Studies for Students.

THE MAKING OF THE GEOLOGICAL TIME-SCALE.

A critical examination of the nomenclature applied to the several divisions of the geological scale reveals a strange mixture of names, the reason for which is not evident to modern students of the science. In the list of system-names we find Carboniferous and Cretaceous, indicative of mineral characters, associated with Tertiary and Quaternary, meaning rank in some undefined order of sequence. The presence of these terms is no less mysterious than the absence of grauwacke and old-red sandstone, and primary and secondary, which were originally included. Triassic is the name of another system and records the three-fold division of the system of rocks to which it was applied; and Devonian, the name of another, reminds us of the county in England in which its rocks were first named. Observing these things, one is tempted to call in question the reliability of a systematic classification so heterogeneously compounded.

Although the older living geologists can remember back almost to the beginnings of the science, those who now are beginning their study of geology may find profit in examining the foundation principles, and the systems which have been devised, and have led to the construction and belief in the present classification—a classification, the adoption and unification of which has been thought worthy of the organization and continuance of an international Congress of Geologists. It is needless to call attention to the necessity of some systematic classification of geological formations, but as a foundation for the scientific study of the history of organisms there is need of a time-scale running back into the past, the degree of accuracy of which is known as well as the extent of its unreliability. In early attempts to classify

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rocks the chronological element of the scale was not considered, but by degrees the classification has passed from a classification of rocks to a classification of periods of time.

The ancients in many respects were keen observers; they knew much about plants, animals, physical and chemical phenomena, and astronomy. But with all their learning, there appears to have been no conception formed of an ancient history of the globe and its inhabitants prior to the earlier centuries of the Christian era. One of the first geological phenomena to become generalized into a theory was that of the formation of mountains by earthquakes, as cited by Avicenus in the tenth century. The gradual change of relative level of land and sea, as seen in the encroaching of the sea or the departure of sea from the shore, gave rise to speculations regarding the great length of time required for the lifting of the whole land by this means. In the sixteenth century, Lyell reminds us, attention was drawn to the meaning of fossils, and dispute arose as to their nature. Leonardo da Vinci doubted the then current belief that the stars were the cause of the fossil shells and pebbles on the mountain sides, and advanced the idea "that the mud of rivers has covered and penetrated into the interior of fossil shells at the time when these were still at the bottom of the sea near the coast" (Lyell's Principles, p. 34).

By degrees, as Lyell has described in such fascinating manner, one after another the foundation principles arose, were discussed, controverted, and finally, by their intrinsic truth, became established. But it was not till nearly the beginning of the present century that enough was known of rocks for the formation of a general systematic classification of geological formations. The belief in a limit of six thousand years for the formation of the world was prevalent. Catastrophy was the universal resort for explanation of phenomena not then understood. And for geological purposes the Noachian deluge was an indispensable agent for the scientific explanation of even the conspicuous phenomena. For these reasons inquiry did not reach into the antiquity of the geological ages. And the first attempts at classi-

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fication took little or no account of actual time-factors in geology.

Lehmann[1] (Johann Gottlob Lehmann died in St. Petersburg, 1767) is generally credited with having first proposed a classification of rocks on the basis of the order of their formation, as Primitive, Secondary, and a third class, the modern or superficial rocks made by the deluge or ordinary river action. Lehmann recognized also a direct relation of origin of the Secondary from the Primitive rocks, and thus arose the beginnings of the geological time-scale. Lehmann recognized three originally distinct kinds of rocks, or rock formations. The volcanic were separated from the others because having no particular connection with either in origin. The distinction, however, between Primitive and Secondary was fundamental. The Primitive was strictly the original, basal rock formed by crystallization from chemical solution before organisms lived; and the Secondary rocks were of secondary origin, made out of fragments of the older and always lying above them. In the original classification of Lehmann, Secondary included all the stratified rocks, as we now consider them, and in the classifications following Lehmann for some years the term Secondary was applied, though in a restricted sense.

