THE RELATION OF BIOLOGY TO GEOLOGICAL INVESTIGATION.

A SERIES OF ESSAYS DISCUSSING THE NATURE AND SCIENTIFIC USES OF FOSSIL REMAINS AND THE NECESSITY FOR THEIR SYSTEMATIC COLLECTION AND PERMANENT CONSERVATION IN PUBLIC MUSEUMS.

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PREFACE.

In the preparation of these essays I have had several objects in view, among which are a further presentation of elementary matter pertaining to biological geology than has before been published, the defense of biology as an indispensable aid in geological investigation and the repudiation of certain untenable claims that have been made in its favor, an application of the principles discussed to the practical work of the geologist, and the demonstration of the necessity of the preservation of fossil remains in public museums as storehouses of evidence upon geological questions. These essays are therefore confined mainly to a discussion of questions pertaining to biological geology, including both its structural and systematic branches, only incidental reference being made to other important branches of geological science, such as mineralogy, lithology, dynamic geology, etc.

I have intended an approximately full statement of the subjects selected for discussion as well as scientific accuracy in my conclusions, but in the manner of their presentation I have chosen to address general readers and students of geology as well as special investigators. I have accordingly presented a more detailed and methodical statement of the principal facts upon which biological geology is based than otherwise would have been thought desirable. Every working geologist is necessarily more or less familiar with the principles and criteria which are based upon these facts, but a comprehensive knowledge of them is not yet accessible to the student except by personal experience or didactic instruction; that is, because these principles and criteria have not yet been systematically and fully stated in published works the greater part of accessible knowledge concerning them is traditional.

It is true that some of the knowledge referred to has been briefly and more or less clearly presented in text-books, but the elements of biological geology are too comprehensive to allow of a satisfactory summary in even the largest of them. All discussions of principles and criteria pertaining to that subject are also usually omitted by authors of other works, evidently upon the reasonable ground that scientific writings ought not to be encumbered by a repetition of elementary principles, and upon the less reasonable assumption that the reader is familiar with and accepts as trustworthy those which they have adopted for their own guidance.

If it were not for my evident need of frequent reference to such elementary matter the desirability of publishing it in this connection might perhaps be questioned by those who are already familiar with it and with the range of its applicability. Still, the working geologist needs only to recall his early embarrassments and later experiences to be assured that the time has not yet passed when even the frequent enunciation of elementary truths is of material benefit to the student. I not only have not hesitated to adopt such a treatment of the subjects of these essays, but I have not sought to avoid numerous trite remarks and commonplace statements. These, however, are employed not so much for the purpose of conveying information as for that of giving logical continuity to the statement of my own ideas and of leaving the least possible room for doubt as to my meaning.

The relation of biology to geological investigation is so fundamental and the facts pertaining to it are so concrete and so accordant with both biological and physical laws, that the prevalence of any opposition to its legitimate claims seems unnatural. It is also unnatural that claims should still be made in favor of that relation which are not supported by the principles of modern biology. Of late years, however, such wide differences of opinion have become prominent, some of them being especially so among American geologists. In their writings some of these authors either entirely ignore biological evidence as furnished by fossil remains or treat the best of it as being of little importance in the investigation of structural geology. Others have taken quite opposite ground, not only making the just claim that biological evidence is indispensable in structural geology, but the untenable one that it is absolute and exclusive in systematic geology. Notwithstanding the prevalence of these extreme views, I have abstained from a controversial attitude in the treatment of the subjects to which they pertain, preferring to attempt their statement in such a way that the reader will necessarily reach correct conclusions.

Because it is necessary to discuss those differences of opinion in these essays, it is desirable to refer briefly to their origin and the causes of their perpetuation. Doubtless some of the causes of their existence are remote or obscure, but it is apparent that they are largely due to the broadening of the field of geological investigation, making it necessary that it should be divided into numerous specialties. In such cases it is natural that differences of opinion should be greatest between those investigators whose chosen studies are most diverse in character. Another cause is doubtless one of inheritance from the early condition of both geological and biological science.

A special cause of the perpetuation of these extreme views evidently exists in the form of personal domination by such of those who entertain them as happen to possess unusual opportunities for their enforcement. It is well known that such influence has at various times and in various ways retarded the progress of geological science and that there is danger of its being exercised in all cases when the personal judgment of an observer is liable to be modified or controlled by official or other temporary authority.

The opinions which have been referred to as the result of inherited errors are mainly those which relate to the application of biology to systematic geology. They are evidently due to the difference of ability or of inclination among the authors who have written upon those subjects, to adjust the early methods of thought which they have adopted to those which were made necessary by the great revolution in the views of naturalists upon the subject of evolution, which took place after standards for both biology and geology had been formulated and generally adopted. I regard this cause as being so important that I have arranged the discussions of the geological scale now in use so that they embrace references to the condition of thought among promoters of geological science from about 25 years before the revolution to the present time.

It is apparent, however, that, besides, the tendency to follow established channels of thought, which has just been referred to the continuance of these differences of opinion, and the consequent differences in practice among geologists, are largely due to the fact that the principles and criteria which are necessary to constitute a standard or series of standards which shall accord with modern views of biology have never been conventionally formulated and published. It is very desirable that concerted attempts toward such formulation should be made, but it is nevertheless true that the necessity for a special exercise of personal judgment in every act of geological investigation renders exact formulation peculiarly difficult.

The attempts toward enunciating principles and formulating criteria which are made in these essays have been suggested by those of my own geological investigations which have been prosecuted mainly from a biological standpoint. Among the incentives to these attempts has been a desire to give to the readers of my published writings upon the subjects referred to a more explicit statement of the grounds of certain opinions therein expressed than it was practicable to make in those writings. Indeed I believe the present general condition of geological science in all its departments demands from its active investigators some more definite public exposition of principles, and even of certain elements, than has yet been published. It is at least apparent that such publications for each subordinate branch of geology would be of great service to students because it would give them greater facility in comprehending the meaning of authors, and it would enable the latter to write more concisely and intelligibly, as well as more accurately, upon the results of their investigations. It would also give authors in the different branches of geology an opportunity to become better acquainted with the character and value of the work done by their colleagues.

The differences of opinion which have been referred to have necessarily produced corresponding differences in practice among geologists, and I have therefore found it necessary to consider them in connection with the application of the principles discussed in these essays to the practical work of the geologist. In doing so I have taken occasion to show that both extremes have had the effect not only to retard the progress of geological science, but to diminish the practical value of geological investigation. Furthermore, I have taken every opportunity to insist that notwithstanding the paramount value of fossil remains in structural and systematic geology the geologist, when investigating these subjects will be without excuse if he should fail to avail himself of every attainable relevant fact, whether biological or physical.

Finally, I have undertaken to point out some of the legitimate claims which geological science may make, not only upon individual investigators, but upon museums, and scientific organizations, and to show that these claims are based upon the necessities of science and not upon a sentimental idea.

I. THE CHARACTER AND ORIGIN OF FOSSIL REMAINS.

In prosecuting the study of the fossil remains of animals and plants, the investigator may have either one or the other of its two leading objects in view, but each being so closely related to the other it is always essential that they should be pursued with direct relation to each other. In the first case, the leading object to be attained is the extension of our knowledge of the animal and vegetable kingdoms far beyond that which may be acquired by the study of living animals and plants, and in the second case it is to apply that knowledge to the study of structural and systematic geology. The object in the first case is purely paleontological; in the second it is not only to acquire paleontological knowledge, but to apply it to various branches of geological investigation.

This essay, like the others which follow it, is written with immediate reference to the latter object, but the facts presented in it are of equal importance to the former. My principal purpose in writing it is the presentation of such facts as indicate the true significance and value of fossil remains in geological investigation that the references which are made in the following chapters may be the better understood. While I endeavor to point out clearly those facts which show the paramount value of fossil remains in geological investigation, I do not hesitate to also point out their imperfection as representatives of formerly existing faunas and floras as well as of separate members of the same. This candid treatment of the subject is not only proper in itself, but it is necessary in view of the fact that in the following essays I oppose certain views which are shown by geological literature to be held by many authors, especially those which indicate an underestimation of the value of all fossil remains on the one hand and the relative overestimation of the value of certain kinds on the other. A large part of this essay is of the most elementary character, but the necessity for having such elementary matter at hand for reference has already been pointed out, and it will further appear in the following essays.

The substance of the bodies of animals considered with reference to the subject of fossilization may conveniently be divided into soft and hard parts. The soft parts are those constituting the organs by which the physiological functions of the body are performed, together with their connecting tissues, while the hard parts are skeletal and protective in their character. Some animals are destitute of either skeletal or hard protective parts, and their bodies are therefore wholly soft or fleshy.

The soft parts of animals are always so soon and so completely decomposed after death that they are never really fossilized, but in rare cases the form of some of them has been preserved in fine sediments in the condition of imprints and molds.* Therefore in the study of fossil zoology we are, with the rare exceptions just indicated, confined to an investigation of the skeletal and protective parts of animals, because these parts alone are capable of true fossilization.

Those parts of the living animal are largely composed of mineral substances, and they are of various kinds and character, some being chitinous and some corneous, but the greater part are composed of lime compounds, the most common of which are bones and shells. They often are of different composition in different families or other divisions of the animal kingdom, and often thus different in different parts of the same animal. Being originally composed of mineral substances in intimate association with a small proportion of animal matter, and being usually still further mineralized by replacement of the animal by mineral matter in the process of fossilization, they become nearly or quite as indestructible as are inorganic minerals. It is, however, true that all kinds of hard parts of animals, even those originally containing the greatest proportion of mineral substance, if exposed continuously to the atmosphere after the death of the animal, will, within a few years at most, become as completely decomposed as will the soft parts. That is, the hard parts of animals may become permanently fossilized under favorable conditions, or they may become as completely decomposed under those that are unfavorable as will the soft parts under all conditions.

Compared with animals, the proportion of the component substance of plants, except that of a few kinds which quickly decompose after death, is very small. Much the greater proportion of the substance of all of them, aside from water, is carbonaceous and comparatively slow to decompose, but none of it resists decomposition so fully as does most of the skeletal and protective parts of animals. Still, the complete decomposition of all plants is certain unless they fall under conditions which are specially favorable to their preservation. Therefore in the study of fossil botany we are confined to an investigation of imprints, mostly of leaves, and of such of the woody parts as may have become antiseptically changed by saturation with certain acids or with soluble salts, or completely mineralized by a process to which I have applied the term histometabasis†. Immense quantities of vegetable substance have in past geological time been accumulated and reduced to the fixed condition of carbon and thus permanently preserved in the form of coal, but this substance has seldom been found of material use in the study of fossil botany.

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* See the close of this essay for an explanation of the different forms and conditions in which fossils are found and the different methods by which they have reached those conditions and acquired those forms.

† See remarks on conditions of fossilization at the close of this essay.

Because even the hardest and most enduring of the component substances of animals and plants become entirely decomposed if continuously exposed to the atmosphere after death, it is necessary to their permanent preservation that they should fall under such conditions as exclude the atmosphere. Almost the only way in which this can be accomplished in a natural manner is by their subaqueous intombment in the constantly accumulating sediments which are deposited at the bottom of all bodies of water. In the cases of aquatic animals such intombment of their remains is a necessary result of the nature of their habitat, but the remains of land animals and plants must reach such intombment accidentally if at all. The manner in which remains of land animals reach the waters, in the sediments of which they become intombed, is by accidentally falling into those waters and sinking there, or into tributary streams which transport them to the intombing sediments, their transportation being sometimes facilitated by buoyant gases which accumulate in recently dead bodies. Furthermore, the annual freshets which sweep the flood plains of rivers transport to such a sedimentary intombment remains of the various animals which at other times safely dwell there. Plant remains reach such intombment in similar ways, and also by the action of the winds. In the latter class of cases they are in the form of leaves and small fragments of the plants which grew in the vicinity of bodies of water. Besides the methods just mentioned remains of both animals and plants not unfrequently become intombed in the slime and flood accretions of marshes.

It will be shown on following pages that the difference in the conditions under which the various kinds of fossil remains have been preserved has much significance to the geologist, but it is proper to remark here that the more quiet the prevailing physical conditions and the less the necessity for the transportation of those remains to reach sedimentary intombment the more likely were they to become fossilized and preserved in a favorable condition for study. The conditions presented by an open seacoast were specially unfavorable because of the constant triturating action of the waves. It is doubtless mainly for this reason that so few remains of land animals and plants are found in marine deposits, notwithstanding the comparatively abundant opportunity that such remains must have had of being cast into marine waters.

It is of such aqueous sediments as have just been referred to that the stratified formations of the earth are composed, and it is such remains of animals and plants as have just been mentioned that constitute the fossils which are found to characterize them.

The statements which have just been made indicate that some kinds of the animals and plants which existed in former geological epochs could not have become represented by fossil remains in the sedimentary formations, because no part of their bodies was fossilizable. They also indicate that of those which might have become thus represented the representation of some of them is necessarily less complete than is that of others, because their fossilizable parts were less indestructible in some cases and the conditions necessary to their fossilization were less favorable in others. Furthermore, they show that while the preservation of the remains of some animals was a natural result of the conditions under which they lived, that of the remains of other animals and of plants was in all cases the result of accidental or unusual conditions.

The following brief review of the animal and vegetable kingdoms is presented for the purpose of further applying the general statements that have just been made to the subject of this essay and of comparing our presumably obtainable knowledge of extinct animal and vegetable forms with our more definite knowledge of those which now exist. The legitimate methods of this comparison have to some extent just been indicated and they will be further shown on subsequent pages. In the following remarks it will be necessary also to make some comparisons of the now living land and aquatic animals, respectively, with those which lived in past geological epochs.

If such a comparison could be made of all living with all extinct animals, the proportion of now living land animals would doubtless be shown to be much greater as a whole than it was during past geological time, because in the earlier geological periods there were probably no land animals in existence, and their proportional numbers have since gradually increased. In discussing certain of the higher classes, however, mammals and birds for example, I assume that the proportion of extinct aquatic to land denizens was not far from the same that it now is, because the latter animals lived only in later geological time, during which time their general conditions of life have probably suffered comparatively little essential change.

Vertebrata.—Excluding some of the lowest and also some doubtful or exceptional forms, all vertebrates possess either well developed teeth or a bony skeleton, and much the greater part of them possess both. Under favorable conditions the fossilization of these animal substances is complete. Therefore, having fallen under such conditions, almost any vertebrate animal which existed in former geological time is likely to have left fossil remains. The epidermal structures, such as horns, hoofs, feathers, etc., which cover either the whole or portions of the bodies of certain vertebrates, being more destructible than bones and teeth, are not often preserved in a fossil condition except as imprints or casts. This remark, however, does not apply to the scales of teleost fishes, which, although epidermal in their character, are nearly or quite as indestructible as are the bones and teeth of those animals.

Although the members of the orders Cetacea and Sirenia, and of the family Phocidæ* of the order Carnivora, are very numerous, they constitute only a small proportion of the whole class Mammalia, and it is these families alone every member of which is fully adapted to an aquatic

*The small family to which the walruses belong should also be included here.

life. A considerable number of other mammals, such as various carnivores, rodents, etc., are amphibious in their habits, but far the greater part of this important class are dwellers upon the land. Therefore, while remains of the extinct representatives of the aquatic animals just mentioned would naturally have become intombed in the sediments of the waters in which they lived, and have there become fossilized, remains of representatives of the strictly land mammals could have reached a similar intombment only in the indirect manner that has already been explained. That is, the intombment of the remains of the aquatic mammals was almost a matter of course, while that of the remains of all others was the result of the exceptional and accidental falling or conveyance of their bodies into the water after death, or of their miring and dying in the slime of ponds and marshes.

The greater part of the remarks which have just been made concerning mammals is applicable to birds, and perhaps in some respects with even greater force, for it is doubtful if so large a proportion of formerly existing birds as of mammals have become represented by fossil remains. Only a small proportion of now existing birds habitually live upon the water, and these, like all others, nest upon the land. The remains of at least a portion of those which habitually resort to the water are of course likely to become quickly intombed in its sediments, while remains of all strictly land birds must reach such intombment, if at all, by indirect or accidental means. Therefore, fossil remains of aquatic birds are more likely to be discovered in sedimentary rocks than are those of any others, although it is quite probable that the terrestrial kinds as greatly preponderated over aquatic kinds in former geological times as they now do.

While all reptiles are air-breathers many of them habitually live in the water and in adjoining swamps and marshes. Many of this class, however, are not only confined to the land, but some of them abound in arid districts. The preservation of reptilian remains is, of course, subject to conditions similar to those under which mammalian and avian remains are preserved, and it is therefore evident that while remains of aquatic and palustral reptiles may readily find sedimentary or slimy intombment those of strictly land reptiles are less likely to become thus preserved. It is doubtless in part for this reason that fossil remains of representatives of now living upland reptiles are so rare as compared with those of representatives of other living forms. It is true that a large proportion of the great extinct subclass of Dinosauria were vegetable feeders, as is shown by their skeletal structure and especially by the character of their teeth, but most of those whose remains have been discovered were probably of lowland or palustral rather than of upland habitat. Their remains were therefore more likely to have undergone intombment than were those of the upland reptiles which may have been contemporary with them. That is, besides the usual methods in the case of land animals, their remains were liable to intombment by miring in the slime of marshes and shallow waters or by receiving a covering of such sediments as river floods usually carry.

A few of the living Batrachia pass their whole lives in the water, but the greater proportion of them are, in their adult state, air-breathing palustral animals. A smaller proportion of them live upon dry land, but these, like all the others, have aqueous respiration during their larval condition. Besides this, as a rule, those which are strictly land animals in their adult state seek the water at the breeding season. Therefore, a larger proportion of batrachian remains are likely to find palustral, than other sedimentary, intombment. The living Batrachia do not constitute so conspicuous a class as do the other vertebrates, and fossil batrachian remains are also comparatively rare, but among the reasons for this rarity is doubtless the fact that few of the class inhabit the larger bodies of water, such as those in which the more important formations were deposited.

Because all fishes are of aquatic habitat the intombment of their remains in the sediments of the waters in which they lived is more a matter of course than it is in the case of any of the other vertebrates. It is true, however, that fossil fish remains are, as a rule, less abundant in the sedimentary formations than might be expected in view of the comparative abundance of fishes in now existing waters. This is difficult to explain, even if it were now necessary to do so, but it is perhaps due in part to the entire destruction of their bodies in many cases by predatory enemies, in part to the large proportion of animal matter in their bones, and in part to other destructive causes acting upon the usually but not always fragile ichthyic skeleton. The absence of a true skeleton in many fishes ought also to be taken into consideration in this connection, extinct fishes of this kind being represented only, or mainly, by teeth and spines.

Mollusca.—The hard parts of mollusks, those which are preservable by sedimentary intombment, consist mainly of lime carbonate with a smaller proportion of animal matter than the hard parts of vertebrates contain. They are sometimes internal; but these, strictly speaking, are not skeletal in the sense that the bones of vertebrates are so. Usually they form a protective shell which envelopes the whole, or the greater part, of the animal. Much the greater proportion of the members of this branch of the animal kingdom have aqueous respiration, and these consequently live only in the water. The others are air-breathers and live either upon the land or at the water's edge. Many species and genera and some whole families of both aquatic and land mollusks have no hard parts, and their bodies are therefore immediately and completely decomposed after death, leaving no trace of their former existence. The hard parts of aquatic mollusks find speedy intombment in the sediments at the bottom of the waters in which they lived, while those of land mollusks are liable to complete atmospheric decomposition, or if thus intombed they must reach those sediments in the accidental manner which has been described on preceding pages.

It is reasonable to assume that at least as great a proportion of extinct, as of living mollusks were destitute of protective shells, and that as great a proportion were provided with only internal or other imperfect shelly parts. This having been the case it is plain that a large part of formerly existing mollusks can have no representation among fossil remains, and that a large proportion of the others must have failed of such representation. Still, mollusks as a class are so generally provided with a complete shelly protection for their bodies that these objects are among the most abundant and valuable fossil remains of which the geologist makes use in his investigations. Their value is enhanced above that of the remains of any other class as a whole by the fact that so large proportion of them were denizens of the waters in which were deposited the sedimentary formations which are now characterized by them.

Annuloida.—The existence in former geological time of others of the Annuloida than those which constitute the class Echinodermata has never been satisfactorily proved by the discovery of their fossil remains, but there seems to be no reason for doubt that some such animals really existed during at least a portion of that time. If such were the case their failure to be represented by fossil remains was doubtless due to the absence or imperfection of hard or fossilizable portions of their bodies. On the contrary, only a few of all the living Echinodermata are destitute of protective hard parts, which generally consist of a nearly or quite complete calcareous spinous test that under favorable conditions preserves the form of the animal after death. Most of them are provided with certain small internal hard parts, but no true skeletal frame.

The abundance of discovered fossil remains of Echinodermata show that the plan of their anatomical structure was essentially the same as that of their living representatives. The living Echinodermata are dwellers in marine waters, and it is presumable that the class has always been confined to a marine habitat. In former geological ages their representatives were abundant and varied, as is shown by their often abundant calcareous remains which are found in many formations, where they readily became intombed when those formations were in the condition of sediments in the waters in which those Echinodermata lived.

Annulosa.—Of the five classes constituting the Annulosa remains of the Crustacea are more likely than those of the others to be preserved by sedimentary intombment, because all the members of this class are provided with a more or less firm chitinous or calcareous covering for their bodies, and because with few and comparatively inconspicuous exceptions they are all of aqueous respiration and aquatic habitat. Being of aquatic habitat the Crustacea of former geological periods are likely to have become quite completely represented by fossil remains, because their crustaceous coverings would have found ready intombment in the sediments of the waters in which they lived. It is nevertheless true that while crustacean remains are by no means rare in paleozoic strata, in mesozoic and later formations remains of this class have rarely or never been found abundant, and often they do not appear among fossil faunas, the members of which would seem to have been their natural associates. This is all the more noteworthy because of the frequent molting of the mature shell by these animals, each individual of which would thus produce many fossilizable counterparts of itself.

The Myriapoda, Arachnida, and Insecta are so generally dwellers upon the land, that, as a rule, their remains can reach sedimentary intombment only by such accidental means as have been mentioned in preceding paragraphs when referring to other land animals. The preservation of such remains of these Annulosa, however, as may undergo sedimentary intombment is favored by the fact that they are generally provided with a covering of chitine, a substance which resists decomposition more effectually than do most other hard parts of animals, not excepting bones, teeth, and calcareous shells.

These three classes, especially the Insecta, are now represented by myriads of mostly minute animals presenting the greatest diversity of form and of habits of life. It cannot be doubted that at least the Insecta were abundantly represented among the faunas of former geological periods, although fossil remains of them are comparatively rare. This rarity is doubtless due to the fact already indicated that their remains could have reached sedimentary intombment only by accidental means, and also in part to the fragile character of the chitinous covering of a large proportion of them. In short, it seems necessary to conclude that comparatively little can ever be known concerning the probably great abundance of Insect, Arachnid, and Myriapodal life of former geological time.

Only the aquatic Annelida need be considered in this connection, because no satisfactory remains of extinct representatives of the others are likely to be found among any of the fossil faunas. Even the aquatic Annelida are of less importance as regards the subject of this essay than are most of the other classes of animals, because, with the exception of the Tubicola, few of them possess such hard parts as instructively represent their different forms after the death of the animal. It is true that some of these are provided with a more or less delicate chitinous covering which sometimes approximately preserves the form of the animal after the decomposition of the soft parts, and some of them also possess minute teeth. Traces of forms similar to these are sometimes discovered in stratified rocks, as are also such minute teeth as compare with those of some living annelids.

The living Tubicola, however, secrete an external shell, usually calcareous and much like that of the Gasteropoda, and such shells as these in considerable variety are found among fossil faunas. Many aquatic annelids burrow in the mud or sand at the bottom of the water in which they live, and similar burrows are not unfrequently found in sedimentary strata, which were doubtless made by extinct annelid species.

Cœlenterata.—The Cœlenterata consist of somewhat numerous orders and families, all of which are aquatic animals and all except a few inconspicuous forms are denizens of saline waters. Therefore if all the living members of this branch of the animal kingdom were possessed of such hard parts as would resist decomposition after death, we would be justified not only in inferring that the bodies of their extinct representatives were similar in structure, but in assuming that all of them have been more or less completely represented by fossil remains. A large part of the living Cœlenterata, however, are entirely destitute of even the most delicate hard parts, while others secrete a more or less massive calcareous or corneous skeleton, or sometimes an external tube, such as the well-known corals, sea fans, etc. It is therefore necessary to infer that while a very large proportion of the Cœlenterata which have existed during past geological time secreted coralline skeletons and tubes in infinite variety, another large proportion have left no material proof of their existence. It is true that casts and impressions in fine sedimentary strata of certain extinct forms of jelly fishes have been discovered;* but this is a rare and remarkable exception to the rule just referred to, the purport of which is that none of the extinct animals whose bodies consisted only of soft parts could have left any satisfactory evidence of their existence. Fossil corals are often so well preserved that they may be as completely studied as the now living forms, but still much of the structure of the extinct polyps must forever remain unknown.

