evidence of these streams coming from that direction in the circumstance that in the Crag at Norwich, Lias Ammonites, Mountain Limestone corals, besides the many fossils from the Chalk, are found. I have found also at the base of the Crag at Weybourn a fragment of fossiliferous Kimeridge Clay, and in the Norwich Crag a fragment of an encrinital column similar to one I have seen in the Red Crag of Sutton, in which latter also occur *Belemnites*, *Ammonites*, *Ostreae*, and *Terebratulæ*, from various Secondary rocks, together with fragments of chert from the Lower Greensand, while the occurrence of the fragments of red granite points to transport from still more distant localities" (op. cit., p. 476).

The Chillesford sands and clays, and the laminated clays which overlie the Norwich Crag, possibly indicate a further submergence, for the sands are finer and less ferruginous, the clays are grey and laminated, and the bivalve shells in them frequently occur in undisturbed position with united valves. At the same time there is a diminution in the number of southern mollusca and a prevalence of northern forms, facts which prove the waters to have become much colder, and suggest that the quantity of ice in the Arctic regions had greatly increased.

The Weybourn Crag mentioned above is of about the same age as the Chillesford Beds, though possibly a little newer, as in it *Tellina balthica* first appears, and the percentage of northern forms is increased to 16 per cent., that of the Chillesford and Norwich beds being only 8 or 9 per cent.

Shelly sands (Scaldisien of the Belgian geologists) similar to our Red Crag cover a considerable area in the north of Belgium, see map, fig. 7, and they extend northward through Holland beneath the Pleistocene deposits of that country; in the deep boring recently made at Utrecht their thickness was found to be no less than 270 feet, the

Scaldisien sands being overlain by 528 feet of Pleistocene deposits and underlain by over 400 feet of Older Pliocene sands.

The highest and latest Pliocene beds known to occur on the borders of the North Sea are those seen on the coast of Norfolk, and known respectively as the Forest Bed and the *Leda myalis* Bed. The so-called Forest Bed is really a set of beds very variable in composition, comprising layers of sand, gravel, clay, and lignite, with a total thickness of 10 to 20 feet; they contain numerous drifted stumps and branches of trees, with fir-cones and other plant remains, bones and teeth of many mammalia, and estuarine mollusca. Its upper surface, however, does in many places present the appearance of an actual land surface, being weathered into a soil and penetrated by rootlets; here and there also it is covered by lacustrine deposits containing freshwater shells and bones of beavers, mice, moles, and other small creatures. A rootlet bed similar to that of Norfolk, and believed to be of the same age, occurs also at Hopton, Corton, and Kessingland in Suffolk, so that similar conditions appear to have prevailed over an area which measured at least 40 or 50 miles from south to north. They do not, however, extend far inland, and the neighbourhood of Norwich appears to have been comparatively high ground at the time of their formation.¹

The beds which underlie this terrestrial surface are clearly such as would be formed in the estuary of a large river, and it is therefore reasonable to regard the gravels and sands as river-borne detritus, and to look to the pebbles composing them as affording a guide to the direction from which the river came. These pebbles have been carefully studied by Mr. Clement Reid; they consist chiefly of flints and light-coloured quartzites, with other stones which seem

¹ Clement Reid, "Geology of the Country around Cromer," p. 55.

to have been derived from Carboniferous, Lower Cretaceous, and Eocene rocks. There is a total absence of Jurassic débris and of the liver-coloured quartzites which are so common in the English Trias. "In fact," to quote Mr. Reid,¹ "if the river had flowed from the south, west, or north, it must have brought quite a different collection of stones. From the north-east [had it come from that direction] it would probably flow entirely over chalk. It therefore seems that only from the south-east or east could the stones be derived." This conclusion, as will be seen in the sequel, is an important factor in the restoration of the physical geography of the North Sea area at this particular time.

Near Cromer these terrestrial deposits are succeeded by the *Leda myalis* bed, which is from 4 to 15 feet thick, and consists of fine loamy sand with marine shells, some of them lying undisturbed in the position of life. It is clear, therefore, that the last change which occurred in this portion of the Pliocene area was a submergence which brought in the sea once more over the lower parts of the newly-formed land. This, however, seems to have been only a temporary change, followed by an elevation of much greater extent, during which the climate underwent an enormous alteration.

§ 2. Geographical Restoration.

Miocene Time.—It will be remembered that the Oligocene epoch was described as one of gradual upheaval, and as closing with a general elevation of western Europe in which the British region participated. That this continental period lasted a long time is proved by the great change which took place in the molluscan and mammalian fauna.²

¹ "Geology of Country around Cromer, Mem. Geol. Surv.," p. 56.

² See "Historical Geology," p. 489.

It was doubtless a period during which the action of rain and rivers effected great changes on the surface of the land, and it is possible that some of the geological features of western and central England were initiated at this time. By this expression I do not mean that the present physical features of these districts were then developed, but that large areas of Chalk and Eocene were then removed by erosion and detrition from the borders of Wales and from the Midland counties, and that the ridge or outline of the great Jurassic escarpment may then have been developed, so that the watershed between the valleys of the Severn and the Thames may have been formed at this period; but as the recession of the Mesozoic escarpments was continued throughout the Pliocene epoch, we must assume that in Miocene times the escarpment of the Chalk lay much nearer that of the Oolites than it does now, and that both were to the westward of their present lines. The valley of the Thames, as first pointed out by Sir A. Ramsay, must be older than the development of the Chalk escarpment through which it passes between Wallingford and Reading. Its course must have been determined when the watershed lay over the Jurassic escarpment, and when a sheet of chalk covered by Eocene strata sloped away eastward from the summit of the Cotteswold Hills.

From the position of the early Pliocene beds on the North Downs overlooking the area of the Weald, we may infer that the anticlinal dome or uplift of this area was much less marked in Miocene time than it is now, and that its central portion was not then relatively lower than the tracts occupied by the Chalk, but that the whole area formed a plateau of low elevation, from which perhaps the Upper Cretaceous rocks had not yet been entirely removed. The outer parts, and in all probability the tracts where Upper Chalk is now at the surface, were then covered by Eocene strata, and the greater part of what we call the

Weald may then have been occupied by broad plains of Chalk marl and gault, with possibly a small central tract of Lower Greensand and Weald Clay. We may at any rate assume that the present drainage system of the Weald was initiated at that stage in the history of its denudation when such was the condition of its surface, though whether this stage was reached in Miocene, or not until Pliocene time, we are hardly yet in a position to determine.

From the facts mentioned on p. 235 we may conclude that, after an interval of unknown duration, a general subsidence at length took place, and the period marked by the Miocene deposits commenced. This subsidence brought the shores of a sea which opened southward within a short distance of the British area, if it did not actually invade it. On the south this sea reached to the Cotentin district of Normandy, and on the east it stretched through Belgium to the eastern shore of England.

Older Pliocene Time.—The subsidence which had set in during the formation of the Miocene beds seems to have been continued during that of the older Pliocene, until the whole of south-eastern England was submerged and the sea covered districts which are now more than 600 feet above its level. The remnants of the older Pliocene beds are however so small and scanty, that it is difficult to draw any trustworthy inferences from their distribution regarding the probable limits of the sea in which they were formed.

The first point which calls for consideration is whether there were two gulfs with an isthmus between them, as in Miocene time, or whether the sea swept across the Channel area and covered the whole of southern England. As remarked by Mr. Clement Reid,¹ “a subsidence sufficient to allow only 20 or 30 fathoms of water over the highest parts of the North Downs would submerge the whole of

¹ “Nature,” Aug. 12, 1886, p. 342.

the east and south of England except a few hills," if it were to be repeated at the present time. He points out, however, that it is very unlikely that the relative levels and contours of the Pliocene land were at all similar to those of modern Europe, that it is much more probable that subsequent differential movements have taken place, the Wealden area having been upraised, while Holland was depressed.

We may therefore start with the assumption that the geography of early Pliocene time, so far as the relative positions of land and sea in southern England are concerned, did not bear much resemblance to that of the present day, and, inversely, that we cannot use the modern physical geography of the country as affording much assistance in a restoration of the early Pliocene geography. It is also certain that great changes took place in the interval between the older and newer Pliocenes, and possibly the geographical conditions of early Pliocene time resembled those of the Miocene more than those of the later Pliocene. It is true there was an eastern sea or German Ocean which spread over a portion of southern England, but there is no evidence that it approached our north-eastern shores, neither is there any proof of the existence of an English Channel. It is quite possible that England was joined to France by land which united the Tertiary and Cretaceous basin of Hampshire with those of northern France, its southern border being perhaps a range of high Chalk Downs, which extended south-eastward from the Isle of Wight and was continuous with the Chalk districts of Normandy. It is conceivable that the Oligo-Miocene upheaval had lifted this tract of country to a considerable elevation above the sea, the rise being greatest over the southern or Isle of Wight axis, but the whole country sharing in the uplift. If this were so, the tract in question would form an isthmus between the eastern and south-

western seas, and may never have been wholly submerged at any subsequent time. The limitation of the Lenham and Diestian Sands to the northern side of this tract, and their apparent absence over the South Downs, are facts which suggest that their original boundary line, and therefore the shore of the early Pliocene sea, lay somewhere over the central axis of the Wealden district between the lines of the North and South Downs, as shown in the map, fig. 7, where the line A A shows the supposed position of this shore-line.

On the other side of the isthmus above mentioned lay another sea, arms of which probably advanced into what is now the area of the English Channel. If Mr. C. Reid is right in thinking that the St. Erth Beds belong to the Older Pliocene epoch, a large part of Cornwall may then have been covered by this southern sea, for, as Mr. Reid observes,¹ "the St. Erth clay was evidently laid down in still water, which would not be found at a less depth than 40 or 50 fathoms in a district exposed like this to the Atlantic swells. The fossils also in that clay point to some considerable depth of water, while the general flattened contour of the country suggests that this district has nearly all been submerged within a comparatively recent period. The lower parts of Cornwall form a smooth undulating country, out of which rise abruptly the higher hills. Round one of these hills, St. Agnes' Beacon, coarse sand is found at a high level. This is probably a beach deposit of the same age as the clay at St. Erth, though all fossils have now disappeared from it. Cornwall seems at that period to have formed a scattered archipelago like the Scilly Isles."

It must be admitted, however, that the separation of these two seas is a doubtful question, and the mere absence

¹ "Nature," Aug. 12, 1886, p. 342.

of early Pliocene deposits from the intermediate area cannot be held as a very serious objection to the view that they communicated across the Hampshire basin. That the Diestian or Coralline Crag sea had some very direct communication with the Mediterranean and west European area is indicated by the large proportion of Mediterranean species among its mollusca, namely 200 out of the 265 living species, or 75 per cent., 17 of them being now confined to the southern area; it is difficult to see in which direction this connection could have existed if not through England and France.

It is generally supposed that the Anglo-Belgian sea of this period opened northward into the Arctic Ocean, but this belief is doubtless founded upon the present extension of the German Ocean, which is really more likely to have been initiated in the later part of what we call Pliocene time. I cannot find, indeed, that there is any good reason for supposing the sea of the Coralline Crag to have stretched far north of Suffolk. In fact, the total absence of any signs of Coralline Crag or of the box-stones in Norfolk, and the manner in which the lower and older portions of the newer crags thin out northward and westward in that county, are significant facts which incline me to believe that Norfolk at any rate did not form part of the early Pliocene sea-floor; in other words, that the Coralline Crag was deposited in a gulf which lay wholly to the south of Norfolk, and was limited by a promontory of land which stretched out north-eastward from Norfolk far into what is now the North Sea, if it did not reach entirely across to the shores of Norway and form a complete barrier between the Anglo-Belgian sea and the Arctic Ocean.

The mere presence of some twelve or fourteen species which have now a northern, *i.e.* Arctic or Scandinavian, habitat, cannot be taken as *proof* that there was any connection with the Arctic sea, for these species may then have

been British and Belgian forms which, at a subsequent period, when circumstances permitted, ranged northward and found a lower temperature more congenial. We do not know how many species of the Pliocene mollusca were forced by the increasing cold of the Glacial period to adapt themselves to a cold climate; some probably would do so, while others were exterminated or driven to more southern climes. Neither does the transportal of the felstone boulder of Sudbourn, even if accomplished by ice, involve the influx of a current from Arctic regions.

All these questions will doubtless be ably discussed by Mr. Clement Reid in the monograph on the British Pliocene Deposits which he has in preparation, and it would be both premature and presumptuous if I were to attempt a solution of so difficult a problem in the present volume. Before dismissing the subject, however, attention may be called to the opinions formed by Messrs. Kendall and Bell from a study of the St. Erth fossils, with regard to the geographical connections of the sea in which they lived. From the prevalence of Mediterranean species they infer a direct communication with that sea through Normandy and the south-west of France; while from the absence of Arctic species they are led to think that the Arctic Ocean did not then open into the Atlantic, but that the land communication which is believed to have existed between Europe and North America in Eocene times, by way of Iceland and Greenland (see p. 215), continued to exist through the Miocene and early Pliocene epochs, so as to form a barrier of separation between the Arctic and Atlantic oceans.

They point out that ¹ a submerged ridge, covered by less than 350 fathoms of water, but with deep water on either side of it, extends from Scotland to the Faroe Isles, and has had, as explained by the late Dr. Jeffreys, a great influence in preventing the intermingling of the marine

¹ "Quart. Journ. Geol. Soc.," vol. xlii. p. 207.

faunas on each side of it. "From the Faroes to Iceland an undulating bottom exists, reaching a depth of 368 fathoms, whence a plunge takes place to 686 fathoms, and within 30 miles recovers to 350 fathoms. Across the Denmark Straits, between Iceland and Eastern Greenland, the depth nowhere reaches 500 fathoms."

If this tract of comparatively shallow water were land, as it is believed to have been in Miocene and Eocene times, and if Greenland was then united to America, as is most probable, no Arctic currents could have entered the Atlantic Ocean, and the climate of its northern shores would be much milder than at present. Under such geographical conditions Greenland and Iceland may have been fitted to support a luxuriant flora, as they undoubtedly did in Eocene times; for Dr. A. R. Wallace observes that "the existence at the present time of an ice-clad Greenland is an anomaly in the northern hemisphere, and only to be explained by the fact that cold currents from the polar seas flow down both sides of it." ¹

Newer Pliocene Time.—From the general relations of the newer to the older Pliocene beds we may conclude that an upheaval of considerable extent took place at the close of the older epoch, and that these older deposits (Coralline Crag, &c.) were raised into the condition of dry land. The present position of the Lenham Sands shows that the uplift was greatest over the Wealden area, while Suffolk was either never raised to such an elevation, or was subsequently depressed to a much greater extent. We may safely say that the waters of the Diestian Sea were entirely displaced from the British, French, and Belgian areas for a certain length of time, and that these three countries were united into one broad mass of land, which stretched northward to Iceland and Greenland, as heretofore throughout the Tertiary era.

¹ "Island Life," 1880, p. 149.

This general elevation was followed by a local and partial subsidence, limited apparently to what is now the North Sea and its borders. This subsidence allowed the waters of an eastern sea once more to invade English territory, and eventually opened up a communication between this sea and the Arctic Ocean.

It is highly probable that it was the movement that led to the formation of the North Sea which gave the easterly dip to the Eocene and Cretaceous rocks of eastern England and an easterly tilt to the whole London Basin; it is certain, at any rate, that any slight easterly dip which they may previously have had was at this time greatly increased. We have seen that the geography of the older Pliocene epoch bore little resemblance to that of modern England, and though some of our Midland hills and valleys may date from Miocene times, yet it is probable that the development of the Cretaceous escarpments and of the corresponding longitudinal valleys, as well as the trenching of these escarpments by certain of our rivers, was accomplished during the period we are now discussing.

That the close of the Pliocene epoch found the main physical features of England fully developed, and the Mesozoic escarpments occupying their present positions, we know from the relations of the Pleistocene (Glacial) deposits to these features. We may, therefore, fairly infer that, though the rivers which flow eastward and cut through the great Chalk escarpment may have first established their channels at an earlier epoch, yet it was the easterly tilting of the country at this time which gave them the power of excavating their present valleys in such a comparatively short space of time, and which enabled their tributaries to remove such large areas of Eocene and Chalk. We must remember, also, that this process of erosion and denudation would proceed contemporaneously with the formation and recession of this Chalk escarpment. I am, therefore, in-

clined to believe that all the great gaps which exist in this escarpment, those of the Thames Valley, the Wash, and the Humber, date from Pliocene times, and are, therefore, pre-Glacial. Let us see how the evidence of the newer Crags and their contents fits in with this theory.

Professor Prestwich has shown that the Red Crag was accumulated in a shallow sea studded with reefs of the Coralline Crag, round which set strong and shifting currents. "The direction of the currents, judging from the nature of the foreign materials found in the Red Crag, seems to have been from the west to the south-east."¹ He thinks the occurrence of unrolled flints and of large blocks of Coralline Crag indicate transportal by shore-ice, but this, I think, is hardly likely; the blocks of Crag are only described as occurring near the cliffs from which they were quarried, and ordinary wave-action is sufficient to account for such limited dispersal. Neither does the presence of unrolled flints really necessitate the existence of *shore-ice*; they may have been carried by uprooted trees borne to sea by rivers in time of flood, or by ground-ice formed in the same rivers during severe winters.