Cuvier and Brongniart proposed the name Tertiary for the rocks classified as Secondary by Lehmann, but lying above what is now known as the Cretaceous system; and Quaternary was introduced by Morlot in 1854 for the rocks of superficial position and of glacial or fluviatile origin. Thus the nomenclature of Lehmann, which was proposed originally to indicate the derivation of the Secondary from the Primitive, was expanded on the basis of stratigraphic succession, and we observe the anomaly of a retention of two names (Tertiary and Quaternary), formed on the principle of Lehmann's terms, but his own terms, as well as his theory as a basis of classification, entirely discarded.

[1] J. G. Lehmann, Versuch einer geschichte von floetz-gebürgen, etc., Berlin, 1756. French translation cited by Lyell. Essai d'un Hist. Nat. des Couches de la Terre, 1759. See Lyell, "Principles," Vol. 1, p. 72, and Conybeare and Phillips "Geology," p. vi, and p. xlii.

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Werner (1750-1817) elaborated Lehmann's scheme and modified it. He was the great teacher of geology at Freiburg, Germany, in 1815, and left his impress upon the geologists of the time, though he wrote little in the way of systematic exposition of his theories of classification. He adopted Lehmann's *Primitiv Gebirge*, but of the Secondary rocks he made a lower class, which he called transition rocks (*Uebergangsgebirge*), which were stratified, contained none or but few fossils, and were more or less oblique in position; these characteristics were observed in northern Europe, where he studied them. The remainder of the original Secondary rocks, he called *Floetzgebirge*, or flat-lying formations, and these were the equivalents of Lehmann's Secondary in the classification of the early part of the century. Later, the Wernerian school called the formations above the Cretaceous *neues Floetzgebirge*, to which, as they were studied in the Paris basin, Cuvier and Brongniart, in the latter decade of the last century, applied the name *Tertiary*, which still remains in the scheme. Werner called the looser, overlying, unconsolidated rocks *angeschwempt Gebirge*, or alluvial formations, which were afterwards, as above stated, called Quaternary by Morlot.

The classification of Lehmann, as perfected by Werner, was then as follows:

German names.	*English equivalents.*
IV. Angeschwempt gebirge,	Alluvial formations.
III. *b.* Neues Floetzgebirge,	Tertiary "
a. Floetzgebirge,	Secondary "
II. Uebergangsgebirge	Transition "
I. Urgebirge	Primitive "

These were the formations which made up the geological series as then recognized. Volcanic rocks were looked upon as local formations, and of small account in general classification. But they came to be more deeply studied by Werner, and his notion that trap was of aqueous origin led to much controversy, and gave chief prominence to his views (the Neptunian theory) and to that classification of rocks which will be next considered.

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The rocks of igneous origin, although sometimes interstratified with sedimentary rocks, do not enter into the present geological time-scale, and for the present purpose further consideration of their classification is unnecessary. There has always been a remnant of rocks at the base of the scale, the consideration of which may be discarded here, because it is known chronologically only as below those rocks of which distinct evidence of their relative age is apparent. The name Primitive has been changed to Primary, and finally to Archæan, a name which was proposed by Dana, and is likely to be retained for some of the basal part of the series.

This first comprehensive classification of rocks may be called the Lehmann classification. It was based upon a structural analysis of the rocks in the order of their actual positions. The nomenclature is applied on the theory of relative order of formation.

Richard Kirwan (Geological Essays, London, 1799), claimed to be the first author to publish a general treatise on Geology in the English language. Although the book is written in a decidedly controversial spirit, the author appears to have had a thorough acquaintance with the various treatises in French, German, Latin and English, in which were expressed contemporaneous opinions regarding geological science. He was a Fellow of the Royal Societies of London and Edinburgh, member of the Royal Irish Academy, and of Academies in Stockholm, Upsala, Berlin, Manchester and Philadelphia, and Inspector General of his majesty's mines in the Kingdom of Ireland. It is probable, therefore, that he presents a fair idea of the opinions which underlay the Lehmann classification. According to Kirwan's book the rocks were originally in a soft or liquid state, the center of the earth was supposed to be hollow, or the whole earth was a solid exterior crust with immense empty caverns within. The materials of the earth were then in a state of fusion or solution, and by condensation, as time progressed, the solids were crystallized out and deposited from the chaotic fluid. The water contracted the surface and lowered upon it by sinking into the interior cavities. With the deposition of the primitive rocks

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from the chaotic fluid, the water became purer. Mountains were conceived of as the local points of original crystallization which drew to them, in the process, the minerals from the general fluid. As the waters gradually withdrew by evaporation and sinking into the interior caverns, they became clarified and capable of supporting organic life.