Protozoa.—All the Protozoa to which reference need be made in this connection are of aquatic habitat, most of them living in marine waters. These are the Foraminifera, Radiolaria, and Spongida, and only these secrete such hard parts as resist decomposition. Their hard parts are sometimes in the form of minute complex calcareous or siliceous shells, sometimes of calcareous or siliceous masses, and they sometimes consist of the well-known substance which constitutes sponges.

Much of protozoan life has no known connection with such hard parts as have just been mentioned, and it is presumable that the proportion of protozoan forms which secrete no hard parts was similar in past geological epochs to that which now obtains. If so, there must have been an abundant representation of such life in the past of which no trace has been left.

Plants.—The natural method by which plants or portions of them may be preserved from decay, and the conditions that during the geo-

* See remarks on conditions of fossilization at the end of this essay.

ogical epochs have been necessary to their fossilization, have already been referred to, but it is desirable to consider to what extent remains of extinct floras may have been so preserved and fossilized.

The true aquatic plants or algæ, except those belonging to the family Corallinaceæ, are usually so succulent that they decompose almost as quickly as do the soft parts of animals, and they are therefore represented in sediments only as casts or impressions. Although the diatoms are represented by abundant remains in both marine and nonmarine waters, comparatively little use has been made of them in the systematic study of fossil remains.

With few and comparatively unimportant exceptions it is only such plants as grow upon marshes which are subject to periodical overflow and sedimentary accretion, and such portions of others as may be cast into adjacent waters by the winds or carried into them by river freshets, that are likely to undergo such sedimentary intombment as would insure their preservation in a condition for satisfactory study. No upland plants, except portions of those which grow in the neighborhood of bodies of water, are likely to become so intombed, and herbaceous plants, most of which wither and remain attached to their roots, as well as the foliage of evergreen trees, are also not likely to be cast into the water together with autumn leaves of deciduous trees. Again, the fruits of deciduous trees, being usually more compact than their leaves, are not likely to be transported by winds to a sedimentary burial.

It is therefore apparent that the representation by fossil remains of every formerly existing flora is necessarily very incomplete, not only because of the accidental character of even the most favorable conditions for their preservation, but because a large, and apparently the larger, part of every flora existed under conditions which rendered the preservation of any portions of it impossible. Furthermore, the process of intombment, as well as of being detached and conveyed to it, necessarily reduced every plant so preserved to a fragmentary condition, and breaking up the rocks in which they are now found they are unavoidably still further injured and often destroyed by even the most careful collector.

The incompleteness of representation of extinct animals and plants by fossil remains when they are considered with reference to the entire bodies of living animals and plants has already been referred to. It has also been shown that a large proportion of the animals which lived in the various geological epochs could have left no recognizable trace of their existence because of the perishable nature of all parts of their bodies. From these and other facts which have been stated the conclusion is necessary that a very large proportion of those extinct animals and plants which possessed fossilizable parts have never been represented by fossil remains, because those parts, not having fallen under conditions favorable to their preservation, have been as completely decomposed and destroyed as have the soft parts of the same bodies.

Besides the facts already indicated the following have special significance in this connection. All fossil remains are more or less imperfect as such because of the destructive natural conditions to which they inevitably have been subjected, and the firm consolidation of most of the rocks containing them has rendered impossible the recovery of the greater part of those which have really been preserved. The successive displacements which have taken place in the crust of the earth have so exposed the sedimentary formations to erosion that during the successive epochs large portions of all of them have been destroyed, together with their fossil contents, thus reducing the paleontological record to that extent. Other large portions of those formations have been so completely covered by succeeding deposits, by debris resulting from their erosion, and by the waters of present lakes and seas that they are inaccessible for study, and the available paleontological record has been thereby still further reduced.

An additional reduction has doubtless been accomplished by metamorphism—that is, in view of many important facts, both physical and biological, it is not unreasonable to conclude that the various series of pre-Cambrian stratified formations which are found in different parts of the world were once fossiliferous, and that the fossils they then contained have been destroyed as such by the metamorphic action which changed the mineral character of the strata.

If fossils were to be treated only as mere tokens of the respective formations in which they are found, their biological classification would be a matter of little consequence, but their broad significance in historical geology as well as in systematic biology renders it necessary that they should be classified as nearly as possible in the same manner that living animals and plants are classified. Considering the imperfection of all fossil remains, the question arises, Can they be classified upon the same general plans and by the same systematic methods that are used for living animals and plants? The answer is mainly in the affirmative, because structural characteristics are possessed by the fossilizable parts of animals and plants which are cognate, coincident, and of a similar classificatory character with those of the unfossilizable parts, although the latter, being more complete and convenient, are mainly relied upon in the classification of living forms.

As regards the classification of animal fossil remains, precisely the same system is available that is used for living animals, the former classification being in fact only an extension of the latter. In the former case, however, the methods and details depend more fully than in the latter upon the well established principles of comparative anatomy, because the direct and complete anatomical study of fossil animals is for obvious reasons impracticable. Indeed, it is upon comparative anatomy that most of the real scientific value of fossils depends, and without its aid they would always remain little more than mere curiosities or arbitrary tokens of the formations in which they are found. With the aid of comparative anatomy and systematic taxonomy these fossils, notwithstanding their imperfection and faunal incompleteness, become not only indispensable in geological investigations, but real representatives of the grand succession of animal life that has existed upon the earth.

In the case of fossil Vertebrata it is the skeleton and teeth almost alone that are used in classification, but so distinctly were the classificatory characteristics of those animals impressed upon the hard parts of their bodies that the nearly or quite complete structure of the whole animal may legitimately be inferred from them. Furthermore, these characteristics are so distinctly impressed upon the teeth and upon certain essential parts of the skeleton that legitimate classification of extinct forms can often be established upon no more than a few scattered teeth or fragmentary portions of the skeleton.

The extinct Mollusca, as has already been shown, are represented by their fossil shells, and these are classified precisely as are the shells of living members of that class.* Moreover, the classification of the fossil molluscan forms accords more completely with that of the living than is the case with the Vertebrata because living mollusks are largely classified by their shells alone, even when the soft parts of the animal are available.

As in the case of the Mollusca the fossil Echinodermata are classified in the same manner and by the same means as are the living forms, because the classification of the latter is based mainly upon those which in the extinct forms become fossilized.

The method of classification of all the fossil Annulosa is essentially the same as that which is used for the living forms, the difference, if any, being mainly due to the usual incompleteness of the fossil specimens. In such cases, as well as in those of the greater part of other fossil remains, more attention is given to certain characteristics of the hard parts than is found necessary when the whole animal is available for study.

While the classification of those living Cœlenterata which have no hard parts is necessarily based wholly upon the structure of their soft bodies, that of those living forms which possess skeletal or protective parts is largely based upon them. In this latter respect the extinct Cœlenterata are classified in the same manner as are their living representatives, namely, by means of their coralline hard parts.

Because the soft bodies of the living Protozoa are so nearly structureless that they can not furnish a satisfactory basis for classification it is necessarily based upon the structure and character of the hard parts in the case of those which secrete them. Therefore the classifica-

*The elaborate classification of the fossil cephalopods by means of their septal flexures may be taken as an exception to this statement.

tion of the fossil Protozoa has precisely the same basis as has that of the living forms.

The classification of fossil plants is, in a general way, similar to that of living plants, and so far as the recognition of the great classes and subclasses is concerned it is the same—that is, each of these higher divisions of the vegetable kingdom is recognizable among fossil-plant remains by its peculiar histological structure and the characteristic plan of its foliage venation; but the method of discrimination of species and genera of fossil plants is wholly different from that which is employed in the study of living plants, the latter method being impracticable because of the imperfection of the fossil material. In the case of living plants the detailed structure of the flower and fruit together with the general structure of the whole plant forms the basis of classification. In the case of fossil plants, however, classification is based almost wholly upon foliage, the main reliance for the discrimination of species being upon the venation of leaves the imprints of which are found upon the riven surfaces of stratified rocks, while their form or marginal outline is the principal reliance for the discrimination of genera. Other data are sometimes used for classification, such as the general form of the plant so far as it may be determinable, the microscopic woody structure, etc.; but these are rarely available and are generally less satisfactory than are those which are furnished by foliage.

In presenting the foregoing statements concerning the character of fossil remains I have taken occasion to indicate their high biological value not only when considered as fossils, but even in comparison with living forms as a standard, especially when studies and comparisons of them are made with reference to the principles of comparative anatomy; and I have also asserted their paramount value in geological investigations. Still, I have not hesitated to call attention to their imperfection and their faunal and floral incompleteness—that is, I have thought it necessary to indicate how incompletely any of the faunas and floras which have formerly existed upon the earth are, or can be, represented by them, and also how imperfect, even as fossils, are a majority of the specimens which reach the geologist's hands. My object in doing this is to show that the boundaries of possible knowledge with reference to the life which has formerly existed upon the earth lie within the limit which some authors have seemed disposed to assign to it, and in the same connection I have called attention to certain other facts which indicate that at least portions of the knowledge which is legitimately attainable may be overestimated or misapplied.

This treatment of the subject would be unfair if it were not accompanied by statements of facts and principles showing the paramount importance of fossil remains in the prosecution of geological investigation. Such a showing will be made in the following essays, and in the same connection the true value and teaching of fossils will also be discussed.

The following explanation of the different conditions in which fossil remains are found will supplement the preceding discussions and add to the description of their character which has already been given.

There are seven different natural conditions in which fossil remains are recognizable, three of which relate to substance, three to form, and one to both. To those relating to substance I have applied the terms permineralization, histometabasis, and carbonization; to those relating to form, the terms molds, imprints, and casts; and to the one relating to both form and substance, the term pseudomorphism.

The term permineralization applies to that condition of fossil remains of animals which differs least from their original condition as parts of living animals, such, for example, as bones of vertebrates, shells of mollusks, tests of crustaceans, etc. It is in this condition that the greater part of all fossil remains are found. In their original condition they were all composed of both mineral and animal matter. Mineral matter greatly preponderated in all of them, but the proportions differed much in the case of different branches of the animal kingdom. For example, the proportion of animal matter is much greater in bones, even in their most solid portions, than in shells of mollusks or tests of most crustaceans. In all cases, however, the proportion of mineral matter was sufficient to perfectly preserve the original form of each specimen during the process of fossilization. Their only material change in this process was the removal by decomposition of the animal matter and its replacement by mineral matter, the latter having been added as a precipitate from its solution in the waters in which the fossilization took place. This having been continued until all the minute interstices originally occupied by the animal matter were filled, the fossils became wholly mineralized and as indestructible as are other minerals of like composition. Indestructibility of these fully mineralized fossils, however, is not in all cases absolute, as will appear by remarks in following paragraphs.

The term histometabasis* is applied to that condition of fossilization in which an entire exchange of the original substance for another has occurred in such a manner as to retain or reproduce the minute and even the microscopic texture of the original. It is especially applicable to silicified wood. In such cases of fossilization the exchange has been made by destructive decomposition, molecule by molecule, of the woody tissues and their immediate replacement by precipitated molecules of the silex held in solution in the water in which the wood was immersed. By this remarkable process not only the original cell structure of various kinds of wood but the characteristic cell markings of each kind are often found to have been so perfectly preserved in the solid agate-like mass that it may be as completely studied as if the specimens were taken from living trees.

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* Etym.: *ἱστός*, tissue; *μετάβασις*, exchange.

Pseudomorphism of fossils is so nearly like that of mineral crystals that this term is equally applicable to both. It consists in the replacement of the original substance of the fossil by a crystallizable or crystallized mineral, such, for example, as calcite, pyrite, quartz in the form of chalcedony, etc., the original form of the fossil being perfectly retained. It is evident that at least a part of the crystallized pseudomorphs were formed by the precipitation of the component mineral from its solution within such cavities as are described as molds in another paragraph. In such cases they differ from casts as described on the next page only in being crystallized, but crystallization is one of the distinguishing characteristics of pseudomorphs. In many cases pseudomorphs were evidently formed by molecular replacement. All those chalcedonic pseudomorphs of shells which sometimes occur in limestone, and from which they often may be freed in a complete condition by acids, have doubtless been produced by molecular replacement.

The term carbonization is applied in this connection only or mainly to such masses of vegetal remains as coal, lignite, and peat. While such remains are of great economic value and often of great importance in structural geology, they are of little paleontological importance, because the organic structure of the plants from which they were derived has been so completely obliterated as to render them useless for such a purpose. Occasionally, however, fruits and other separate parts of plants are found to have acquired a carbonized condition in which their botanical character may be approximately determined.

Molds are cavities in sedimentary rocks which were originally occupied by fossils, the latter having been subsequently removed by the percolation of water containing a solvent of the fossils but not of the rock. Such solvents, while completely removing certain kinds of fossils sometimes left others unaffected, and sometimes they acted unequally upon fossils of essentially the same chemical composition. For example, the shells of the Ostreidæ almost always have resisted such solvents more than have most other shells. The original surface features and markings of fossils are often minutely preserved in molds, but they are frequently obscured in different ways; for example, by compression of the mold after it was formed, or by its having received a drusy lining.

Imprints do not differ materially in character from molds, the former term being usually applied to impressions left in the rock by thin substances like leaves of plants, wings of insects, etc., after their removal by decomposition. Sometimes, however, the molds of shells and other fossils have been reduced to the character of imprints by the extreme pressure to which the strata containing them have been subjected. The details of imprints have often been obscured by pressure, as in the case of molds, but they are often preserved with the greatest degree of minuteness.

Casts are counterparts of fossils, having been produced by the filling of molds with a substance other than that of the original fossil. It may have been by the injection, caused by pressure or otherwise, of substance derived from the matrix or inclosing rock, or by the precipitation of substances brought into the cavity suspended in percolating water. If in the latter case the cast is composed of a crystallized mineral, the term pseudomorph is applied to it, as already stated. Natural stony casts of the interior of shells and other fossils are often found within the molds which were formed by the solution and removal of the fossil itself, and they are also often found filling permineralized shells. The student of fossils often finds it desirable to take artificial casts of natural molds, especially in case he can obtain no other representation of the species he desires to study. By such a cast the original form and surface features are often reproduced with the greatest accuracy.

In the foregoing paragraphs are described the principal conditions in which fossils occur or by which they are represented, but one occasionally finds specimens which indicate certain conditions that are not fully recognized in the foregoing descriptions.

These cases, however, are less important than are those which have been considered, and they need not be further mentioned, but it is desirable to refer to certain conditions under which the soft parts of animals have sometimes been represented by impressions in sedimentary rocks, or under which they have been preserved from ordinary decay for an unusual length of time.

The fact was referred to on page 252, that although the soft parts of animals could never have become really fossilized, cases have occurred of the preservation in fine sediments of their form and even parts of their structure, in the condition of imprints or casts. A most remarkable and exceptional case of this kind is that of the jelly-fishes of the Jurassic slates of Solenhofen, where, in the fine sediments of which the slates were originally composed, not only their shape but the essential parts of their structure are preserved. Impressions, presumably of similar animals, have been found in older rocks, but these are less perfect than the Solenhofen specimens.

Fossilization or petrefaction of human bodies is often popularly reported to have occurred, but these are only cases of the change of the adipose and muscular tissues of the body to the wax-like substance adipocere, which process only delays but does not prevent final and complete decomposition. This change frequently occurs in other animal bodies that have become buried in wet or constantly damp earth, and packages of pork recovered from old river wrecks have often been found to have undergone the same change.

Every specimen of fossilized man is really only a skeleton, but the wonderful cases of preservation of the human form in the partially hardened volcanic ash of Pompeii are worthy of mention in this connection as illustrating more than one of the facts that have been stated in the foregoing paragraphs. While excavating the buried city the workmen came upon molds of the bodies of persons who were suffocated by, and buried beneath, the shower of ashes from Vesuvius. The body, even including the bones, long ago decomposed and was removed by the percolation of water which fell from the clouds. Casts of these molds, when discovered, were made by pouring them full of plaster, and when the comparatively soft inclosing matrix was removed an exact counterpart of the body was disclosed just as it fell in death well nigh two thousand years ago.

II. SEDIMENTARY FORMATIONS, THEIR CHARACTER AND LIMITATION.

It is apparent from statements made in the preceding essay that, as a rule, to which there are no geologically important exceptions, fossils have been preserved only in those accumulations of aqueous sediments which are now known as the sedimentary or stratified rocks of the earth, and that it is therefore these rocks only which furnish biological data for geological investigation. Furthermore, it is upon the general classification of these rocks, based upon both their physical and biological characteristics, that the whole system of historical geology depends, and it is their fossil contents that furnish the most efficient aid in the study of structural geology. The following essay will be devoted to discussions of these subjects, and it is therefore desirable first to present some remarks upon the stratified rocks with reference to the origin and limitation of the formations into which they are naturally divided. These remarks will necessarily include both the physical and paleontological definition of formations, and a reference to their use as units of stratigraphic classification.

There has been much difference of custom among geologists as regards the use of the term formation, some applying it to the smallest assemblages of strata which possess common characteristics, while others designate by the same term those series of formations to which the term system has been generally applied. That is, some apply the term formation to local or limited developments of strata, while others apply it to such systems as the Devonian, Carboniferous, Cretaceous, etc. This term has generally been confined to the stratified rocks, but by a few authors it has been applied to the eruptive, and also to the great crystalline rock masses. In these essays, however, the use of the term formation is not only confined to the stratified rocks, but it is restricted to those assemblages of strata which have common distinguishing characteristics, whether they have little or great geographical extent, or whether they aggregate a few feet or thousands of feet in thickness. That is, the use of the term is herein confined to those assemblages of stratified rocks of sedimentary origin* to which many authors have applied the term group, and others the term terraine.

A formation of this kind consists of an assemblage of strata which bears evidence of having been deposited by continuous sedimentation in a broad body of water, the sediments in different formations and

* To avoid frequent repetition, the terms sedimentary formation and stratified formation are used interchangeably when applied to formations as defined in this essay. The terms sedimentary rocks, stratified rocks, and fossiliferous rocks are also used interchangeably, but with a somewhat more general meaning than is intended by the two former terms.

sometimes in different parts of the same formation having varied in condition from that of impalpable fineness to that of sand and gravel. They are composed of calcareous, argillaceous, or siliceous materials which in process of time have become more or less completely hardened into rock and which in their separate condition are limestones, sandstones, and shales, respectively. These materials may, and often do, occur thus separately, not only in different formations, but in different parts of the same formation. Besides this, the different materials are often mechanically commingled, producing rocks of a mixed character; and sometimes the character of all kinds of stratified rocks is found to have been materially changed by metamorphism.

Formations differ greatly in thickness because the rate of accumulation of sediments was necessarily very variable and because their upper and lower limitation was coincident with, and due to, accidental changes of physical conditions which occurred at irregular intervals of time. That is, their limitation was caused by such movements of the earth's crust, including both land and sea bottom, as produced a more or less complete interruption of sedimentation, or change in the character of the same, and consequently a more or less complete extinction, or geographical transference, of the life that existed in the water in which the sediments were deposited. This is an almost invariable rule, but in rare cases the faunal and physical delimitations were not fully coincident. In such cases an abrupt faunal change has occurred within the vertical range, or at the upper limit, of a formation where sedimentation seems to have been unbroken between it and the next succeeding one. Such cases plainly resulted from a change in the character of the water as a faunal habitat, which was not accompanied by a corresponding arrest of, or even by a material change in, the character of the sedimentation.*

Formations may sometimes be continuously traced by the eye for considerable distances, especially if the débris of erosion has been well removed by denudation. In such cases no question can be raised as to their identity. Sometimes also a formation may be satisfactorily recognized at separate but not distant localities by means of its lithological characteristics alone when actual continuity is obscured or hidden from view by succeeding formations or other overlying material. In their greater geographical extension, however, formations undergo such changes of lithological character, and they often so closely simulate some one or more associated formations, that their lithological identification is uncertain or impracticable. Therefore, with the minor exceptions mentioned, the only known means by which a formation may be certainly identified at any other than its originally discovered locality is that which is afforded by its contained fossil remains.

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*Reference is here made particularly to conditions that are observable among the Upper Cretaceous formations of the interior portion of North America.

Because of the frequent displacements of portions of the earth crust which have occurred during geological time, and also because of the resulting great erosion of the materials of which formations are composed, none of them now exists in its original entirety, but it is desirable to consider them with reference to their origin as well as to their present condition, the better to understand their character.

Every formation originally consisted of sediments, which, within a portion of geological time of limited but uncertain duration, were deposited in any broad body of water, whether inland or marine, during all of which time both the body of water and the surrounding or adjacent land remained comparatively unaffected by displacements of the earth's crust or by any other adverse physical changes. Under favorable conditions every such body of water was the congenial habitat of aquatic animals, remains of which became fossilized in the constantly accumulating sediments. These animals constituted more or less distinct faunas, the geographical range of each of which was, in the case of inland waters, throughout the whole area occupied by each, and in the case of oceanic waters, throughout each of such large portions as were circumscribed by natural intramarine limits to faunal distribution, these limits having been in a general way barriers between faunal areas, although they were never sharply defined and were usually indefinite.

Within these more or less indefinite intramarine barriers the various forms of aquatic life constituted a separately recognizable fauna, and the sedimentary deposits became a separately recognizable formation. Still, those barriers are properly designated as indefinite because it is evident that the sedimentary deposits of any one of those ancient oceanic areas always blended to a greater or less degree with those of adjacent areas, and that certain members of every fauna ranged into adjacent faunal areas, just as certain species of every living marine fauna have a much wider geographical range than have most of their associates.

Much the greater part of the sedimentary formations of the earth were deposited in marine waters, as is shown by the character of their contained fossils, and most of those waters were then, as now, of oceanic extent. The character of the contained fossils of a comparatively small but important part of the sedimentary formations, however, show that they were deposited in inland bodies of water, some of which were fresh and some brackish. Some of those inland bodies of water were comparatively small, but others were of such extent that their deposits rival marine formations in that respect.

Every formation resulting from deposits in inland waters having had practically the same geographical extent as the body of water in which it was deposited, the original boundary of the whole formation was coincident with the shore line, but this can not be assumed with regard to the formations which were deposited in waters of oceanic extent. These, like existing marine waters, notwithstanding their extensive continental and island shore lines, which became in part original limits to formations, had world-wide continuity, but it is evident to every geologist that the most extensive of the marine formations in their separate physical and biological identity have rarely exceeded a few hundred miles in extent, and they are often much less. The variable physical limits to the areas of sedimentation within which were produced the separately recognizable formations were coincident with the indefinite intra-marine faunal barriers just mentioned, and all marine formations more or less completely merged both their physical and faunal identity into that of those which were deposited in adjacent waters. It is to be inferred that climatic influences, or rather those of temperature, had much to do with faunal limitation, but temperature was doubtless in large part equalized by the currents which conveyed the sediments that produced the formations.

The geographical definition of marine sedimentary and faunal areas, and consequently that of the resulting formations, was mainly or wholly due to the various and shifting conditions of land and sea bottom, which in different parts of the world and during successive geological epochs modified or changed the distribution of sediments within the great areas into which the oceanic waters were thus divided, and it was generally accomplished without affecting the aqueous continuity between them. In a large proportion of cases these shifting conditions did not affect the continuity of those waters, and they were sometimes so slight as to leave the resulting formation with illy defined upper and lower limitations, as well as with their usual indefinite geographical boundaries. They were often so great, however, as to elevate and long retain the former ocean bottom above the water level, and to thus produce a greater or less unconformity of, or a longer or shorter time hiatus between formations.

While shifting conditions of sea bottom constituted the principal factor in limiting areas of sedimentation, they sometimes caused the partial overlapping of the borders of contemporary formations by having alternately shifted those of adjacent sedimentary areas, thus adding to the usual indefiniteness of such boundaries.

The upper and lower limits of formations were sometimes produced by the elevation of sea bottom above water level and its resubmergence, in which case those limits were sharply defined. In other cases the movements of elevation and depression were too slight to entirely interrupt sedimentation, and those or other physical changes were too slight to prevent the survival of certain members of the earlier fauna as members of the later one. Indeed, it is through such survivals that continuity of life has been preserved during the whole range of geological time. In such cases the physical difference between the formations is usually slight. This, added to the partial commingling of their faunas, sometimes renders it difficult to fix upon a dividing line between them, and makes it especially necessary in determining the characteristics of each formation to study their respective faunas each as a whole. Still, it is usually the case that the vertical range of a large proportion of the species is not found to pass beyond the vertical limits of the formation in which they occur.

The beginning and ending of the sedimentation which produced each formation having been dependent upon the unstable conditions of the earth's crust, the occurrence of the displacements of which were irregular in time and variable in extent, formations are necessarily not only very unequal as regards their geographical extension, but also as regards their relative value in stratigraphical classification. For these, among other causes, they are also unequal in their relative importance as representing stages in biological development.