Speaking of the Norwich Crag Mr. H. B. Woodward remarks, "A study of the subject in conjunction with the Suffolk Crag leads to the suggestion that the area was gradually being depressed, and that the land to the north was being slowly submerged, so that the Chalk cliffs which then formed the coast-line were gradually destroyed northwards and westwards, and the neighbourhood of Norwich came within the influence of the Crag sea before that of the Bure valley. This gradual submergence perhaps led to the introduction of *Tellina balthica* by the opening up of a connection with some previously distinct area."²

¹ "Quart. Journ. Geol. Soc.," vol. xxvii. p. 354.

² "Geology of the Country around Norwich," Geol. Surv. Mem., p. 37.

The contents of the Norwich Crag (see p. 244) plainly show that the rivers which entered the shallow sea came from the westward and carried débris which had been derived from the central parts of England. From the great depth of the Crag at Southwold (147 feet), and at Beccles¹ (80 feet), where the muddy nature of the deposits is also remarkable, we might suppose that one of these rivers traversed what is now the valley of the Waveney, this being continued westward into that of the Little Ouse, which may then have been occupied by a river coming from the region of Bedford and Bucks, where the Ouse now takes its rise. This stream, however, could hardly have carried the Carboniferous fossils which have been found in the Crag, and unless these were drifted along the coast from some far northern locality, Derbyshire and Leicestershire are the nearest and most probable sources. The valley of the Trent at once suggests itself as a possible channel of transport, for we know that the ancient course of this river was not that which it now follows, but through the Jurassic escarpment along the valley now occupied by the Witham into the basin of the Wash.² Further, its drainage system is such that its tributaries could derive all the stones which have been recorded as occurring in the Norwich Crag.

Bearing in mind these facts and the general considerations mentioned on p. 254, there is nothing improbable in the suggestion that the breach in the Chalk escarpment which is now occupied by the Wash was initiated by the combined forces of the rivers Trent, Witham, Welland, and Nen, before this escarpment had receded to anything like its present position. There is every reason to suppose that in later Pliocene time all these rivers traversed the

¹ Woodward, "Geology of the Country around Norwich," p. 156.

² See "Quart. Journ. Geol. Soc.," vol. xxxix. p. 606, and "Geology of the Country around Lincoln," Mem. Geol. Survey.

Jurassic ridge, although only two of them (the Welland and Nen) now retain their ancient channels, and we may fairly assume that the bay of the Wash did not then exist, but that the combined streams of the above-mentioned rivers occupied a broad valley which passed along or just outside the northern coast of Norfolk, and opened into an estuary somewhere to the north-east of that county (see Plate XIII.). That a river of some size did at a much later date pursue such a course has been surmised from the peculiar geological features presented by the northern coast of Norfolk. This coast is bordered by a continuous strip of alluvium, the western part of which rests on boulder-clay which is banked against a steep slope of chalk. Referring to the alluvium, Mr. H. B. Woodward remarks,¹ "the physical characteristics of the area suggest that this low ground was originally an old river-valley, and that the heights which bordered it on the north have been destroyed by the ravages of the sea."

Passing now from these details of the Pliocene river-system, let us consider what other changes may have been caused by the depression which led to the formation of the North Sea. The most direct and important change was the submergence of the land which had hitherto from the commencement of Tertiary time united Scandinavia with Scotland and Iceland. Not only did this depression open a communication with the Arctic Ocean, but in all probability with the North Atlantic also, by the temporary breaching of the isthmus between Scotland and the Faroe Islands, and by the conversion of the deep valley or hollow north of these islands into a strait. By these passages many North Atlantic and American species of mollusca gained access to the Anglo-Belgian part of the Pliocene Sea, no fewer than eighteen American species occurring in

¹ "Geology of the Country around Fakenham," Geol. Surv. Mem., p. 44.

the newer Crag, only seven of which still live on the Scandinavian coast, the remainder being now confined to the North American region.

This view of late Pliocene geography is represented on Plate XIII., and this differs from previous restorations chiefly in those particulars where recent information has afforded more correct data than were formerly available. The first attempt to give an outline of Pliocene geography was by Mr. Godwin-Austen, who, in 1866,¹ published a map on which the supposed area of "the Crag Sea" was delineated. At that time, however, it was unknown that the sands of the Coralline Crag ranged so far south and to such a high level; while many deposits were then called Crag which have since been proved to be of Pleistocene age; consequently, his map combines portions of the geographical conditions of several distinct periods, and is not correct for any one portion of them.

Professor Boyd Dawkins has given a map of Pliocene Britain² which may be taken as an approximation to that of the later portion of the period, but since its publication Mr. Jamieson has shown that the supposed Crag of Aberdeen is a remanié deposit of Pleistocene age,³ and consequently there is no proof of the Red Crag sea having touched any part of the Scottish coast. In the region of the Faroe Islands, also, Professor Dawkins shows a greater area of water than I deem probable; for it should be remembered that the whole of the newly-formed North Sea may have been very shallow. No deep-sea deposits of Pliocene age have yet been found in north-western Europe, and the phenomena of the Forest Bed show that a very slight upheaval was sufficient to convert a large area of it into dry land.

¹ "Quart. Journ. Geol. Soc.," vol. xxii. p. 240.

² "Early Man in Britain," 1880, p. 73.

³ "Quart. Journ. Geol. Soc.," 1882, vol. xxxviii. p. 145.



PLATE XIII. GEOGRAPHY OF THE NEWER PLIOCENE EPOCH.
The closer lines representing sea-areas at the time of the Forest Bed.

In fact, at the time of the Cromer and Kessingland "rootlet bed," it is probable that much of the southern part of the North Sea area passed into the condition of a broad plain of dry land studded with large shallow lakes, like the "broads" of modern Norfolk. Such is the opinion which Mr. C. Reid was led to form from a study of the Forest Bed and its associated deposits; and the following remarks are quoted from his memoir:¹—"The large number of mammals already known from the Forest Bed seems clearly to point to a connection with the continent;" but "both the fauna and flora, leaving out the large mammals and other extinct forms, are curiously like that of the 'broad' district of Norfolk at the present day; and this, like the rest of the evidence, points to a wide alluvial plain with lakes and sluggish streams, bounded on the west by a slightly higher sandy country covered with fir-forests and distant from any hills."

It is supposed that this plain was traversed by a large river coming from the south-east, as stated on p. 246, and that this river was no other than a continuation of the Rhine; a view first suggested by Mr. Gunn in 1867, but adopted and strengthened by subsequent writers. Thus Professor Prestwich, writing in 1871, remarks that on the table-land above the Meuse in Belgium there is a gravel of very similar character, and though, according to Mr. C. Reid, this contains veined quartzites of a character unknown in the Forest Bed gravels, yet the general similarity of the gravels suggests that they belong to one and the same system of drainage. Mr. Reid himself suggests that the fragments of Carboniferous slate and chert may have been derived from rocks that "came to the surface as part of the old ridge which Mr. Godwin-Austen has described," and as the Ardennes are part of this ridge, it is difficult to see why he should have any hesitation in assenting to Professor Prest-

¹ "Geology of the Neighbourhood of Cromer," pp. 60, 61.

wich's view: the Meuse was then in all probability a tributary of the Rhine, and it is to the Rhine itself that Mr. Reid refers the transport of the pebbles in question. In his memoir on the neighbourhood of Cromer Mr. Reid has given a sketch-map representing the probable position of the estuary of the Rhine during the formation of the Forest Bed. This is reproduced with slight alterations in Plate XIII., the limits of the sea at the close of the Pliocene epoch being shown by the boundary of the darker tint. It is assumed that the whole area of the North Sea was greatly contracted by upheaval from its previous extent, though whether this elevation included the Scoto-Icelandic area, and was sufficient to raise the connecting isthmus once more above the sea, is doubtful, but such a connection is shown on Plate XIII. because it is suggested in the sequel that a further elevation to this extent did supervene in the interval between the Pliocene and Pleistocene epochs.

CHAPTER XIII.

ICENIAN PERIOD.

PLEISTOCENE EPOCH.

FOR a detailed account of the deposits of this period I must refer the reader to my previous volume on "Historical Geology," and to Mr. H. B. Woodward's "Geology of England and Wales." For my present purpose it is only necessary to give such a summary of what is known respecting the distribution and succession of these deposits in England, Ireland, and Scotland as may afford a basis for considering the physical and geographical changes which took place during the period.

The Pleistocene deposits are generally treated under the heads of Glacial and Post-glacial Beds by British writers, but, though this is a convenient division in dealing with the deposits of a limited area, it becomes misleading when those of a larger region are compared with one another, as for instance those of southern and northern England. The so-called Ice Age or Glacial Period must be regarded as a special episode or phase of Pleistocene time, and though its influence may be traceable over a large area of the earth's surface, yet the deposits which owe their origin to the direct action of ice are limited to certain regions within the 40th parallels of latitude in both hemispheres.

There is no doubt that what took place in the Glacial period was simply an extension of the glacial conditions which now exist in the polar regions. The fauna of the Pliocene Beds affords evidence of the gradual refrigeration

of the climate in that period, and there can be little doubt that glacial conditions prevailed in high northern regions while the Craggs were being formed in the east of England. The ice must have been creeping southward for a long time before it reached the latitude of Norfolk and led to the formation of the remarkable accumulations which succeed the Pliocene beds of that district. Again, it is certain that ice lingered in Scotland, and in the mountain districts of England and Ireland, long after it had disappeared from the southern part of our country.

§ 1. Stratigraphical Evidence.

In our review of the Pleistocene period it will therefore be best to consider the whole succession of deposits which occur in different parts of our islands consecutively, so far as that succession has been ascertained.

Scotland.

Glacial Deposits.—Many attempts have been made to classify the Boulder-clays and gravels of Scotland, but no two writers seem to be quite agreed as to the precise sequence; some still speak of *the* Boulder-clay of Scotland, as if there were only one, and others are willing to believe in any number of such clays if only they are separated by fossiliferous sands or gravels. Mr. Jamieson, however, has shown that there are at least two distinct Boulder-clays,¹ and from Professor James Geikie's descriptions² we may infer that there are at least three sets of Glacial deposits. The oldest are Boulder-clays of the hard and compact kind which is locally known as *Till*; the stones which they

¹ "Quart. Journ. Geol. Soc.," vol. xxi. p. 162, and vol. xxxviii. p. 160.

² "Prehistoric Europe," pp. 261 and 386; "Great Ice Age," second edition, p. 216.

contain show that the ice under which they were formed radiated outwards from the main watersheds of the country, and they do not contain any intercalated marine deposits. Elsewhere, as in Lewis, Caithness, Aberdeen, Arran, and the central Lowlands, there are Boulder-clays which contain broken sea-shells and include sands and gravels of marine origin; these deposits have not yet been found for certain much above 500 feet, but Mr. Jamieson has described stratified drifts occurring at a much greater height. Lastly, there is a set of stratified deposits (soft sands, gravels, and clays) which contain some Arctic species of shells, but do not occur above the 100-foot contour line, and pass into ancient river-gravels above that level. These last appear to have been contemporaneous with the kames or eskers, and with the moraines of the later glaciers in the Highland valleys.

This succession of deposits is particularly clear in Aberdeenshire, where, resting on a rock-surface that is glaciated from west to east, lies a tough grey Boulder-clay containing stones which have clearly been brought from western localities, or derived from the rocks in the neighbourhood. This clay varies greatly in thickness, as if it had suffered from subsequent erosion, and is sometimes reduced to a layer of grey rubbish and boulders. Above this, or in its absence resting on a rock-surface that is glaciated from the south and S.S.W., is a red Boulder-clay containing stones which have come from localities to the southward. This clay is sometimes as much as 100 feet thick, and it is associated with sands and gravels which contain broken marine shells; it ascends to a level of 300 feet above the sea, and gravelly deposits containing similar stones occur up to 500 feet. Lastly, by the estuaries of the Tay and the Earn, there is a mass of stratified drift, the upper surface of which is almost flat and is about 100 feet above the sea; it maintains this level all the way from the coast to Dalreoch in

the valley of the Earn, and to Luncarty, above Perth, in that of the Tay, passing ultimately into gravels of torrential origin, which descend from the valleys of the Grampian Hills. To the same stage belong the fossiliferous brick-clays of the Forth and Clyde valleys.

Post-Glacial Deposits.—These consist of raised beaches and clay-flats lying between low-water mark and the contour of 50 feet above mean sea-level. The most important and widely distributed deposit is that known as the Carse-clay, or the estuarine clay which forms the elevated alluvial levels which are known as Carse-lands. The surface of these levels near the sea-board is from 25 to 30 feet above the sea, and their borders coincide with a line of raised sea-beach at the same level. When traced inland up the valleys their surface rises gradually to a level of about 45 or 50 feet, at which level they pass into freshwater alluvium, while their lateral portions thin off against the raised beach, which occupies the 50-foot contour. The clays and silts contain marine shells, of which *Scrobicularia piperata* is one of the commonest; but at or near the base there is frequently a bed of peat in which trunks and rooted stools of trees occur, and in some places this peat bed passes below the mean level of the sea and is then called a submarine forest-bed. The modern river-valley is excavated through the Carse-clays, and contains fluviatile deposits of the ordinary recent freshwater type.

In some cases, as in that of the Tay,¹ there are river-gravels beneath the Peat and Carse-clay, and these, as well as the submarine extension of the Peat, show that the land stood at a higher level and had a farther seaward extension than it has now. The Carse-clay marks a period

¹ J. Geikie in "Prehistoric Europe," p. 316, and Jamieson, "Quart. Journ. Geol. Soc.," vol. xxi. p. 184.

of subsidence, and the modern river-gravels one of emergence.

England and Wales.

Glacial Deposits.—In the mountain districts, as in Scotland, there are traces of Boulder-clays and morainic deposits which contain local débris and have other special characters, and sometimes these are seen to pass beneath newer clays which contain far-travelled boulders and are associated with sands containing marine shells. These two sets of Glacial deposits are well developed in Lancashire, Cheshire, and North Wales, and their differences have been described by Mr. Mellard Reade¹ and Mr. A. Strahan.²

So long ago as 1852 Sir Andrew Ramsay showed that in North Wales there had been an early glaciation by glaciers, followed by a submergence of at least 1,400 and probably of 2,000 feet, and that when the land again emerged from the sea it was once more occupied by a system of glaciers which have left their terminal moraines in many of the valleys. The proofs of submergence consist in the existence of stratified marine deposits at high levels; thus, on Moel Tryfaen in Carnarvonshire there are sands and gravels containing shells and overlain by Boulder-clay at a level of 1,350 feet. Most of the stones and boulders are of local rocks, but among them are pieces of granite from Eskdale in Cumberland, and flints probably derived from the Chalk of Ireland. In the county of Flint, between levels of 1,100 and 1,250 feet, there are gravels containing broken shells and erratics which have come from the Snowdon and Arenig ranges to the eastward, while close by are trains of boulders which have come from the northward. What relation these deposits bear to the low-level

¹ "Quart. Journ. Geol. Soc.," vol. xxxix. p. 83.

² *Ibid.*, vol. xlii. p. 369.

marine drifts which spread over so large a part of Cheshire and Lancashire has not yet been ascertained, but high-level marine beds have been found at a height of 1,200 feet near Macclesfield.

In the midland and eastern counties, also, two distinct groups of Glacial deposits are found. The older group is well developed in East Anglia, and it is generally supposed that the oldest Pleistocene beds in England are those which succeed the Pliocene series near Cromer. These consist of laminated clays, sands, and boulder-clays, overlain by a mass of contorted loam, sand, and gravel, the whole attaining a thickness of nearly 200 feet, and yielding shells of marine species; these beds are believed to pass inland beneath the grey or chalky Boulder-clay which has such a wide extension to the south, west, and north-west. Some doubts indeed have recently been thrown on this presumed succession,¹ but the difficulties experienced in the mapping of north-east Norfolk can hardly be allowed to invalidate the succession which holds good over such large areas to the southward, where the deposits are less disturbed and contorted; it may, in fact, be stated that throughout Essex, Herts, Suffolk, and south Norfolk, except where the height of the ground rises above 300 feet, there is a lower set of loams, clays, sands, and gravels, which sometimes contain fragments of marine shells, and are overlain by a chalky Boulder-clay which is quite destitute of such remains. Beyond these counties there is no such definite succession, but the upper Boulder-clay spreads over large areas to the westward and is associated with irregular masses of sand and gravel.

There are certain facts connected with the surface elevation of the eastern parts of Norfolk and Suffolk, and with the distribution of the chalky Boulder-clay, which are

¹ Reid, "Geology of the Country around Cromer," p. 115, and Woodward, "Geology of the Country around Fakenham," &c., p. 19.

very striking and suggestive. From Hunstanton and Burnham to the latitude of Bury St. Edmunds, the whole country presents the appearance of having been planed down by some powerful agency. No part of the surface rises above the level of 270 feet, and the greater portion is much lower. The slopes of the Chalk hills do not present the bold features which they possess in Cambridgeshire, and there is no continuous ridge which could be dignified with the name of an escarpment, that feature only really commencing with the hills south-east of Newmarket. The height of these latter hills is nearly 400 feet, and south of the Cam Valley the escarpment rises to more than 500 feet. It is true that the Boulder-clay climbs these slopes, but it dies out on the heights above Hitchin, at a level of about 550 feet, giving place to loams which have been formed from the material of the clays and sands of the Reading Beds, and are often merely reconstructed plastic clay, just as the chalky clay is often only reconstructed chalk. At lower levels, however, the typical chalky Boulder-clay continues much farther south, extending through Herts and into Middlesex as far as Finchley, and on the western side of the Chiltern Hills to the neighbourhood of Aylesbury and Buckingham.