Kirwan says (p. 26): "The level of the ancient ocean being lowered to the height of 8,500 or 9,000 feet, then and not before, it began to be peopled with fish." (Under the name fish he included shell-fish, and all other petrifactions). The plains were formed of depositions from the water of argillaceous, siliceous and ferruginous particles, mingled with those derived by erosion from the already protruding mountains. All the rocks above the height mentioned, he observed, quoting from testimony of numerous travelers, are lacking in fossils; even the limestones are crystalline or "primative" limestones and marbles. These observations were cited in refutation of Buffon's "error" in claiming that all limestones were derived from comminuted shells. According to some authorities, primitive mountains should include rocks of even less height than 8,000 feet, and the occasional presence of fossils at a greater elevation was by them accounted for by their transference to that elevation by the deluge. This account of Kirwan's will suggest the way in which the rock formation came at to be first called "*gebirge*," or mountains. Rocks were supposed to lie as they were originally formed, and thus in classifying rocks the larger aggregates were naturally mountain masses. As the conception of movements in the earth's crust with folding and displacement came into the science, the idea of classification and grouping of rocks was retained, but that their grouping was based upon present massing above the surface as mountains ceased to be accepted as truth. In the German language the term "*Gebirge*" was retained, and apparently with restricted meaning. Kirwan apparently translated the term directly into English as mountains. *Formation* however took the place of *mountain*, as applied to rock classification, in the early part of the century.

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Lehmann's classification, in so far as it goes, expressed established facts of nature. There are Primitive, Secondary, Tertiary and Quaternary formations, but the theory that they may be defined and determined by physical structure and present relative position is only approximately true. All crystalline rocks are not primitive, all the secondary rocks are not merely consolidated fragments of primitive rocks. Some of them are fully metamorphosed. All Tertiary rocks are not unconsolidated, as the Tertiaries of California illustrate, and we now know that altitude above the sea, or relative position of the various formations, are by no means uniform and form no criterion for their determination.

The next important advance in the classification of rocks was started by Werner and his pupils. It was a classification based upon the mineral constitution of the rocks. As the study of geology advanced Lehmann's classification was found difficult to apply with precision, and it was found to be unnatural in that rocks of apparently similar kind were dissociated, while rocks of unlike character were brought into the same class. And the mineral character and composition of rocks was found to be an accurate means of defining them. As the mineral characters became clearly understood, the rock masses received their names from the chief minerals in them, and finally the mineral nomenclature entirely superseded the nomenclature of Lehmann, and a second classification arose in which the theory of the original order of formation of the rocks gave place to the actual sequence of mineral aggregates, one after another, in examined sections of the earth's crust. In this study of minerals Werner was a conspicuous leader, and the classifications at the beginning of the present century were mainly his or adaptations of them. The form which the geological scale assumed in English geological systems is seen in typical form in Conybeare and Phillip's Geology of England and Wales, 1822.

Arranged in order from above downwards, it is as follows:

I. *Superior order.* (Neues Floetzgebirge, of Werner).

II. *Supermedial order.* (Floetzgebirge, "

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(1) Chalk formation.
(2) Ferruginous sands.
(3) Oölitic system or series.
(4) { Red marle or New Red sandstone.
Newer Magnesian or conglomerate limestone.

III. *Medial, or Carboniferous order.*
(1) Coal measures.
(2) Millstone, grit and shales.
(3) Mountain limestone.
(4) Old Red sandstone.