The foregoing remarks apply especially to marine formations, and they are of general applicability. The manner, however, in which occurred the upper and lower delimitation of the series of fresh water formations in the interior region of North America was evidently somewhat exceptional. These deposits took place in waters which rested above ocean level, and their differentiation into formations was evidently largely due to the shifting level of the waters in which they were respectively laid down, as well as to the shifting of the areas of denudation from which their sediments were derived. The latter was doubtless also the cause of the differences in lithological charactistics of those formations.

Because both the time and areal limits of marine faunas were always indefinite, especially as regards both the time and geographical range of certain species, it is plain that it is the fauna as a whole, and not separate members of it, that must be regarded as characterizing a formation, although a single species is often sufficient for its identification within a limited district or region after its characterization has been determined by means of its fauna, aided by its physical features.

The remains of aquatic faunas only have been considered in connection with the foregoing discussions of the origin and limitation of the sedimentary formations, because the life history of those faunas only was intimately connected with their production. The greater part of the fossiliferous formations of the earth contain no other remains than those of aquatic faunas, but in many formations remains of members of contemporary land faunas and floras are found commingled with those of aquatic faunas. The latter were intombed where they originated, but the others reached their intombment by the indirect way that was described in the preceding essay. It is therefore plain that the remains of denizens of the waters in which a given formation was deposited are more characteristic of it than those of contemporaneous land animals and plants could be, because the aquatic fauna which they represent, whatever may be its value as representing a stage of biological development, was dependent for its existence upon the same conditions which were necessary to the production of the formation.

It is true that fossil remains of certain species of land animals and plants may be, and often are, found only within the limits of a certain formation. In that respect they may be regarded as among its characteristic fossils, but the time range of a land fauna or flora is likely to have fallen short of, or to have exceeded that of an aquatic fauna whose own duration is known to have been at least in part contemporaneous, because the physical conditions which were the principal factors in establishing and extinguishing an aquatic fauna would not necessarily have materially affected the existence of adjacent and contemporaneous land faunas and floras. These questions, however, will be more fully referred to in following essays.

The foregoing remarks concerning the characterization of formations have been made with special reference to those which are more or less fossiliferous. It sometimes happens, however, that fossils do not exist, or are not discovered, in certain formations which are evidently of sedimentary origin. This may have been due in some cases to the uncongeniality as a faunal habitat of the waters in which the formation was deposited, and in others to their failure to receive any fossilizable remains of animals and plants from the land. In other cases the absence of fossils may have been due to their destruction or obliteration. The latter has probably been the case with many metamorphic rocks and with the great pre-Cambrian series of stratified rocks generally. In all these cases the formations, while they may possess more or less distinct physical characteristics, lack the chief characteristics of sedimentary formations, namely, the biological.

The occurrence of an unfossiliferous sedimentary formation as a member of an otherwise fossiliferous series is unusual, but in such a case its definition and limitation would be effectually accomplished by the underlying and overlying formations. In the case, however, of a great unfossiliferous series of stratified rocks like the pre-Cambrian it is necessary to adopt a method for their study and classification based wholly upon physical data, after the fact that they are pre-Cambrian has been determined from biological data. Such a method of classifying and characterizing those unfossiliferous stratified rocks as they occur in North America has been proposed by Prof. R. D. Irving* and afterward elaborated by others. This great series of rocks as it is developed on this continent has such distinguishing general characteristics and such magnitude and geographical extent that some geologists have thought it worthy of being assigned to a special division of study, but because no certain traces of organic forms have been discovered in them they have, so far as it is now known, only the indirect relation to biological geology that has just been referred to. Still I regard it as not improbable that those strata were once fos-

* Irving, R. D.: Classification of the Early Cambrian and pre-Cambrian formations. Seventh Ann. Rep. U. S. Geol. Survey, pp. 371–399.

siliferous and that the great series was once made up of formations similar to those which have been defined on preceding pages, but it does not necessarily follow that the divisions which are now recognizable by physical characteristics correspond to those formations. It is probable that they more nearly correspond to systems or to the larger divisions of systems as they are recognized in the great scale of the fossiliferous rocks of the earth. Therefore the discussion of formations in this essay does not necessarily apply to the pre-Cambrian stratified rocks.

The following conclusions concerning formations are deducible from the facts which are stated in the foregoing paragraphs:

While they are physical objects and have only a physical existence their proper characterization is chiefly biological.

They are characterizable mainly by the fossil remains of aquatic faunas.

Neither their physical nor biological limits are sharply defined except as a result of accidental causes.

Their geographical limitations are indefinite except those which were occasioned by shore lines.

They do not necessarily bear any close relation to one another as to geographical area, thickness, or the duration of time in their accumulation.

Although they are thus unequal to one another they constitute the only available physical units for local or regional stratigraphic classification.

Because of their limited geographical extent they can not be used as units of the universal classification of the stratified rocks.

III.—THE RELATION OF FOSSIL REMAINS TO STRUCTURAL GEOLOGY.

The character and origin of fossil remains and the character and limitation of the sedimentary formations, as well as the manner in which the latter originated and became fossiliferous, have been discussed in the preceding essays. It is necessary that such discussions should have preceded those which are embraced in this and following essays, because they contain numerous statements of fact which it will be constantly necessary to refer to or to bear in mind in connection with the subjects now to be discussed and without which those subjects could not be intelligibly presented.

There are two methods by which the study of fossils may legitimately be applied to geological investigation, the following statement of the character of which is in part explanatory of the results that may be obtained by their aid. For convenience one of them may be termed empirical and the other philosophical, because in the one case results are obtained by experience and in the other by reasoning upon the various results thus obtained. Still, discrimination between these two methods can not usually be sharply drawn, because while all geological investigation is largely empirical it is always more or less philosophical. Such a division of the subject, however, besides being a present convenience, gives me an opportunity to emphasize the fact that a large proportion of the work that is done in structural geology is based mainly upon the empirical observation and collection of biological data.

Both these methods are not only important but indispensable, the one not less so than the other. Both may be, and often are, used together, but the empirical method is more largely used in practical field studies than in others, because in such studies fossils are to a large extent treated as characteristic tokens of formations or as arbitrary means of identifying them and distinguishing them from one another. Such identification necessarily constitutes one of the first steps in the practical study of structural geology, but the subsequent study of the fossils thus empirically used is necessarily more philosophical.

Furthermore, in the prosecution of field studies it is often necessary to make special philosophical use of fossils, not only with reference to questions which are discussed in following essays, but to some of those which relate more particularly to the subject of this. Among such questions are those which relate to the conditions of origin of formations, the character and quality of the waters in which they were deposited, and the various conditions of habitat of the faunas and floras whose remains characterize them.

The philosophical method of treating fossil remains, however, is largely applicable to systematic geology or those branches which pertain to the universal chronological classification of the sedimentary formations and to their correlation in different parts of the world. The naturalist studies fossil remains as representatives of the long succession of progressively and differentially developed organic forms which during geological time have existed and become extinct and of which succession the now existing forms of life constitute only the terminal portion. It is the results of such studies as these that the geologist uses in the philosophical studies referred to. While these questions are discussed in following essays this one is devoted more especially to questions pertaining to the practical study of geology in the field.

The idea of using fossils as characteristic tokens of formations by means of which they may be distinguished from one another and identified in their geographical extension began to prevail with the earliest studies of structural geology. Originally they were apparently regarded as of little or no more valne in the identification of formations than was their lithological composition, to which, indeed, their use seems at first to have been merely auxiliary. Although the use of fossils soon came to be recognized as indispensable in the characterization and identification of formations, and their investigation came to constitute a leading feature in geological research, it was long before they began to be studied in a philosophical rather than in an empirical manner.

That increase in their philosophical use did not diminish their value in other respects, as is apparent from the fact that a large proportion of the practical field work of to-day is necessarily based upon the empirical use of fossils as tokens of formations. That is, a large proportion of all the field work in structural geology depends upon the specific identification of fossil remains with, necessarily, only incidental reference to their systematic biological classification, and with no necessry reference to their value in other respects. Therefore the empirical use of fossils is even now held to terms as simple as those which were employed by the early geologists. Although it is essential that geological observations of all kinds should always be made with reference to all related physical as well as biological facts which may be available, it is not to be expected or desired that this primitive empirical use of fossil remains will ever be either discarded or diminished.

The foregoing remarks are made in defense of even the simple use of fossils just indicated, because it is evident that their value in that respect, as well as in others, is often underestimated, even by some geologists. The full measure of their usefulness, however, even in the identification and characterization of formations, can be attained only by a thorough investigation of comprehensive collections, prosecuted with direct reference to, and a rational interpretation of, the biological laws that governed the existence of the respective faunas and floras which they represent, and with equally direct reference to the physical laws which governed the production of the formations which they characterize.

It was shown in the preceding essay that although formations as they are there defined are not, and cannot be, the units of a universal classification of the stratified rocks they are the true units of local or regional classification of those rocks, and their use as such is indispensable in field studies of structural geology. Therefore the accurate identification of formations is indispensable, and because of this the means of correctly identifying them is of prime importance. It is true, as already stated, that formations have really only a physical existence, but their biological characteristics become in fact a part of their identity, and these characteristics constitute the principal, and in most cases the only criteria of identification. The criteria of identification of formations will be specially discussed in Essay VI, but it is necessary to consider them briefly in this connection.

Of the two ways in which formations are naturally charaterizable one is physical and the other biological. Physical characterization may be direct or general, that is, it may be by identity of kind or kinds of rock of which the formation is composed or by its possession of that more general or indefinite property or condition which indicates homogeny.

The physical or, more specially, the lithological, characteristics of any given formation may be so different from those of an underlying or overlying one that the contrast may be an efficient aid in its identification, but this is too seldom the case to be generally relied upon, the physical difference between them being usually no greater than that which may occur between different parts of one and the same formation in its geographical extension. Again the physical identification of an unfossiliferous formation may sometimes be satisfactorily determined from its position with relation to overlying or underlying formations whose biological characteristics are known, but such methods are usually too indefinite to meet the requirements of practical field studies.

It is true that in certain regions where erosion, corrasion, and denudation have been especially active, the field geologist may trace formations continuously and completely for many miles by means of their lithological and other physical characteristics and without the aid of fossils, but usually they have become so obscured by the overlapping of one upon another, or by being overlain by glacial or other drift or the débris resulting from their own erosion, that they are exposed to view only at wide intervals, and then incompletely. It is also true, that as a result of a long series of observations at such limited exposures of formations as those just referred to, one may obtain an approximately clear idea of the identity of a formation from the physical evidence which it presents of its homogenesis. Although in late years it has become the custom of some geologists in seeking to identify formations to rely upon these indications to the exclusion of others, a careful consideration of all available relevant facts will make it plain that the principal value of these indications consists in their availability as accessories to biological evidence. These physical indications of the identity of formations are further discussed in Essay VI. They are mentioned here only for the purpose of comparing them with biological indications.

Formations are biologically characterized only by the fossil remains of animals and plants which lived while they were in process of deposition, and the more intimate the natural relation of any of those animals and plants to the physical conditions which produced a formation, the more characteristic of it are their remains. This implies that while no kind of fossil remains is to be rejected in practical studies of structural geology, there is much difference in the value of the different kinds for this purpose. These differences in value will be specially discussed in following essays.

In the preceding essay it was shown that there was an intimate relation between the geographical boundaries of each aqueous area within which the sedimentation took place that resulted in the production of a formation and those of the habitat of the aquatic fauna the remains of which are now found to characterize it. Also that each aquatic fauna began its existence as such with the beginning of the deposition of the formation and ended its faunal existence with the completion of that deposition, although, as a rule there was some genetic connection with both the preceding and succeeding faunas. Again it was shown that the conditions which attended the establishment of those boundaries and controlled the deposition of the sediments also constituted each area a congenial habitat for its aquatic fauna and that consequently the whole life history of each of those faunas was intimately connected with the production of the formation in which its remains are found, while contemporary land faunas and floras bore no such direct relation to it. Furthermore, reasons were given why it may be accepted as a fact that as a necessary consequence of the conditions of their habitat, every species of every aquatic fauna which possessed fossilizable parts, was originally fully represented in the formation to which the fauna pertained, while all other kinds of fossil remains have always very imperfectly represented the faunas and floras to which they belonged. Besides this, their presence in any formation was always the result of accident.

Although these are sufficient reasons why remains of aquatic faunas are always of greater value than any other in the identification of formations, that fact does not imply that other kinds are not of the highest value for other purposes nor that they are valueless for this purpose. For example, although land faunas and floras bore no direct relation to the production of a formation, it is evident that the effects of the physical changes which respectively inaugurated and closed its deposition would in each case have been of such a character, and that they would have been so extended upon the land, as to cause important changes in the contemporaneous land fauna and flora. Therefore it is to be assumed that such faunas and floras in their entirety bore an important indirect relation to the respective formations with the production of which they were contemporaneous, and that such of their remains as found intombment in their sediments would be largely characteristic of them.

Still, the incongruity of the biological relation and of the physical conditions of existence of land faunas and floras to aquatic faunas, and the accidental relation of such of the remains of the former as became fossilized to the sediments in which they were intombed render it difficult to treat the evidence afforded by fossils of terrestrial origin as concurrent with that which is afforded by aquatic fossil faunas. This difficulty is increased by the incompleteness of representation by fossil remains of land animals as entire faunas, and that of plants not only as entire floras but as individual members of them.

Furthermore, remains of land animals and plants have never been found in any of the fossiliferous formations of the earlier geological ages, and in the marine formations of the later ages* they are rarely, and usually never, found.† Therefore their study, except in cases of doubtful value, is confined to the nonmarine formations of the carboniferous and later ages. The restricted range of such studies as compared with that of the study of other fossils is the more apparent when it is remembered how small is the proportion of non marine to marine formations. These remarks are by no means to be understood as suggesting the rejection of any kind of evidence in any case or as calling in question the general paleontological, and the purely biological, value of fossil remains of terrestrial origin. It is only claimed that their value in the characterization, identification, and limitation of formations is below that of remains of aquatic faunas.

It was also mentioned in the preceding essay that the biological characterization of any formation is fully recognizable only by means of its fossil fauna or flora, each as a whole, and not by separate members of either, although separate members, especially of an aquatic fauna, because of their limited vertical range, are often sufficient for its identification after its characterization has been fully established. This fact is of importance in every estimate of the true value of fossil remains in practical geology, because, notwithstanding their paramount value as evidence in the cases referred to, no evidence in such cases is ever so complete as to be beyond the need of accessory support.

The foregoing remarks apply to that direct practical use of fossils which is necessary from the beginning to the close of every investigation of structural geology. The following apply to their more indirect use in reaching conclusions of a general character, but which are also

* See table on Plate XIV, showing time ranges of animals and plants.

† Diatomaceous remains are not considered in connection with this statement.

of practical importance in all such investigations. Besides other applications that may be made of the facts mentioned in those remarks, they show the necessity for the study of the different kinds of aquatic faunas with relation to one another, and make it evident that so great a difference in their kinds and in the conditions of their origin implies a wide range of practical applicability to geological studies.

Comparative studies of this kind are prosecuted mainly by the philosophical method and require a consideration of various biological and physical facts. Among them are those which relate to the various general conditions under which sedimentary formations were produced and the more special conditions under which the aquatic faunas lived whose remains now characterize them. The general conditions referred to are largely of a geographical character, while the more special relate to the quality of the water in which the respective faunas lived as the element of their habitation.

The fact that the fossil remains of aquatic animals generally possess inherent and unmistakable evidence as to the character and quality of the respective bodies of water in which were deposited the sedimentary rocks which are now found to contain them was recognized at an early date, and the character of that evidence is such that there never has been any important disagreement among geologists as to its trustworthiness.* Indeed they usually and properly assume that there is as little room for reasonable doubt as to the quality of the water in which each fossil aquatic fauna lived as would be the case if those waters were still subject to a gustatory test or to chemical analysis.† Admissible evidence as to the quality of the water relates only or mainly to the presence and comparative proportion of salt in, or to its absence from, the various bodies of water which have existed during geological time, and in which sedimentary deposits were made. In other words, it is the kind of evidence that indicates whether those waters were fresh, brackish, or of marine saltness. Such evidence indicates whether the water in which a given formation was deposited was marine, estuarine, lacustrine, or fluviatile, and all this evidence, although relating to physical questions, rests upon comparisons of fossil remains of aquatic faunas with corresponding parts of members of now living faunas whose structural characteristics and restrictions of habitat are known. The marine so greatly preponderate over all other kinds of aquatic faunas that it is convenient in discussing the sedimentary formations to make the general distinction of marine and nonmarine, the former term not

*The criteria of the character of formerly existing bodies of water are discussed in Essay VII, but they are briefly referred to here in discussing the subject of this essay.

†It is probable that the earliest oceanic waters were much less salt than are those of the present day because the earth has ever since been subjected to a process of leaching, with the oceans as a reservoir, but the comparisons here made apply mainly to comparatively late portions of geological time.

needing definition, the latter being applied to all faunas that are regarded as having lived in either brackish or fresh waters.

In making practical application of the evidence which has been referred to, it is the general conditions which are indicated by the special that will most need to be considered. For example, the marine character of a fauna having been ascertained, the conclusion is legitimate, in the absence of conflicting evidence, that the area which constituted its habitat was bordered wholly or mainly by other marine areas, and that their sediments and faunas blended to a greater or less extent with one another. In other words, such a fauna indicates that its habitat was part of a great oceanic expanse which was occupied by other more or less similar faunas.

In case a fossil aquatic fauna should present intrinsic evidence of its brackish water origin the inference would be legitimate that its habitat was either an estuary or an inland sea, and in case the fauna should prove to be of fresh water origin we must conclude that the habitat was either a river or a lake. In all of these nonmarine cases the habitat had more definite boundaries than could have been the case with that of any marine fauna, and usually, but not necessarily always, a nonmarine formation has a less geographical extent than have marine formations. It is true that an estuary fauna blends in part with the adjacent marine fauna on the one hand and with the fluviatile fauna on the other, but its other limits are shore lines such as alone constitute the faunal boundaries of all other nonmarine bodies of water.

The estuarine, fluviatile, or lacustrine origin of a deposit or formation having been ascertained by means of the character of its fossil remains, aided by the accompanying physical indications, important inferences are to be drawn as to the geographical conditions which prevailed in that region at the time of its deposition. For example, the existence of an estuary deposit implies that contemporaneously with its deposition there was an adjacent body of marine water, and also a large land, if not a continental, area which was drained by the inflowing river.* Again, every lake or inland sea, the former existence of which may be determined by the character of the fossil aquatic fauna which the formation representing it contains, was necessarily surrounded by a broad land area.

The foregoing remarks apply to methods of distinguishing between formations of marine and nonmarine origin, and to the legitimate inferences that may be drawn from them, respectively, as to the physical conditions which prevailed while they were accumulating. In closing this essay it is desirable to present some remarks upon the relative value in practical geological field work of the fossils found in marine and nonmarine formations, respectively.

That the fossil remains of marine faunas are far more valuable as in-

* There are, of course, estuaries at the mouths of those rivers which flow into lakes, but brackish water estuaries only are here referred to

dicators of the chronological divisions of the geological scale and of the correlation of its divisions in different parts of the world than are those of nonmarine faunas is apparent to everyone who is familiar with even the general facts of biological geology, but it does not follow, and it is not true, that the latter are intrinsically less valuable than are the former in field studies of practical geology. For this practical work both marine and nonmarine fossils are treated by the empirical method already explained, and both are found to characterize the respective formations in the same manner.

Certain conditions, however, give each an advantage over the other under different circumstances. For example, the geographical range of the nonmarine invertebrate fossil faunas, especially those of fresh water, having been sharply defined by shore lines, the species which constituted them are to that extent more characteristic of the formations in which they occur than is the case with marine faunas. Certain species of the latter faunas, as already shown, usually ranged beyond the limits of the area which was occupied by each fauna as a whole.

Nonmarine formations as a rule occur singly in a series of marine formations, in which case the vertical as well as the geographical range of their invertebrate species is sharply defined. It is true that in the interior portion of North America there is a continuous series of fresh water formations and that certain of the species range from one into another. These, however, are notable exceptions to the rule referred to, and they at most only make such nonmarine faunas equal to the average marine fauna as regards exceptional vertical range of species. Again, nonmarine formations usually have the advantage of the presence of remains of plants and of land vertebrates and invertebrates, which in marine formations are usually so extremely rare as to be unavailable.

On the other hand, marine faunas embrace such a wide diversity of forms as compared with the nonmarine, and their progressive and differential evolution from epoch to epoch has been so much greater that they offer as faunas much more abundant means for the characterization and identification of formations. It is clear, however, that the opinion which some geologists have expressed or implied that the fossil contents of nonmarine formations are of little value in practical geological investigation is not well founded. The following are the principal conclusions reached in the foregoing discussions:

Formations being the only true units of local or regional stratigraphic classification, their correct identification is the first, and an indispensable, step in the practical field work of structural geology.

Although formations as such have only a physical existence, their biological characteristics are always the best, and often the only, means of their identification, and therefore the exhaustive study of fossils is of paramount importance in connection with all practical investigations of that kind.

The value of fossils in this respect is as purely practical as is that of any other aid to geological investigation, and it may be made available without reference to their great value in other respects.

Although all fossil remains are valuable for this practical use, those of aquatic faunas are more valuable than any others.

Remains of nonmarine faunas are of similar value for this purpose to those of marine origin.

IV. THE RELATION OF BIOLOGY TO SYSTEMATIC AND HISTORICAL GEOLOGY.

The preceding essay was devoted to discussions showing the importance of all fossil remains as well as the interrelative value of the different kinds of the same in the prosecution of geological field work. A leading object of that essay was to show that fossils constitute the most important of the distinguishing characteristics of all sedimentary formations and also the principal means of their identification as physical units of stratigraphic classification within any district or region. This essay is devoted to discussions of the more general relation of fossil remains to geological investigation; that is, to general discussions of the relation of biology, the science which they, together with living animals and plants, represent, to certain of the broader subjects of geological study. These subjects embrace systematic geology, or the general classification of the stratified rocks of the earth, historical geology, or the establishment of that classification upon a chronological basis, and correlative geology, or the adjustment to one another of the full chronological series of stratified rocks which occur on each continent or large division of the same. The latter subject, however, will be more specially discussed in Essay VI.

It has been made apparent in the preceding essays that each case of structural classification of stratified rocks based upon formations as physical units is independent of all others, and that its application is necessarily of limited geographical extent, because formations are themselves thus limited. It therefore follows that the structural geology of any district or region, embracing even an extensive series of formations, may be practically and thoroughly investigated, as regards both scientific accuracy and economic requirements, independently of that of any other district or region, especially of those regions which are not adjacent. It is now to be shown how the multitude of series of formations thus locally classified throughout the world have been grouped into a universal system of classification in connection with a scale having its divisions arranged in chronological order.

The grandest and most comprehensive of the ideas which were conceived and developed by the early geologists relates to the construction of this scale and the consequent reduction of geology to a universal system; but it is remarkable that although this idea is now known to have an almost exclusively biological basis, its original conception was not the result of correct biological knowledge as now understood, but of empirical observation of physical and biological facts and a sagacious perception of their interrelation.

It is true that while the early geologists relied mainly upon fossils as indicators of the relative age of formations, the belief was at first somewhat general among them that the consolidation of the sedimentary rocks, and also in part their displacements, were secularly accomplished and therefore that such conditions are to that extent indicators of their relative age; but these views did not long survive.

When the fossil faunas and floras which characterize each of a given series of sedimentary formations are compared with those which severally characterize the formations of the next preceding and succeeding series, and the whole are systematically compared with living faunas and floras, there is to be observed among those fossil forms, when studied in connection with an unbroken vertical range of formations, an order of successive changes and modifications indicative of a general advance in biological rank and also an indication of structural relationship. Furthermore, when the faunas and floras of a given series of formations are compared with those of other series in other parts of the world, it frequently appears that there is a close similarity between those of a certain portion of each series which indicates their correlation. In such cases an order of biological rank is to be observed similar to that which was observed in the original case. It also frequently occurs that the range of rank is found to be greater in one or both directions than is to be observed in other cases. By such means a knowledge of the order of faunal and floral, as well as of stratigraphical, succession far beyond that which could be obtained in any one region, has been acquired.