How far to the westward this clay originally extended we do not yet know, but no trace of it has been found beyond the limits of a line drawn through the central parts of Oxfordshire, Warwickshire, and Staffordshire. Northward the clay is known to extend through the counties of Nottingham, Rutland, and Lincoln, and it probably reaches into the Vale of York.

In these last counties, as well as in Staffordshire, Derbyshire, Cheshire, and Lancashire, there is another very different group of deposits. These consist of reddish or chocolate-brown Boulder-clays, with interstratified beds of sand, loam, and gravel, the latter containing in some

places marine shells of species which now live on neighbouring shores. These deposits occupy areas from which the older clay appears to have been removed, and no clear section has yet been found where the one clay overlies the other, but there are several localities where the relative ages of the two clays can be inferred from their relative positions, and in every case the evidence points to the conclusion that the chalky clay is older than the red and brown clays.¹

The most recent and most detailed observations on the later Glacial series of Yorkshire,² Lincolnshire,³ Cheshire,⁴ and Lancashire,⁵ have shown that the supposed division of these beds into an upper and lower Boulder-clay, separated by a set of marine sands and gravels, is incorrect, the sands and gravels being only lenticular beds and occurring at various horizons in the series.

The southern limit of these newer clays in the Midland counties has not yet been definitely ascertained, but probably they do not extend far to the south of the valley of the Trent and its tributaries. It is worthy of mention also that clay which closely resembles the red (Hessle) clay of Lincolnshire occurs in the north of Norfolk, and occupies a narrow strip of low ground between Hunstanton and Wells.

Plateaux Gravels and Raised Beaches.—South of the area covered by the later Boulder-clays the latest Glacial deposit is a coarse gravel, consisting chiefly of quartzite pebbles from the Trias and of flints from the Chalk, a deposit which has the appearance of having been formed, partly from the

¹ See "Quart. Journ. Geol. Soc.," vol. xli. p. 114 *et seq.*

² "Geology of Holderness," C. Reid, "Mem. Geol. Surv.," 1886.

³ "Geology of East Lincolnshire," 1887, p. 76, and "Quart. Journ. Geol. Soc.," vol. xli. p. 114.

⁴ A. Strahan, "Quart. Journ. Geol. Soc.," vol. xlii. p. 369.

⁵ Mellard Reade, "Quart. Journ. Geol. Soc.," vol. xxxix. p. 83.

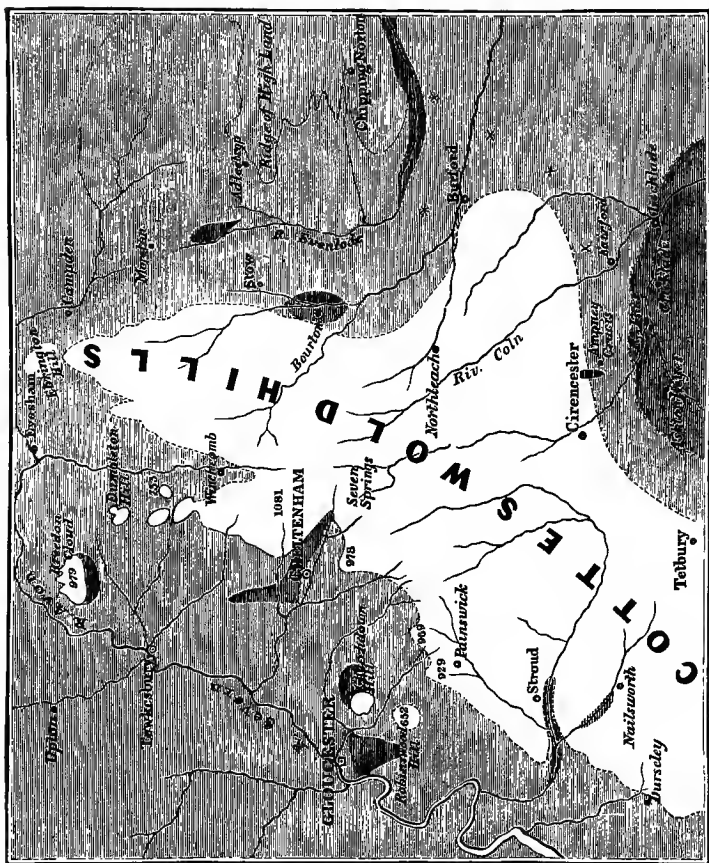


Fig. 8. Map of the Cotswold Hills (by Professor Hull).

The unshaded parts are the areas which are not covered by Drift. The figures indicate heights in feet. Scale about 7 miles to an inch.

destruction of the older Boulder-clay, and partly from the disintegration of the Chalk, only the hardest stones having survived the violent processes of erosion and transport. These "plateaux gravels" occupy such positions as lead to the inference that they once formed a nearly continuous sheet over the southern Midlands. South-westward they occur on the higher parts of the low ground between the Chalk escarpment and the Cotteswold Hills, but are not found far above a level of 600 feet, the higher parts of both ranges being entirely free from this northern Drift. The limits of this Drift in the Cotteswold district were first described by Professor Hull,¹ and represented on a map which is reproduced in fig. 8 by permission of its author and the Council of the Geological Society. It has been suggested that the area covered by these gravels was a land surface at the close of the Glacial epoch, and that the deposit was spread over its surface by the floods and torrents resulting from the melting of the masses of snow which had accumulated on this part of the land.

In Hampshire there are gravels which occupy similar positions, the portions preserved showing that they originally covered a wide plain or table-land which had a gentle slope to the southward. The higher patches of these gravels rise to a level of over 400 feet, and their lower portions appear to be connected with certain marine deposits or raised beaches which occur between the heights of 20 and 100 feet above the present sea level.² Mr. Codrington infers that the lower gravels were deposited in a shallow inlet of the sea during a period of upheaval, by which the inlet was gradually narrowed into an estuary which received the waters of rivers draining country to the north, east, and south, the Isle of Wight being then con-

¹ "Quart. Journ. Geol. Soc.," vol. xi. p. 477.

² Codrington in "Quart. Journ. Geol. Soc.," vol. xxvi. p. 528.

nected with the mainland of Dorsetshire and having a much further extension to the southward.

All the raised beaches of the southern and south-western coasts of England appear to belong to an early Pleistocene period, though it is remarkable that the shells they contain do not indicate a low temperature, but, on the contrary, one rather higher than now prevails on the coast. Thus among the shells of the Selsea deposits, several belong to species which are now confined to the Mediterranean. In Cornwall and Devon the height of the raised beaches is much less than those of Dorset, Hants, and Sussex, but Mr. Ussher has given good reasons for considering them to be older than the stony loam ("Head") and the submerged forests.¹

Fluviatile and Terrestrial Deposits.—All the Glacial deposits, including the "plateaux gravels" last described, are now trenched by valleys, in which are found river-formed gravels of various ages and at various heights above the level of the modern stream.

Some of the oldest of these gravels contain two molluscs which are now extinct in England, namely, *Cyrena fluminalis* and *Unio littoralis*, together with bones of *Elephas antiquus*, *Rhinoceros tichorhinus*, *Rh. leptorhinus*, and other extinct mammalia, and the stone implements of Palæolithic man. Such gravels are, however, confined to the southern and south-eastern counties, outside the limits of the area in which the later Boulder-clays occur.

The Palæolithic river-gravels are, therefore, only post-glacial in the sense that they are later than the Glacial deposits of the counties in which they occur,² but these

¹ "The Post-Tertiary Geology of Cornwall," 1879, p. 43.

² The Glacial age of the brick-earths near Brandon, which contain flint implements, has not yet been proved, for detailed evidence has never been published; the statement rests on the simple assertion of Mr. Skertchly, and is not universally accepted, in spite of its adoption by Professor James Geikie in "Prehistoric Europe," p. 263.

belong to the older Glacial series, and when we reach the districts which are occupied by the newer Boulder-clays, river-gravels are not so extensively developed, and appear to be comparable only with the later river-deposits of southern England, for they do not contain Palæolithic implements or the fauna of the older southern gravels. Moreover, *Cyrena fluminalis* and remains of some of the older mammals have been found in Lincolnshire and Yorkshire beneath the highest sheet of Boulder-clay—a fact which raises the presumption that some of the so-called Post-glacial gravels may have been contemporaneous with the latest Glacial deposits on either side the Pennine Hills.¹

The same assemblage of animals which occurs in the older river-gravels is also found in the lower layers of the cave-earths throughout the country, and it has been surmised that many of these caves date from a period anterior to the later Glacial deposits of northern England. In the case of certain caves in the valley of the Clwyd in North Wales, it is asserted that these deposits are banked against the entrance of the cave in which mammalian bones and flint implements have been found; but the exact relation of the inside and outside deposits is still a matter of doubt.

The old river-gravels are found in patches and terraces which are as much as 80 or 100 feet above the level of the nearest stream, and it is difficult to understand how the rivers can have deepened their valleys to such an extent since the formation of the gravels unless the land stood for a long time at a much higher level than it does now. This conclusion is confirmed by the depth of the valley-beds below the sea-level near the coast, in some cases amounting to 70 or 80 feet, for it is obvious that the stream

¹ This was first suggested by Professor J. Geikie, see "The Great Ice Age," second edition, p. 526.

could not excavate its channel below the level of low-water mark.

The submerged forests which occur at so many points round our coasts point to the same conclusion. A terrestrial surface with rooted trees was found in Portsmouth 29 feet below high-water mark, and overlain by clay with marine shells. In Cornwall a similar bed occurred at 67 feet below high-water mark; but at varying levels above this are other peat and forest beds indicating progressive subsidence, and in southern England there is no evidence of any subsequent elevation.

Ireland.

Glacial Deposits.—These resemble the Glacial deposits of Wales and western England, and there are probably two groups or series of Boulder-clays, though these have not yet been completely differentiated. In the mountain districts there are tough Boulder-clays like those of northern England and Scotland, and over the central plain there is a wide spread of stony clays and gravels which consist largely of the débris of the Carboniferous limestone. Where this Limestone Drift reaches to mountain districts it seems to have completely filled up the pre-glacial valleys, and the aspect now presented by such valleys is thus described by Professor Jukes:—"The steeper hills, as they descend into the valleys, are met by gently sloping plateaus of Drift, forming inclined planes from the heads of the valleys towards their mouths; these inclined planes seeming once to have stretched continuously across the valleys, but being now deeply trenched by the ravines at the bottom of which the present brooks run. These have excavated channels for themselves either through the Drift, or between it and the solid rock, leaving the gently sloping surface of the Drift often most dis-

tingly marked along the flanks of the more abruptly rising hills on each side of the valleys." ¹

This Limestone Drift seems to be connected with a period of submergence, for it sweeps up to heights of 1,200 and 1,300 feet, and at these heights there are marine deposits like those of Wales, containing shells which do not indicate any great intensity of cold, but include some species which have a southern range, such as *Venus casina* and *V. striatula*.

In the north-east of Ireland and along the borders of the Irish Sea deposits occur which are in part similar to the low-level marine Drifts of western England, but the notion that these and the older Boulder-clay on which they rest constitute three distinct stages, namely, a set of sands and gravels between two sheets of Boulder-clay, appears to have been founded on a double misconception. In the first place, such a general threefold division does not exist in Lancashire (see p. 268); in the second, and assuming that it does so appear in Ireland, it does not follow that the lowest clay there is the same as the lowest Boulder-clay in Lancashire; that it is, in fact, a very different clay we have the following testimony by Mr. Mellard Reade: ²—
“What Hull calls the Lower Boulder-clay in Ireland is a deposit of an entirely different nature to that of Lancashire, which is undoubtedly marine, containing rounded boulders of travelled stones as well as shell fragments. Whereas the Irish Lower Boulder-clay is distinguished by the local character of the stones it contains, the absence of shells or shell-fragments, and the general appearance (? resemblance) it bears to moraine matter.”

Neither do the facts recorded by Messrs. Hull, J. Geikie, and Hardman, ³ afford sufficient ground for labelling any

¹ “Manual of Geology,” second edition, p. 676.

² “Notes on the Geology of Ireland,” Proc. Liverp. Geol. Soc., 1879.

³ See “The Great Ice Age,” second edition, p. 395, for details and references.

group of marine sands and gravels either in Ireland or England as "Interglacial," that is to say, they are not justified in regarding such beds as belonging to a phase of Pleistocene time which was distinct and separate from the epochs when Boulder-clay was formed. In Ireland, as in England, there appear to be two groups of Glacial deposits, an older and a newer, each including Boulder-clays and gravels; and the sands and gravels which occur at low levels on the eastern coast and contain marine shells are closely connected with the sandy Boulder-clay which overlies them.

Non-Glacial Deposits.—Raised beaches occur at many places, especially round the northern half of Ireland, but there is much difference of opinion regarding their number and relative levels. Mr. Kinahan describes two distinct and well-marked beaches,¹ a lower at or below 12 feet from high-water mark, and a higher between 20 and 25 feet; but Professor Hull states² that the level of the 20-foot terrace declines southward, so that between the mouth of the Boyne and the north shores of Dublin Bay it varies from 8 to 3 or 4 feet, and along the south shores the terrace cannot be identified, as it merges into the present strand. Possibly this local declination is due to a change in the position of the "head of the tide," as Mr. Kinahan suggests, and the Dublin beach may belong rather to the 12-foot terrace.

No ancient river-gravels containing Palæolithic implements have yet been found in Ireland, the Welsh hills and glaciers having apparently formed a barrier to the migration of man at that time. The mammoth and many of its congeners have, however, left their remains in some of the caves of southern Ireland, and the inland lakes and bogs

¹ "Geology of Ireland," p. 252 *et seq.*

² "Expl. of Sheets 102 and 112 of Geol. Survey of Ireland," 1875, p. 69.

have yielded numerous remains of the reindeer, Irish elk, &c.

Submerged forests are of frequent occurrence round the western, southern, and eastern coasts ; they pass below low-water mark, and peat is said to have been found in some places below four or five fathoms of water. In the estuary of the Barrow the depth of alluvial matter extends to between 60 and 70 feet below high-water mark.¹

2. Physical History and Geographical Changes.

Amid the conflicting opinions which are held by different geologists regarding the physical conditions that prevailed during the early part of the Pleistocene period, it is very difficult to come to any decided conclusion. Everyone admits that it was a time when the action of ice was paramount, but what form of ice chiefly prevailed over the British Islands at the climax of this ice age, and whether at this particular epoch the land surface stood at a higher level than now, or was submerged beneath the waters of an ice-laden sea, are matters of dispute.

That this should be the case with a period of such a late geological date, of which we have such complete records, and of which so many competent observers have made a study, might be deemed a remarkable fact, and one that did not redound to the credit of geologists generally ; but the prevailing uncertainty is, without doubt, caused by the difficulty of realizing the exceptional conditions which must have existed in the British area at this time. The ice-regions of the present day are difficult of access, and we cannot study the action of ice-masses with the same facility that we can observe the action of rivers or of sea-waves. Here and there we may find a retreating glacier, and can

¹ Kinahan, "Geology of Ireland," pp. 265 and 266.

examine the work it has done and the deposits it has left behind, but a country from which an ice-sheet has recently retreated has yet to be found and described. It is quite conceivable that the action of an extensive ice-sheet may be different from that of a single glacier; while the action of sea-ice on a sinking shore is likely to be very different from both.

As however very little is known about these agencies, the students of Glacial deposits labour under the disadvantage of being without positive knowledge of what takes place at the present day under the conditions which they postulate as having existed at a past period in Britain. They are obliged to draw largely on the imagination, and there has been a great tendency to refer all the phenomena of the Glacial epoch to one set of conditions or the other without duly considering the differences of the deposits. Probably in this, as in so many other much debated questions, the truth lies between the opposite extremes, and the investigator who is most likely to arrive at the truth is he who takes care to steer a safe course between the Scylla of universal land-ice on the one hand, and the Charybdis of floating icebergs on the other.

In the following pages I shall not attempt to give a complete history of the physical and geographical changes which took place in the British area, but shall content myself with giving some reasons for not accepting the accounts which have been given by Professor James Geikie,¹ and shall then fix the reader's attention on certain epochs concerning which there is a more general agreement of opinion.