De la Beche (Geology, 3d edition, 1833) carries out the system more completely, calling the first, or superior order, *Supercretaceous group*, and applying the terms *Cretaceous*, *Oölitic* and *Red sandstone* to three groups into which he divides the second order, and giving the third the name *Carboniferous group*. Below these he recognizes Werner's Grauwacke group, for what was the lower part of the original *Uebergangsgebirge* of his earlier classification, and below this were the *inferior stratified or non-fossiliferous rocks, and the unstratified rocks*. All of the names, it will be observed, are names indicative of mineral characters. If we turn back to the year 1817 we find the same Wernerian system applied to the classification of North American rocks by William Maclure (Observations on the Geology of the United States of America, Philadelphia, 1817). The author writes: "Necessity dictates the adoption of some system so far as respects the classification and arrangement of names. The Wernerian seems to be the most suitable, first, because it is the most perfect and extensive in its general outlines; and secondly, the nature and relative situation of the minerals in the United States, whilst they are certainly the most extensive of any field yet examined, may perhaps be found the most correct elucidation of the general accuracy of that theory, so far as respects the relative position of the different series of rocks." (Observations, etc., p. 28). The classification there set forth is as follows (in the order from below upwards):

Class I. *Primitive rocks.*

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Class II. *Transition rocks*—including (1) transition limestone, (2) transition trap, (3) greywacke, (4) transition flinty slate, (5) transition gypsum.

Class III. *Floetz or secondary rocks*—including (1) old red sandstone, (2) 1st floetz limestone, (3) 1st floetz gypsum, (4) 2d variegated sandstone, (5) 2d floetz gypsum, (6) 2d floetz limestone, (7) 3d floetz sandstone, (8) rock salt formation, (9) chalk formation, (10) floetz trap formation, (11) independent coal formation, (12) newest floetz trap formation.

Class IV. *Alluvial rocks*—including (1) peat, (2) sand and gravel, (3) loam, (4) bog iron ore, (5) nagel fluh, (6) calc tuff, (7) calc sinter.

Notice in this classification that the "coal formation" is placed near the top of the secondary rocks, the "rock salt formation" near its middle, and the "old red sandstone" at its base. Later investigations did not confirm Maclure's opinion of the accuracy of Werner's system as applied to American rocks. Amos Eaton's classification of New York rocks (as exhibited in his "Geological and Agricultural Survey of the district adjoining the Erie Canal in the State of New York, Albany, 1824) is an elaboration of the same system.

In each of these classifications, except in a few cases of the retention of distinctions based upon the structural analysis, the whole nomenclature and classification is based upon mineralogical composition of the rocks. In the succeeding progress of the science a great part of the nomenclature has been replaced by other names composed on a different principle, but many of the divisions here recorded are still retained. This latter fact we may interpret to mean that distinctions based upon mineral or lithological characters are of some real and permanent value in geological classification. The history of development of this system from the first, or Lehmann's system, shows that the linear order of the series of formations in the list is based on the con-

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ception of a time-scale, and a natural order of succession of the several formations.

The Wernerian classification in this respect was a correct one for the rocks in Northern Germany for which it was constructed. The English scale expressed the facts of sequence, so far as known, for the English rocks, but the attempt to fit either of them to the facts in North America emphasized their imperfection. The fundamental error in the Wernerian system was the assumption that the scale of Northern Germany was a universal scale, or, expressed in general terms, that the mineralogical constitution of a rock has any necessary relation to its place in the stratigraphical series.

The next step of progress in making the geological time-scale arose from the study of fossils. Fossils had been observed and recognized as organic remains for centuries before Lehmann and Cuvier. Lehmann, and he not the first, observed that Primitive rocks did not contain fossils, while Secondary rocks contained some, and what are now called Tertiary rocks contained them abundantly. But it was not until fossils were closely studied, their characters examined, and the species compared and classified that their importance was realized. Cuvier and Brongniart are generally credited with being the first to establish the scientific importance of fossils. (On the Mineral Geography and Organic Remains of the Neighborhood of Paris, 1808). In 1796 Cuvier had called attention to the fact that elephant bones discovered by him in the Paris basin were different from the bones of living species. In thus drawing a distinction between living and extinct animals, as implying present and past groups of living beings, the foundation was laid, not only of Palæontology, but of the whole field of investigation into the history and evolution of organisms. Cuvier and Brongniart, applying their methods of analysis to the rocks of the Paris basin, succeeded in classifying them into strata, and in defining the separate stratigraphical divisions in terms of the contained fossils. The Paris basin rocks being found to lie above the Cretaceous rocks of France and England, which represent the top member of the

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secondary formation of the Lehmann classification, were named Tertiary to indicate their geological importance and their relative position in the geological scale. These naturalists did not, however, perfect the geological classification which their biological studies suggested.