It is upon such empirical facts as these that the early geologists based their investigations concerning the chronological arrangement of the sedimentary formations of the earth, the grand result of which was the adoption of a general scheme and the construction of a corresponding scale for their classification. This scale, which in its present condition is a masterpiece of inductive reasoning, necessarily originated in Europe, because it was there that geology was first systematically studied, and it is there also that its adaptation is more complete than elsewhere. The first of the two following tables, the one to which, for the sake of convenience, the date 1840 is given, represents the scale in a condensed form as it was recognized and approved by leading geologists at, and a few years both prior and subsequent to, the date mentioned.[1]

The second table, the one bearing the date 1890, has been compiled

[1] It is not my purpose to discuss historically any of the questions referred to in these essays, but it is proper to remark that Cuvier and Brongniart seem to have been the first to apply paleontology to the study of structural geology (1800–1812), and that William Smith did the same, apparently independently of the two authors just named, in 1816, 1817. In 1819 Brongniart advanced the idea of correlating distinctly separated formations by means of fossils. After the latter date these ideas rapidly gained acceptance, and the first steps toward the construction of a general geological scale soon followed.

from European text-books of geology, and is intended to represent the scale as it is now generally accepted and approved by geologists. It will of course be understood that only a general outline of the great scale which has been established by the concurrent labors of European geologists is represented by these tables, but they are deemed sufficient for illustrating the following remarks and discussions.

*Condensed scale of the fossiliferous rocks, No. 1, 1840.**

Recent and Postpliocene.		
Pliocene		
Miocene		Tertiary.
Eocene		
Maestricht		
White Chalk		
Chloritic Series	Cretaceous	
Gault		
Neocomian		
Wealden		
Purbeck Beds		
Portland Stone		
Kimmeridge Clay		Secondary.
Coral Rag		
Oxford Clay	Jurassic	
Great Oölite		
Inferior Oölite		
Lias		
Upper New Red Sandstone	Triassic	
Lower New Red Sandstone	Permian	
Coal Measures	Carboniferous	
Mountain Limestone		
Old Red Sandstone	Devonian	Primary.
Upper Silurian	Silurian	
Lower Silurian		
Cambrian ?	Cambrian ?	

Condensed scale of the fossiliferous rocks, No. 2, 1890.

Recent and Postpliocene.		
Pliocene		
Miocene		
Oligocene	Tertiary	Cenozoic.
Eocene		

*At the date here indicated there was much difference of opinion as to the proper method of dividing the scale. This table is intended to represent the leading opinion, mainly as expressed by Lyell.

Condensed scale of the fossiliferous rocks, No. 2, 1890—Continued.

Danian	Cretaceous	Mesozoic.
Senonian		
Turonian		
Cenomanian		
Gault		
Neocomian		
Portlandian	Jurassic	
Oxfordian		
Bathonian		
Lias, or Schwarzen Jura		
Rhætic	Triassic	
Keuper		
Muschelkalk		
Bunter		
Permian, or Dias		Paleozoic.
Coal Measures	Carboniferous	
Millstone Grit		
Carboniferous Limestone		
Upper Devonian	Devonian	
Middle Devonian		
Lower Devonian		
Upper Silurian	Silurian	
Lower Silurian		
Upper Cambrian	Cambrian	
Lower Cambrian		

It was the intention of the founders of this scale, as it is and has been of all other geologists, that it should represent the whole of geological time from the beginning of life upon the earth until the beginning of the epoch of human history,* and that its divisions in the order in which they are named in the tables should represent consecutive portions of that time. It is necessarily assumed that each of these time divisions was represented by sedimentary deposits wherever during its continuance bodies of water existed upon the earth, and where they did not exist the passage of time was not recorded at all, or that it was not so recorded as to be understood without reference to the aqueous record as represented by the scale. That is, it is necessarily assumed that although during every epoch of geological time there were portions of the earth's surface upon which no sedimentary deposits were made because they were then above water level, there were during every epoch large portions of it beneath waters which were constantly depositing sediments. Thus, contemporaneously with such breaks in sedimentation within certain regions as have just been men-

* This statement may be taken as a definition of the term geological time, in the use of which term no direct reference is made to sidereal time.

tioned, sedimentation was continuous and comparatively undisturbed in others. Therefore, notwithstanding the occurrence of numerous and extensive breaks, there has been an abundant and continuous sedimentary record made for the whole earth. It is to this continuous record that the great geological scale is applied. Although the statement that sedimentation has been continuous upon the larger part of the earth's surface during every epoch of geological time now accords with the views of all geologists, it will be seen by proposition 3, on page 291 that in certain particulars it does not agree with those of the early geologists; but this matter will be discussed on following pages.

In dividing and subdividing the scale geologists have generally recognized three grades of divisions, as is shown by the three columns of names in each of the two preceding tables, the second grade being subordinate to the first, and the third to the second. The divisions of the first grade are general, only three in number, and evidently very unequal as to the actual duration of time represented by each. Those of the second grade are more, and those of the third still more special. The divisions of the third grade may each be locally represented by a single formation or by more than one. That is, formations are not the natural units of this scale.

The different divisions of each of these three grades are unequal to one another, but for convenience of classification they are treated as of similar rank in each grade. It is not, however, to be understood that the different divisions of the same grade represent at best more than a remote approximation to equal portions of time or to equal average advances of animals and plants in biographical rank Besides this, the sedimentary accumulations which represent any one of the divisions of the respective grades may be many times greater than those of another division of the same grade, but the bulk of formations is not an index of the relative length of time within which each was accumulated, because the rate of sedimentary accumultion was always extremely variable.

In discussing the divisions of such a classification as these tables represent it is desirable that for the sake of clearness of statement each of them should have both a structural and chronological designation. That is, the general designation given to each of the assemblages of strata which constitutes a division or subdivision in such a classification ought, if practicable, to have a time correlative. The general failure of authors to agree upon such a plan is doubtless due to the natural difficulty of correlating a chronological idea with physical objects which among themselves are of unequal quantity and, to a certain extent, of variable quality. In my own writings, however, I have generally used the term epoch as a time correlative of formation, and the term age as a time correlative of system,* but for present convenience I shall vary my custom in the latter respect which will be the less objectionable because

* See for example, Geology of Iowa, White, 1870, vol. I, p. 25.

the custom of geologists has not been uniform as to the general designation given to each of the three grades represented by the three columns of the tables. In referring to and discussing these tables I shall therefore apply the time term stage instead of age to systems or divisions of the second grade or middle column of the tables and the term substage to the divisions of the third grade or left hand column.

It will be seen by the foregoing statements that although the great scale in its entirety is comprehensive and trustworthy it is indefinite and unequal in its divisions and subdivisions, respectively. The significance of this indefiniteness and inequality is made more or less apparent in the discussions which are recorded on following pages.

Although the purpose of this scale is the classification of the sedimentary rocks of the earth its real units are not physical but chronological. That is, formations are not the units in this case as they are in the structural geology of districts or limited regions, but these units are such divisions of time as are indicated by the successive changes in the structure and character of the animals and plants which have existed upon the earth from the beginning of life until now. It is true, as has already been shown, that the chronological order of succession of a few formations may sometimes be determined within limited regions by means of their actually observed superposition, without reference to the fossil remains which they may contain. Such a method of determining that order, however, is wholly inadequate for general purposes because opportunities for observing successive cases of superposition are comparatively rare and because formations never possess any other than biological characteristics which originally could have suggested the idea of their age with reference to the full course of geological time. Therefore, a rational scheme of universal stratigraphic classification can have no other than a biological basis. That is, its real basis must be the evidence which fossils afford of the progressive evolution of organic forms during the progress of geological time and the various divisions and subdivisions of a resulting scale, while they must of necessity be locally recognized with reference to formations and systems, must coincide with widely recognizable secular stages in the progress of the evolution. In short, the true basis of such a scheme of classification is essentially a great biological idea to which material expression is given by its application to the successive accumulations of sedimentary deposits which now constitute the stratified rocks of the earth.

A comparison of the two preceding tables, although they represent only an abridgment of the great scale, will show at a glance how well the early geologists accomplished the work of constructing it. It will be observed that after more than fifty years of active scientific investigation the only essential changes that have been found necessary are the filling of a few gaps and the more complete definition of the Cambrian system at its base. Still, it is a fact that those pioneers of geological science builded better than they knew, for they accomplished their work at a time when the views of naturalists upon the vital principles of biology were radically different from those which now prevail.* They, therefore, misconceived the true character of the basis of the scheme upon which they constructed their scale, and yet their structure remains without need of material change after a revolution in the methods of thought upon the subjects to which its fundamental idea pertains, the equal of which has never been known in the history of scientific investigation.† That is, the scale, notwithstanding their misconception of its underlying principles, was constructed in accordance with certain immutable facts which they used wisely in their structure but interpreted wrongly as to the relation to those principles of the facts which they so clearly perceived. It is to their erroneous interpretation of facts and the influence which that interpretation has had upon later investigators that I now desire to call special attention.

Although the scale now in use was established before the truth of the progressive evolution of organic forms was accepted by naturalists and when all differences between those forms was believed to be due to special creations, general progression in average biological rank during geological time was perceived by the early geologists as well as by those of the present day, but with them it was the perception of a progressive succession in rank of faunal and floral groups of great assemblages of organic forms, and not the recognition of the principle of evolution. Therefore they sought methods of explaining the facts and conditions which they observed with reference to the geological scale which they had established that should accord with the biological views which then prevailed, and which were largely of a supernatural character. Indeed, in the absence of the now prevalent natural method of explaining these facts the supernatural method of the early geologists seems to have been necessary.

The following deductive propositions which now remind a naturalist of the articles of a creed more than of a statement of scientific principles, are presented as indicating the fundamental ideas held by the early geologists in connection with the construction of the geological scale and as illustrating the state of prevalent opinion among leading geologists upon biological subjects in their time. It is true that no one

* It is true that during those early years of geological investigation there were a few advanced thinkers who held a belief in the progressive evolution of all organic forms, but their views were then at best only tolerated by the great body of naturalists.

† This revolution occurred about midway of the time that is discussed with reference to the two preceding tables—that is, about midway between 1840 and 1893. The fact that this time embraces nearly the whole history of really scientific geological investigation is suggestive of a hope that within less than a like number of years all the inherited effects of the erroneous views of the pioneers upon biological geology will have been eliminated.

author has ever published these propositions in the exact form in which they are here presented, but I have formulated them from the published utterances of numerous authors and from my personal recollections of an active participation in geological work during a number of years immediately preceding the great revolution in methods of biological thought and investigation which has been referred to. In stating these propositions reference is necessarily made to the divisions and subdivisions of the table on page 286, representing the geological scale for 1840, and to the paragraphs preceding and following it. These propositions are:

(1) That every species of animals and plants, both living and extinct, was specially created, and that they are, and always have been, immutable. That genera, and also the higher groups into which both the animal and vegetable kingdoms are systematically divisible, are categories of creative thought, and that they also are immutable.

(2) That although secular extinction of certain species, and even genera, occurred during every stage of the geological scale, at the close of each stage, except the Tertiary, all life upon the earth was simultaneously destroyed, and that at the close of each substage life was at least in large part destroyed.

(3) That, at the close of each stage coincidently with, and the divinely ordained instrument of, the complete extinction of life there was a universal physical catastrophe, and that the close of each substage was, at least in part, physically catastrophic.

(4) That all life for each successive stage was created anew.

(5) That the life of each stage embraced specially ordained generic, or more general, types which were distinctive of and peculiar to it, and that their distribution was world-wide.

(6) That there was a special ordination of characteristic types for each substage, which received world-wide and simultaneous distribution within its narrow time limits.

(7) That no identical and few similar, specific forms were created for any two or more stages.

(8) That the world-wide distribution of the distinctive types of animals and plants which were ordained to characterize any stage or substage was effected in connection with the act by which their respective faunas and floras were created; or that in the case of species not having a world-wide distribution the typical integrity of faunas and floras was preserved by the introduction of representative, that is, closely similar, but distinct species.

(9) That by creative design the average biological rank of each new creation was higher than that of the next preceding one.

(10) That upon the fossilizable parts of the animals and plants which were created for each stage, and upon those designed to characterize each substage, was impressed not only their own structural features, but recognizable evidence of their chronological ordination.

These propositions represent only those views of the pioneer geologists which pertain to biological geology. Other views which were held by them are unassailable, even in the light of the present advance of science, and their biological views are not introduced here for the purpose of disparagement, but to show that they gave origin to certain erroneous methods which are in part retained as an inheritance by some paleontologists* even though they ostensibly accept the principles of modern biology.

It is evident from these propositions that the methods adopted by the early geologists of explaining the phenomena with which they had to deal, when any explanation was attempted, were based upon a belief in the supernatural origin and direct divine ordination of those phenomena, and not upon what is now accepted as a correct knowledge of natural laws. It will also be seen that among their leading ideas was that of sharp definition, not only of all the forms of animal and vegetable life, but of the divisions of the geological scale, and consequently of all the divisions of geological time. Of all the ideas which they conceived and held, to which proper exception can be taken, the influence of the one just mentioned, notwithstanding its inconsistency with natural laws, has evidently produced the most lasting influence upon modern geology. Some of the effects of this influence will be shown in the following propositions and in the remarks which follow them respectively.

The foregoing propositions relate to what were regarded by the early geologists as fundamental ideas in the construction of the geological scale, while the following relate to those ideas which are now held to constitute its true basis because they only accord with natural laws. These are therefore essentially a counter statement of the preceding propositions, but the principal object of their preparation is to point out the true relation of biology to systematic, historical and correlative geology. They consist largely of the statement of certain of the principles involved in the theory of organic evolution, but they are by no means intended as a full statement of those principles, nor are they presented for the purpose of either discussing or defining them as such. That is, the statements are made not for the purpose of formally enunciating these principles, but for the purpose of making practical application of them to the subject in hand. I have selected for statement and comment such of them as I believe to be accepted by all naturalists who admit the truth of organic evolution, and I make such application of them as I believe will necessarily commend itself to all geologists who admit that truth and its applicability to biological geology.

These propositions are not intended to embrace the whole range of biological geology, but only such of its leading principles as are discussed

*As a rule I do not use the term paleontologist to indicate a geologist who prosecutes his investigations mainly from a biological standpoint. He has no more need of a special designation than one who devotes himself to geological dynamics or to stratigraphy, and much less than one who rejects the aid of fossil remains in the latter branch of geological investigation. In the present instance, however, I refer to those who regard paleontological evidence not merely as essential in systematic geology, but as independent of physical evidence. The latter claim will on following pages be shown to be without rational foundation.

in these essays. Therefore, a certain lack of immediate relevancy will appear in the order in which they are stated.

(1) All species of animals and plants have originated genetically from preëxisting forms, and therefore all are more or less mutable as regards their reproduction. These, together with the various divisions higher than species into which the animal and vegetable kingdoms are divisible, have respectively acquired their distinguishing characteristics by differential and gradually progressive evolution. The extinction of all species and other divisions of the animal and vegetable kingdoms which has taken place during geological time has always been by natural means and in accordance with natural laws. It has generally been secular and gradual, but in many cases locally or regionally accidental. No universal extinction has ever occurred.

This proposition is presented mainly as a countercheck to those portions of the preceding series of propositions which assert the special creation and periodically universal extinction of species, and also as a necessary concomitant of the propositions which follow. It is proper in this connection, however, to make some general remarks concerning species.

It was comparatively easy to define a species in accordance with the views of the early naturalists, but it is more difficult to do so in accordance with the principles of modern biology. Because of this, and doubtless in part because of the lingering influence of those early views, there is much difference of opinion as to what constitutes a species. This is especially observable among those who describe and publish fossil remains. Some treat every form which is describably different from another as a distinct species, while others treat these closely similar forms, especially if they evidently belong to the same fauna, as varieties, and apply the term species in a more comprehensive manner.

I adopt the latter method in these essays, and regard as belonging to one and the same species all assemblages of individual forms, even if they are very variable, which occur in strata of the same stage, or if they occur in adjacent or other stages, which there is reason to believe freely interbred and were capable of producing the same kind with its varieties,—that is, I regard species as being variable as well as mutable. Still, although species are more or less variable, they have a recognizable entity, for while they are mutable they possess a certain tendency to stability of characteristics which has remained through long lines of reproduction or until gradually overcome by evolutional change.

(2) Coincident with the progress of evolution, notwithstanding the retardation, inertion, and even degradation that have occurred along certain lines, there has been during geological time a general average advancement in biological rank of animal and vegetable forms, evidence of which is afforded by certain characteristics of their fossil remains. The evidence of this general advancement constitutes the ultimate standard of measures of geological time as a whole and the principal means of ascertaining the order of full succession of the events which attended the production of the stratified rocks of the earth.

It is true, as was briefly mentioned in Essay II, that the practical geologist finds numerous local indications of the relative age of formations and of the order of occurrence of geological events, such as the resting of one formation upon another, lava overflows, faults and other displacements, subaerial erosion, etc. All such indications, however, are of service only in local, or at best in regional, investigations, and although they may be numerous and of great local value, they are always so disconnected that they can never be reduced to a general system of chronological classification, or even to a part of it, without the aid of fossil remains. It, therefore, can not be too earnestly asserted that the general advancement which has occurred during geological time in the biological rank of organic forms, notwithstanding its variations and numerous discrepancies, together with their multifarious differentiation, constitutes the only means of measuring that time as a whole or of any considerable portions of it. It is to this abstract measure of time that material form has been given in the construction of the geological scale.

Notwithstanding the indispensability and general trustworthiness of this time-measure in the study of historical geology, it can not be denied that it is not comparable in precision with the standard of sidereal time, because the latter is mathematically definable, while the former is based upon past biological conditions which were subject to infinite and often great variation.

(3) The chronological features which fossils possess are not of a special character as such, but they are among those upon which their biological classification is based, all of which features have resulted from both progressive and differential evolution.

Progressive, and differential evolution were more or less completely concurrent, but it was sometimes the case that the latter was greatly in excess of the former. From progressive evolution we have successive stages in biological rank, and from differential evolution the infinite variety of forms which occur in approximately the same rank. Both are often exemplified by one and the same series of fossil forms, but in the study of historical geology the results obtained from each are of different applicability. Those of progressive evolution are directly chronological in character, and therefore of broader significance, than are those of differential evolution, the results of the latter being only indirectly chronological in character and of empirical applicability in geological studies.

Progressive evolution has produced from the great mass of life which has continuously existed upon the earth variously connected genetic lines of organic forms, the aggregate of which lines extended through the whole of geological time. The varying structure of these forms exhibits grades of biological rank, which, by their continuity and their relation to one another, become chronological in character as well as constituting the basis of their biological classification.

Differential evolution has produced a great diversity of forms in each of the principal grades of biological rank which have successively existed during geological time, and these are found by empirical study to characterize the respective stages and substages of the geological scale. While the principal evidence of the full chronological order of the stages and substages of the scale has been derived from results of progressive evolution alone, the results of the empirical studies just mentioned are of the utmost importance in systematic geology as well as in all practical geological investigations. Indeed, not only the first steps in the construction of the geological scale, but the working out of all its details, are the result of empirical study, while the result of the philosophical study of all its fossil forms followed and completed it as a chronological standard.

(4) The average rate of progessive evolution for the different branches or divisions of both the animal and vegetable kingdoms has not been the same for each in all parts of the world, nor the same for all in any one part of the world, during all the time they have coexisted.

While the various divisions of geological time as expressed in the construction of the great geological scale are satisfactorily recognizable by their respective fossil faunas and floras, each as a whole, their limits are often obscured not only by the ranging of certain specific forms from one to another, but by the relative acceleration and retardation of the rate of progressive evolution of certain of the types which are distinctive of the divisions of the scale. Such retardation and acceleration have occurred in various divisions of both the animal and vegetable kingdoms, which has not only resulted in obscuring the limits of the recognized divisions of the scale, but in imparing to some extent the relative chronological value of the characteristics possessed by fossil remains belonging to different branches respectively of the animal and vegetable kingdoms.

These differences in rate were no doubt largely due to inherent differences between those great groups of organic forms respectively, but they were also largely due to differences in the effects of the same environing conditions upon different groups; that is, the conditions which were congenial to the existence of marine, fresh water, and land faunas and land floras, respectively, or, in short, the conditions under which marine and continental life, each as a whole existed, have been so different and in many cases so incongruous that their relative rate of advancement in progressive evolution was necessarily unequal even under similar climatic and hydrographic conditions, and much more unequal when these conditions were different.

For example, in Europe a certain progressive grade was reached for the whole of animal and vegetable life which all geologists recognize as Cretaceous. In North America remains of invertebrate life, and in part those of vertebrate life, exhibit evidence of essentially the same Cretaceous grade, but associated remains of vegetable life show a much more advanced grade, while a few vertebrate types show an earlier or retarded grade, all being judged by the European standard.

The foregoing remarks apply particularly to the first part of proposition 4. The second part finds abundant illustration in the great disparity of advancement in rank between molluscan and mammalian life during Tertiary time and between molluscan and dinosaurian life during Mesozoic time. The disparity is seen to be all the greater if only the fresh water mollusca are considered, the slight differential development of which during successive epochs of geological time is mentioned and referred to in following paragraphs.

In these essays the term type* is usually employed with reference to the chronological significance of the forms or groups of forms thus designated. Their succession in time was not necessarily coincident with progressive evolution, but they were always the result of differential evolution. Their chronological value to the geologist depends upon the definiteness of the limits of their time range. Usually their time range was comparatively short, but sometimes they continued their existence through long periods of time. A considerable number of types are specially characteristic of each stage of the geological scale, but any of them were liable to range beyond its limits.

(5) The rate of differential evolution among the forms constituting certain divisions of the animal and vegetable kingdoms was greater than that among those constituting other divisions; and it was greater for some of the members of a given division under certain conditions than it was for other members of the same division under other conditions.

The truth of this proposition may be more clearly shown by examples than by explanation. Some of the most remarkable examples of slight differential evolution during a succession of geological periods being furnished by fresh water and land molluscan faunas, these may first be mentioned.

Fossil remains of numerous fresh water gill-bearing molluscan faunas have been found in North American strata belonging to nearly every geological period from the Jurassic to the post-Tertiary, inclusive, each fauna consisting of members most, and sometimes all, of which belong to genera that are abundantly represented by living species; that is, only a small proportion at most of extinct genera, and no extinct families are known to have been included in any of these faunas. In short, the differential evolution of the North American fresh water mollusca during the Mesozoic and Cenozoic eras seems

*Because the term "type" is used in these essays in a special and also a somewhat variable sense, it requires explanatory definition. It is herein used to indicate groups of animal or vegetable forms which have certain recognizable but often difficultly describable, characteristics in common. Such groups are sometimes identical with genera, but they are sometimes less, and often more comprehensive, even embracing families and, in rare cases, orders. They usually have only an incidental relation to the groups which are recognized as divisions of the systematic classification of animals and plants, but they sometimes coincide with them or constitute accessory features of such classification. Types thus designated are recognizable by general form, peculiar details of essential parts of structure, accessory features, or a general summary of peculiarities of structure or biological characteristics.

to have been confined mainly to specific variation, and in many cases this also was slight. These remarks apply equally to the gasteropods and lamellibranchiates. Furthermore, the land and palustral pulmonate mollusks which were contemporary with those just mentioned seem as a whole to have been subject to little if any greater degree of differential evolution than were the others. It is true that progressive evolution in the case of all these mollusks was also very slight, but that does not explain the cause of the slight differential evolution.

During the time that all those fresh water and land mollusks were so slightly affected by evolutional change marine mollusks were not only extremely differentiated, but many genera and some families successively became extinct and many others were introduced. During that time also some of the most important advances were made in both progressive and differential evolution of animal and vegetable forms that have ever occurred upon the earth. So far as is now known all exogenous plants began their existence since those mollusks began theirs, and the earlier ones mentioned were contemporaneous with the most flourishing period of the dinosaurs. That great reptilian subclass passed its climax of development and became extinct, and yet those mollusks were meantime but little changed.

An example of extreme differential evolution is afforded by the Trilobites, which in the early geological ages became greatly differentiated, but from the time the order became established to that of its extinction there was comparatively little advancement in biological rank. A somewhat similar example is afforded by the dinosaurs. While their rank among reptiles was the highest the difference in average rank between the earliest and latest known forms belonging to that subclass is comparatively small and little, if any, in favor of the latter forms. The Mammalia afford a notable example of both progressive and differential evolution, ranging in time from the early Tertiary and in rank ending with man.

(6) The succession of gradual mutations in the development of the leading classificatory features which characterize certain groups of fossil forms was not necessarily concurrent with consecutive portions of time.

For example, the mutations of the flexures of the dental sac which produced the various structural features of the teeth by which the different groups of the mammalia were characterized, or those of the mantle in the production of the lobes and saddles of the septa of chambered cephalopods, did not in either case occur along a single line of progressive evolution, but along numerous differential lines coincident with each of which the rate of biological progress was different from that of others. Therefore advanced stages of progress must necessarily have been reached on certain of those lines contemporaneously with much retarded stages on others, and similar stages of progress were reached at more or less widely separated intervals of time.

This statement concerning the dental features of the Mammalia and the septal features of the chambered cephalopods* is only intended to show that while they really have a good degree of chronological value they can not be relied upon to indicate consecutive portions of time, nor as absolute tokens of substages of the geological scale.

(7) The progress of secular extinction of species and other divisions of the animal and vegetable kingdoms, including the types which specially characterize the various stages and substages of the geological scale, was accelerated by adverse changes of environing conditions and were retarded by a continuance of congenial conditions. The final consummation of the extinction of the types was naturally often, and perhaps usually, caused by catastrophic changes of conditions which occurred within the limited areas to which they were reduced by approaching secular extinction.