In the first place, Professor James Geikie probably errs in attributing all ice-scratched surfaces to the action of land-ice, and in not admitting that some of them may be

¹ In "The Great Ice Age" and "Prehistoric Europe."

due to the action of floe-ice carried in a definite direction by a steady current. In the next place, he assumes that all Boulder-clays are the "ground-moraines" of confluent glaciers or ice-sheets, and that they have invariably been formed between such ice-sheets and the land surfaces over which the ice passed. That such confluent glaciers existed during the Ice Age in Britain I would not deny, but it by no means follows that the various Boulder-clays were each and all formed on the surface of the land. There is great difficulty in understanding how a country could be glaciated and at the same time covered with an almost universal mantle of Boulder-clay if both processes were effected by an ice-sheet moving over dry land. For if the thickness and weight of the ice were such that its base conformed to the surface of the country, and the pressure it exercised so great that every slight prominence was scratched, grooved and moulded by the stones frozen into the ice, how could there be room at the same time for a layer or pad of compacted mud to accumulate between the ice and the rock? Professor Geikie has been confronted with this difficulty, and he admits that it is impossible for the two operations to take place at the same place and at the same time, but he suggests that the clay was formed under those parts of the ice where the pressure was least, and that the rock was only scratched where the pressure was greatest. If Boulder-clay was found to fill lake-like hollows this explanation might be accepted, but since it behaves as if it had originally formed an almost universal mantle over all the lower parts of the country, the supposition cannot be admitted. Moreover, Professor Geikie often disregards his own suggestion and refers the formation of a Boulder-clay overlying a glaciated surface to the action of the ice which scratched that surface. To most minds I think the obvious inference would be that the scratching must have been done first, and that the clay

was subsequently laid down upon it; and further, that the conditions which permitted the clay to accumulate were different from those which allowed the rock to be scratched.

Finally, those who hold the land-ice theory are compelled to admit not one Glacial period only, nor even two, but an indefinite number of such periods, separated by an equal number of non-glacial and comparatively warm periods, solely because beds of stratified sand and gravel containing marine shells are frequently found between sheets of Boulder-clay. Every such bed is for them a record of an "Interglacial period," and each sheet of Boulder-clay is the record of a distinct Glacial period separated from that of the clay below by an enormous interval of time! To anyone who is familiar with the Glacial series of England, where such intercalations of sand, gravel, and loam are frequent, such a view must seem a very forced and unnatural method of explanation.

Professor J. Geikie's presentation of the ice-sheet theory is, however, by no means the only way in which this theory can be applied, and it is quite conceivable that a modification of it is capable of explaining the Glacial phenomena of Scotland. We may grant that the moulding and grooving of the rock surface has been accomplished by an ice-sheet composed of confluent Scottish glaciers, and indeed few could read Dr. Archibald Geikie's admirable descriptions of Scottish scenery¹ without admitting the former presence of such an agent; but we must urge that some change took place before this surface could have been so largely covered with Boulder-clay. A possible supposition is that the ice-sheet remained, but that a general subsidence of the whole country occurred; the detritus which was being scoured off the face of the land would then come to rest where the pressure of the ice-sheet was relieved by

¹ "The Scenery of Scotland," second edition, 1887.

the letting in of sea-water beneath it, and this would take place at a considerable depth below the surface of the sea, all wave-action being completely prevented by the mass of ice above. The inland extension of the Boulder-clay which was thus allowed to form beneath the ice and the land would only be limited by the progress of the submergence and the variations in the thickness of the ice. Dr. J. Young, the Rev. Boog Watson, and others have felt the same difficulty in understanding the formation of Boulder-clay underneath land-ice, and have suggested an explanation which is substantially the same as that above offered.¹

If, for instance, this subsidence took place before the climax of the Glacial period, and the ice continued to increase in thickness, a pause in the downward movement would enable it to exercise pressure and erosion on the material which had accumulated beneath it. Nay, it is conceivable that the partial flotation of the Scandinavian ice-sheet might enable this to cross the great plain of the North Sea and to impinge upon the edge of the Scottish ice-sheet, as Dr. Croll has suggested that it did (without any such assistance). The increased pressure so caused, and the different direction given to the movement of the ice-masses, would then explain the existence of two distinct lines of glaciation in Aberdeenshire, a point to which Professor J. Geikie gives far too little attention. Probably all the phenomena of the Glacial deposits of Scotland could be explained more satisfactorily on the hypothesis of one subsidence, and a subsequent upheaval during the prevalence of glacial conditions, than on that proposed by the author of "The Great Ice Age," for he admits a submergence in late Glacial times which depressed the country at least 500 feet, and probably from the evidence in England and Wales to a much greater extent.

¹ "Geol. Mag.," 1878, p. 162, and "Trans. Roy. Soc. Edin.," vol. xxiii. p. 539.

I do not propose, however, to venture on any detailed application of the hypothesis, but only to note that when the land had risen again to within 100 feet of its present level in Scotland, there seems to have been a pause, during which the latest marine beds containing Arctic shells were formed, while glaciers still occupied the Highland valleys. Lastly, it may be observed that the action of these last glaciers has hardly been sufficiently studied. Mr. Jamieson has discussed some of their effects¹ in the way of sweeping out the traces of the marine occupation of the country; but it is not unlikely that the present patchy distribution of Boulder-clay in the higher parts of certain valleys is due to their action, the clay being left where these comparatively feeble glaciers had not sufficient power to remove it. Again, the arrangement of Boulder-clay into "drums," "sow-backs," and similar ridges is more likely to be the work of retreating than of advancing ice.

Mr. J. G. Goodchild has suggested another explanation of the formation of Boulder-clay, which has much to recommend it.² He has evidently felt the difficulty of conceiving the possibility of material accumulating under an *advancing* ice-sheet, and sees that Professor J. Geikie's theory is incapable of explaining either the internal structure or the external configuration of Drift mounds. He relies on the fact that both glacier-ice and polar-ice are always more or less dirty, and on J. D. Forbes' observation that the lower layers of glacier-ice work up toward the surface as the whole moves onward. He naturally infers that the rock detritus does not remain at the bottom of the moving ice, but that the whole mass becomes charged with the products of erosion, both in the form of mud and of stones and boulders. So long as the ice is in-

¹ "Quart. Journ. Geol. Soc.," vol. xxx. p. 320.

² Ibid. vol. xxxi. p. 55; "Geol. Mag.," Dec. 2, vol. i. p. 496, and "Trans. Cumb. and West. Assoc.," 1887, No. xi. p. 111.

creasing and advancing he does not think any Boulder-clay would be formed, but when it ceased to move and began to melt, the load which it carried would be gradually deposited, and most of it would eventually settle down on the surface over which the ice came to rest. Melting would go on over both the lower and the upper surfaces of the ice, which, though ceasing to glacialize, would still exercise great vertical pressure, compacting the material thawed out of its lower layers into Boulder-clay, except here and there where this might undergo a rearrangement by sub-glacial streams.

Mr. Goodchild only applies this hypothesis to the Drifts of mountain districts, and does not seem to have considered what might take place in those areas where the ice had usurped the place of the sea. Indeed, he is needlessly sceptical about the submergence which even the most extreme glacialists are prepared to admit; but it would probably repay anyone who was studying an area where marine Drifts abutted against a mountain district to consider whether some modification of Mr. Goodchild's hypothesis would not explain the intercalation of marine sands and shelly Boulder-clays.

With regard to the Glacial deposits of England and Ireland, the hypothesis which assumes that the Boulder-clays were laid down on an actual land surface is still more inapplicable than in the case of Scotland. The proofs of the presence of sea-water are much more apparent and universal; the Glacial deposits extend over much broader areas of comparatively low ground, and though a certain kind of succession can be made out in some localities, there is nothing like the definite arrangement of Boulder-clays which Professor J. Geikie has assumed, and which three or four distinct ice-sheets ought certainly to have produced.

To commence with the oldest or Cromer Drifts, the

following are points which call for explanation: (1) that the lowest Boulder-clays are not persistent sheets, but are lenticular beds seldom more than ten feet thick, and separated by laminated and ripple-marked sands and clays, and these beds are broken off and worked up into contortions of the overlying beds to the northward of Trimmingham; (2) that the Contorted Drift contains the spoils of a sea-bottom, together with boulders which probably came from Scandinavia, while the upper Chalky clay does not; (3) that the inland sands and gravels often include irregular and contorted masses of Boulder-clay similar to the Chalky clay which overlies them, and also contain broken marine shells; (4) that the upper Boulder-clay contains Lower Cretaceous and Jurassic detritus, the quantity of which increases north-westward, a fact which proves the ice which formed it to have come chiefly from that direction.

Passing to the later Glacial deposits described on pp. 267 and 268, it may be remarked that the abolition of the old classification of these beds deprives the author of "Pre-historic Europe" of the basis on which he constructed his account of the conditions which prevailed during the formation of the Purple and Hesse Clays (op. cit., pp. 266, 267), and adds force to the objections which have already been urged against his theory of the formation of Boulder-clays.

The presence of the sea during the period of their formation is still more marked than in the case of the East Anglian Drifts, and the materials of which they consist have all been transported from a greater or less distance, so that they contrast strongly in this respect with the older Chalky Boulder-clay, but whether they were accumulated during the uprise of the land from a previous great submergence, or whether a fresh land surface was first formed and a second submergence took place, cannot yet be deter-

mined, though I have elsewhere recorded facts which seem to favour the latter supposition.¹

I would here remark that though Professor J. Geikie admits the occurrence of a great submergence by which England, Wales, and Ireland were depressed to at least 1,500, and probably to 2,000 feet below the sea-level, yet the deposits which he would refer to the epoch of this grand subsidence are few and physically unimportant. He excludes every Boulder-clay from the category of marine deposits, and explains the absence of thicker and more extensive records of this important episode by the hypothesis that they were swept out and worked up into the Boulder-clays formed by a second great ice-sheet after the country emerged from the sea. He is therefore under the necessity of supposing that the second ice-sheet was nearly as extensive and as massive as the first, a result which he himself appears to consider surprising, as it certainly is. If, however, we admit that the later Boulder-clays were formed *during* the submergence and on the sea-floor, no such necessity arises, and we possess in them, and the shelly sands associated with them, a set of deposits which is more proportionate to the magnitude of the subsidence and the time it must have occupied.

It is remarkable that no Drift with marine shells has been found at similar high levels in Scotland, a fact which seems explicable only on the supposition that the conditions in England and Scotland were essentially different, and that the mass of ice which had previously accumulated over Scotland was so thick as to keep out the sea-water and to prevent its ever rising much above the contour of 500 feet. Professor Geikie himself estimates the thickness of the Scotch ice at more than 2,000 feet, and observes that "to cause such a mass to float, the sea around Scotland

¹ "Quart. Journ. Geol. Soc.," vol. xli. p. 128, and "Geol. Mag.," 1887, p. 147.

would require to become deeper than now by 1,400 or 1,500 feet at the least.”¹ Now if we add the latter depth to the height at which marine shells occur at Chapelhall (526 feet) we obtain a total of over 2,000 feet, which is just the extreme amount of subsidence indicated by the Welsh Drifts.

This consideration appears also capable of explaining what Professor J. Geikie calls an “insuperable objection” to Mr. Mackintosh’s views regarding the dispersal of erratics over England. Many of these erratics have come from Criffel in Galloway, and Professor Geikie thinks it “very strange that there is not a vestige or trace of any such submergence either in the neighbourhood of Criffel itself or in the region to the north of it;”² but if the ice had anything like the thickness he supposes, it is clear that it would never lose hold of Criffel during the subsidence unless it was melted off by a rise of temperature, and the absence of marine shells consequently ceases to be surprising, if indeed it ever was very much to be wondered at.

Admitting, however, that in the present state of knowledge and opinion it is unsafe to attempt any connected account of the physical history of the Great Ice Age in Britain, there are, nevertheless, certain well-ascertained facts upon the interpretation of which nearly everyone is agreed, and these enable us to indicate with tolerable certainty some of the geographical changes which took place during the prevalence of Glacial conditions; changes which were largely concerned in the development of the present geographical outlines and physical features of the British Islands.

It was stated on p. 246 that the slight submergence with

¹ “The Great Ice Age,” second edition, p. 186.

² “The Intercrossing of Erratics in Glacial Deposits” (“Scottish Naturalist,” 1882).

which the Pliocene period seems to have closed was not of long duration, and that it was succeeded by a movement of upward tendency. One proof of this is the occurrence of a peculiar bed containing Arctic plants and animals and small land-shells between the *Leda myalis* bed and the lowest Boulder-clay of the Norfolk coast. The fauna and flora of this bed (so far as at present known) are so very different from those of the Forest Bed below,¹ and so much more Arctic in character, that the change in the climatal conditions must have been very great, and could hardly have taken place in a short space of time; it would appear, therefore, that the period of time which elapsed between the formation of the Forest Bed and this Arctic plant Bed was a long one, and that in the course of this unrepresented time the whole of East Anglia, and probably the whole of Britain, was raised far above the level of the sea.

This important conclusion, however, does not rest entirely upon the evidence of the Arctic plant Bed, it is supported by other facts, and especially by a consideration of the buried river-valleys which occur round our northern coasts and the depth to which they were evidently excavated during the interval between the formation of the Pliocene and Pleistocene deposits of Norfolk. The position of the latest Pliocene beds proves that the country at the close of that period was at a rather lower level than it is now, while the depth to which the valleys were cut before they were filled with Boulder-clay proves that the land had at some intervening time stood at a much higher level than it does now. Thus the bottom of the valley formed by the rivers which flowed through the gap in the Chalk escarpment now filled by the Wash (see p. 256) is at Boston 180 feet below the sea-level; the pre-glacial channel of the Tees is 200 feet below the sea, and that of an old

¹ See "Geology of Cromer," Mem. Geol. Survey, by C. Reid, p. 83.

valley opening into the Firth of Forth at Grangemouth is 260 feet below the same level.

It is clear, therefore, that the difference between the level of the late Pliocene and early Pleistocene land surfaces amounted to several hundred feet. This upheaval was doubtless sufficient to restore the land connection between Scotland and Greenland which had been temporarily interrupted during Pliocene times, and the influence of this geographical change in accelerating the rate at which snow and ice were accumulating in our latitudes must have been very great. Changes in the direction of the Arctic currents, and possibly also a deflection of the Gulf Stream (see "Historical Geology," p. 562) were likewise important factors in producing that intensity of Arctic cold and that southerly extension of the Arctic climate which is known as the Glacial Period. For if at the present time Britain were united to Greenland and the Gulf Stream deflected from our shores, so that both our eastern and western coasts were washed by currents from the Arctic regions, it is certain that the climate would return to something very like the conditions of the Glacial Period.

It was probably during this elevation of the British area that the early glaciation of Scotland and northern England was accomplished, and it can hardly be doubted that the agents concerned in this glaciation were confluent glaciers or ice-sheets. The relation of the Boulder-clays to this glaciation is a matter which has already been partially discussed, and as I wish to avoid asserting that all Boulder-clays were formed in the same manner, I will ask the reader to consider that the application of the following remarks is confined to the Glacial deposits of the English lowlands and the borders of the Irish Channel, and more especially to the later portions of these deposits.

The change which led to the formation of these deposits appears to have been a general subsidence by which the

outer parts of the great ice-sheets which had accumulated over Scandinavia, Scotland, the Lake District, Wales, and parts of Ireland, were brought within the reach of the waves. As successive tracts of land and ice were carried beneath the level of the sea, the ice would be broken up into large floes and bergs, which, mingled with others brought from the Arctic regions by the northern currents, would form powerful agents of corrasion, propulsion, and compression of material on any shores against which they might be driven.

During this phase of the period the material which had previously been swept by glaciers out of the mountain valleys on to lower ground would come under the action of coast-ice and marine currents; by these agencies it would be re-arranged, much of it kneaded up into Boulder-clay and spread out as wide sheets of that material, while other portions were sorted into beds of loam, sand, and gravel. It was probably by the action of coast-ice on subsiding tracts of land that stones and boulders derived from sites at comparatively low levels were carried up to the positions where they are now found.

It was at this time, too, and by the ordinary action of waves on an exposed coast-line, that so much of Yorkshire and Lincolnshire was destroyed, that the bay of the Wash was formed, and a line of cliffs carved out of the eastern side of the Chalk Wolds of Lincolnshire; cliffs that were afterwards battered into slopes by the impact of ice-floes, and finally buried under the accumulation of Boulder-clay which now conceals them.

The opponents of the formation of Boulder-clays by marine ice have often asked the upholders of that view to point to the occurrence of deposits containing perfect and undisturbed marine shells in association with Boulder-clay. It is of course very seldom that such deposits would be preserved, but the fossiliferous loams of North Lincolnshire

are, I believe, calculated to satisfy these requirements. As the land sank lower and lower, such deposits were carried farther and farther over its surface, and their accumulation only ceased when Britain was reduced to a group of islands, the high-level shelly gravels being probably nearly the last deposits formed during the great subsidence, and possibly these were formed after it had reached its maximum extent.

Mr. Mackintosh thinks that the water-worn character of the pebbles in the high-level gravels of Wales, as contrasted with the angular character of the blocks at lower levels, indicates a decrease in the rate of submergence, and says, "at this period the district was probably in the condition of a littoral zone, which may have lasted for a time sufficient to enable the waves to round the stones, and to allow the mollusca to multiply in the littoral and sublittoral zones."¹ The occurrence of such shelly gravels at about the same level in Ireland, Wales, and at Macclesfield Forest confirms this idea of Britain having remained stationary for some time when the sea was at this level. It must be remembered, too, that the submergence of the land would partially ameliorate the severity of the climate and enable some mollusca of less Arctic habit to live in the sea which then covered our islands.