William Smith in England ("Tabular view," 1790, and in unpublished maps and sections of the first and second decades of this century) emphasized the value of fossils as means of identifying strata in different regions, and others had some part in the elaboration of the principle involved, but Lyell more than any one else perfected the scheme of classification of geological formations on the basis of their fossil contents. We find him saying, in the second edition of his Elements of Geology, published in 1841, "When engaged in 1828, in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of Tertiary strata in four groups, and endeavoring to find characters for each, expressive of their different degrees of affinity to the living fauna" (p. 280). A mathematical comparison was made between the proportionate numbers of recent and of extinct species to the several divisions of the Tertiary rocks of England. The result is given in the following table (copied from his "Elements," 2d Ed., Vol. I, p. 284).

Period.	Locality.	Per Cent. of Recent Species.	Number of fossils compared.
Post-Pliocene,	Freshwater, Thames Valley,	99–100	40
Newer-Pliocene,	Marine Strata near Glasgow,	85– 90	160
Older Pliocene,	Norwich Crag,	60– 70	111
Miocene,	Suffolk, red and coralline crag,	20– 30	450
Eocene,	London and Hampshire,	1– 2	400

In the nomenclature here proposed Eocene is derived from the Greek ηως, dawn, and καίνος, recent; Miocene from μείον καίνος, less recent; Pliocene from πλειον καίνος, more recent, and the definite meaning of the nomenclature and the classification is to signify that the strata called Eocene contain the first traces of the fauna now living, the Miocene strata a small proportion of the living species, the Pliocene and Post-Pliocene more and still more of the living types, and that the whole of the Tertiary

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is distinguished from the Secondary and all older beds by containing some representatives of the faunas now living.

In this earliest attempt to estimate time-relations by biological data, Lyell, as others of his time, considered species to be sharply defined natural groups, and therefore it was that the relations between a fossil fauna and its recent representatives could be expressed in mathematical terms, indicating the number of identical species. The principle underlying the classification, however, was of a deeper nature, and concerned the orderly succession of faunas and floras in time. From the application of this method of time-analysis to the Tertiary beds, it was extended to an analysis of the whole series of geological formations on the basis of their organic remains, and the Lyellian classification took the place of the older Lehmann classification as follows :

In place	of	Tertiary	we have	Cainozoic.
"	"	Secondary	"	Mesozoic.
"	"	Transition	"	Palæozoic.
"	"	Primitive	"	Azoic.

This latter classification and nomenclature was gradually built up, and mainly by English Geologists, as the Lehmann and Wernerian classification was largely elaborated by German and French Geologists.

Edward Forbes proposed to divide the known faunas and floras into two great groups, Neozoic (modern) and Palæozoic (ancient). The two terms Palæozoic and Protozoic were proposed about the same time. Palæozoic by Sedgwick, for the formations known to be fossiliferous, extending from his lower Cambrian upwards to include Murchison's Silurian system, and Protozoic was a provisional name proposed for pre-Cambrian rocks which might be found to contain fossils. (Sedgwick, Proc. Geol. Soc., Vol. II, p. 675, London, 1838).

In his Silurian System, Murchison proposed Protozoic in the following words : "For this purpose I venture to suggest the term "Protozoic Rocks," thereby to imply the first or lowest

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formations in which animals or vegetables appear." (Murchison, Silurian System, p. 11).

Without entering into the delicate question of apportioning the honors due to each of these great English geologists (see *American Journal of Science*, Vol. xxxix., p. 167, 1890), it may be said that in this early usage of the terms, the distinction between Protozoic and Palæozoic was ideal—and in later developments, Palæozoic has been retained for that lower great division of the scale containing distinct remains of organisms, with the Cambrian system at the bottom. To show the connection with the older nomenclature, it may be noted that Palæozoic is equivalent to Primary fossiliferous, and in this system Azoic was applied to the Primitive rocks of the Lehmann system.