Secular extinction of all of these forms would naturally begin in those localities which first became uncongenial and would be longest deferred where congenial conditions lingered longest. It has thus happened that certain of the types which specially characterized a given stage or substage of the geological scale have survived in some parts of the world long after they became extinct in other parts, and indeed after the close of the stage or substage which they and their associates had specially characterized. In such cases the surviving types are found associated with those which characterize a later stage or substage than the one in which they originated.

In this way, for example, it is possible that a given assemblage of strata in one region which upon *ex parte* paleontological evidence would be assigned to the Cretaceous was actually contemporaneous with another assemblage elsewhere, which, upon other *ex parte* evidence would be assigned to the Tertiary. A similar statement may be made concerning any of the other systems or stages of the geological scale with reference to those which adjoin them respectively.

It is not necessary to infer that the locally catastrophic changes which completed the final act of extinction of species and types were always, or even generally, due to violent physical movements of the earth's crust. Such physical changes as would diminish food supply, increase the number and relative strength of enemies, alter climatic conditions, or affect the quality of habitable waters were doubtless the usual immediate causes of final extinction.

(8) The geographical distribution of species within the time limits of the stages and substages of the geological scale, and consequently that of the distinguishing types which the species constitute, has been effected by natural means. Such means included not only locomotory and mechanical dispersion within those time-limits from one original center which was then the terminus of an evolutional line, but, at least in the same cases, survival in various regions by separate evolutional lines from the faunas of preceding stages and substages was also included.

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*Because these septal features were extraneous to the bodily structure and bore no known relation to that structure or to any animal function it may well be questioned whether a classification based upon them is accordant with that which their anatomical structure might have furnished. Indeed the philosophical naturalist can not be entirely satisfied with such a classification. The case is different, however, as regards mammalian dentition, which has direct relation to essential structure and bodily functions.

It can not be reasonably doubted that as a rule the specific forms which constitute the fossil aquatic fauna of any stage or substage of the geological scale reached the localities where they are found by geographical dispersion from a single genetic center, even in cases of unusually great dispersion. Still, it seems impossible that all the fossil forms which geologists usually feel obliged to regard as representing separate species could have originated and become dispersed in that manner. It therefore may be reasonably assumed that each of the really or apparently identical forms which occur in different regions, but which belong to one certain stage or substage, may have reached their respective geographical stations within that stage or substage by separate evolutional lines from a common ancestral form which existed in a preceding stage, which lines were too slightly differentiated to produce new specific characteristics. In short, paleontological evidence seems to warrant the conclusion that in many cases, at least, both generic and specific forms have originated independently in different parts of the world, not only contemporaneously, but at successive intervals of time.

If species and genera really had such a diversity of origin as has been suggested, the various types which they constitute and which are held to characterize the various stages and substages of the geological scale may be assumed to have originated in a similarly diverse manner. Furthermore, the variable rate of differential evolution suggests a reason why certain of the characteristic types of a given stage or substage might naturally have survived the others and continued their existence into the next substage, as indicated in the paragraph following proposition 9.

(9) The animal and vegetable life of each stage of the geological scale was in the aggregate different as to its forms from that of all others, and each stage and substage was further specially characterized by certain generic, and also more general, types or peculiar groups of species. These types, however, were not necessarily confined within absolute time-limits.

So distinctive are the assemblages of types of organic forms which characterize each of the stages or systems of stratified rocks that, notwithstanding the exceptions mentioned in preceding paragraphs, the experienced geologist upon such evidence alone readily assigns to its proper stage of the great geological scale comprehensive collections of fossil remains from any given series of stratified rocks in any part of the world. For example, the great Carboniferous system has been by means of its fossils as distinctly recognized in Asia and in North and South America as in Europe where it was first studied, and in all those parts of the world it has been supposed to be sharply definable and wholly distinct, as to its fossil forms, from the Triassic above and the Devonian beneath. Later investigations, however, have shown that Devonian and Carboniferous types are often commingled upon the lower, and Carboniferous and Triassic types upon the upper, confines of the Carboniferous system.

Such a commingling of types is known to occur upon the confines of other systems as well as the Corboniferous, and the discovery of similar faunal conditions is to be expected in the case of any of them in all regions where the successive series of stratified rocks is complete. That is, where there is a sharply defined boundary between any two systems it has been due to such physical changes as broke the continuity of sedimentation and of life for the region in which it occurred.

(10) Although movements and displacements of the earth's crust have from time to time occurred over large portions of its surface, arresting sedimentation or changing its character and causing great destruction of life, there has never been a universal catastrophe of that kind. On the contrary, during all the time that disastrous conditions prevailed in any given area, conditions congenial to the existence and perpetuity of life prevailed in other and greater areas.

It is this persistence of congenial physical conditions over large portions of the earth's surface while smaller portions were disastrously affected that has not only insured the perpetuity of life in general, but that has insured the survival of certain chronological types of living forms in some parts of the earth after their complete extinction in other parts. Furthermore it is the evidence of the unbroken continuity of sedimentation attending those congenial conditions, as well as that of the unbroken continuity of life, which renders it difficult and often impracticable to draw distinct physical, as well as biological, lines of demarcation between contiguous stages and substages of the geological scale, especially when attempting to determine the correlation of the divisions of the scale for different parts of the world.

The second of the two sets of propositions, together with the accompanying remarks, which are recorded on the preceding pages, show that certain of the views held by the early geologists, notably those which assumed the universally sharp definition of all the divisions of the geological scale, were radically wrong. Still, it is evident to every one who is familiar with modern geological literature that those views have continued to exert an adverse influence upon the biological branch of geological investigation long after they have been formally rejected, even by those who continued to be influenced by them. The early geologists adopted methods of investigation which were consistent with their biological views, but I have shown that from the present standpoint of biology certain of those views were so fundamentally wrong that the methods which were based upon them are quite out of place in modern investigation. Still, those methods of our energetic predecessors have come down to the present time with such force and with such evidence of the general correctness of the scale which they had established by them that it has been difficult for their successors to adopt the modification of methods which has been necessitated by the great subsequent revolution in biological thought and methods of investigation.

The facts which have been presented on the preceding pages show that, while the scale which the early geologists established is a wonderful production of human reasoning and the best possible general standard which can be adopted before a comparatively full investigation of the geology of the whole earth has been made, it is not, and can not be except in a general way, of universal applicability. That is, while the respective stages and substages of the scale are recognizable only by means of their characteristic fossil remains, it has been shown that any of those characteristic forms are so liable to range from one stage or substage to another that it is impossible to sharply define the limits of stages, and often impossible to distinguish substages in one part of the world as they are known in another part.

The facts and principles which are enunciated and explained in this essay are of great importance in discussions of the relative chronological value of the different kinds of fossil remains and of the correlation of series of strata in separate regions of the earth, both of which subjects will, however, be specially discussed in following essays.

There is another subject which, if more data were available, might be profitably discussed at length in this connection. This subject relates to what may be designated as paleoclimatic conditions,* that is, to formerly existing conditions, which in certain parts of the earth were more or less materially different from those which now exist in the same parts. The evidence that such climatic changes have occurred upon the earth's surface consists of the presence of the fossil remains of kinds of animals and plants the living congeners of which could not exist in such a climate as now prevails there. For example, abundant fossil remains of arboreal floras are found in Greenland far north of the present northern limit of trees, and fossil corals are found at various localities in similar latitudes which are still farther beyond the northern limit of living coral-forming polyps.

These and similar cases must be taken as positive proof that great changes of climate have occurred upon the earth, but there are other cases which are frequently accepted as evidence of such changes that are of a more doubtful character. That is, there is much reason to believe that certain kinds of animals and plants formerly lived under climatic conditions which their nearest living congeners seem incapable of enduring. For example, the natural range of living elephants, rhinoceroses, and palms does not reach beyond a warm-temperature climate, but remains of certain species of those animals have been found where arctic winters prevail, and they are known to have been provided with a hairy protection against the cold. Remains of palms have also been found associated with those of fossil floras that indicate at least a cool temperate, if not a more severe, climate.

There is a multitude of other facts which bear upon this subject, but only these references to it are introduced here to indicate it as one of those which the geologist needs to bear in mind in all his biological investigations, especially those which pertain to correlation.

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* *Παλαιός*, ancient; *Κλιμα*, climate.

V. THE RELATIVE CHRONOLOGICAL VALUE OF FOSSIL REMAINS.

The discussions in the preceding essay of the positive value of fossil remains in systematic and historical geology have made it apparent that there is much difference in their relative value, especially as regards their use in characterizing the different stages of the geological scale and in determining the geological age of the strata in which they may be discovered. It is this subject, the relative chronological value of fossil remains, which I propose to discuss in this essay.

The basis of comparison of such values is a matter of much importance. The early geologists believed that all kinds of animals and plants were specially endowed at their creation with a certain chronological impress, but that this impress, being more distinctly recognizable in the fossil remains of some kinds than in those of others, they are consequently of greater chronological value. According to this idea the relative value of fossil remains consists only in the greater or less distinctness with which that impress can be recognized. The acceptance of the theory of the evolutional development of organic forms necessitates the rejection of this idea of the early geologists, which was one of the strongest influences in shaping their views of historical geology, but as already intimated its adverse influence is still observable in the practice of certain modern authors, even though they may theoretically disavow it.

Rejecting the idea of special endowment just referred to, we must consider the relative chronological value of fossil remains with reference to the natural laws which have produced their characteristics and governed the various conditions of their origin. Much may profitably be said concerning the comparative chronological value of the different genera, families, etc., belonging to one and the same class of any branch of either the animal or vegetable kingdom, or to different classes, but I propose to discuss only the broader relations to one another of the more general kinds of fossil remains. These discussions will relate to the time range of each of those general kinds, the various conditions under which they have been preserved, the various conditions of habitat of the animals and plants which they represent, the relative rate of evolutional development of the different kinds and their differences of reciprocal relation to one another.

No fact in historical geology is more conspicuous than that of the great differences in time range of the various kinds of organic forms, some of them having ranged through the whole of the time represented by the geological scale, while others, and among them some of the biologically most important kinds, ranged through only a comparatively small part of it.

The various conditions under which the different kinds of fossil re-

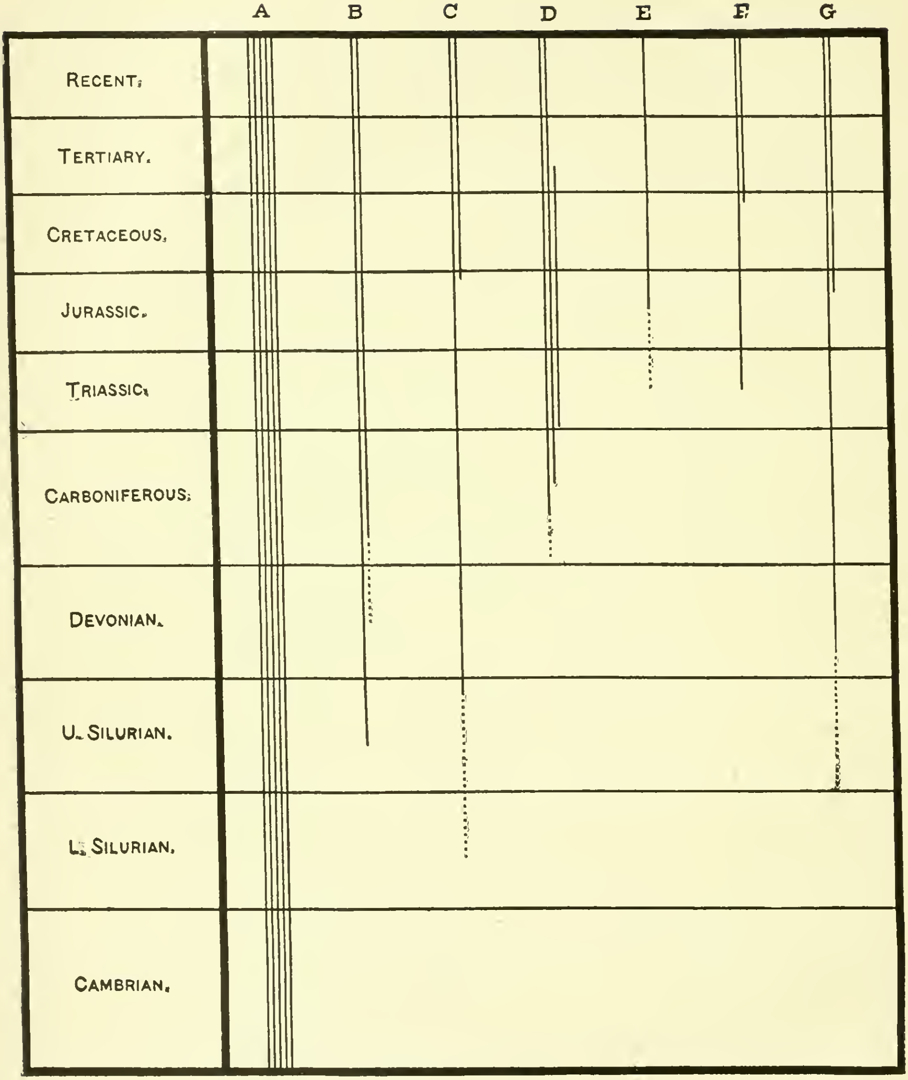

TABLE SHOWING THE TIME-RANGE OF CERTAIN KINDS OF ANIMALS AND PLANTS.

A. Marine invertebrates.
B. Non-marine and land invertebrates.
C. Fishes.
D. Batrachians and reptiles.
E. Birds.
F. Mammals.
G. Land plants.

mains have been preserved is also of great importance in this connection. Some of them have been preserved only in marine deposits and others only in nonmarine. Marine deposits have been continuous through the whole of geological time, while nonmarine deposits are not known among the older formations, and those which are known have necessarily been isolated and have had little or no direct relation either to one another or to marine deposits. The various conditions of habitat of the animals and plants which have furnished fossil remains also have much significance with reference to these discussions because of their essential relation to the differences between the kinds and to their differences of relation to one another.

It was shown in the preceding essay that while the general advancement in biological rank of organic forms which has occurred during geological time constitutes the ultimate standard of measure for that time, there has not been a uniform secular advancement for all kinds, but that there has been much difference in the rate of evolutional advancement for the various kinds of both animals and plants. Again, the differences of reciprocal relation between the various kinds of animals and plants which have furnished fossil remains are intimately connected with the causes which have produced the differences of chronological value of those remains. That is, certain kinds were not only radically different from others, but they lived under such wide differences of condition and were so nearly free from reciprocal relation to others, that they could not have produced a closely similar chronological record.

The facts thus briefly stated are of themselves clearly suggestive of the subject of this essay, that is, of wide difference in the relative value of the different kinds of fossil remains as means of characterizing the different stages of the geological scale and of determining the geological age of the strata in which they are found. These differences, however, will be discussed at some length on the following pages, but it is proper to say at the outset that while certain of the kinds mentioned are much more valuable for the purpose indicated than are others, it is inexcusable in any geologist, in attempting to determine the geological age of formations, to reject any kind as valueless, or to fail to give due weight to every accessible relevant fact, whether biological or physical.

A special grouping of the different kinds of fossil remains is more appropriate for these discussions than is a strictly systematic one, and I have therefore adopted the following: (*a*) marine invertebrates, (*b*) nonmarine and land invertebrates, (*c*) fishes, (*d*) batrachians and reptiles, (*e*) birds, (*f*) mammals, and (*g*) land plants. For convenience of reference our present knowledge of the time-range of these kinds may be presented in tabular form. The accompanying table, Plate XIV, representing the whole of geological time by its height, indicates in a general way by perpendicular lines the time range of the kinds just mentioned, and remarks in following paragraphs further explain the known range of some of the subordinate, as well as that of the principal kinds.

The horizontal spaces of the table represent the systems or stages of the geological scale. The proportionate width of the spaces which contain the names of those systems or stages is not intended to indicate the actual ratio of geological time for each, but it may be stated as the general opinion of competent investigators that the portion of the scale from the Cambrian to the Carboniferous inclusive represents a much greater length of time than does the portion from the Trias to the Tertiary inclusive. In other words, it is generally believed that the Paleozoic portion of the geological scale was of much longer duration than was that of the Mesozoic and Cenozoic portions together.

The perpendicular lines in the table, which are placed singly or in pairs or groups under letters of the alphabet from A to G inclusive, represent the time range of the kinds of animals and plants which have already been mentioned, and which for convenience of reference are again recorded opposite corresponding letters at the foot of the table. This method of grouping the different kinds of animals and plants, as already intimated, is adopted only for present convenience in making comparisons of chronological values. All the principal kinds which are designated in the usual systematic classification are, however, included in these special groups, the few that are omitted being regarded as of little or no importance in this connection. The dotted portion of certain of the lines indicates uncertainty as to the real extent of the time range which is shown by them because of imperfect or doubtful representation of those kinds by discovered fossil remains.

Of all the animals which have existed upon the earth whose remains have been discovered only those of marine invertebrates have been found to range through the whole geological scale. The time range of these important portions of the animal kingdom is represented by the group of five perpendicular lines under the letter A. The marine invertebrate life thus represented includes the Protozoa, Cœlenterata, Annuloida, Annulosa, and Mollusca, the latter including the Molluscoida. That is, it includes five of the six subkingdoms or branches of the animal kingdom.

The nonmarine and land invertebrates whose time range is intended to be represented in the table by the two perpendicular lines under the letter B are only insects and fresh-water, brackish-water, and land mollusks. The discovered fossil remains of all other nonmarine and land invertebrates are regarded as either too rare or too unimportant to be profitably considered in the comparisons which are to follow. The longer of the two lines may be taken as representing the known time range of insects and the shorter that of land and nonmarine mollusca.

The pair of perpendicular lines in the table under the letter C shows the approximate time range of all the various kinds of animal remains which have been referred to the fishes. The shorter of the two lines indicates the known range of the teliost fishes and the longer which of the other kinds, the latter including certain forms that differ materially from any living fishes.

The time range of Batrachians and reptiles, so far as it is known, is shown by the three perpendicular lines in the table under the letter D, that of the dinosaurs alone being represented by the shortest line of the three.

The known time range of birds is represented by the single line under the letter E. It is here assumed that most, if not all, the fossil tracks found in Triassic strata and formerly referred to birds are those of dinosaurs.

The two lines in the table under the letter F represent the known time range of mammals, the longer line representing that of the nonplacental and the shorter that of the placental mammals.

The known time range of land plants is represented by the two lines under the letter G. The shorter line represents the range of the dicotyledons and palms and the longer one that of all other kinds. The algæ and diatoms are omitted from the table as being of little or no importance in the comparisons and discussions which are to follow.

The earlier portion of the time-range for each of the kinds of animals and plants as shown by the perpendicular lines in the table is naturally more incompletely and indefinitely represented by fossil remains than is the later portion, because of the smaller variety and greater rarity of those earlier remains and also in most cases because of the increasing difference in character from living forms which is observable from later to earlier formations. In some cases, however, the early portion of the time range as it is now known begins so suddenly and with forms of such high biological rank as to make it evident that its real beginning was much earlier than it has yet been proved to be by actual discovery of fossil remains. The last-mentioned fact is of great importance in many respects, but it does not necessarily affect the question under consideration, because all estimates of the relative chronological value of fossil remains must be confined to the kinds already known, and the application of such estimates must be confined to those portions of the geological scale in the strata pertaining to which the remains are known to occur.

Although much the greater part of all the known fossil remains of the earth are of marine origin, it is a significant fact that most of the general kinds represented in the table are either of nonmarine or land origin. The extreme diversity of these conditions of habitat implies a wide diversity of character and suggests a wide difference of values. It is this diversity which makes it necessary to discuss the different kinds of fossil remains with reference to both habitat and conditions of preservation.

While a greater or less number of other kinds of animals, such as the Cetacea, Sirenia, birds, reptiles, etc., resort to or live in marine waters, only invertebrates and fishes have marine aqueous respiration. It is therefore evident that with the forementioned exceptions, together with that of their ancient representatives, these kinds of animals only have ever been denizens of marine waters, and it is also evident that with the exception of a few migratory kinds the remains of denizens of marine waters found intombment in no other than marine sedimentary deposits.

The character of the physiological functions of all the other animals which are represented by fossil remains made them denizens either of the land or of nonmarine waters. In view of this fact and of others which have been mentioned in Essay I, it is apparent that with few and mostly accidental exceptions their remains became fossilized only in nonmarine sedimentary deposits.

The land in the vicinity of inland bodies of water naturally constituted a more congenial habitat for such plants as have in part become fossilized than did open seacoasts, and, as shown in Essay I, plant remains were much more likely to have become preserved in nonmarine than in marine sediments. This statement is supported by the fact that, with rare exceptions, all discovered plant remains, especially such as are preserved in a classifiable condition, are found in nonmarine deposits, which are shown to be such by the character of the accompanying remains of aquatic faunas. Among the apparent exceptions to this rule are the beds of coal, and of shale containing plant remains, which are found to alternate with other beds bearing remains of unmistakably marine animals. These cases, however, are regarded as representing alternate subsidence and slight emergence of marshy land with relation to the level of shallow marine waters. Such conditions are accordant with the forementioned alternation of the remains of land plants with those of marine animals, and also with the fact that the actual commingling in one and the same bed of the two kinds of remains has very rarely been discovered.

The foregoing facts make it evident that as a rule, having only the exceptions just indicated, strata of marine origin contain no other fossil remains than those of invertebrates and fishes. It should also be remarked in this connection that fish remains are often absent from strata that contain invertebrate remains in great abundance, and that in all other cases the proportion of the former to the latter is very small as regards both numbers and variety—that is, as a rule, fish remains are comparatively so rare that a large proportion of the marine formations are found to contain no other fossil remains than those of invertebrates. Those facts also make it evident that with few and comparatively unimportant exceptions the remains of all land animals, as well as those of all land plants, are found only in sedimentary deposits of nonmarine origin.

By referring to the table on Plate XIV it will be seen that the time range of none of the nonmarine kinds of fossil remains extends much beyond the estimated later half of geological time, and that the range of a part of them is much less. It will also be observed that the time range of marine invertebrates is from the beginning to the end of the time represented by the geological scale. Therefore, there is no possibility of making comparisons between remains of marine animals and those of all other animals as well as those of land plants for a very large early part of the geological scale, because none of the latter kinds have been discovered there. Indeed, opportunities for any such comparisons for the whole Paleozoic portion of the scale, besides those which are practicable between remains of the marine animals and those of the land plants of the Carboniferous system, are very few and comparatively unimportant. It is probable that many and important nonmarine deposits were formed during Paleozoic time and that they contained the remains of nonmarine faunas, but reference is here made only to the present extent of our knowledge in that direction.

For the Mesozoic and Cenozoic portions of the geological scale opportunities are much more numerous for comparing fossil remains of marine with those of nonmarine origin than they are for the Paleozoic portion. This is because nonmarine formations are of more frequent occurrence among the sedimentary rocks of the two later eras than among those of Paleozoic era, and also because of the greater abundance and variety of the remains of nonmarine and land faunas and of land floras in those later formations. It is, however, a fact of great importance in this connection that the aggregate proportion of nonmarine formations to those of marine origin, even for the Mesozoic and Cenozoic portions of the scale, is very small.

It is thus apparent that for the Paleozoic portion of the scale it is marine formations almost exclusively with which the geologist has to deal, and that for the remainder of the scale marine formations are far in excess of the nonmarine. Indeed, they are so far in excess that, with the exception of a few regions like the interior portion of North America, for example, the occurrence of nonmarine formations is quite exceptional.

The absence of marine deposits among the formations of the earlier part of the geological scale and the great excess of the marine over the nonmarine among those of the later part, even where the latter are most abundant, is a great impediment to the comparisons which it is desirable to make between them and their fossil contents respectively. Still, this is not a greater impediment to such comparisons than is the incongruity or want of reciprocal relation not only between the marine and nonmarine, but between the different kinds of the latter.*

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* Dr. Theodore Gill has clearly pointed out the incongruity between land and marine faunas from the standpoint of recent biology. See Proc. Biolog. Soc., Washington, Vol. 2, p. 32, 1885; and The Nation, Vol. 24, p. 43, 1877.

The physical incongruity between marine and nonmarine formations is manifest in the fact that the presence of one or more of the latter in a series of the former kind of formations always implies that there have been such disturbances of physical conditions as to cause at least a local break in the continuity of marine sedimentation as well as in that of faunal succession. Such breaks also imply a greater or less interruption of the chronological record, the extent and character of which can be determined, if at all, only by indirect means. It is, however, the want of reciprocal relation between marine faunas on the one hand and nonmarine and land faunas and land floras on the other that more concerns the question of the relative value of the different kinds of fossil remains in characterizing the time divisions of the geological scale than does a similar want with reference to other kinds.