From the icy sea by which it was submerged Britain gradually rose again, and as the mountains rose higher and higher above the water they were again covered by ice and snow, but these did not accumulate to anything like their previous thickness, because the conditions which had caused the Glacial episode in the northern hemisphere were now passing away. Snowfields, however, formed on the hills of Scotland, Ireland, Cumberland, and Wales, generating local glaciers, which have left small moraines to mark the

¹ "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 362.

limits of their descent. The lower ground, when it rose above the sea, appears to have been quite free from permanent snow, and was tenanted by the numerous animals which have left their bones in the caves and the river-gravels.

The rainfall, however, was probably greater than it is now, and the country being covered with an almost universal mantle of Boulder-clay, no large tracts of pervious rock were then exposed, such as now absorb a portion of the rainfall; consequently, nearly all the rain was shed off the land in the shape of running water, all the streams and rivers were larger and swifter than they are at present, and the process of valley erosion was thus carried on at a rapid rate.

Since the Glacial deposits to a great extent draped the pre-glacial surface of the country without completely filling up the pre-existent valleys, the streams were naturally directed into the same depressions; but the channel which each began to carve out of the Glacial Beds did not everywhere coincide with that of the river which occupied the valley in pre-glacial times, so that in many cases we have a post-glacial valley system superimposed upon an antecedent one, as in the case of the Mersey and of many rivers in Scotland ("Physical Geology," p. 61). Cases also occur where the older valleys have been so blocked up by Glacial deposits at certain points that the post-glacial streams were ponded back, and have made new channels for themselves through the country between the older valleys; interesting instances of this occur in Lincolnshire.¹

It is not certain, however, that there was only one epoch of submergence during the continuance of glacial conditions, and there are reasons for thinking that there were two such epochs. Again, it is possible that the upheaval

¹ See "Quart. Journ. Geol. Soc.," vol. xl. p. 160.

which followed the deepest submergence was not of uniform extent, and that southern England was raised above the sea, while large parts of northern Britain were still below it, and while Boulder-clays were still being accumulated over them. Those who take this view would probably regard the plateau gravels as deposits formed by snow-fed torrents during this period of elevation. Certainly the phenomena of the river-gravels of this part of England are such as to make it probable that it has never been overwhelmed either by water or ice since an early date in Pleistocene time.

Without therefore attempting to fix the exact relative dates of the surface deposits of northern and southern England, the inferences to be deduced from a study of the latter region may be put in the form of three propositions.

(1) That at some period after the greater submergence southern England and Ireland were raised to a much higher level than their present position above the sea, and Britain was united to France.

(2) That this was followed by a gradual subsidence which, assisted by the action of the sea, was eventually sufficient to disunite England from Ireland and from the Continent.

(3) That the present geography of Britain was produced by a differential movement, England continuing to sink, while Scotland was raised to its present level.

To the first of these conclusions, that England formed part of the European continent and Ireland was united to England, and probably also to Scotland, we are led by three distinct lines of evidence, viz., (1) the existence of the mammalian fauna which is known as that of the older cave-earths and river-gravels (later Pleistocene of Professor Dawkins) over the greater part of England and in the south of Ireland; (2) the position of the older river-gravels in the valleys, and their abrupt termination near the mouths of

the present rivers; (3) the occurrence of mammalian remains on the bed of the North Sea, and especially on the Dogger Bank.

In the first place, it is certain that when Palæolithic man and the animals which are associated with his remains invaded Britain, the rigour of the Ice Age must have passed away, and the climate of the southern portion of the country must have been mild enough for the growth of an abundant vegetation; the country must, in fact, have been in a condition to support large herds of herbivorous animals.

To enable terrestrial animals to cross freely from France and Belgium to England, the elevation required would not be more than 25 fathoms (150 feet); but the central part of the Irish Sea and St. George's Channel is everywhere more than 50 fathoms deep, except over a small area opposite Cardigan Bay, where the deepest parts are between 40 and 50 fathoms. It would therefore require an elevation of at least 50 fathoms (about 300 feet) to unite Ireland with Wales. Even then long and deep lakes would remain in the bed of the Irish Sea, for there is a tract extending from off the west coast of Carnarvon to the Sound of Jura, where the soundings are continuously over 50 fathoms, and generally over 60, so that if the elevation reached the latter figure these lakes and their excurrent river would form a definite line of separation between Great Britain and Ireland.¹

It might be supposed that the formation of the Straits of Dover and of St. George's Channel was effected by marine erosion rather than by subsidence, and that the present depth of these channels could not be taken as affording any measure of the elevation of the land previous to their formation; so that in order to restore the condi-

¹ J. Geikie in "The Great Ice Age," second edition, p. 294, and map. See also "Prehistoric Europe," by the same author.

tions of the time when the countries were united it would only be necessary to imagine the replacement of material cut away by the sea. But if the whole displacement were due to marine erosion, we should expect the minimum depth of the two channels to be approximately the same, whereas the actual difference is very great, being no less than 120 feet. Again, we know that subsidence has actually taken place, and it is more reasonable to suppose that it was this movement which carried the sea over the greater part of the submerged area, only the final breach being directly accomplished by the waves. The vertical displacement so effected would be small, and we may, I think, fairly regard the present depth of the channels as indicating the relative levels of the connecting isthmuses, unless it can be shown that the submergence was not of uniform extent.

To account, therefore, for the dispersion of these large extinct quadrupeds we must suppose that at one time the whole of Britain stood at least 300 feet higher than it does now, so that they could make their way westwards along the bed of the Bristol Channel to the south of Ireland.

From the river-gravels we cannot learn much as to the absolute elevation of the land, but their abrupt terminations prove that the rivers had far longer courses than they have now. Thus in the case of the Thames the height of the old gravels above the present estuary (over 100 feet at Dartford Heath), and the entire absence of estuarine shells in them, prove that the course of the ancient river was continued far beyond its present mouth.

The Dogger Bank affords more precise evidence. This bank may be described as a submerged island in the middle of the southern part of the North Sea; its border is about 75 miles E.N.E. of Flamborough Head, and that part of its surface which rises to within a depth of 10 fathoms is

no less than 250 square nautical miles in extent; a still larger area is within the 15-fathom line, while it is separated from England by a channel which is from 27 to 40 fathoms deep.¹ From this bank many hundred specimens of bones, teeth, and antlers have been dredged up, belonging to the mammoth, woolly rhinoceros, horse, bison, urus, reindeer, Irish elk, stag, hyæna, bear, wolf, and beaver.²

Professor Dawkins points out that they cannot have been carried there by sea currents, and thinks that the carcasses were "collected in the eddies of a river that helped to form the Dogger Bank." It is difficult, however, to see how a river could form so large a bank, though it may be credited with having formed the adjoining channel or valley. Mr. J. Murray was of opinion that the channel, and the deep water generally round the bank, were due to the circulation of the tidal currents, and that the bank itself had resulted from the heaping up of materials in the centre of the circulating water. The occurrence of so many osseous remains on the bank is, however, against the view that it has been heaped up in this manner, and it is just as probable that the pre-existence of the bank and the channels was the cause of the present circulation of the water.

The bank is in fact a submerged plateau, which before submergence appears to have supported large tracts of sands and gravels deposited by the rivers which had coursed over its surface, these tracts doubtless forming patches and ridges similar in their mode of occurrence to those that exist in the eastern counties at the present time.³ The Dogger Bank is not the only spot in the bed of the

¹ See J. Murray, "On the North Sea, Proc. Inst. Civ. Eng.," vol. xx, p. 320.

² Boyd Dawkins, "Early Man in Britain," p. 149.

³ Mr. H. B. Woodward takes the same view; see "Geology of England and Wales," second edition, p. 516.

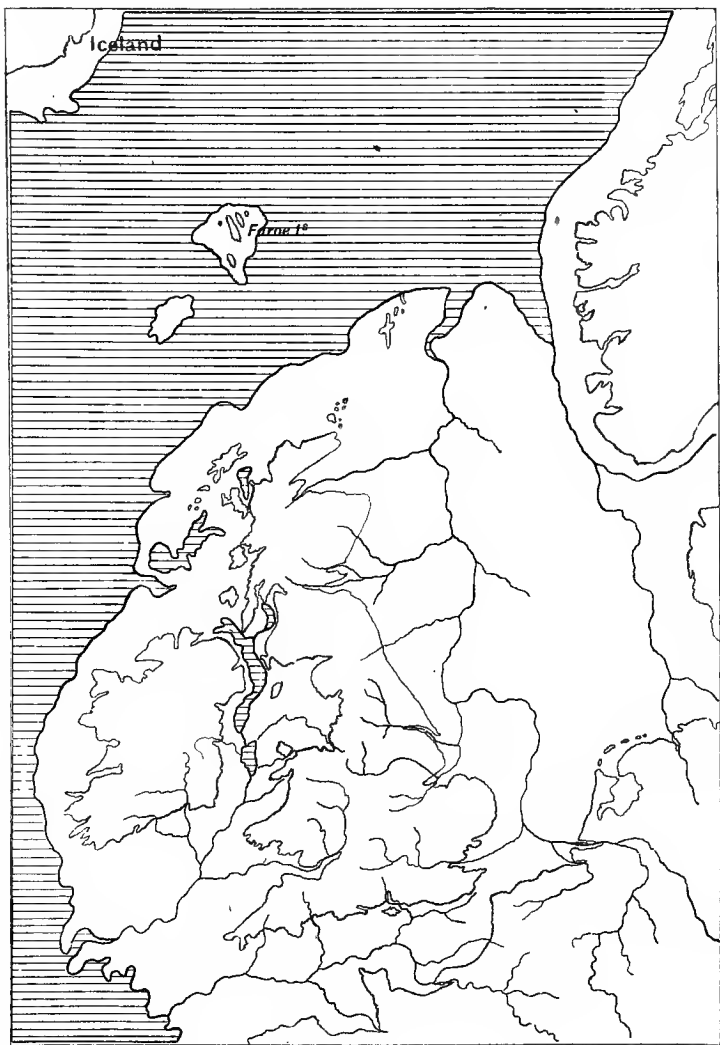


PLATE XIV. GEOGRAPHY OF THE EPOCH IN PLEISTOCENE TIME, WHEN THE COAST-LINE COINCIDED WITH THE CONTOUR OF 80 FATHOMS.

North Sea where bones have been dredged, but Pleistocene remains are not so abundant elsewhere.

An elevation of the bed and borders of the North Sea to the extent of 40 fathoms (240 feet) would now convert the Dogger Bank and all the surrounding parts of the sea-bed into land. The Rhine would make its way through the upraised country, and the rivers of eastern England would at once become its tributaries. A subsequent submergence of 20 fathoms would convert the Dogger into an island round which the currents would circulate as they do now, and it is probably to this isolation of the plateau that the preservation of the ossiferous gravels is due; sandbanks and beaches would be formed round its shores as it gradually sank, and though the gravels would be re-distributed, the larger stones, teeth, and bones would not be destroyed, but would be scattered over the submerged surfaces. It is indeed possible that some of the remains are those of animals which were left on the island at the time of its separation from the Continent, and were alive when the final and complete submergence took place.

By the phenomena of the Dogger Bank, therefore, we are led to look back to a time when it was neither a bank nor an island, but a portion of western Europe, its southern and western sides being washed by the waters of a large river, which drained a large region to the south of the bank and flowed northwards along what is now the deeper part of the North Sea. In point of fact, a consideration of all the evidence brings us to the conclusion that the North Sea had then no existence, and that the western coast-line of Europe ran outside our islands somewhere between the contour-lines of 40 and 100 fathoms. It was the opinion of Godwin-Austen, De la Beche, Lyell, and nearly all subsequent writers, that the 100-fathom contour should be taken as the coast-line of this period, but there is no proof that the elevation was quite so great, and in

Plate XIV. I have taken the line of 80 fathoms (480 feet) as the extreme limit, though it does not make much difference with respect to the extent of the land which line is taken. As stated already, the river flowing through the North Sea was the Rhine, the Thames, Ouse, and all other British rivers which now flow into that sea being its tributaries.

The English Channel was a wide valley through which the united waters of the Seine and Somme, with many tributaries from southern England, ran westward to the Atlantic. The Bristol Channel was a similar valley watered by a continuation of the river Severn, and opening westward on to a vast plain which lay to the south of Ireland. Thus Professor Dawkins, alluding to a cave on Caldy Island off the coast of South Wales, in which numerous remains of large mammalia have been found, remarks, "It may, therefore, be reasonably concluded that when they perished in the fissures Caldy was not an island, but a precipitous hill overlooking the broad valley now occupied by the Bristol Channel, but then affording abundant pasture. We must, therefore, picture to ourselves a fertile plain occupying the whole of the Bristol Channel, and supporting herds of reindeer, horses, and bisons, many elephants and rhinoceroses, and now and then being traversed by a stray hippopotamus, which would afford abundant prey to the lions, bears, and hyænas inhabiting all the accessible caves, as well as to their great enemy and destroyer—Man."

St. George's Channel and the Irish Sea formed another large area of low-lying ground, the centre of which, as already mentioned, was occupied by a long but comparatively narrow lake; this lake received the waters of all the rivers which drained the surrounding parts of Ireland, Wales, England, and Scotland, and the Admiralty charts show that the excurrent river ran from its southern

extremity and joined that which traversed the Bristol Channel.¹

The great lake in the Irish Sea was not the only one which existed on the great tracts of undulating ground which surrounded the more hilly districts of Great Britain and Ireland. Many other lakes existed off the west coast of Scotland, the sites of these being indicated by the areas of deeper soundings.² Others appear to have existed in the English Channel and in the bed of the North Sea, but some of these are probably portions of the ancient river valleys, and are now hollows because of the unequal distribution of detritus over the sea-floor, or because they are exposed to the scour of currents.

How long the land remained at such a high level we cannot say, but there are reasons for thinking that physical changes of considerable magnitude occurred in the northern districts, while little change took place in the physical condition of southern England; the record of these changes, however, has not yet been satisfactorily deciphered. The union of Ireland to England and of England to France and Belgium seems to have continued throughout the later Pleistocene period; it lasted long enough for Palæolithic man to be supplanted by Neolithic man, and for a large number of mammalia to become extinct.

There is, however, good reason to believe that during the immigration of the existing fauna into Britain a gradual subsidence of the whole region was taking place,

¹ In the map given by Professor B. Dawkins ("Early Man in Britain," p. 150) the Irish Sea is made by some oversight to drain northward instead of southward; but an inspection of the reduced Hydrographic Chart of the British Isles shows that there is a continuous ridge between Mull and Malin Head where the soundings are under 40 fathoms, and which must have formed a watershed under the conditions assumed.

² See map in J. Geikie's "Great Ice Age," and chap. xxiv., second edition.

and that by this subsidence Ireland was first of all separated from England, and then a little later on England was severed from the Continent. This gradual severance before the complete establishment of the European fauna in our islands seems to be indicated by the peculiar distribution of species, and especially of the mammals and reptiles, at the present time. This was first pointed out by Professor E. Forbes, and has been more fully investigated by Mr. A. R. Wallace,¹ who gives the following figures:—

Germany	has	90	species	of	Mammalia.
Britain	„	40	„	„	„
Ireland	„	22	„	„	„
Belgium	has	22	species	of	Reptilia and Amphibia.
Britain	„	13	„	„	„
Ireland	„	4	„	„	„

We must suppose, therefore, that the land did not remain very long at the elevation shown in Plate XIV., and that the connection between England and Ireland was soon reduced to the condition of an isthmus, which was submerged before more than four out of the twenty-two continental species of reptiles had crossed in sufficient numbers to effect a permanent settlement in Ireland. Measured in number of years the time taken to effect this may have been long, but geologically speaking it was short. Ireland then became an island, while England still remained a part of the Continent, and there was doubtless a time when the line of 40 fathoms formed the coast-line of Britain, and when the geography was such as is represented in Plate XV., which shows the area that would be converted into land by an upheaval of 40 fathoms (240 feet) at the present time.

The coincidence of the coast-line with the 40-fathom line was, however, only an epoch in the history of the

¹ "Island Life," p. 319 *et seq.*

subsidence; the downward movement continued, and the area of land was gradually reduced, the sea advanced further and further up the valley of the English Channel and over the plain of the North Sea, till at length the plateau of the Dogger Bank was converted into an island, and the waters met across the watershed which we now call the Straits of Dover. As above mentioned, we may infer that the final separation of England and France took place before all the wild animals which now exist in Europe had reached the western coasts of that continent, or at any rate before they had occupied the British area in such numbers as to become permanent colonists.

It was probably to this subsidence, and the changes of geography and climate which it brought about, that the extinction of the mammoth and its associates was due. It must be remembered that the fauna associated with Neolithic man is a direct continuation of the fauna of Palæolithic time, the differences consisting only in the absence of certain species (by extinction or migration) and in the presence of certain domesticated animals introduced by man.

We now come to the phenomena of buried forests, and to the consideration of the final movements which brought about the existing relations of sea and land. In the first place, I would deprecate the use of the term "Forest period" in the sense of any special and distinct Post-glacial epoch. Europe was doubtless clothed with forests throughout the Pleistocene period wherever and whenever conditions were suitable for the growth of forest trees; in all probability, too, dense forests flourished in the southern part of England during the time of its occupation by Palæolithic man, and at any rate during the whole period of subsidence which has been described above. The relics of the ancient forests which are now found beneath our bogs and fenlands, and at various levels around our coasts,

can hardly be referred to one and the same period of time ; some are undoubtedly much older than others, and as Professor B. Dawkins has suggested, those which contain remains of the mammoth are probably much older than those which contain the bones and tools of Neolithic man.¹

It is quite possible that some of the submerged forests date back to a time before the severance of England from France, and that Neolithic man made his way dry-shod across the valley of the Channel, but Professor Dawkins believes that he crossed in canoes after the formation of the Straits of Dover. On this point we must wait for further evidence. All the forests of which we have knowledge at present would stand above the sea-level if the land were raised 70 feet, and even allowing for the consideration that such trees would not grow to such dimensions on the sea-coast, it is not necessary to suppose that England was then more than 90 feet (or 15 fathoms) above her present level.