John Phillips, in 1841, proposed to extend the method of classification to the whole geological series, and as his scheme was apparently the first complete classification constructed on this basis, it is offered as it appeared in "Palæozoic fossils of Devon and Cornwall," London, 1841, p. 160 (see also Penny Cyclopædia, articles Geology, Palæozoic Rocks, Saliferous system, etc).

Proposed titles depending on the series of Organic Affinities.			*Ordinary title.*
Cainozoic strata	Upper	=	Pliocene Tertiaries.
	Middle	=	Miocene Tertiaries.
	Lower	=	Eocene Tertiaries.
Mesozoic strata	Upper	=	Cretaceous system.
	Middle	=	Oölitic system.
	Lower	=	New Red formation.
Palæozoic strata	Upper?		Magnesian limestone formation Carboniferous system.
	Middle?		Eifel and South Devon.
	Lower	=	Transition strata. Primary srata.

(The terms are founded on the verb. ζαω or ζωω—to live, combined with καινος recent, μεσος medial or middle, and παλαιος ancient).

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Professor Le Conte has proposed Psychozoic, on the same principle for the latest geological period, in which man has appeared. (See Le Conte, Elements of Geology, New York). Lyell proposed to make, on this basis, a geological time-scale and applied the term Period to each of the several divisions of the scale. Thus we find in his Geology, second edition, published in 1841, a recognition of the time element in classification, without as yet the adoption of the biological nomenclature. He gives a table "Showing the order of superposition, or chronological succession, of the principal European groups of fossiliferous rocks. Under the heading "Periods and Groups" we find the following:

I. Post-Pliocene Period	A. Recent. B. Post Pliocene.
II. Tertiary Period	C. Newer Pliocene. D. Older Pliocene. E. Miocene. F. Eocene.
III. Secondary Period	G. Cretaceous group. H. Wealden group. I. Oölite, or Jura limestone group. K. Lias group. L. Trias, or New Red sandstone group. M. Magnesian limestone group. N. Carboniferous group. O. Old Red Sandstone, or Devonian group.
IV. Primary fossiliferous Period—	P. Silurian group. ? Q. Cambrian group.

(Lyell, Elements of Geology, second edition, London, 1841. Vol. ii, p. 178).

Later Lyell adopted the biological nomenclature, and was prominent among geologists in developing and elaborating the idea of the successive appearance of new types of organisms coördinate with the progress of geological time.

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One of the fullest elaborations of this biological classification of the geological series to form a time-scale is found in Dana's Manual of Geology. (Manuel of Geology; treating of the principles of the science with special reference to American Geological History, by James D. Dana, 3d ed., New York, 1880.) Here we find the larger divisions called times: I, Archean; II, Palæozoic; III, Mesozoic and IV, Cenozoic times. The Palæozoic time is classified into ages, viz: The age of Invertebrates, the Cambrian and Silurian; the age of Fishes, the Devonian; the age of Coal Plants, the Carboniferous. The Mezozoic is called the age of Reptiles. The Cenozoic time includes the age of mammals and the age of man.

Each of the ages is subdivided into periods and epochs, in which the stratigraphical groups and formations form the basis, and the particular faunas and floras of each constitute the data of determination for the time divisions. Thus the Devonian age includes the following:

Periods.

Catskill
Chemung
Hamilton
Corniferous } = Devonian Age;

and, as an example, the Corniferous Period includes the following epochs:

Corniferous
Schoharie
Cauda-galli } = Corniferous Period.

The distinctions upon which these subdivisions are made are primarily stratigraphical, and we have still to seek a time-classification on a purely biological basis for the whole geological series.

One of the earliest attempts at systematic classification upon a purely biological basis, was made by Dr. Oppel in classifying the Jurassic formations on the basis of the successive Ammonites characterizing the beds. (A. Oppel, *Die Juraformation*, *Eng-*

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lands, Frankreichs und des südwestlichen Deutschlands, 1856–1858). Oppel divided the lower part of the Jurassic system (the Lias) into 14 zones or beds; characterized successively from below upwards by their dominant fossil forms, chiefly ammonites.