The biological contrast between marine faunas and land floras and between their respective conditions of existence is so complete that it is unreasonable to assume that the evolutional changes which have taken place in each during geological time were chronologically concurrent. Therefore, whatever of intrinsic value in the characterization of the divisions of the scale the fossil remains of the one series may possess, it is quite independent of that of the other.

It is true that the biological contrast between marine faunas and land faunas is not so complete as it is between marine faunas and land floras, but as regards interdependence and common conditions of existence the want of reciprocal relation between marine faunas and a large proportion of the members of all the land faunas is well nigh complete. Real or apparent exceptions to such completeness are observable in the exclusively marine habitat, or marine resort for subsistence, of certain mammals, reptiles, and birds, but these are cases of adaptation to conditions which are abnormal or exceptional for the respective classes to which they belong.

Notwithstanding these exceptions it is evident that during geological time there has been no necessary concurrence of rate or degree of progressive evolution between marine and land faunas, and therefore that the chronological value of the one series of faunas has in no case a necessary relation to that of the other, or no other than a common secular relation,* which is at best obscure.

The relation of the marine to the nonmarine aquatic faunas is less incongruous than it is in the case of the land faunas already noticed, the respective members of nonmarine faunas having much in common with corresponding members of marine faunas as regards zoological affinity. Such a relation, however, does not make nonmarine fossil faunas of concurrent chronological value with the marine, because of the conspicuous fact that the rate of both progressive and differential evolution has been remarkably slow in the case of nonmarine, especially

*The difficulty or impossibility of correlating marine deposits with those of nonmarine origin is discussed at the close of Essay VI.

fresh-water faunas. Among illustrations of this tardiness of evolution may be mentioned the close similarity to one another of the Jurassic, Cretaceous, Tertiary, and recent fresh-water molluscan faunas, and also the fact that much the greater part of the ancient ichthyic types which have survived to the present day are found among the fresh-water fishes.

The foregoing comparisons have been made between marine faunas on the one hand and all other faunas and the land floras on the other. When we come to compare the various kinds of land animals with one another, and with land plants, we find that while reciprocal biological relation between them is more or less intimate in certain respects, there is no such relation as would necessarily have produced a concurrent rate of progressive evolution in all of them. On the contrary, when we come to examine the fossil land faunas and floras we find that there has been a great difference among them as to the rate of progressive evolution for each, and also a marked difference in the relative extent of differential evolution.

For example, the earliest known dinosaurs were introduced before the earliest known dicotyledonous plants. The former, after a wonderfully differentiated development, became extinct, together with the enaliosaurs, about the time of the introduction of the earliest known of the placental mammals. Other reptilian families, and even closely related genera, which were contemporary with the dinosaurs and enaliosaurs, have survived to the present day. Long before the extinction of the dinosaurs, and before the introduction of the earliest known placental mammals, a dicotyledonous flora prevailed, composed largely of families which are well represented by living plants, several of which families contain genera that are common among living floras.*

Up to the close of the Cretaceous the general rate of progressive evolution of land plants was, as shown in the preceding essay, more rapid for North America than for Europe; but it was afterward much less rapid on this continent than was that of the contemporary placental mammals.

For the time that the dinosaurs are known to have existed their rate of progressive evolution was very slow and their differential evolution very great. That is, while their differential evolution resulted in an infinite variety of forms and their adaptation to the greatest extremes in methods of locomotion and of dietetic subsistence, the average biological rank of the Jurassic and Cretaceous dinosaurs seems not to have been appreciably higher than is that of their Triassic predecessors. Indeed, it is an admitted fact that many of the latest known North American dinosaurs have strong Jurassic affinities; and it may also be remarked that the affinities of their associated nonplacental mammalian remains are similar in this respect.

*All these comparisons are made with special reference to North American paleontology.

Two extremes of rate of evolution are exemplified by the fresh-water mollusca on the one hand and the placental mammals on the other. The evolution of the former has been slower than that of any other animals of equal biological rank, and the evolution of the latter more rapid than that of any others, even among their contemporary forms of life.

Applying the foregoing statements to the methods which have been adopted in the construction of the geological scale and in the recognition of its divisions, we observe that for the portion which may reasonably be assumed to represent fully the first half of geological time the work has been accomplished entirely by means of marine invertebrate fossils. These only were available for that purpose, but they were sufficient. We further find that the remainder of the Paleozoic portion of the scale was constructed by means of marine invertebrate remains with only the auxiliary aid of plant and fish remains. The latter aid was not really necessary, because the succession and completeness of Paleozoic marine life was unbroken, and the remains which those forms of life afforded constitute of themselves abundant material for characterizing consecutive divisions of the scale.

The opinion formerly prevailed among geologists that at the close of Paleozoic time there was a material and general break in the succession of marine life coincident with that which was assumed to have taken place in the case of land plants, and which was also assumed to have been at least approximately coincident with the introduction of dinosaurs, birds, and nonplacental mammals.

It is now known, however, that the succession of marine invertebrate life was as complete from Paleozoic to Mesozoic time and from Mesozoic to Cenozoic time as it was for any other portions of the geological scale. Furthermore the remains of Mesozoic and Cenozoic marine invertebrates are as sufficient for the characterization of those divisions of the scale as are remains of marine invertebrates for the Paleozoic portion.

It is thus apparent that there has been a continuous and full succession of marine invertebrate life through the whole time range of the geological scale, and that its remains are as sufficient as any fossil remains can be for the characterization of every one of its divisions wherever they are represented by fossiliferous rocks of marine origin. Furthermore, from the beginning to the end of geological time, there has been a good degree of uniformity of the rate of development of marine invertebrates, and the reciprocal relation of the various kinds to one another, so far as concerns its bearing upon geological questions, has always been intimate and of a comparatively uniform character. Therefore, the paleontological record which they have produced is to a great degree complete in itself and harmonious in all its parts.

On the other hand it is apparent that the longest known time range of the fossil remains of any of the other kinds of animals or of land plants falls very far short of the full range of the scale, while the range of each of the more important of these kinds is at best through only a portion of the later half of the scale. Besides this, the incongruity which has been shown to have existed between the different kinds of these nonmarine and land animals and land plants respectively, and the difference in the rate of evolution of each, were such that their respective time ranges could not have been so complemental of one another as to constitute of themselves a consecutive and harmonious paleontological record for that portion of the geological scale in which they occur. At least a record thus produced could not have been so complete as is that which has been produced for the whole scale by the combined ranges of the different kinds of marine invertebrates.

If the fossil remains of the nonmarine and land faunas and land floras can not be used conjointly as a standard for the characterization and recognition of the divisions of the geological scale it is evident that none of the kinds which they embrace can be separately so used. It has been claimed by some authors that, although their complexity of structure was the predisposing cause, the exciting cause of the remarkably rapid progressive, and the wide differential, evolution of the placental mammals was their sensitiveness to physical changes which were so slight that they produced little or no effect upon associated faunas. They further claim that this sensitiveness to slight physical changes has made the remains of those animals more valuable as indicators of the divisions of geological time than are any other fossil remains.

Whatever may have been the cause of the rapid changes which took place among those mammals it is true that their remains are often valuable for distinguishing subordinate horizons which other fossils do not clearly indicate. It is plain, however, that a chronological classification based upon such rapidly changing forms alone will not harmonize with that which we are obliged to use for all that great earlier portion of the scale in the strata of which such remains do not occur, nor with the continuation of that classification which is necessarily used for the remaining portion of the scale.

If the remains which the placental mammals have left had shown any such approach to a direct succession of faunas as have the marine, and especially the nonmarine, invertebrates they would be much more valuable in the way just mentioned than they are now found to be. That is, there are great faunal breaks among themselves so far as their succession is known, and an especially wide faunal hiatus between the earliest of them and the nonplacental mammals and the dinosaurs which preceded them, while the known succession or continuous existence of species of gill-bearing mollusks show that the stratigraphic record is continuous.

For example, certain species of gill-bearing fresh water mollusks are found associated with dinosaurian remains in the interior region of

North America, and the same species have been found in an overlying formation which is characterized by an abundant placental mammalian fauna. Such a survival of gill-bearing mollusks implies the continuation of a congenial aquatic habitat, continuous sedimentation, and a continuous record of time. In this way specific molluscan forms are found to have bridged the gap between characteristic mesozoic, and equally characteristic cenozoic vertebrate forms so far as the existence of the latter has been proved by the discovery of fossil remains. It is, therefore, evident that neither the exceptionally rapid rate of evolution like that of the placental mammals, nor the exceptionally slow rate, like that of the fresh water mollusca, can be used independently as a standard of geological time.

It has been shown on preceding pages that it is the general advancement in biological rank for all organic forms and for the whole of geological time that constitutes the ideal ultimate standard of measure for that time. It does not necessarily follow, however, that the geological scale is actually based upon the combined average rate of advancement of all those forms because this is a factor which can not be definitely ascertained. Still, in all cases it is necessary to apply that idea so far as is practicable.

In view of the facts recorded in the preceding paragraphs we must necessarily place the highest estimate of chronological value upon the fossil remains of those kinds which have existed under the most nearly uniform conditions through the whole of geological time, and which give evidence of the most nearly uniform advancement in biological rank. Accordingly the remains of marine invertebrates possess legitimate claims to a higher estimate of chronological value than do those of any other kinds of animals or of plants.

It is true that the rate of development in biological rank of marine invertebrates does not embrace the entire advance for the whole animal kingdom because it begins in the scale as it is now known with many highly organized forms and ends without including the vertebrates, but this fact does not affect any of the necessary elements of their superior chronological value which have just been mentioned. The following summary of facts relating to the marine invertebrates show their principal claims to the highest estimate of value in characterizing the divisions of the geological scale and in determining the geological age of the strata in which their remains are found.

The marine invertebrates embrace five of the six subkingdoms or branches of the animal kingdom.

They have coexisted in every stage of geological time while the known time-range of other animals, as well as of land plants, has been very much less.

The preservation of their remains having been a natural consequence of the character of their habitat they are faunally more complete than are those of any land animals, and for the same reason they are florally more complete than are remains of land plants.

They all lived under the same or closely similar conditions, and those conditions were more nearly uniform throughout all geological time than were those under which any other forms of life existed. Their remains have, therefore, produced a more nearly uniform chronological record.

Their relations to one another were wholly congruous, while the relations of all of them to all nonmarine faunas and land floras was more or less incongruous, and in many cases extremely so.

The formations containing their remains are for the whole world and the whole of the geological scale far in excess of those which contain the remains of any other forms of life, especially the remains of land plants and land animals.

VI.—CORRELATIVE GEOLOGY AND ITS CRITERIA.

The term correlative geology is not in common use but it is adopted as a present convenience in discussing the correlation of assemblages of strata as divisions or subdivisions of the geological scale as it is developed in separate regions, and the identification of formations within one and the same district or region. As here used the term correlation refers to geological systems or other comprehensive series of stratified rocks which occur in different and more or less widely separated parts of the world between which parts there is no physical continuity of strata, or none that it is possible to discover. Correlation applies to general geology, identification to local or regional investigations.

The latter may be discussed under two heads, direct and relative. Direct identification applies to formations the characteristics of which at one or more localities have been ascertained, and as these are naturally of limited geographical extent* the application is similarly restricted.

If a formation were exposed at the surface throughout its whole geographical extent its identity at all points would be self-evident, but all formations being more or less covered from view by one another or by surface débris, they are usually accessible for study only where they have been corraded by drainage streams or brought to the surface by movements of the earth's crust where their exposure has been effected by subaerial erosion and denudation. It is at such localities only that they can be satisfactorily identified, but such identification implies the actual or original continuity of the formation between all the localities at which the identification has been made.

It is the identification of formations and not their characterization which is here discussed. The latter, as indicated in Essay II, must be determined by original studies at one or more localities from a variety of data, chief among which are the biological, although the physical are always indispensable, while identification refers to a recognition of those characteristics elsewhere.

Specific identity of fossils affords the surest test of the direct identity of a formation at localities between which its physical continuity can not be traced, but lithological similarity, general evidence of homogeny and other physical indications are often efficient aids in such identification, and in case of failure of biological evidence they are often in a good degree satisfactory.

By the term relative identification is meant the recognition of the proper place of a given formation in a series the taxonomic order of

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* The term formation is herein used in accordance with the restricted definition and the characterization which are given in Essay II.

which has been determined by the previous study of formations which have been directly identified. Therefore, while direct identification is confined to the geological limits of separate formations, relative identification may extend throughout a large region by the overlapping of formations. Such a recognition of the taxonomic position of formations is usually the direct result of empirical study of a given series within a limited region, but it is often the result of those philosophical studies which have been made in connection with the construction of the great geological scale, especially in cases where a wide time-hiatus exists between formations.* The latter, however, approaches correlation in character.

Identification, except in the relative cases just mentioned, is always the result of empirical studies; but correlation is more philosophically determined. The latter not only implies the existence of closely similar biological characteristics in systems or series of formations in different and widely separated parts of the world, but in each case it has reference to a similarity of relation to preceding and succeeding series of formations respectively. That is, correlation relates to the serial recognition of the various divisions of the geological scale in more or less widely separated parts of the world, and is based wholly upon biology, those divisions coinciding with stages in the evolutional progress of development of organic forms which has occurred during geological time.

In the practical study of the structural geology of a region the principal use of correlation is to apply universally acceptable names to the different groups of formation. That is, the structural geology of great regions, or even of the greater part if not the whole of continents, may be minutely and comprehensively studied and all the stratified rocks accurately classified in chronological order by means of direct and relative identification of formations and without necessary reference to their correlation with those of any other part of the world except as a means of detecting such cases of wide time-hiatus between formations as are not otherwise clearly revealed.

Because fossil remains constitute the principal criteria in the practical identification of formations it is desirable in this connection to consider the relative value of the different kinds for this purpose, although the subject has been briefly discussed and frequently referred to in the preceding essays.

Fossils being the remains of animals and plants most of the principal kinds of which lived under different physical conditions, some of them have a more direct relation than others to the formations in which they are found. Therefore they differ materially as to their

* What I have here designated as relative identification has often been by authors included under the head of correlation. I also have done so in Bulletin U. S. Geological Survey, No. 82, pp 17-25, but the more clearly to state the principles involved I herein restrict the use of that term as indicated in preceding paragraphs.

relative value in the identification of formations. Naturally the remains of aquatic faunas exceed all others in value for this purpose because the faunas not only found a congenial habitat in the waters in which were deposited the formations that now contain their fossil remains, but they could have existed in no other. Their whole life history, with the minor exception of migratory fishes, especially such as entered nonmarine waters, was therefore intimately and wholly connected with the production of those formations.

A large proportion of all the formations which are characterized by the remains of aquatic faunas contain none of land faunas and floras, but in other formations remains of the latter kind are found commingled with those of aquatic faunas. In all such cases the remains of land faunas and floras reached their intombment by accidental means while the intombment of the remains of aquatic faunas was a natural result of the character of their habitat. Moreover, all the members of extinct aquatic faunas which possessed fossilizable parts are likely to have been represented by fossil remains, because in their intombment they were not separated from their habitat, while the intombment of all remains of land faunas and floras was not only accidental but necessarily partial as regards the faunas and floras from which they were derived.*

Again, the existence of every extinct aquatic fauna had not only an intimate connection with the conditions which produced the formation in which the remains are found, but it began its existence as a fauna with the establishment of those conditions and was extinguished as such when the conditions were changed, and largely or wholly in consequence of the change. It might easily, and evidently often did, happen that changes of physical conditions which caused the extinction of one aquatic fauna and the introduction of a succeeding one would not materially affect the continued existence of the fauna and flora of the adjacent land which were contemporary with the extinguished fauna. In such a case the land fauna or flora began its existence before, or continued it after, that of the aquatic fauna, or its existence may have extended continuously from the epoch before to that after the one in which the aquatic fauna lived. In such a case also, while the aquatic fauna was characteristic of only one formation and one epoch, the land fauna and flora may have characterized two or three formations and as many epochs. Furthermore, geologists sometimes find evidence from the association of their remains with those of aquatic faunas that land faunas and floras were repeatedly and materially changed during a period within which aquatic faunas of the same region suffered comparatively little change.

It is true, as mentioned in those paragraphs of essay II, in which methods of defining and characterizing formations are discussed, that

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*See pages 254–261.

fossil remains of certain kinds of land animals and plants may be and often are found only within the limits of a given formation, and in that respect they may be regarded as characteristic of it; but that does not affect the accuracy of the foregoing statements.

The foregoing comparisons of the relative value of fossil remains of aquatic and terrestrial animals can not be of unlimited application because no remains of terrestrial animals have been found in the formations of the earlier geological periods, and it is generally believed that none existed then. Indeed, such comparisons are of little applicability in the case of any formations earlier than the Mesozoic, and they mainly pertain to the Cenozoic.

The facts mentioned in the foregoing paragraphs have far-reaching significance other than that which directly relates to the identification of formations. They are to be again mentioned, but only for the purpose of showing that whatever of value fossil remains of land animals and plants may possess other than that which has been referred to, they are, as a rule, of much less value in identifying and characterizing formations than are those of aquatic animals.

Marine waters having always been of world-wide extent, and marine conditions more nearly uniform or subject to far less vicissitude than either nonmarine or terrestrial conditions, the fossil remains of the marine faunas naturally constitute a better medium for a continous chronological record by organic evolution than do those of terrestrial faunas and floras or those of fresh-water faunas. This fact, however, does not make the fossil remains of fresh-water faunas any less trustworthy than are those of marine faunas for the identification of the formations which they characterize.*

With the exception of fishes and a few mammals and reptiles vertebrates of the kinds whose remains are available in geological studies are mostly land animals, while those of invertebrates of the kinds whose remains are thus available are mostly aquatic animals. The superior value of the latter has already been pointed out; but it should be added that remains of fishes, in case of equally complete faunal representation, are of no less value than are those of aquatic invertebrates. The migratory habits of a greater or less proportion of fishes, however, has in some cases caused their remains to be commingled with those of more than one fauna and to be deposited in more than one formation.

The remains of other vertebrate aquatic animals are sometimes available in the identification of formations, but they are generally of less value than are the remains of fishes, because the aerial respiration and amphibious habits of most of them generally restricted their range within narrower limits. Furthermore, their range in geological time is even less extended than that of fishes. That is, air-breathing vertebrates are not yet known to have existed earlier than the Carboniferous, and

* For discussions of this subject see pages 281–283.

during that age they were comparatively unimportant. Although fishes existed earlier than other vertebrates, their remains afford little material for comparison with those of invertebrates in earlier rocks than those of Devonian age. Therefore the identification of all those earlier formations, comprising a large part of the whole geological series, must be made by means of invertebrate remains alone.

When considering the relative value of fossil remains of animals and plants in the identification of formations, only terrestrial plants* are worthy of notice, because of the low grade of aquatic plants proper, and because our definite knowledge of terrestrial plants extends no farther back in geological time than the Devonian. Furthermore, their remains being very rare in rocks of that age, a satisfactory comparison of plant remains with those of animals is necessarily restricted to formations of the Carboniferous and later ages.

Again, the disparity of value between the remains of aquatic and terrestrial faunas, which has already been mentioned, is not only equally great between those aquatic faunas and land floras, but for reasons stated in Essay I plant remains in all cases much less completely represent the floras from which they were derived than do the remains of aquatic animals the faunas in which they originated.

From the foregoing statements it is seen that, although fossils in all cases constitute not only much the most, but usually the only, trustworthy criteria for such identification of formations as is indispensable in the study of structural geology, the various kinds differ materially as to their relative value. This value, however, has no necessary relation to that which they may possess as indicators of geological time or of the correlation of the strata containing them with those of other parts of the world. The two values are distinct, although one kind of fossil remains may often possess both.

Other criteria of identification than those of fossil remains were briefly referred to in a preceding paragraph as being chiefly homogeny and lithological similarity, both of which are valuable aids when paleontological criteria are deficient, and both may often be relied upon in cases of the absence of those criteria. Except in the more or less constant use of lithological characteristics, that ought always to be made in connection with the biological identification of formations, those characteristics are at best of limited applicability as criteria, and they are available only in either direct or indirect relation to biological criteria. Their indirect availability is that which has just been referred to. Their direct availability is mainly in connection with what in a preceding paragraph has been designated as relative identification, because it can be made only with reference to some one or more of already known biological horizons.

Sometimes the relative stratigraphical position of a single unfossiliferous sedimentary formation may be determined by means of its relation to

* Palustral plants are included in this designation.

those which underlie and overlie it and which have been biologically identified, or the relative age of a formation of volcanic origin intercalated between known fossiliferous formations may be thus determined. Again, there may be a great series of unfossiliferous stratified rocks, such as is the pre-Cambrian, the divisions of which are identifiable by means of lithological criteria aided by the general evidence of homogeny.

In the case of single unfossiliferous sedimentary formations such as have just been referred to, their relative identity is determinable by the underlying and overlying fossiliferous formations. The same is true in case of the formations of volcanic origin which have also been referred to, the claim formerly made that the geological age of this kind of rocks can be determined by the mineral composition having been generally abandoned. The geological age of the pre-Cambrian formations also have not been determined by any inherent evidence, but only by their ascertained stratigraphic relation to the fossiliferous Cambrian rocks. That is, their geological age or relative identification could be ascertained only by reference to biological criteria.

While fossil remains unquestionably afford the most trustworthy and often the only means of either direct or indirect identification of formations, in the absence of these means the geologist often reaches conclusions in this respect by methods of reasoning that it would be difficult even for himself to formulate, and these conclusions are valuable in proportion to his acquirements and experience. Among these less clearly definable methods is that which takes cognizance of homogeny; that is, of a method in connection with which certain inherent lithological and stratigraphical characteristics, which are possessed by a formation or series of strata in one part of a given region under investigation, are accepted as evidence that it had a common origin with a formation or series presenting similar characteristics in another part of the same region. Such a conclusion necessarily implies that originally there was physical continuity of similar strata between such localities, and that it has either been destroyed or obscured.

This method of identifying formations is one of minor importance as compared with that which is based upon fossil remains, but unfortunately it has, especially within the last few years, been adopted by certain geologists in charge of important works almost to the entire exclusion of paleontological considerations. Although it can not be denied that in the hands of an experienced and broad-minded investigator this method of identifying formations is of great value, the fact remains that some of the most grievous mistakes that have ever thrown discredit upon geological investigation have occurred by its adoption to the exclusion of paleontological evidence.

The term correlation, as restricted by the preceding definition and distinguished from identification, is applied to a comparison of the stages and substages of the geological scale as they are respectively recognizable in distinctly separate regions. Such regions as are referred to are now separated from one another by intervening broad bodies of water beneath which there may or may not have ever been stratigraphical continuity, or by terrestrial conditions which have made it impossible to trace such continuity if it ever existed.

Thus, while correlation in this restricted sense is usually confined to a comparison of great series of stratified rocks as they occur on separate continents, it is sometimes quite as applicable to different parts of one and the same continent as is the case, for example, with the eastern and western portions of North America.

In considering the subject of correlation as thus restricted, we find that it not only depends quite as fully upon the study of fossil remains as does the identification of formations, but having reference to regions too distinctly separate from one another to have recognizable stratigraphical continuity between them, such questions as those pertaining to physical characteristics and identity are eliminated. We also find that the manner of dependence upon fossil remains in the two classes of cases is different; that is, in the one case it is mainly specific identification that is relied upon, and in the other reliance is placed only upon the recognition of various general faunal and floral types, such as are referred to on pages 296–300.

As was stated in Essay II, formations being physical units of local, but not universal, stratigraphic classification, the term identification is especially appropriate when referring to studies of their relation to one another in the field. The determination of correlation is also in some sense an act of identification; that is, it is the identification, or, more properly speaking, the recognition of the divisions or subdivisions of the great geological scale in different and distinctly separate parts of the world. The fact that the divisions and subdivisions of the scale may thus be more or less completely recognized being fully admitted by all geologists, the only question that need be discussed in that connection relates to the manner of their characterization, the distinctness of their limitation, the completeness of their representation, and to synchronism or contemporaneity and homotaxy.

The idea of correlation presupposes a standard, and as every standard must be either absolute or conventional it is necessary to consider what must be the character of one by which correlation as herein defined may be recognized, because upon this depends an intelligible discussion of the subject. If the standard of correlation is an absolute one, there can be no question as to the definiteness and completeness of its applicability in all cases and in all parts of the world where the necessary observations can be made. If, however, the standard is a conventional one, its recognition as such implies more or less uncertainty as to the definiteness and completeness of its universal applicability, but a conventional standard may be based upon such an array of admissible facts that in all cases where those facts are recognizable uncertainty and indefiniteness in its practical application are reduced to comparatively narrow limits. This, briefly, is my conception of the true character of the only standard of correlation that may legitimately be used, because it is the only one that agrees with a rational interpretation of natural laws.