Neither is there any valid reason for supposing that Scotland was then higher and more extensive than it would appear if the sea-level coincided with the contour of 15 fathoms. The latest deposits assigned to the Glacial period are unquestionably marine ; upheaval ensued, but there is no geological evidence to show that Scotland attained any very great elevation before subsidence again ensued. Professor J. Geikie has indeed suggested that this was a second continental period, and has designed a map of Europe in the "Forest period,"² on the assumption that the coast-line north of Scotland coincided approximately with the line of 500 fathoms, and that the Faroe Islands were thus united to Scotland. The chief reason he gives for such an extraordinary elevation of British land at a time so little removed from the present is the

¹ "Early Man in Britain," 1880, p. 255.

² In "Prehistoric Europe."

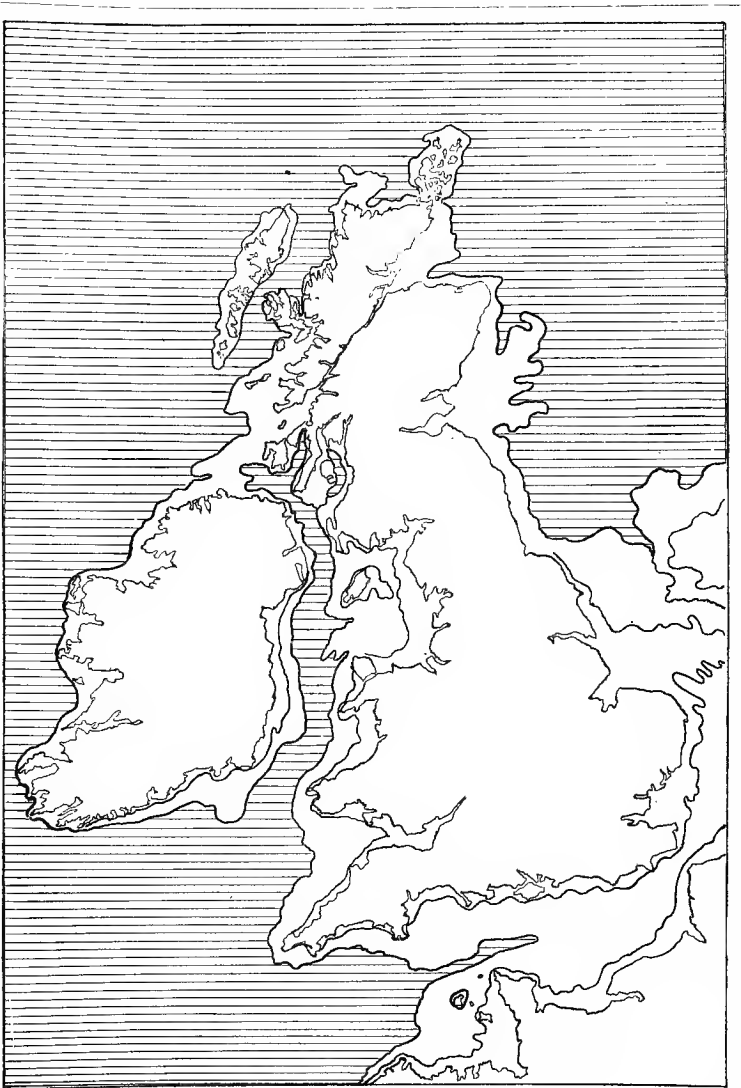


PLATE XV. PLEISTOCENE GEOGRAPHY, COAST-LINE COINCIDING WITH THE
CONTOUR OF 40 FATHOMS.

The inner blue line round England, France, and part of Ireland, is the line of 15 fathoms.

difficulty of understanding how the existing flora of the Faroe Islands, which is of Scandinavian origin, could have reached them without a land connection with northern Europe in Post-glacial times. Mr. A. R. Wallace, however, has shown that the distribution of plants can be effected by other means than those necessary for the distribution of terrestrial animals, and that it is very unsafe to draw inferences from island floras similar to those which may be drawn from their mammalian faunas. His remarks on the flora of the Azores¹ are very convincing, and he concludes with saying that, "we have in such facts as these a complete disproof of the necessity for those great changes of sea and land which are continually appealed to by those who think land connection the only efficient means of accounting for the migration of animals and plants."

The Scandinavian character of the Faroe flora can be explained by other means than the great elevation which would have been required to unite it to Scotland, and we may therefore dismiss Professor Geikie's view of the geography of this period as quite unwarranted by the facts which are known to us. Professor Dawkins stands on safer ground when he assumes that the coast-line during the occupation of Britain by Neolithic man coincided roughly with the 10-fathom contour, but, as already stated, there is good reason for believing that some of the Cornish forests date from a time when the sea did not reach beyond the line of 15 fathoms, and whether the Neolithic invasion took place under these geographical conditions, or at an earlier epoch, it is certain that there was a time when the position of the English and French coasts was approximately that indicated by the inner line on the map, Plate XV.

It is equally clear that in the south of England subsidence

¹ "Island Life," 1880, p. 479.

continued, and that the sea encroached farther and farther on the forest-clad land, the submerged levels being covered with a greater or less thickness of marine clays and sands, while the valleys were converted into estuaries and filled with thick accumulations of alluvial mud. These are the conditions which now exist on our southern and south-eastern shores; everything points to a recent submergence, with pauses during which peat beds were formed, and there is no evidence of any more recent upheaval.¹ Similar phenomena occur as far north as Lancashire and the south of Yorkshire, but are not found much farther north. I am informed by Mr. Hugh Miller that on the east coast north of Durham there is no proof that the valleys have ever been cut to a lower level, since the Glacial period, than their present depth; and when we reach the Forths of the Forth and Clyde the phenomena connected with valley erosion are altogether different. There are buried forests, and they are covered by marine alluvial clays, but the forests seldom run below low-water mark, and the marine clays are now raised high above it, forming wide plains or "carse-lands" from 30 to 45 feet above mean sea-level.

In Scotland, therefore, it is clear that the last movement was one of upheaval, and it would appear that this upheaval was contemporaneous with or later than what we may call the Neolithic subsidence of England, for the Carse-clays contain relics of Neolithic man. If the last movement which our islands have experienced had been similar throughout their extent, England would have had her carse-lands, and the lower tiers of raised beaches which

¹ The raised beaches of Brighton, Selsea, Portland, and the Cornish coasts are generally regarded as much older than the submerged forests. They probably date from the previous elevation (Palæolithic time), and must not be confounded with the 25 and 50-foot terraces of the Scottish coast.

occur on the Scottish shores would have been traceable along the rocky coasts of Wales and Ireland. As a matter of fact, the lowest or 25-foot beach descends to lower and lower levels along the east coast of Ireland, and coincides with the present level of the sea in the neighbourhood of Dublin.

We may therefore conclude that though the buried forests of Scotland grew, like those of England, during a period of subsidence, either this subsidence did not last so long in the former country as it did in England, but was succeeded by a reverse movement while the south of England was still sinking, or else that after the subsidence had affected both countries to the same extent, an upheaval took place in Scotland while the greater part of England and Ireland remained in a stationary condition. It is only on one of these two suppositions that the phenomena of raised beaches and buried forests in England, Scotland, and Ireland can be satisfactorily accounted for.

CHAPTER XIV.

SUMMARY OF THE GEOGRAPHICAL EVOLUTION OF THE BRITISH ISLES.

IN this concluding chapter it is my intention to review the series of geographical mutations which have been described in the preceding pages, to take note of the relative age of the diverse physical districts which make up the British Islands, and to consider how far the geographical restorations which have been attempted can be regarded as consecutive stages in the building and fashioning of that part of north-western Europe which may be called the British region, meaning by this term not only the actual land-tracts which constitute Great Britain, Ireland, and the adjacent islands, but also the narrow seas which separate them from one another and from the continent of Europe.

Geologists can hardly now subscribe to the Huttonian dictum that no traces are to be found of a beginning in the world's economy, but the glimpses which we have obtained into the physical conditions of the earliest Cambrian epoch do not warrant us in attempting any definite delineation of land and sea. Nor is our knowledge of the succeeding Palæozoic periods sufficiently complete to make our reconstructions more than guesses at the truth. Indeed, the geologist who is attempting to restore the geography of any epoch of Palæozoic time may be compared to an archæologist who is examining the ruins of a temple

which is so ancient as to be different from any previously known, and who is endeavouring to restore the ground-plan of the original building from the scanty fragments which remain; he observes a piece of wall here, a corner of masonry there, a broken arch in one place, and a prostrate column in another; he has to consider the probable relations of these remnants to one another, and to evolve a connected whole by imagining the position of the missing parts. So the geologist finds indications of dry land in one place, of deep sea in another, of an island here, and of a long coast-line elsewhere, and he has to piece the puzzle together and to supply the missing connections as best he can with the knowledge at his command.

At present, therefore, the maps of early Palæozoic geographies are only pictorial representations of the ideal views which are suggested to our minds by the inferences obtained from the study of a few small and disconnected areas. This is more particularly the case with the geographical restorations of Cambrian, Ordovician, Silurian, and Devonian times; that of the Carboniferous period does, indeed, stand on a wider and more trustworthy basis, because various circumstances have contributed to put us in possession of a more complete record of this period than we have of those which preceded it, and we did therefore pause to attempt a more detailed reconstruction of the geography of the British region during the formation of the Carboniferous Limestone. We may, perhaps, assume that the restoration given in Plate IV. is so far approximately correct as to show the real connections of the seas and the general outlines of the land areas of the period in question.

We can, at any rate, say that certain districts which form part of modern Britain were also portions of the early Carboniferous land, and that they were then structurally the same as they are now, so that as rock-masses

they may be said to date from this period, or from that of the Upper Old Red Sandstone, which immediately preceded it. The greater part of Wales and Shropshire, with tracts of rock which are now buried beneath newer strata in the counties of Stafford, Warwick, and Leicester, form one such district; the Lake District of Cumberland and Westmoreland is another; the southern uplands of Scotland are a third, and the Scottish Highlands seem to have formed part of a continent which also included certain tracts in the north-west of Ireland. Land appears also to have extended from the borders of Wales across the Irish Sea, and to have included small portions of the eastern sea-board of modern Ireland.

But although we can truly say that the foundations of our islands had been laid at or before the commencement of the Carboniferous period, and though we can point to certain districts which seem to be the worn-down remnants of Carboniferous land-tracts, yet we must remember that this period was a time when there was more land than water where the Atlantic Ocean now rolls, and when the broad platform on which the British Islands now stand did not exist; it is true there was what might be termed a British island, but it lay neither over England, Ireland, or Scotland, the greater part of it occupying the place of the sea which now divides them, while the continent to which this island was subsidiary lay, not to the south and east of it, but to the north and north-west of the British area. Such a state of physical geography is so different from the present order of things, that it would seem rather as if the seas and continents of the Palæozoic world had an evolutionary history of their own which culminated in the geographical conditions of the Carboniferous period, than as if we could treat this period as a phase in the evolution of the existent oceans and continents of the world. But whether such a view is correct or not, we know so little

about the sequence of the great physical changes which ensued in later Carboniferous and in Permian times that we are hardly in a position to take the early Carboniferous geography as the starting point for any connected evolutionary history of the British Islands.

To the Carboniferous succeeded a great transitional period, during which immense geographical changes seem to have taken place throughout the northern hemisphere. In Britain this is represented by two great stratigraphical breaks with an intercalated group of peculiar deposits, and opinion is divided whether the greatest physical changes took place before or after the formation of these Permian or Dyassic deposits. For our present purpose we may regard the whole as one period, and the final pre-Triassic movements may be considered as the culminating effort, as it were, of the disturbing forces which had been set in action at the close of the Carboniferous period, and which seem to have acquired unusual power and energy from the state of tension induced by the long antecedent period of quiet accumulation.

The general result was the formation of a large continental territory over the northern part of the European area, and the platform on which the British Islands stand formed part of this Triassic continent. Not only so, but the regional blocks which form the more salient portions of our islands had already been rough hewn, as it were, and set up in the places which they now occupy to be gradually carved and sculptured during the long Neozoic ages into the forms and features which they now exhibit. The principal hill-ranges of western and northern England, of Ireland, and of Scotland, were then in existence, and bore in most cases the same general relations to the lower ground around them as they do at the present time.

It is true that the east of England bore a very different appearance from its modern aspect, forming as it then did

part of a high rocky and mountainous region which stretched eastward across the area of the North Sea, but the gradual detrition, planation, and burial of this ancient land can be deciphered from the record of the Mesozoic rocks, and does not constitute any difficulty in the way of tracing the geographical evolution of Britain out of that part of the Triassic continent which covered the British area.

It is conceivable that the progress of Geology may enable some future student to restore the features and outlines of the pre-Carboniferous land to the same extent as we can now indicate those of the Triassic continent, and by tracing the series of transformations which took place in late Carboniferous and Permian times to describe the processes which led to the growth of the great continents that existed in the northern hemisphere at the beginning of Neozoic time. But even when this is done the Triassic period will still form a new point of departure whence to follow the series of changes that occupied the long ages of Neozoic time and culminated in the evolution of the modern continents and oceans.

With the Trias, in fact, we reach a stage in the geological history of Europe from which we can start with a reasonable expectation of being able to describe the gradual building up of that Pliocene and Pleistocene continent out of which the British Islands have been carved. Let us, therefore, commence with a brief review of the geography of the British region in Triassic time.

The special features of the early Triassic land were the broad plains and valleys which in the later part of the period were converted into one long and branching lake-basin, and which have left an impression on the physical geography of Britain that has lasted to the present day. The broadest of these plains lay over central England, and was prolonged north-westward on the one hand through

Cheshire and Lancashire across the Irish Sea, and north-eastward on the other hand through Nottingham, Lincoln, and York, far into what is now the bed of the North Sea, while to the southward a basin which seems to have been always more or less filled with water occupied the southern part of England and the central area of the English Channel.

Between the two northern plains, and between the arms of the great lake into which the low ground was subsequently converted, rose the mountain range which is now known as the Pennine chain. This must have lifted its crests and escarpments much higher above the flanking low lands than it does at the present time; we may suppose that in those places where patches of the Lower Coal-measures had escaped destruction and lay over the Millstone grit the hills were nearly 2,000 feet higher than they are now, that being the thickness of the grits and gannister measures which once capped such table-lands as that of the Peak country and Kinder Scout. These hills may, therefore, have risen to heights of between 3,000 and 4,000 feet above the surface of the plains.

Northward then, as now, the Pennine range widened out and was continuous with the Cheviots and the southern uplands of Scotland, the hilly country being penetrated by many deep valleys the lower parts of which afterwards became inlets of the great salt lake. Whether the Scottish lowlands were lowlands then we do not know, but the Highlands were certainly part of a mountainous region in the hollows of which other lakes came eventually to be formed.

To the westward of this central tract of country, with its several lake-basins, lay a vast region of hills and mountains, with possibly other plains and lakes, which stretched westward into the Atlantic at least as far as the present contour-line of 1,000 fathoms. Of this region

Ireland, Wales, and the Ocrynian peninsula are the only remnants, but these territories were doubtless then united to one another, as well as to Brittany on the south and to the Hebridean land on the north.

The country that lay to the south of the British lacustrine area was probably low and flat, though whether in the condition of a *steppe* or of a desert-plain can hardly be decided, though the close proximity of salt lakes makes it probable that most of the surrounding land was either a rocky or sandy desert. To the eastward there appears to have been another tract of high and rocky land separating the lake-basin and the southern plains from those of Germany and Russia; part of this high land lay over the north-east of France, Belgium, and the east of England, with the intervening portion of the North Sea area, but whether it extended northward to the Scandinavian area, or was divided from that by desert plains connecting those round the salt lakes of Germany with the north-eastern end of the British lake, we are unable to say from lack of evidence.

Thus the picture which is presented to our mental view as that of the British region at the close of Triassic time is a dry and arid country, comprising rocky mountains, deep valleys, desert plains and large lakes, the most important sheet of water being apparently as salt, as clear and heavy, and as nearly lifeless, as the modern waters of the Dead Sea or of the Great Salt Lake of Utah.

The next picture in our geological gallery is a very different one, so far as local colouring and general environment are concerned: a magic touch has altered the character of the soil, the humidity of the air, and the salinity of the waters, so that the land supports a luxuriant vegetation, and the waters, now those of an open sea, swarm with creatures of various kinds. But the geographical change which produced such great climatic effects was a com-

paratively small one; it was simply that the subsidence of the land, which probably had been in progress for some time, led at last to the submergence of the French Triassic plains beneath the waters of the Liassic sea, which thus obtained access to the British area and converted the Triassic lake into a gulf of that sea.