Thus the successive zones were those of: 1, *Ammonites planorbis*; 2, *A. angulatus*; 3, *A. Bucklandi*; 4, *Pentacrinus tuberculatus*; 5, *A. obtusus*; 6, *A. oxynotus*; 7, *A. raricostatus*; 8, *A. armatus*; 9, *A. Jamesoni*; 10, *A. ibex*; 11, *A. Davæi*; 12, *A. margaritatus*; 13, *A. spinatus*; 14, *Posidonomya Bronnii*. Later classifications, elaborations or revisions of Oppel's system have been made by Wright, in 1860; Judd, 1875; Tate and Blake, 1876, etc. This method of classification recognized the principle of temporary continuance of species and of associated faunas; and it has been applied with greater or less success all through the geological scale of formations for the definition of the lesser divisions.

As early as 1838 the importance of the biological evidence in determining the time-scale was clearly enunciated by Murchison, who wrote in the introduction to the Silurian System, "that the *zoölogical* contents of rocks, when coupled with their order of superposition, are the only safe criteria of their *age*." (The Silurian System, p. 9).

The making of the geological time-scale has now progressed to the stage when it is pretty clearly seen that the ordinary classification of geological formations, as found in our text-books, includes two distinct series of facts: (1) *geological terranes*, arranged stratigraphically and classified by their positions relative to each other and by their lithological characters; and (2) *chronological time-periods*, which may be locally marked by the stratigraphical division planes, but which depend, fundamentally, upon biological evidence for their interpretation and classification. Gilbert[1] has concisely expressed the important fact of the purely local nature of the division-planes separating the formations stratigraphically into stages, series, systems or groups in

[1] Gilbert, G. K. The work of the International Congress of Geologists. Proc. Am. Ass. Adv. Sc., August, 1887. Vol. xxxvi., p. 191.

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the words: "There does not exist a world-wide system nor a world-wide group, but every system and every group is local." "The classification developed in one place is perfectly applicable only there. At a short distance away some of its beds disappear and others are introduced; farther on its stages cannot be recognized; then its series fail and finally its systems and its groups."

If we accept the correctness of this statement, it is evident that geological terranes and the stratigraphical division-planes by which they are marked, although indicative of time succession, present nothing in themselves to indicate the particular place they occupy in a time-scale. Even were the age of a particular stratum in one section accurately determined by other means, there is no stratigraphical or lithological mark upon the rock stratum, by which the corresponding age can be recognized in another section. This is not meant to imply that it is impossible to trace a stratum or formation from one section to another in the same general geological province, for in such case it is a process of tracing with slight interruption the continuity of the one terrane. But when we pass from one basin to another, the physical continuity is broken, and the stratigraphy and lithology were made on a separate basis. Hence we reach the conclusion that the perfecting of the geological time-scale must be wrought by the means, primarily, of organic remains. Chronological time-periods in geology are not only recognized by means of the fossil remains preserved in the strata, but it is to them chiefly that we must look for the determination and classification of the rocks on a time basis.

This principle is clearly enunciated in the rules adopted by the United States Geological Survey for the direction of the survey.[1] "Among the clastic rocks there shall be recognized two classes or divisions, viz: structural divisions and time divisions." "The structural divisions shall be the units of cartography and shall be designated *formations*. Their discriminations shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic char-

[1] Report of the Director for the Tenth Annual Report, 1890, pp. 63–65.

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acters change." . . . "The time divisions shall be defined primarily by palæontology and secondarily by structure, and they shall be called *periods*" (p. 65). We have thus reached the stage in the making of the geological time-scale in which the ideas of the *geological formation* and the *geological period* have become thoroughly differentiated. The geological period as a time-unit is primarily defined by the characters of the fossil remains in the rock, so that the elaborating further and making more precise of the geological time-scale must come from a direct study of the life history of organisms as recorded in the stratigraphical formations.

H. S. WILLIAMS.

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