It has, however, been the custom of a large proportion of geologists to regard the geological scale as it has been established in Europe as the absolute standard for the whole earth. A necessary consequence of this view is their assumption that the systems which physically constitute that scale, and at least most of the divisions of those systems, may not only be recognized, but as clearly defined in all parts of the earth as they are in Europe, if in those parts contemporaneous deposits were made and still remain intact.

While fully accepting the fact of the existence of a rational standard of correlation and of its great practical value, it is my purpose to oppose the idea of its absoluteness which is still entertained by many geologists, and which was formerly entertained by all. Before proceeding with those remarks, however, it is desirable to inquire briefly as to the origin of that idea and the probable reason of its survival, and to refer to other ideas which were entertained by the early geologists but which have long been abandoned.

One of the abandoned ideas referred to relates to the recognition of lithological identity as a criterion of correlation. This idea is indicated in various ways by the writings of those early authors and to some extent by their application of names to the divisions of the scale—such, for example, as Old Red Sandstone and New Red Sandstone* for the Devonian and Triassic systems, respectively. Another relates to the degree of consolidation or compactness that sedimentary rocks have acquired, and still another to the degree of general disturbance which they have suffered. As already stated, those pioneers regarded these conditions as indicating relative age and also as being an aid to lithological identification as a criterion of correlation.

These ideas were abandoned because they were found to be untenable even from the standpoint of their originators, and yet they are scarcely less rational than is that which ascribes absoluteness to the European scale as a standard of correlation. The only cause that I can suggest for the survival of the latter idea while the former ideas have been abandoned is a general conservative disinclination of the mind to adjust itself to new methods of thought, especially if the old methods have been rendered plausible by artificial adjustment to indisputable facts, and are intricate by the complex nature of the subject. The idea of the chronological value in the study of systematic geology of lithological character and conditions seems to have been abandoned not only because it was fallacious but because the portion of the subject to

* The Permian was by the early geologists sometimes included with the Triassic under the name New Red Sandstone.

which it pertains not being complex the idea was readily dismissed. The idea of the absoluteness of the geological scale now in general use as a standard for the whole earth pertains to an unusually complex subject, involving various concurrent lines of systematic thought. It was probably for this reason that it was not fully dislodged even by the great biological revolution which has been referred to in the last essay, notwithstanding the fact that its subject is essentially a biological one.

Originally the idea of correlation involved that of actual and complete contemporaneity. That is, in accordance with their belief in special creations the early geologists assumed that every faunal and floral type, as well as every species, having been specially created* each one of those types which characterize any given stage or substage of the geological scale was simultaneously deposited. They also believed that all the divisions and subdivisions of the geological scale were divinely ordained and sharply definable, and their acceptance of that scale as an absolute universal standard of correlation was a necessary result of that belief. Notwithstanding the great revolution in methods of biological thought and practice which has been referred to, paleontological literature abounds with proof that the idea of absoluteness of correlation is still held even by authors who ostensibly reject all the beliefs which alone could have given origin to such an idea.

Sufficient reasons have been given why formations as such can not be considered in discussing correlation, but I again refer to the fact for the purpose of emphasizing the statements that true correlation is essentially a biological and not a physical matter, that its application is necessarily restricted to divisions of the geological scale that are more comprehensive than those which may be represented by even the greatest of the formations as they are defined in Essay II, and that in the determination of such correlation specific identity of fossils can rarely be considered. It is therefore necessary to consider what divisions of the scale may be satisfactorily correlated and what are the character and attributes of the biological forms that constitute the criteria of their correlation.

Naturally the larger divisions of the scale are more readily recognizable than are the smaller, because, besides other reasons, the faunal and floral characteristics of the former are more general than are those of the latter, and their vertical range also is greater. Thus the systems, or stages, as I have designated them on preceding pages when discussing the geological scale, are readily recognizable in widely separated parts of the world by means of more or less numerous general types of fossil forms, while the characteristic types of their divisions are fewer and more special. By means of those more general indications the whole series of systems from the Cambrian to the Tertiary, inclu-

* See pages 291–299.

sive, are recognizable in North America with as much certainty as they are in Europe, although some of them, the Triassic and Jurassic, for example, have not been so completely recognized.

On the other hand the recognition of the substages, or division of systems, which are more or less clearly definable in Europe, has in no case been made with rational satisfaction in North America, although many geologists have attempted their full recognition on this continent, and some have even attempted that of secondary divisions of systems not only in North America but in other parts of the world, by means of their European characteristics.

I do not mean to say that at least some of the more general divisions of systems are not distinguishable in North America as well as in Europe, such for example as the Upper, Middle and Lower Devonian, Upper and Lower Cretaceous, etc. I also do not mean to say that certain of the faunal and floral types which characterize divisions or substages, such as those of the European Cretaceous from the Neocomian to the Danian, inclusive, as well as similar divisions of other systems, have not been discovered in North American strata and in those of other parts of the world.*

I claim, however, that while the systems are satisfactorily recognizable as already stated, their upper and lower limits are often illy definable, and that they often do not accord with the recognized limits in Europe, and that the same is also the case with the large general divisions of systems referred to. Furthermore, I claim that in case of the presence in North American strata of types which characterize any of those divisions of the European Cretaceous and other systems just referred to they are so often commingled with certain of those types which characterize one or more other divisions of the same system there that they can not have the same chronological significance on the two continents. That is, types which are characteristic of different divisions of a system in Europe, and which occur there in a certain order of succession, are known to occur in American divisions of the same system in a different order of succession. It is therefore evident that the presence in a group of American strata of any one, or even more, of the types which characterize a given division of a system in Europe does not prove the absolute identity of that division in America.

Although, as before stated, all the systems of the European scale have been satisfactorily recognized in North America, their upper and lower limits are not only often illy definable and sometimes discordant with those of corresponding systems in Europe, but those limits have been designated as occurring at different horizons by those geologists respectively who rely upon different kinds of fossil remains. For exam-

*Although I more particularly compare North American strata with those of Europe, and oftener refer to the Cretaceous system than to others, I assume that the facts and principles involved are of world-wide application.

ple, abundant remains of a flora, consisting of types which in Europe are characteristically Tertiary, are found in American strata, which are shown by all other known evidence, which is abundant, to be of Cretaceous age. Again nonplacental mammalian remains of generally accepted Jurassic types are found in American strata which other evidence shows can not be of earlier age than the uppermost Cretaceous, if, indeed, they are not of Tertiary age. Associated with these mammalian remains are those of dinosaurs which are so characteristic of that great subclass in its prime, and show so little evidence of its decadence that when they were first discovered they were believed to be of Jurassic age.

The cause of this association of types in the strata of certain systems, or in those of certain of its divisions as they occur in some parts of the world with those which characterize other systems or others of their divisions in another part, must be sought in the facts and principles stated in the propositions and remarks on pages 293 to 300, which propositions have been presented for the purpose of such reference. From the facts thus stated and referred to it may be seen that such a commingling of types, so far from being an abnormal condition, is wholly natural and what ought to be expected. It is thus shown that the average rate of progressive evolution which produced the types that characterize the different systems and their respective divisions was not the same in all parts of the world for each of the different branches of the animal and vegetable kingdoms, nor the same for the same part of the world during all the time those branches have coexisted.

In view of the foregoing statements of facts and principles the idea held by the early geologists, as well as by some of those now living, that identity of fossil types proves synchronism or exact contemporaneity of origin of any two or more series of strata containing them, is quite untenable. The facts which have been presented also suggest that the term homotaxy must be used with some degree of latitude as to its application to the subdivisions of systems, because the order of sequence in the occurrence of the types which characterize them, respectively, in one part of the world is in another part sometimes partially reversed or partially interchanged. That is, the taxonomy of those subdivisions as biologically indicated is not the same for all parts of the world.

Although the foregoing statements contain expressions of earnest dissent from certain views which have been more or less prevalent, it is not to be inferred that I discard any of the legitimate principles upon which correlative and historical geology are based. Indeed, the evidence is incontestable that the successive stages of the geological scale were in a general but an effective way characterized by peculiar secularly developed groups of organic types, and that those types have wonderfully wide distribution within their respective stages. With reference to such characterization it is the adequacy of those types to sharply define the limits of stages or to clearly identify substages in widely separated parts of the world that I deny. This denial, of course, implies what has before been stated, that the geological scale now in general use is not an absolute standard for the correlation of the stratified rocks of the whole earth, but I repeat what was said in connection with that statement, that this scale is unquestionably the best that it has been possible to devise, and make the additional statement that it needs adjustment rather than material change.*

The foregoing discussions having required frequent reference to certain erroneous views which have prevailed upon the subject of correlation that subject has necessarily been somewhat antagonistically presented. That is, its scope has been to a large extent negatively rather than positively indicated.

It has been shown that the presence in widely separated parts of the world of all the systems of the geological scale, as well as of some of their larger divisions, has been demonstrated by the labors of a multitude of geologists and that the fact of correlation is therefore not to be called in question. The principal questions which have been raised concern the scope of correlation or the limitation of the assemblages of strata the relation of which to respective divisions of the scale is more or less obvious. These questions are of practical application in the study of the structural geology of any part of the world other than that in which the geological scale was established, but they are of such a character that they must be conventionally rather than arbitrarily determined.

For example, in discussing the questions which have arisen concerning the earlier and later limits of the systems of the geological scale in North America the difference of opinion as to those limits have been wider and more various with regard to the later systems than to the earlier. This is because of the greater number and variety of the kinds of fossil remains to be considered in such discussions of the later systems, their difference from the earlier in this respect being plainly indicated by the table on Plate XIV, and by the accompanying statements relating to it. It is therefore evident that in reaching a conclusion as to the limitation of any of these systems, or of any of their subdivisions, it is necessary to take into consideration all available facts, physical as well as well biological. It is equally evident that it is the duty of every American geologist to hold in abeyance any final decision as to the correlation of the groups of strata which he may study with divisions of the European scale until all such facts have been duly and

*Although the views concerning correlation which are enunciated in this essay are opposed to those which were generally held by the early geologists, some of those pioneers held views which are much in accord with those herein advocated. See, for example, de la Beche, Henry T.: Sketch of a Classification of the European Rocks. Am. Jour. Sci., 1st ser. Vol. XVIII, pp. 26–37, 1830.

justly considered. In short, the idea of absoluteness in such cases is as much out of place as is the assertion or recognition of personal authority.

Although the remarks in the last paragraph refer directly to North American geology and geologists, they are equally applicable to other parts of the world when reference is made to the scale as represented by the European rocks.

Notwithstanding the great excellence of the scale now in general use and the fact that so little change has been made in it since it was first devised by the early geologists, the future progress of geological science will demand modifications the necessity for which will be especially urgent when the true character of correlation for all the principal parts of the earth has been ascertained. Hitherto correlation has been investigated with the single purpose of adjusting the series of formations which occur in each of the various parts of the world to the scale now in use, but although its general applicability to that purpose is not to be questioned the ultimate result of the study of correlation will be to modify this scale and adjust it to the systematic geology of the whole earth. That is, the scheme of stratigraphic classification which has been the main factor in adjusting the elements of systematic geology, must in turn be itself adjusted to the great system which it will have been the principal agent in producing.

There is another subject which properly pertains to correlative geology, but which does not come under the head of identification of formations and only in part under that of correlation as the term has been defined and the subject discussed on preceding pages. It relates to the great obscurity or absence of evidence of chronological relation between the marine and fresh water deposits which may occur upon one and the same continent, and also to the equally great uncertainty as to the correlation with one another of the nonmarine deposits of widely separated parts of the earth.

When the geologist is seeking to systematically classify the formations of a continent or region which consist of both marine and fresh water deposits, among the physical facts with which he is confronted is that in no case can a formation of one of these kinds be continuous with one of the other kind because they were necessarily deposited in separate bodies of water. Therefore there can in no case be any direct physical proof of contemporaneity of a fresh-water with a marine formation, and there can be no physical indication of chronological relation between them except in case of observable superposition. These remarks are made with special reference to intracontinental fresh-water deposits on the one hand and border-region marine deposits on the other.

He is also confronted with the biological fact stated on preceding pages that the fossil faunas pertaining to fresh-water formations are so different from those pertaining to marine formations, and the two kinds are so incongruous in their respective characters, even in case of actual contemporaneity of origin, that they can not be used as concurrent chronological evidence.

The latter statement applies chiefly to the remains of aquatic faunas, but the case is little if any changed by the association with them of remains of land faunas and floras unless such faunas and floras should be represented in the fresh-water as well as the marine formation. Such association and identity are to be regarded as the only direct evidence of contemporaneity of a fresh-water and marine deposit. All other evidence is indirect and of more or less uncertain value.

Such a dual commingling of remains of a land fauna and flora with those of aquatic faunas implies that the two bodies of water in which the commingling took place were separated by a land area, the whole breadth of which was occupied by the fauna and flora represented by the remains. It also implies that those remains reached their intombment in the sediments of both bodies of water in the manner described in Essay I. It is a fact, however, as already pointed out, that remains of land animals and plants are very rarely found in marine deposits, even in case there is reason to believe they lived abundantly in the vicinity of the waters in which those deposits were made. This circumstance greatly lessens the chances of discovering direct proof of contemporaneity of fresh water and marine formations.

The indirect evidence of contemporaneity of fresh water and marine formations which may occur upon one and the same continent is in part that which is afforded by the position of each in their order of succession in a series of formations of known geological age, and in part that which pertains to the general subject of correlation. I have already shown that the best of the evidence which pertains to that subject, especially when applied to so small a portion of the geological scale as is represented by even the greatest of the fresh water formations or series of deposits, is of very uncertain value. I may now add that such evidence is still less valuable when it rests upon the remains of fresh-water faunas alone, because of their remarkably slow evolution, both progressive and differential, during the whole of that portion of geological time in which they are known to have existed. It should also be stated that whatever of accuracy may have been attained in assigning the fresh water formations of Europe to their respective taxonomic positions in the geological scale it does not necessarily follow that fresh water formations upon other continents bearing closely similar faunal and floral fossil remains can be assigned upon such evidence alone to exactly the same taxonomic positions. Therefore, in attempting to correlate interior fresh-water formations with border region marine formations, such as those which occur in North America, for example, the geologist must, as a rule, to which no exceptions are yet known, rely upon general indications and cumulative evidence.

VII. CRITERIA OF PAST AQUEOUS CONDITIONS.

Among the more conspicuous facts in geology are some of those which relate to the manner of origin as well as to the original and present condition of the sedimentary formations. These subjects have been discussed at some length in Essay II, and among those discussions are some references to the character of the water in which each formation was deposited. Studies of the sedimentary formations, especially those made from a biological standpoint, have demonstrated that the bodies of water in which they were deposited were of the various kinds that are now known; that is, some were marine, some fresh, and some brackish.

It is by no means for biological reasons alone that it is desirable to obtain a knowledge of the character of formerly existing bodies of water and of the character of their respective aquatic faunas. On the contrary, such knowledge conveys important information concerning various subjects in general geology, notably concerning formerly existing physical conditions and many of the physical changes which took place from epoch to epoch of geological time. For example, the presence of a marine formation within any given geographical area shows that when it was deposited that area was beneath ocean level, and consequently that marine waters prevailed there. The presence of a nonmarine formation shows that land areas surrounded the body of water in which it was deposited and separated it more or less completely from marine waters. Therefore, an extensive nonmarine formation necessarily implies that a large land area, which may have been of continental extent, surrounded the body of water in which it was deposited.

In the present advanced state of geological knowledge the distinguishing characteristics of marine formations are well understood, because they have been exhaustively studied by geologists, and found to agree in general character with the faunas and deposits of existing seas, and because opportunities for the study of these formations are abundant in almost all parts of the world. For various reasons the distinguishing characteristics of nonmarine formations are generally not so thoroughly understood as are those of marine origin, among which reasons are their comparative rarity and usually their comparatively small geographical extent. Usually, also, they are not so abundantly fossiliferous as are marine formations, and, therefore, the principal means for their characterization are often not available. Moreover, these formations require some modification of the usual methods of investigation because they are themselves of different kinds, as is shown by inherent evidence possessed by each, and because they have in common certain characteristics which distinguish them from those of marine origin.

The facts which constitute the evidence as to the variety and character of the nonmarine formations, and that of their distinction from those of marine origin, are usually well understood by those geologists who are also naturalists because the subject to which they relate is mainly biological, but they are often not so well understood by the general reader, nor by those who pursue their geological studies wholly upon physical grounds. For these reasons the following statements and discussions, while they are in some respects necessarily technical, are, so far as practicable, expressed in an elementary manner.

The evidence that the greater part of the sedimentary rocks of the earth, those which constitute the formations containing the records of its past biological history, are of marine origin is based almost wholly upon the character of their contained fossil remains, and is, as has just been intimated, so abundant and complete that it can not be seriously questioned. That is, it is evident that they were deposited either in oceanic waters or in those of similar saltness whose geographical extent were more restricted by land areas, such, for example, as the present oceans on the one hand, and the Mediterranean and Red seas on the other. All these are designated as marine deposits, and the waters in which they were formed are understood to have rested at that world-wide level which is usually termed sea level, but which is herein written ocean level, because in this essay the term sea is used in a somewhat restricted sense.

The other sedimentary rocks were deposited in other than oceanic waters. Most of them so much resemble marine formations in lithological and stratigraphical character, that it is only by means of the peculiar character of their fossil remains that it is known that their deposition took place either in fresh waters or in those which contained salt in less proportion than it is contained in oceanic waters. All these are designated as nonmarine deposits. They usually occupy smaller districts than do marine deposits but a few of them rival the latter in thickness and geographical extent.

Nonmarine deposits are more varied in both character and origin than is indicated by the mere evidence which they may afford that salt was present in, or absent from, the waters in which they were accumulated, because the physical conditions were in each class of cases considerably different. Under the head of nonmarine sedimentary deposits are placed those which, from the inherent evidence they respectively afford, are assumed to have been formed in fluviatile, estuarine or lacustrine waters, or in the waters of lagoons, bays, or inland seas. The first three terms just mentioned are of themselves sufficient to indicate that the deposits to which they are applied were laid down in formerly existing rivers, estuaries or lakes. There are certain other nonmarine deposits with which the geologist sometimes comes in contact, namely, those of littoral and of palustral origin. The former are produced along the shores of broad bodies of water and the latter in the swamps and shoals which frequently border the same.

The terms lagoons and bays as here used are applied to such partially landlocked bodies of water as now exist along oceanic borders but which are often, at least in part, of less than marine saltness because of inflowing streams. The restricted use in this essay of the terms lake and inland sea is indicated in the following paragraphs:

In accordance with the elementary nature of these remarks it is thought desirable to briefly characterize the various kinds of existing bodies of water in which sediments similar to those which constitute the various sedimentary formations are now in process of deposition. Such a characterization is made to consist in part of an explanation of the special terms just referred to.

The term lake is properly applied, and ought to be restricted, to inland bodies of fresh water. It will be so used in this essay except in those cases where a contrary practice has resulted in a public recognition of such proper names as Great Salt lake, etc.

The source of the water supply of lakes is rainfall, which is drained into them from the surrounding land. It is therefore fresh in the ordinary acceptation of that term, but as it enters the lake it always contains at least a minute proportion of soluble salts derived from their original home, the land, by leaching. The amount of salts in such cases being inappreciable by gustatory test, lacustrine waters are properly designated as fresh, but to remain fresh a lake must have free outflow and not excessive evaporation from its surface. Otherwise it will become distinctly saline by the gradual accumulation of soluble salts which inflowing streams constantly bring from the land.

The term inland sea, as used in connection with the terms indicating other bodies of water and with reference to certain formations with which the geologist sometimes has to deal, is applied to any body of water more or less completely surrounded by land which holds in solution a sufficient proportion of saline matter to modify or characterize its aquatic fauna, or which holds a so much greater proportion as to be sufficient to prevent the existence in it of such a fauna. Therefore an inland sea, especially one that has an outlet, differs physically from a lake only by the presence of at least a readily appreciable amount of soluble salts in its waters. This restricted use of the term sea is warranted by prevalent custom with reference to the Black, Caspian, Dead, and other existing seas.

While the difference between inland seas and lakes is important as regards their respective aquatic faunas the distinguishing character of both is subject to change because in both cases it depends upon physical conditions the stability of which is uncertain, and because any considerable change of those conditions will result in a change of character. For example such a change in the physical conditions which surround a lake as would reduce the proportion of outflow to influx of water and increase evaporation from its surface would, according to the definition just given, change it to an inland sea. That is, soluble salts would accumulate in its waters to such an extent and of such a character as to modify or destroy its aquatic fauna. A reversal of such conditions would change an inland sea to a lake, because soluble salts would cease to accumulate in its waters and the previous surplus would gradually be removed by the free outflow which would result from such a change.

Inland seas may hold either more or less saline matter in solution than does the ocean. In those which by reason of having no outlet hold more, or hold a large proportion of other salts than sodium chloride, little or no gill-bearing animal life exists. Such seas may lie above ocean level, as does Great Salt lake, in Utah, or below it, as does the Dead sea.

But the waters of some existing inland seas which have no outlet have not yet become so impregnated with soluble salts as to destroy, or to prevent the accession of aquatic life. This is at present the condition of the Caspian sea, excepting some of its bays where from excessive evaporation the water contains an excess of saline matter, but if surrounding physical conditions continue the same as they now are the present average degree of saltness of this sea will continually increase. Its surface being more than 80 feet below ocean level it can of course have no outlet. The land area which is drained into it, being very large there is a considerable and constant accession of saline matter to its waters. Therefore it can not be doubted that if surrounding conditions should remain unchanged the natural increase of soluble saline matter will ultimately destroy all aquatic life in this sea.

The Black sea is an example of an inland sea lying nearly at ocean level, the difference between its level and that of the Mediterranean and of the ocean really amounting to little or no more than the short and slight river slope of the Bosphorus and of the Hellespont. The proportion of soluble salts in the waters of this sea, like those of the Caspian, Baltic, and other seas, differs greatly in different parts and at different depths, the average proportion being less than that of the oceans; but any cause which should diminish or increase its supply of drainage water would increase or diminish its average saltness, as already explained; and such increase or diminution would correspondingly affect the character of its aquatic fauna.

The general statements contained in the last three paragraphs concerning the conditions which prevail in connection with existing lakes and inland seas, and the circumstances upon which those conditions depend, are introduced here for the purpose already indicated, and also that they may be referred to in connection with the criteria which are discussed in the following paragraphs:

Because the waters in which even the latest of the sedimentary formations of the earth were deposited have long ago passed away, and their beds changed to dry land, the grounds upon which geologists assume that of the formations which they have to investigate, some were deposited in marine, and others in nonmarine waters, and that some of the latter deposits were formed in inland seas, some in lakes, and some in estuaries or rivers, are necessarily inferential in character. Still, the former existence of those previous conditions is held to be demonstrated by means of certain accepted criteria.

The only criteria of this kind which may be regarded as trustworthy are based upon conditions which are observable with reference to now existing oceanic and inland waters, and upon the character of the organic forms which inhabit those waters respectively. They are therefore of two kinds, physical and biological. The physical criteria pertain to conditions surrounding, or prevailing in the region adjacent to, each of such bodies of water. The biological criteria pertain to the organic forms for which any given body of water constitutes a congenial habitat. As used in geological investigation, physical criteria are applied mainly to the stratigraphical and lithological character of sedimentary formations or deposits, to the method of their accumulation and to the action of those natural forces which have characterized them or controlled their production. Biological criteria are applied to the fossil remains of animals and plants which the formations respectively are found to contain. In some instances, however, the character of the fossil remains is such as to imply the coexistence of certain physical conditions which may not otherwise be plainly indicated.

The distinguishing physical characteristics of fluviatile deposits, besides the narrowness of their limits and the effects of self-corrasion of their valleys, which are shown in terraces and bluffs, are the prevaalence of shingle and sand in their channels, and of silt upon their flood plains, and the absence of such regular stratification of any of these materials as is to be observed in those which constitute marine and lacustrine deposits. These characteristics are more or less plainly apparent in the few ancient fluviatile deposits which have been discovered in association with formations which have been deposited in broad bodies of water. It is true, however, that shingle and silt sometimes accumulate in the marine waters of narrow straits or channels in such a manner as to resemble fluviatile deposits, and that their wave-worn bluffs often resemble some of those which have been produced by river corrasion. While therefore it is sometimes practicable to recognize among geological formations such fluviatile deposits as these by means of physical data alone, it is always difficult and often impracticable to do so, especially if their true character has become obscured by displacement and erosion, or by the overlapping of other formations.

These remarks are made with particular reference to those ancient river channels which have been corraded out of sedimentary formations and covered by others of a similar kind, and not to those later channels, some of which have become covered by glacial drift and others by lava outflows. The earlier are usually less distinct and characteristic than are some of the later ones, doubtless because the effects of a receding and encroaching shore line, and other results of the elevation and depression of the land surface upon which they were formed, generally were of a destructive character. It is of course only portions of any of these ancient fluviatile deposits that have been discovered, but portions of some of the later ones have fallen under unusually preservative conditions.