So far as we can tell, the geography of Liassic Britain was precisely the same as in Triassic time, except that the site of the great lake was occupied by a sea which opened southward, and probably that the area covered by water was somewhat larger. The position of the land-tracts was not, so far as we know, otherwise altered, but they were probably exposed to more rapid processes of surface disintegration, and the removal of material from higher to lower levels was correspondingly accelerated.

Neither was this geographical arrangement materially altered during the formation of the sands and limestones of the Middle Jurassic series. We find proofs, however, in certain portions of this series that large rivers were in existence and poured large quantities of material into the sea, so as to fill up portions of it and convert them into shallow bays surrounded by tracts of swampy alluvial land. Further, it would appear that subsidence ceased for a time, and that some portions of the sea-bottom were raised while other parts remained stationary, the result of these movements being the formation of several distinct basins separated from one another by submarine ridges like those of the Mediterranean Sea; one of these ridges was a prolongation of the Mendip uplift, and another crossed the central part of England.

The period of the Upper Jurassic clays was one of general and extensive subsidence; there can be little doubt that during their deposition the coast-lines were carried backward and the area of the sea was greatly widened, but how far this recession continued, and how much of the

surrounding land was submerged at the time of greatest depression, are points upon which we must be content to confess our ignorance. The greater part of England was probably submerged, but the submarine ridge which stretched across the central part of the sea still influenced deposition, for only 500 feet of sediment was deposited over it during Upper Jurassic time, while the southern basins received from 1,300 to 2,000 feet, and the northern basin about 1,000 feet of sediment (in Yorkshire). Possibly this unequal distribution of material reacted on the initial cause, and the intervening ridge was kept from sinking to the same extent as the basins on either hand by the pressure arising from the weight of the sediment poured into those basins. However this may have been, it is certain that the whole sea-bed was not levelled up when subsidence ceased and upheaval set in, for it was the central ridge which first became land and formed an isthmus separating the northern and southern gulfs of the Portlandian Sea (see Plate VIII.). The southern gulf being the deepest, this remained in the form of a large lake when the rest of the Jurassic sea-bed was converted into the Purbeck and Wealden land.

The land of early Cretaceous times therefore differed in some important particulars from that of the Trias. The western arm of the Triassic lake and Jurassic sea became a broad and fertile plain which opened south-eastward on to a still wider and probably slightly higher undulating tract of country, the watershed of which stretched across what are now the Midland counties to the eastern tract of Palæozoic rocks, which we may call the eastern uplands. Whether these uplands were originally as lofty as the mountains which lay to the west of the Jurassic sea we have no means of knowing, but it would certainly appear that their comparative elevation in Cretaceous times was very much less than it had previously been. Either the post-Jurassic up-

heaval was greater in the western than in the eastern part of the British region, or the later Cretaceous subsidence was deeper in the eastern area; it is very likely indeed that both movements contributed to the same result, *i.e.* of reducing the whole eastern tract to a lower relative level than it had occupied throughout Jurassic time.

The early Cretaceous subsidence seems to have been fairly equable, and the Vectian sea does not seem to have encroached much on these eastern uplands, though it is probable that the relative levels of the two areas were so far altered that the sea covered a wider tract on the east and a much narrower one on the west than would have been submerged by a depression of the same vertical extent in Jurassic time. In the succeeding epoch this was certainly the case, and we know that the whole of eastern England sank below the waters of the Gault sea, while there is good reason to believe that this sea did not extend to Wales or over the north-west of England. The subsequent subsidence, however, was much more extensive; not only did it bury the remaining portions of the eastern land under a continuous sheet of Chalk, but the western land was converted into an archipelago, and great sheets of chalk and greensand were deposited far beyond the limits of the Jurassic strata over the slopes of the western and northern highlands.

The chief result of these changes therefore, so far as the geographical evolution of Britain is concerned, was the complete suppression and burial of the rocky land which had previously existed over the areas now occupied by the North Sea and the eastern counties of England. This land has never again been uncovered, and its extent has only been gradually revealed to us by the deep borings which have been made in England, France, and Belgium. Its coverings were indeed repeatedly added to in Tertiary times, while erosion was busy over the rest of England.

The evidence on which to found any conclusions as to the aspect of the country when it emerged from the waters of the Cretaceous sea is of the slenderest, but we may assume that England, Scotland, and Ireland were bound together into one mass of land, and that the water-spaces which now separate our islands were then filled up by a greater or less thickness of Jurassic strata, covered and levelled up by wide-spreading sheets of greensand and chalk. The Atlantic sea-board then lay considerably to the west of our islands, re-occupying a line along the submarine slope which now plunges from 100 to 1,000 fathoms. There is good reason to suppose that there were land connections, on the one hand between Scotland and Greenland by way of the Faroes and Iceland, and on the other between Scotland and Scandinavia, thus completely isolating the Arctic Ocean and preventing any influx of cold northern currents into the Atlantic or west European seas. On the south-west also there would appear to have been a continuous tract of land uniting Ireland and Wales with Brittany and the central part of France.

During the progress of the Eocene period the south-east of England came alternately under the influence of an eastern and a southern sea, but the delimitation of these two seas is one of the most difficult problems of Tertiary geography. With the evidence at our command it is impossible to say in which direction the great gulf whose waters covered so much of England and Belgium in the time of the London Clay communicated with the open sea; the probabilities are much against any northward opening; there is no trace of an easterly one, while the deposits of Lower Eocene age seem to thin out and disappear in westerly, southerly, and south-easterly directions. The difficulty is in fact such as to raise a doubt whether the accepted views of the correlation of the French and English Eocenes are altogether correct. During the formation

of the Upper Eocenes (or Nummulitic series) the seas which covered parts of England certainly opened southward into a great southern or Mediterranean sea, whence perhaps we may conclude that the sea of the London Clay had a similar but narrower opening in the same direction.

In Oligocene time the western and southern European seas were greatly contracted, but a shallow northern sea was gradually formed which extended over south-western Russia, Prussia, Holland, and Belgium, but does not appear to have reached quite so far west as England. There was, however, a smaller and possibly isolated sea lying over northern France, and receiving the waters of a large river which drained the western part of the British region and had its estuary over Hampshire and the Isle of Wight.

Even after the early Miocene upheaval, and when subsidence again led to the formation of deposits in France and Belgium, the sea seems to have re-occupied portions of the same basins, for the Miocene and early Pliocene beds occur in similar positions and in the same localities as those of Oligocene age. It is true that the sea of the Diestian Sands spread westward into the east of England, and that the precise limits of this sea are very doubtful, but there is no proof that it had any great northerly extension, or that the belt of land enclosing the Arctic Ocean had as yet been broken through either to the north or east of Scotland.

But while the eastern and southern portions of the British region were receiving here and there fresh accessions of stratified material, a very different process was in operation over the western and northern portions of the same region. There can be little doubt that these districts remained in the condition of dry land throughout the duration of the Eocene, Oligocene, Miocene, and Pliocene periods, and that their surface was profoundly modified by the continued action of rain, frost, and running water.

From the fragments of terrestrial surfaces preserved beneath the Eocene lavas of Ireland and the Western Isles, we know that rivers were actively engaged in carving channels out of the Secondary rocks which surrounded the volcanic district, and that during the course of the Eocene period a large amount of material must have been carried seaward by these streams.

Further, if we may assume that the plateau of Antrim is still approximately in the same position which the whole volcanic district originally occupied with regard to the surrounding country, we may infer that the rest of the plain or plateau over which the lavas were poured has since sunk considerably below this level; we may suppose, in fact, that when the volcanic activity finally ceased, large parts of the area began to sink inwards, the subsidence being greatest to the west of Scotland. This conclusion is confirmed by the actual proofs of inward subsidence round the volcano of Mull, as observed by Professor Judd, by the inclined position of the lavas of Skye and Raasay, and by the existence of powerful post-Eocene faults which have dropped portions of the volcanic masses below their original level.¹ To this local subsidence we may attribute the great depression which is now filled by the waters of the Minch and the Sea of the Hebrides, large parts of which are deeper than the outer plateau on which the Hebrides stand, and would form extensive lakes if the whole region were raised to the extent of 500 or 600 feet.

We have no further record of the progress of the great denudation which was continued uninterruptedly through Eocene, Oligocene, Miocene, and older Pliocene times, but we know that it resulted in the removal of all the Cretaceous and Jurassic rocks (except the few remnants which survive), together with large portions of the Trias from

¹ "Quart. Journ. Geol. Soc.," vol. xxx. p. 257, and vol. xxxiv. pp. 673, 674.

the west of Scotland and from the area of the Irish Sea, as well as from the north-western counties of England. Portions of the older Neozoic rocks were doubtless removed during the earlier part of the Cretaceous period, but the greater part of the work was doubtless accomplished in Tertiary times.

With regard to the formation of St. George's Channel between Wales and Ireland we have very little evidence to guide us, but it may have originated in a minor valley like that of the Clwyd in North Wales opening northward into the basin or plain of the Irish Sea. All the probabilities and analogies of the case lead us to conclude that its origin was post-Carboniferous and pre-Cretaceous, and that Wales was completely isolated during the great Cretaceous subsidence. We may therefore assume with much reason that a chalk-filled channel (narrower of course than the present one) existed at the beginning of the Eocene period, and that during the course of the ensuing epochs it was re-excavated by subaerial agencies and widened to nearly its present dimensions.

In the south of England also great changes were in progress during the interval between Eocene and Pliocene times; the curvature of the London and Hampshire basins was completed, and the intervening Wealden axis was largely denuded of its original coverings, receiving its final planation from the waves of the older Pliocene sea. Thence it emerged to form a tract of elevated land 600 or 700 feet above the sea-level of newer Pliocene time, and stretching continuously across the Straits of Dover through the north of France to the region of the Ardennes.

We now arrive at another important epoch in the development of British geography, the time which is indicated by the break between the older and newer Pliocene deposits, and during which the movements that led to the formation of the North Sea basin appear to have taken

place. These movements, so far as we can judge, produced the geographical conditions represented in Plate XIII., Britain then forming a broad and roughly triangular promontory based on the northern part of France and ending northwards beyond the Shetland Isles. The western coastline lay probably between the contours of 200 and 300 fathoms, at any rate off the north-western coast, so that the isthmus between Scotland and the Faroe Isles was completely submerged. The eastern coast, however, along the western border of the newly-formed North Sea, approximated closely to the outline it now presents.

Before the close of the period, indeed, the agencies which had been busily and continuously engaged throughout the whole of antecedent Tertiary time in modelling and carving the surface of the British region, had almost completed their task. All the principal physical features of our islands had then been developed, and the general aspect of Britain in later Pliocene time can hardly have differed very much from that of modern Britain, except that it stood bodily higher above the level of the ocean, so that the seas and channels which now separate our islands from one another and from France were then in the condition of fertile plains and valleys. In minor details there was of course a considerable difference; the North Downs, and probably also the South Downs, were continuous across what is now the head of the English Channel, and the surface features of the country, in the absence of the superficial clays and gravels which now cover such large areas, must necessarily have had a different aspect.

The Pliocene surface had of course its terrestrial and fluviatile deposits; the long-continued action of wind, frost, rain, and rivers must have resulted in the formation of long slopes of débris among the hills, of thick deposits of sand and gravel in the valleys, of deep beds of clay and marl in the lake-basins, and in the production of a thick

mantle of soil over other parts of the land. Such was the state of Britain at the beginning of that remarkable episode which is known as the Glacial Period; when snow began to accumulate on the mountains and to form glaciers which crept farther and farther down the valleys. By these advancing ice-ploughs the higher parts of the country were swept clean of all surface accumulations, the materials being carried down to lower levels and ultimately worked up into the Glacial Boulder-clays, gravels, and loams.

The uncertainty which exists with regard to the real succession, and to the precise mode of formation of these Glacial deposits, makes it unsafe to attempt a geographical restoration of any of the several phases of the Glacial epoch. It would be easy to follow Professor J. Geikie and Professor Hull, and to give a pictorial representation of a huge ice-sheet covering nearly the whole of Britain and Ireland, but the accuracy of such a picture depends on the assumption that every district where ice-marks and Boulder-clays occur was simultaneously covered by one continuous mass of ice.

There are, however, indisputable proofs that the whole country sank from a position of considerable height above the sea to one of 1,800 or 2,000 feet below its present level, and it has been thought that these conditions could be represented by a map showing the archipelago of islands that would remain above water if the British Isles were now submerged to that extent. But to omit ice from such a map is to omit one of its most important features, for there is good reason to suppose that the extent and thickness of the Scottish ice was such as to keep the sea from ever being in contact with Scottish ground above a level of 550 feet, so that the greater part of Scotland was practically unsubmerged when the contour of 2,000 feet was the coast-line of Wales.

Leaving these problems for future solution, we must pass to the time when the rigour of the Ice Age had moderated, and when the British region had emerged from the Glacial sea; when the land-ice had retreated to the mountain-valleys, and had left the lowlands free of ice and snow, though covered with the thick mantle of Boulder-clay and gravel which was the gift of the Glacial period. The movement of upheaval continued till Britain again stood high above the sea and was united to the Continent across the valley of the English Channel and the plains of the North Sea.

This phase of Pleistocene geography is represented in Plate XIV., and on comparing it with that of the Pliocene in Plate XIII. it will be observed that the chief difference is in the relative level of the floor of the North Sea. In Pliocene times this area was below the sea-level, though the general level of the land was higher than in the later period; but the cause of this difference is probably to be found in the large quantities of detritus which must have been carried into this sea by the Scottish and Scandinavian ice, and which must have buried the Pliocene sea-bed under several hundred feet of ice-borne material. A recent boring at Utrecht has proved that the surface of the Pliocene deposits is more than 500 feet below that part of Holland, and, as the Pliocene sea probably deepened northward, it is therefore hardly too much to assume that the same surface lies some 100 fathoms below the present bed of the North Sea between Norway and Britain, and consequently that the upheaval necessary to convert this sea into land after the Glacial Period was 100 fathoms less than would have been required to effect the same result in later Pliocene time.

The sea-beds on the western side of England and Scotland were doubtless shallowed in a similar manner, and even on higher ground many of the Pliocene valleys were

completely masked and buried beneath the Glacial detritus, so that the Pleistocene rivers were compelled to make fresh channels for themselves, and it was not therefore till this time that our present river-system was perfected. So long as the British coast-line lay near the contour of 80 fathoms our modern streams were but tributaries of the three great rivers which ran outside the present limits of Great Britain, that to the east being a continuation of the Rhine, that to the south a prolongation of the Seine, and that to the west a river to which no modern name could be applied, but of which all the rivers of western England, southern and eastern Ireland, were the tributaries.

It was not long, however, before a reverse movement set in, and subsidence caused a rapid recession of the coast-line; the North Sea crept southward over the plains between England and Holland, while the Atlantic crept round Ireland and up the valley of the English Channel till only a narrow isthmus separated England from France. The Straits of Dover doubtless mark the position of the lowest part of the watershed between the river-systems of the Rhine and the Seine during the progress of this subsidence. It is not unlikely that the actual straits are the site of a valley formed by a river which ran northward, nearer France than England, and cut through the northern escarpment of the Chalk, as the Stour and Medway do at the present day; while a second stream ran south-westward, nearer the British coast, and cut through the continuation of the South Downs east of Beachy Head. The watershed between these two rivers is possibly marked by the line of sandbanks which runs southward from the Varne Bank and Colbart Ridge; it would at any rate be of no great elevation, and probably consisted of Weald clay, like that between the rivers Wey and Arun at the western end of the Wealden district. Subsidence under

these circumstances would enable the sea to creep up the valleys of the two rivers, and eventually to submerge part of the low watershed between them; waves and currents would soon widen the breach, and have continued to widen it from that time to the present day.

Thus was Britain finally separated from the Continent to which it had been united throughout the greater part of Tertiary time, and thus was the geographical evolution of the British Isles at length accomplished; for though certain minor changes took place after the formation of the Straits of Dover, yet this severance of England from the Continent gave Britain the geographical position she now holds, and must therefore be regarded as the final act in the long series of operations which conduced to the building and fashioning of the British Isles.

Under the combined effect of subsidence and marine erosion the British coast-lines continued to recede after the formation of the Straits of Dover, but when after a time the subsidence ceased, recession proceeded at a much slower rate, and only along those shores which were exposed to the direct action of currents, while the loss so caused was partially counterbalanced by the silting up of bays and estuaries. In Scotland, moreover, a vertical upheaval of nearly 50 feet resulted in an important accession of land. The present outline of the British coast is therefore the outcome of all these minor operations, the balance of gain and loss being apparently very nearly equal in the case of Scotland, but decidedly on the side of loss in the south of England.

Minor geographical changes are even now in progress, and there is no reason to suppose that the present arrangement of land and sea is the final geographical condition of Europe, or that the British Islands will never again be subjected to movements of upheaval and depression like those which they have experienced in the past. It is very

probable, however, that the period in which we are now living is one of those quiescent times which, as we have seen, generally succeed periods of rapid movement and disturbance. The earth's crust appears to be in a comparatively fixed and stable condition, and the movements which are known to be in progress are so slight, or rather the rate of change is so slow in relation to the short span of human life, that we may safely rely on the permanency of the present geographical conditions for a very long period of future time.

Professor Prestwich arrives at a similar conclusion from somewhat different premises. He thinks that the great cosmical cold of the Glacial epoch accelerated the contraction of the earth's crust, and that the disturbances consequent upon this contraction were greater during the prevalence of this cold than in the immediately preceding and succeeding ages; that, therefore, "during a certain number of years succeeding to and to be measured by the length of the Glacial period (whether that be 10,000 or 20,000, or any other number of years), the disturbances of the crust would be at a minimum, and its stability at a maximum. This is the condition under which I conceive the crust of the earth is now placed, and which, as I have before suggested, ensures that state of repose and immobility which renders it fit and suitable for the habitation of civilized man."¹

¹ "Geology," by J. Prestwich, vol. ii, p. 549.

CHAPTER XV.

THE THEORY OF THE PERMANENCE OF CONTINENTS AND OCEANS.

IT seems only fitting that a study of the geographical changes of the past, even though it is concerned with no more than a small portion of a continent, should conclude with some expression of opinion regarding the debated question of the permanence or permutation of oceans and continents.

The theory of their permanence, that is to say, the view that the position of the continents was fixed at the beginning of geological time, and that oceans and continents have ever since occupied their present relative positions, was originated by Professor Dana, and has more recently been independently maintained by Dr. A. R. Wallace and Dr. A. Geikie.

The theory of their permutation or interchange was that held by Sir Charles Lyell and other geologists, who regarded the continents and ocean-basins as great upward and downward bendings of the earth's crust, and consequently liable to shift their positions entirely in the course of ages, so that what was once an ocean-bed might become a continent, and *vice versa*.¹

The data on which Professor Dana bases his opinion are entirely hypothetical; it is, in fact, merely an inference—but a necessary and unavoidable inference—from his hypothesis of the manner in which the crust of the earth

¹ "Principles of Geology," eleventh edition, vol. i. p. 258.

originally solidified; and this inference must of course be accepted or rejected, according as physicists may decide upon the probability or improbability of the hypothesis upon which it depends. Now this hypothesis is itself based on the assumption that the earth was originally, and is now, of unlike composition along different radii, or on different sides; the continental portions of the crust, according to Professor Dana, being composed of denser materials than the oceanic.

Mr. W. O. Crosby¹ has ably discussed this question; he points out that this initial assumption is entirely unsupported by evidence, and that even if it were to be admitted, Professor Dana's hypothesis involves so many other uncertainties and improbabilities that it would not be worthy of acceptance unless it was strongly confirmed by geological evidence.

Dr. Wallace takes very different ground, and boldly endeavours to support the theory of permanence by discussing the geological evidence, but he too has been answered by Mr. Crosby (*loc. cit.*), by Mr. G. S. Gardner,² and by Professor Hull.³

Dr. Wallace's chief arguments, as stated in his "Island Life," may be summarized as follows:—

1. That the modern oceanic deposits are different from any that occur among the rocks composing continental land.

2. That the formations which compose our continents are chiefly shore-deposits, and that the constant neighbourhood of land is proved by the frequency of estuarine and lacustrine deposits.

3. That formations of similar constitution and contem-

¹ "Geol. Mag.," Dec. 2, vol. x. (1883), p. 241.

² *Ibid.*, Dec. 2, vol. viii. (1881), p. 241, and Dec. 2, vol. ix. p. 546.

³ "Contributions to the Phys. Hist. of Brit. Isles," chap. iv.

poraneous origin, and more than 150 or 200 miles wide, seldom form part of continental land.

4. That the Chalk, though it is an extensive formation, was formed in comparatively shallow water, the depth of which would have been measured by hundreds and not thousands of fathoms.

5. That no modern oceanic islands, except New Zealand and the Seychelles, contain any Palæozoic or Mesozoic rocks, such as might be expected to occur in remnants of old continental land.

To these arguments it is replied that :—

1. The first statement is to a large extent true ; nothing exactly like either the calcareous ooze or the red clays of the modern ocean-beds has yet been found in the earth's crust. It may be observed, however, that as a matter of fact the limestones formed at one period of the earth's history are seldom of exactly similar composition and aspect to any formed at another period. Further, that the resemblances between European Chalk and modern oceanic ooze are so great that, allowing for a slight original difference in the relative proportion of calcareous matter, and for a certain amount of subsequent change, it must be admitted that the original condition of the Chalk was almost identical with that of the ooze ; and, consequently, that it was an oceanic deposit. This will be further discussed under the fourth head. With regard to the red clay, even if it is true that no such deposit does occur among stratified rocks, this does not really prove more than that the ancient oceans did not possess such abyssal depths as those of the present day ; for the existence of this red clay seems to depend entirely on depth and not on distance from land. The existence of abyssal depths is surely not essential to the idea of an ocean ; a wide expanse of comparatively shallow water (*i.e.* under 1,000 fathoms) would be as correctly called an ocean as a wide expanse of land which

did not anywhere rise to elevations of more than 6,000 feet would be correctly called a continent.

2. As to the second statement, it is perfectly true that the marginal belts of comparatively shallow water which have always surrounded the tracts of continental land have been from the earliest geological times the principal areas of deposition. It would indeed be very surprising if it were otherwise, for most of the materials carried down from any tract of land must come to rest within a certain distance of the shore, and thus geological deposits are *chiefly* shore deposits. Dr. A. Geikie, however, goes farther, and remarks that "the more attentively the stratified rocks of the earth are studied, the more striking becomes the *absence* of any formations among them which can legitimately be considered those of a *deep sea*. They have *all* been deposited in comparatively shallow water."¹ This also is probably true if by comparatively shallow water Dr. Geikie means any depth not exceeding 1,000 fathoms. Compared with the depth of modern ocean-troughs water of only 700 or 800 fathoms is shallow, but it might fairly be called a deep sea; and, as we shall presently see, there is at any rate one formation which was probably formed in a sea of at least that depth.

The absence or rarity of deep-sea deposits is in fact more conspicuous among Palæozoic than Neozoic rocks, but this fact can hardly be taken as evidence of the fixity of oceans and continents; it would be more logical to regard the absence of such deposits as evidence of the absence of oceans, and to suppose that in these early times the relative proportion of land was greater than it is now, or that the arrangement of land and sea was such that neither covered very large spaces of the earth's surface.

3. That Dr. Wallace should seriously argue that "de-

¹ "Geographical Evolution, Proc. Roy. Geograph. Soc.," 1879, p. 426. The italics are mine.

posits uniform in character and more than 150 or 200 miles wide were rarely, *if ever*, formed at the same time" ("Island Life," p. 101), is rather surprising when on a previous page (p. 91) he quotes Sir Charles Lyell's estimate of the range of the Chalk beds of nearly uniform aspect and composition extending from the north of Ireland to the Crimea, a distance of about 1,140 geographical miles, and in an opposite direction from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles.

In point of fact, all that Dr. Wallace succeeds in proving in Chapter VI. of his "Island Life" is that deep-sea deposits are of rare occurrence beneath the soil of modern continents. This, however, is a very different thing from proving a universal negative, which is what he sets himself to do. It only amounts to this, that the conversion of even a comparatively shallow ocean into continental land is a stupendous operation, requiring many geological ages for its accomplishment, and consequently that it has not happened many times in the course of geological history.

4. The argument derivable from the differences between Chalk and oceanic ooze has already been partially refuted, but may now be more fully discussed. In the first place, it is unreasonable to assume that the constituents of deep-sea ooze, and the proportions of these constituents, should have been just the same in the Cretaceous period as they are now; and, in the second place, it has been shown that the differences between the two kinds of material is not so great as Dr. Wallace supposed. It would appear that the relative abundance of pelagic Foraminifera is largely dependent on the temperature of the water, and that they only occur in great abundance where the water is comparatively warm. This was especially remarked by M. Pourtales¹ with regard to the character of the deep-sea deposits

¹ See "Geol. Mag.," vol. viii. 1871, p. 425.

off the eastern and southern coasts of North America, the purely calcareous deposits being confined to the areas warmed by the Gulf Stream; and the fact is confirmed by the observations of Wallich, Carpenter, and Wyville Thomson. Now it is probable that the European Cretaceous sea was considerably warmer than the present Atlantic, and consequently it is not surprising to find a greater relative proportion of calcareous matter in the Chalk.

Again, some beds of Chalk are very largely composed of minute fragments of *Inoceramus* shell; the molluscs which formed these shells must have been very abundant on the floor of the Chalk sea, but they have long been extinct, and no mollusc with a similar shell is found abundantly on modern ocean-beds; consequently this kind of chalk has a special composition, which is apparent under the microscope, and which causes its chemical analysis to differ from that of modern calcareous ooze.

But in spite of these and some other differences there is sufficient resemblance between the analyses of the calcareous ooze and of certain beds of Chalk to make it probable that the original state of the latter was very similar to the present state of the former. In the first place, we must remember that the calcareous ooze still retains its full proportion of disseminated silica, whereas this silica has clearly been abstracted from the greater part of the Chalk, and has been concentrated into the flint nodules. If, therefore, the ooze be compared with that part of the Chalk which contains flints, the soluble silica should be deducted and the proportions of the other ingredients re-calculated.

It should be also observed that in ordinary analyses of the ooze there is a much larger proportion of moisture and organic matter, often entered as "loss on ignition," than in analyses of chalk. If, therefore, this loss and the silica be taken into account, the proportion of carbonate of lime to the remaining ingredients is at once made much larger.

Take, for instance, the analysis of an ooze from the depth of 450 fathoms, which contained 84.27 of carbonate of lime, 2.60 of silica, and 4 per cent. of material lost on ignition; deducting the two latter from the total, we find that 84.27 of 93.40 is equivalent to a fraction over 90 per cent.; and the analysis of this ooze is really much more like Chalk than appears at first sight. Another sample of ooze taken from 1,420 fathoms, and containing only 80.69 of carbonate of lime, really possesses a proportion of 87.70 to the material remaining after the abstraction of the silica and loss on ignition (which amount to 7.94 per cent.). It would, however, be much more satisfactory to compare the ooze with analyses of those portions of the Chalk which still retain a certain amount of the disseminated soluble silica, and are not largely made up of the detritus of *Inoceramus* shells. Such beds are known to occur in the Lower Chalk, but very few analyses have yet been made of them; that, however, of a hard bed in the Lower Chalk of Farnham yielded to Professor Way 2.11 per cent. of soluble silica, and only 85.95 per cent. of carbonate of lime, proportions which approximate closely to those of the same minerals in the ooze from 450 fathoms. It may, therefore, be concluded that the composition of the material which we call chalk was originally analogous to, though not identical with, that of modern oceanic ooze, and consequently that it was formed under similar conditions.

5. The truth of Dr. Wallace's last argument depends much on the definition of an oceanic island, and, moreover, our knowledge is not yet sufficient to justify so sweeping a statement. Many oceanic islands have not yet been geologically examined, but rocks of pre-Tertiary age have certainly been found on some islands which fairly come under this category. Thus New Zealand and the Seychelles Islands are admitted by Dr. Wallace to be exceptions to his assumed rule, but he minimizes the value of New Zea-

land as an instance by doubting whether it can truly be called an oceanic island. To this Mr. Crosby replies that "it is difficult to see how it can be differently classified, since the ocean between it and Australia is one thousand miles broad and three miles deep." He proceeds, moreover, to show that there are other exceptions: Spitzbergen, may fairly be called an oceanic island, as it is more than 400 miles from the nearest part of Europe, but it consists largely of Palæozoic and Mesozoic rocks. The Philippine Islands again are certainly extra-continental, being surrounded on all sides by very deep water, yet rocks of Secondary age occur in them. Lastly, stratified rocks, both of Palæozoic and Mesozoic age, are stated to occur in New Caledonia, which is separated by 700 miles of deep water from the nearest land (Australia). Besides these there are other reported occurrences of pre-Tertiary rocks on oceanic islands which require confirmation.

Finally, Mr. Crosby observes, "the oceanic islands are of course merely the tops of submerged mountains, and it is only with the highest points of the continents that they can be properly compared. Now supposing the existing continents were submerged to a depth of 15,000 feet, what would be the geological character of the land remaining above the sea? Palæozoic and Mesozoic rocks would probably be about as scarce in it as in modern oceanic islands. As a rule the loftiest mountains of the globe are composed of eruptive rocks, and in many cases they are extinct or even active volcanoes; although the main mass of every mountain system is formed of stratified formations."¹ This being so, it is only to be expected that the mountain tops of a submerged continent should generally consist of volcanic rocks, and even these are often covered and concealed by the recent growth of coral-rock.

From the above considerations it is clear that the case

¹ "Geol. Mag.," Dec. 2, vol. x. p. 251.

for the permanence of oceans and continents has by no means been made out, and that when the arguments which have been urged in its favour are carefully examined, none of them are found to be very convincing, and certainly none are unanswerable. A review of the great geographical transformations which the western part of Europe has undergone leads to the conclusion that the present continent, meaning by this any compact mass of land occupying the position of modern Europe, does not date back farther than the beginning of Eocene time, and possibly not beyond Oligocene time. The range of the Eocene Nummulitic limestones proves that the whole of southern Europe, together with large parts of Asia Minor and of Northern Africa, were at that time the site of a fairly deep sea, but it is true that there was a considerable amount of land over the northern part of the European region, and it may therefore be argued that the continent existed, though its limits were then very much circumscribed.

When, however, we go back to the Cretaceous period, it must be admitted that the sea in which the Chalk was deposited had an extent (see p. 328) that fairly entitles it to be called an ocean, and further, that very little land could then have existed over the site of Europe, such portions of northern Europe as were then land belonging in fact to a more northern continent which could not by any reasonable method of nomenclature be identified with modern Europe. We need not, therefore, go farther afield or farther back in time to find evidence for the interchange of an ocean and a continent.

It may readily be admitted that the deeper parts of the existent oceans are of great antiquity, and it is probably not too much to say that they have never been land since an early date in Mesozoic time, but this admission is very different from the assertion that they date their existence from the very beginning of geological history. Such geo-

logical evidence as we possess is certainly in favour of there having been a large area of land on the site of the North Atlantic Ocean during part of Palæozoic time, but how far this land trenched on the deeper parts of the Atlantic we have no means of knowing. I agree, therefore, with Professor Prestwich, who has recently expressed the opinion "that it is only the deeper portions of the great ocean-troughs that can claim the high antiquity which is now advocated for them by many eminent American and English geologists."¹

Stated in general terms, the conclusion at which we have arrived may be expressed as follows:—That while the position of our modern oceans and continents has not been permanent from the earliest geological times, they are nevertheless of very ancient date; and we may infer that the replacement of an ocean by a continent, or *vice versâ*, is a process which has not taken place many times in the history of any one portion of the earth's surface.

To my mind, indeed, the study of the geological evidence suggests an inference which is different from either of the theories which have been discussed. It has already been observed that the absence of anything like deep oceanic deposits among the Palæozoic rocks may be taken as indicative of a great difference in the general relations and proportional areas of land and sea, the probability being that there were neither oceans nor continents like those which now exist, but an irregular distribution of comparatively shallow seas among land-tracts of moderate elevation. In Neozoic times we find proof of the existence of oceans, though these do not seem to have been so deep as those of the present day; that there were also large tracts of continental land is proved by the traces of large rivers and large inland lakes, but so far as we know these land-tracts did not form the nuclei of the modern continents of

¹ Prestwich's "Geology," vol. ii. p. 547.

Europe, Asia, and Africa, or bear any other definite relation to these continents.

If these inferences are correct, may we not deduce the still more comprehensive conclusion, that the deep ocean-basins and lofty mountain ranges of the modern world have been formed by a long process of geographical evolution, which has proceeded *pari passu* with the development and differentiation of the animals and plants which inhabit them, the tendency of all recent geographical changes having been to deepen the ocean-basins and to raise the mountain-peaks to higher and higher elevations.

This theory has at any rate the advantage of being based on definite facts, of reconciling many points of difficulty, of avoiding extremes, and of being in accordance with the general principle of Evolution. I state it in order that it may receive consideration from capable critics, and time will prove whether or not it is a tenable view. That it avoids the two extremes of complete permanence and frequent interchange is by no means its least recommendation, for the history of scientific controversies shows that antagonistic views have often been reconciled by an hypothesis which concedes something to both sides, for scientific men are not exempt from the common failing of veering too rapidly from one extreme to another, when in so many cases the truth lies midway between the extreme views. The advice which Horace gave to his friend Licinius, and which Ovid so tersely expresses by the words,—

“*medio tutissimus ibis,*”

is equally applicable to the ways of science and philosophy.

Thus I feel convinced that the truth is neither with those who assert the complete permanence of oceans and continents, nor with those who teach the frequent conversion of one into the other. Similarly, that the existence of the calcareous ooze in modern oceans should be regarded as

proving the present to be only a continuation of the Cretaceous period, I hold to be as untrue as the opinion that the Chalk is not the product of a Cretaceous *ocean*. So also with the arguments of those who urge and those who oppose the doctrine of Uniformity in the rate of geologic change; the Uniformitarian may push his advocacy to such an extreme that he departs almost as far from the truth in one direction as the Convulsionist does in another.

Avoiding these extremes, we may believe in the long-continued existence of continents and oceans, and yet admit that the Chalk is a genuine oceanic deposit; we may adopt the doctrine of Uniformity as our guiding principle in the interpretation of the past, and yet believe in the theory of Evolution.

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