Those narrow bodies of water, usually called lagoons, which are separated from the open ocean only by sand reefs, often partake of the character of estuaries as regards both their aquatic life and their varying proportion of soluble salts. Their deposits also so often resemble those of estuaries that upon physical grounds alone it probably will always be difficult and generally impracticable to distinguish from each other the ancient deposits of these two kinds which may exist among geological formations.

The extent of an estuarine deposit of course depends largely upon the size of the inflowing river, the largest sometimes rivaling in extent the deposits of lakes and inland seas. In some respects their physical characteristics resemble those of fluviatile deposits. That is, like the latter, they contain accumulations of silt and shingle, and they generally are wanting in that regularity of stratification which characterizes the deposits of broad bodies of water. This irregularity is usually apparent even upon the outer border of an estuary, where it shows the effects of the litoral wash of the great body of water between which and the inflowing river it holds an intermediate place. Estuaries exist upon the borders of both lacustrine and marine waters, but the physical character of their deposits is essentially the same in both cases. It therefore is impracticable upon physical grounds alone to distinguish an estuary deposit made upon the border of marine waters from one made upon a lake border.

The physical characteristics of those sedimentary deposits which are made in lakes and inland seas are similar in all essential respects to those made in marine waters, except that, as a rule, calcareous material is more prevalent among marine deposits than any other. The materials of which they are composed, like those of marine deposits, are more or less evenly bedded, and they constitute characteristic members of that great class of sedimentary deposits to which the term stratified rocks is applied. Because of this uniformity of general characteristics it is always difficult, and generally impossible, to demonstrate by means of physical data alone whether a given formation was deposited in marine waters or in those of a lake or an inland sea. Still, a geologist who has much experience in the application of all available evidence may often approximate a correct judgment in such cases by means of physical data, but the almost certain presence in such strata of biological data leaves him without excuse for relying only upon the physical.

It is apparent from the foregoing remarks that upon physical evidence alone it is not practicable to satisfactorily classify the sedimentary formations of the earth in such a manner as to serve the purpose of thorough geological investigation. Therefore such data are in this, as in most other cases, chiefly valuable as being accessory to the evidence afforded by biological data.

The biological criteria which are relied upon by geologists to distinguish from one another the sedimentary formations which have been produced in marine waters, or in those of inland seas, lakes, rivers, or estuaries, relate to the characteristics of faunas which now inhabit those waters respectively, and to the differences from one another of such faunas. That is, the conclusions which geologists reach concerning the questions just indicated are based upon now-existing physical conditions, upon the known character, structure, and habits of animals with relation to those conditions, and upon the assumption that in past geological epochs animals of a given character and structure had similar habits, and lived under conditions similar to those which are congenial to their living congeners.

To aid in defining these criteria it is necessary to review the animal kingdom as it now exists, and to select for consideration those portions of it which furnish data upon which to base the necessary definitions. This selection is based mainly upon the function of aqueous respiration, because it is only animals possessing this function that have a direct relation to the character of the water in the sediments of which their remains may become intombed, and because these sediments and their organic contents are similar in their origin to those which constitute the fossiliferous formations with which the geologist has to deal. Land animals are only briefly referred to in this review because they have at best only incidental relation to the character of the respective bodies of water near which they live and to the sediments which are deposited in them, and for a similar reason plants also will be only briefly considered. Still, remains of land animals and plants have an indirect value in this connection. For example, it is obvious that such remains are more likely to find intombment in inland than in marine waters. We also may assume that they rarely reach those of the open ocean or that they quickly become destroyed by the triturating action of the waves if they reach oceanic waters.

All those aquatic animals whose bodies possess no internal or external skeleton, or such portions as resist decomposition after death, are also excluded or only incidentally mentioned, because it is those parts only that really become fossilized, as has already been explained in Essay I, and also because in the application to paleontological investigation of the facts to be presented in this review reference can be made only to the fossil remains of animals similar to those now living. All extinct animals are also excluded from this review because it is these to which the criteria based upon living forms are to be applied.

VERTEBRATA.

Although the Vertebrata constitute the highest division of the animal kingdom, for the reasons just mentioned, comparatively few of them except the fishes have a direct bearing upon any inquiry concerning the character of formerly existing bodies of water. That is, much the greater part of all the other vertebrates consist of land animals the natural habitats of which have at best only an indirect relation to the character of the waters in the sediments of which their remains may find intombment.

Mammalia.—The Mammalia are so generally dwellers upon the dry land that while a few are amphibious in their habits only the orders Cetacea and Sirenia and the Phocidæ and Odobænidæ of the order Carnivora are confined to an aquatic habitat, at least so far as concerns their locomotion. Besides this, all these animals being air-breathers their aquatic habitat may be regarded as a matter of special adaptation.

Fossil remains of any of the larger Cetacea may be taken as presumptive evidence of the marine origin of the deposits in which they may be found, but so many of the smaller members of that order live in estuaries that other evidence is usually required to determine the character of the deposits in which fossil remains of such animals occur. Because the structure and habits of the Sirenia restrict them to an estuarine or littoral habitat, fossil remains of such animals have much significance as to the character of the deposits in which they may occur, and as to the proximity of the land to the place where such deposits were made. Although the Phocidæ and Odobænidæ usually inhabit marine waters, they often range into estuaries and occasionally, but rarely, some of the former inhabit fresh waters. Therefore, fossil remains of such animals is strong presumptive, but not positive, evidence of the marine origin of the formations in which they may be found.

The foregoing remarks apply to those mammals which live in, or habitually resort to the water, but the larger part of all discovered fossil mammalian remains are those of strictly land animals. The manner in which such remains have found intombment in aqueous sediments, and the probable reasons why they are much oftener found in nonmarine than in marine formations have been indicated on preceding pages.

Aves.—As a class, birds have little bearing upon the subject of this review, because their respiration is aerial, and comparatively few of them habitually live in the water as a permanent habitat. Furthermore, with apparently the exception of the Spheniscidæ and some of the Laridæ, those which resort to an aquatic habitat find saline and fresh waters equally congenial. Avian fossil remains are therefore of comparatively little value as indicating the character of the water in which any given formation was deposited. Still, as is the case with the mammals and other land animals, avian remains are more likely to be found in the sediments of inland than of marine waters.

Reptilia.—All reptiles are air-breathers, and a large part of them are strictly land animals. Many are amphibious, and some are habitually aquatic in their habits. Among aquatic reptiles are the Hydrophidæ and some of the Chelonia, which live in marine waters, and others of the latter order which live in fresh waters. The Crocodilia also usually inhabit fresh waters and the shores of the same, but they frequently range into the saline waters of estuaries and lagoons. The greater part of all living reptiles of aquatic habits, however, are found in fresh waters, and therefore fossil reptilian remains referable to living families are regarded as more likely to indicate a nonmarine than a marine origin for the formation containing them.

The abundance and great variety of known fossil reptiles show that the class is only partially represented by all those now living. Furthermore, most of the extinct reptiles differed so much from any living kinds that comparatively little inference may be drawn as to the character of their respective habitats by a consideration of those of living reptiles. The character of the habitat of those of extinct reptiles must be learned mainly from their osseous structure and their dentition; but in the case of those whose aquatic habitat is thus determined, the marine or nonmarine character of the waters in which they lived is rarely indicated. Therefore, while a great, and doubtless the greater, part of the preserved remains of extinct reptiles were intombed in nonmarine sediments, whether those sediments were deposited in brackish or fresh waters must usually be learned, if learned at all, from other evidence than that which is furnished by the remains themselves.

Batrachia.—In their larval, gill-bearing condition all Batrachians are denizens of fresh waters, usually those of pools and marshes. A few of them retain their gills and fresh-water habitat during life, but most of them become air-breathers. A part of these become denizens of the dry land, but the remainder continue to live in the palustral habitat in which their larval stage was passed. Therefore it is assumed that batrachian fossil remains are much more likely to be found in strata of fresh, than of marine, or even of brackish, water origin.

*Pisces.**—Because all fishes have aqueous respiration it is desirable for the present purpose to review the whole class by families. The general facts concerning the habitat of each family are well exhibited by the following tabular arrangement of their names, the three columns of the table representing marine, brackish, and fresh waters, respectively. The occurrence of the name of a family only in the left hand column indicates that no representative of it is known in any other than marine waters; and in case the name occurs only in the right

* The classification here used is that of Dr. Theodore Gill in his arrangement of the families of fishes as published in Smithsonian Miscellaneous Collections No. 247, pp. 1–25 and personally revised by him for this essay. Dr. Gill has long had in hand an elaborate revision of this classification; but that which is here presented is deemed sufficient for the illustration of these discussions.

hand column an exclusively fresh-water habitat is indicated for that family. The occurrence of the name of a family in more than one of the columns indicates that it has representatives in more than one of the three kinds of habitat. The two kinds of cases first mentioned need no further explanation, but a variety of facts connected with the latter kind need to be considered. These will be briefly stated in the series of explanatory notes following the table, and certain other facts and considerations will be presented in the closing paragraphs of this review.

TELEOSTEI.

Marine.	Brackish.	Fresh.
Orthagoriscidæ		
Tetrodontidæ		Tetrodontidæ.
Triodontidæ		
Ostraciontidæ		
Balistidæ		
Triacanthidæ		
Hippocampidæ	Hippocampidæ	
Syngnathidæ	Syngnathidæ	Syngnathidæ.
Solenostomidæ		
Maltheidæ		
Lophiidæ		
Ceratiidæ		
Antennariidæ		
Soleidæ		Soleidæ.
Pleuronectidæ	Pleuronectidæ	Pleuronectidæ.
Macruridæ		
Congrogadidæ		
Fierasferidæ		
Ophidiidæ		
Brotulidæ		Brotulidæ.
Brotulophididæ		
Bregmacerotidæ		
Ranicepitidæ		
Gadidæ		Gadidæ.
Merluciidæ		
Lycodidæ		
Ateleopodidæ		
Xenocephalidæ		
Ammodytidæ		
		Gadopsidæ.
Cryptacanthidæ		
Stichæidæ		
Xiphidiontidæ		
Acanthoclinidæ		
Chænopsidæ		
Nemophididæ		
Anarrhichadidæ		
Cebidichthyidæ		
Blenniidæ	Blenniidæ	Blenniidæ.
Patæcidæ		
Batrachidæ	Batrachidæ	Batrachidæ.
Leptoscopidæ		
Dactyloscopidæ		

TELEOSTEI—Continued.

Marine.	Brackish.	Fresh.
Uranoscopidæ		
Trachinidæ		
Trichodontidæ		
Gobiesocidæ		
Liparididæ		
Cyclopteridæ		
Platypteridæ		
Callionymidæ		
Gobiidæ	Gobiidæ	Gobiidæ.
Triglidæ		
Agonidæ		
Cottidæ		Cottidæ.
Platycephalidæ		
Hemitripteridæ		
Scorpænidæ		
Chiridæ		
Scaridæ		
Siphonognathidæ		
Labridæ		
Pomacentridæ	Pomacentridæ	
		Cichlidæ.
Embiotocidæ		Embiotocidæ.
Gerridæ	Gerridæ	
		Helostomidæ.
		Anabantidæ.
		Osphromenidæ.
Polynemidæ	Polynemidæ	
Acanthuridæ		
Amphacanthidæ		
Toxotidæ		
Chætodontidæ		
Ephippiidæ		
Xiphiidæ		
Trichiuridæ		
Scombridæ		
Carangidæ		
Drepanidæ		
Coryphænidæ		
Nematistiidæ		
Stromateidæ		
Zeidæ		
Pteraclididæ		
Bramidæ		
Lamprididæ		
Dianidæ		
Kurtidæ		
Capridæ		
Nomeidæ		
Sillaginidæ		
Chænichthyidæ		
Harpagiferidæ		
Nototheniidæ		
Bovichthyidæ		
Latilidæ		
Mullidæ		

TELEOSTEI—Continued.

Marine.	Brackish.	Fresh.
Polymixiidæ		
Monocentridæ		
Berycidæ		
Sciænidæ	Sciænidæ	Sciænidæ.
Sparidæ	Sparidæ	
Pimelepteridæ		
Mænididæ		
Pristipomatidæ	Pristipomatidæ	Pristipomatidæ.
		Centrarchidæ.
Serranidæ	Serranidæ	Serranidæ.
		Percidæ.
Centropomidæ	Centropomidæ	Centropomidæ.
Pegasidæ		
Priacanthidæ		
Hoplegnathidæ		
		Nandidæ.
Plesiopidæ		
		Polycentridæ.
Cirrhitidæ		
		Aphredoderidæ.
Sphyrænidæ		
Echeneididæ		
Oxudercidæ		
		Comephoridæ.
Trachypteridæ		
Lophotidæ		
		Luciocephalidæ.
		Ophiocephalidæ.
Trichonotidæ		
Cepolidæ		
Psychrolutidæ		
Atherinidæ	Atherinidæ	Atherinidæ.
Tetragonuridæ		
Mugilidæ	Mugilidæ	Mugilidæ.
Gasterosteidæ	Gasterosteidæ	Gasterosteidæ.
Aulorhynchidæ	Aulorhynchidæ	
Aulostomidæ		
Fistulariidæ		
Centriscidæ		
Amphisilidæ		
Belonidæ	Belonidæ	Belonidæ.
Scomberesocidæ	Scomberesocidæ	Scomberesocidæ.
		Amblyopsidæ.
		Esocidæ.
		Umbridæ.
Cyprinodontidæ	Cyprinodontidæ	Cyprinodontidæ.
		Characinidæ.
		Percopsidæ.
		Haplochitonidæ.
		Galaxiidæ.
		Osteoglossidæ.
		Notopteridæ.
Halosauridæ		
Chauliodontidæ		
Sternoptychidæ		

TELEOSTEI—Continued.

Marine.	Brackish.	Fresh.
Stomiatidæ		
Scopelidæ		
Aulopidæ		
Synodontidæ		
Microstomidæ		Microstomidæ.
Salmonidæ	Salmonidæ	Salmonidæ.
Salangidæ	Salangidæ	
Alepidosauridæ		
Paralepididæ		
Alepocephalidæ		
Gonorhynchidæ		
		Hyodontidæ.
Albulidæ		
Elopidæ	Elopidæ	Elopidæ.
Chanoidæ		
Dussumieridæ		
Clupeidæ	Clupeidæ	Clupeidæ.
Dorosomidæ	Dorosomidæ	Dorosomidæ.
Engraulididæ		
Chirocentridæ		
		Catastomidæ.
		Cyprinidæ.
		Cobitidæ.
		Homalopteridæ.
		Kneriidæ.
		Sternopygidæ.
		Electrophoridæ.
		Mormyridæ.
		Gymnarchidæ.
		Hypophthalmidæ.
		Trichomycteridæ.
Siluridæ	Siluridæ	Siluridæ.
		Chacidæ.
Plotosidæ	Plotosidæ	Plotosidæ.
		Clariidæ.
		Callichthyidæ.
		Argiidæ.
		Loricariidæ.
		Sisoridæ.
		Aspredinidæ.
		Monopteridæ.
		Symbrachidæ.
		Amphipnoidæ.
Murenæsocidæ		
Congridæ		
Anguillidæ	Anguillidæ	Anguillidæ.
Rataburidæ		
Murænidæ		
Chilobranchidæ		
Nemichthyidæ		
Synapobranchidæ		
Saccopharyngidæ		
		Mastacembelidæ.
Notacanthidæ		

GANOIDEI.

Marine.	Brackish.	Fresh.
		Amiidæ.
		Lepidosteidæ.
		Polypteridæ.
		Lepidosirenidæ.
		Ceratodontidæ.
		Polyodontidæ.
Acipenseridæ	Acipenseridæ	Acipenseridæ.

ELASMOBRANCHII.

Marine.	Brackish.	Fresh.
Chimæridæ		
Myliobatidæ		
Cephalopteridæ		
Trygonidæ	Trygonidæ	Trygonidæ.
Torpedinidæ		
Raiidæ	Raiidæ	Raiidæ.
Rhinobatidæ		
Rhampholbatidæ		
Pristidæ	Pristidæ	Pristidæ.
Squatinidæ		
Heterodontidæ		
Notidanidæ		
Rhinodontidæ		
Cetorhinidæ		
Lamnidæ		
Odontaspididæ		
Alopeciidæ		
Sphyrnidæ		
Galeorhinidæ	Galeorhinidæ	Galeorhinidæ.
Scylliidæ		
Ginglymostomatidæ		
Crossorhinidæ		
Spinacidæ		
Scymnidæ		
Oxynotidæ		
Pristiophoridæ		

The following remarks apply only to those families which have representatives in more than one of the three kinds of aquatic habitat which are indicated in the foregoing table. The presence of the name of a family in only one of the three columns is alone a complete expression of the fact that no representative of it is known in any other habitat than the one thus indicated. It must be remembered, however, that almost any fish whose habitat ranges along the seacoast may occasionally run up into brackish water. Consequently the families enumerated under the head of "brackish" are such only as have representatives habitually living in brackish waters.

Although the Tetrodontidæ are a typically marine family, one species of it is known in South American fresh waters.

Most of the Syngnathidæ inhabit marine waters, but some of them range into estuaries, and a few are found in fresh waters.

As a rule the Soleidæ are marine fishes, but representatives of the family are known in South American and other fresh waters.

The Pleuronectidæ are also typically marine, but some species range into estuaries, and some of these range into adjacent fresh waters.

The Brotulidæ are mainly marine, many being found in abyssal depths; but two blind species, representing two genera, are found in the fresh waters of Cuban caves.

The Gadidæ, with the known exception of only one species, are marine fishes. This species is common to Europe and North America and is confined to fresh waters.

One species of the Blenniidæ in Europe inhabits fresh waters. Most of the known representatives of the family are marine, but some, especially in Australia, range into estuaries and fresh water.

Three South American species of the Batrachidæ range from marine and brackish into fresh waters. Almost all other known members of the family are denizens of marine waters.

The greater part of the Gobiidæ inhabit marine waters exclusively, but several species range into estuaries and adjacent fresh waters. Some species are confined to fresh waters.

A majority of the Cottidæ are confined to marine waters, but certain genera are of exclusively fresh-water habitat.

The Cichlidæ are a typically fresh-water family, but one genus usually referred to it is found in marine and estuarine waters.

The Embiotocidæ are mostly marine, but one genus is confined to fresh waters.

Most of the Gerridæ are of exclusively marine habitat, but some species range into estuaries and some even into adjacent fresh waters.

The Polynemidæ are typically marine, but some species range into estuaries.

The Sciænidæ are mainly of estuarine habitat; some range into fresh waters, and one North American genus is confined to fresh waters.

The Pristipomatidæ are mostly marine fishes, but certain Australian forms are known to range into brackish and fresh waters.

The Serranidæ are also mostly marine fishes, but some species occur in brackish waters, and a few North American forms live almost exclusively in fresh waters.

The Percidæ are a fresh-water family, but some species range down into mildly brackish waters.

Most of the Centropomidæ are denizens of marine waters, but some species find a congenial habitat in estuarine, and even in adjacent fresh waters.

The Atherinidæ are mainly marine, but some range into fresh waters, and one genus is confined to fresh waters.

The Mugilidæ are mostly of marine habitat, but some range into estuaries, and several species are confined to fresh water.

Some of the Gasterosteidæ are confined to marine waters and others to fresh. Most species are found in brackish waters.

The Belonidæ are mostly marine, some of them ranging into estuaries and even into fresh water. One genus is of exclusively fresh-water habitat.

The Scomberesocidæ are also mostly marine, some ranging into estuaries and even into the adjacent fresh waters.

The Cyprinodontidæ are mainly fresh-water fishes, but some range into estuaries and some are denizens of salt waters.

The Microstomidæ are mainly marine, but one species occurs also in fresh waters.

Some of the Salmonidæ have an exclusively fresh-water habitat, never migrating to salt waters. A large proportion of them migrate from marine to fresh waters for reproduction, but none of the family is wholly confined to marine waters.

The Salangidæ are typically marine, but some range into estuaries.

The Elopidæ are mostly marine, but some range into estuaries, and one species is found in the fresh waters of Lake Nicaragua.

Some of the Clupeidæ are confined to marine waters, and at least one species is known only in fresh waters. A large proportion of them, however, range from marine into fresh waters for reproduction.

The range of habitat of the Dorosomidæ is similar to that of the Clupeidæ.

The Siluridæ are mainly denizens of fresh waters, but one section of the family is confined to marine waters.

The Plotosidæ are mostly marine, but some species range into brackish waters and in some cases into fresh waters also.

The Anguillidæ all range from marine to fresh waters, returning to marine waters for reproduction.

The Acipenseridæ are usually found in fresh waters, but some of them range down into estuaries and even into waters of full marine saltness.

The Trygonidæ are mainly confined to marine waters, but one section of the family is peculiar to South American fresh waters.

The Raiidæ are almost exclusively of marine habitat, but some range into estuaries, and they have occasionally been found in waters that are nearly or quite fresh.

All the Pristidæ, with very few known exceptions, are confined to marine waters. One species is found in the fresh waters of Lake Nicaragua and another in the Philippine islands ranges from marine into fresh waters.

One species of the Galeorhinidæ is also found in Lake Nicaragua and another ranges from marine to fresh waters in the Philippine islands. All other known species are confined to marine waters.

Of the thirty-nine families mentioned in the foregoing notes as having representatives in more than one of the three kinds of habitat designated in the table, 28 of them are so generally confined to marine waters that geologists usually regard the discovery of remains of similar fishes in any given geological formation as evidence of its marine origin. Still, members of certain of these families present remarkable exceptions to the general rule thus indicated; such, for example, as the presence of Selachians in Lake Nicaragua and other fresh waters. Therefore, in case the fossils associated with such fish remains should distinctly indicate the fresh-water origin of the strata containing them, their presence may be held as not necessarily constituting conflicting evidence because of the known exceptions to the rule that their living congeners have a marine habitat.

Of the remaining eleven families mentioned in the foregoing notes three are more abundantly represented in fresh than in saline waters. To these the converse of the foregoing remarks will apply. Because of the varying range of habitat of the remaining eight families mentioned in the foregoing notes the discovery of remains referable to any of them in a given formation would be of little value as evidence in determining the character of the water in which it was deposited unless supported by other and more definite evidence.

The Marsipobranchii and Leptocardii are by some authors included in the class of fishes proper, but Dr. Gill and others regard them as separate classes coördinate with fishes, reptiles, etc.

Two of the three families belonging to the Marsipobranchii are known only in marine waters. Most of the members of the other family, namely, the Petromyzontidæ, range from marine into brackish and fresh waters, as is well known in the case of the lampreys.

No representation of the Leptocardii are known in other than marine waters.

This review of the fishes is confined to those families which have living representatives, and the criteria relating to the different kinds of aquatic habitat of fossil fishes which may be based upon this review apply directly only to the families here named.

Fossil remains of a large number of kinds of fishes have been discovered, especially in the paleozoic formations, which differ so much from all living kinds that they can be referred to no family, and sometimes to no order, which has living representatives.

The character of the water in which such fishes lived might be conjectured by reference to their most nearly related forms, but the most reliable indication is furnished by such other fossil remains as may be found associated with them.

MOLLUSCA.*

The Mollusca are of peculiar importance in connection with the subject of this review, because the greater part of the members of this subkingdom have aqueous respiration, and because in the matter of

* The classification of the Mollusca used in this review is that of Dr. Theodore Gill's "Arrangement of the Families of Mollusks." See Smithsonian Miscellaneous Publications, No. 227, 1871.

distinguishing marine from nonmarine formations and the latter from one another it is with their often abundant fossil remains that the geologist has more frequently to deal than with those of any other animals.

Cephalopoda.—Every known member of all the families of this class is exclusively marine, therefore the presence of fossil remains referable to any member of the class in any formation is regarded as sufficient evidence of its marine origin, provided that its character and condition indicate that the animals thus represented were denizens of the waters in which the formation was deposited.

Gasteropoda.—The following table, constructed upon the same plan as that of the fishes, is intended to give a synoptical view of the aquatic habitat of each of the families of living gasteropods which have direct relation to the subject of this review. For obvious reasons all those families are omitted which include only air-breathers as well as those families all the members of which possess no shell, either internal or external. As in the case of the preceding table, this one is followed by explanatory notes setting forth certain facts which are not clearly expressed by means of such a tabular arrangement:

Dioeca.

ORDER PECTINIBRANCHIATA.

Marine.	Brackish.	Fresh.
Conidæ		
Pleurotomidæ		
Melatomidæ		
Haliidæ		
Terebridæ		
Cancellariidæ		
Admetidæ		
Cystiscidæ		
Marginellidæ		
Volutidæ		
Fasciolariidæ		
Mitridæ		
Melongenidæ		
Buccinidæ	Buccinidæ	Buccinidæ.
Nassidæ	Nassidæ	
Cynodontidæ		
Turbinellidæ		
Turridæ		
Olividæ		
Harpidæ		
Ptychatractidæ		
Muricidæ		
Columbellidæ		
		Ampullariidæ.
		Valvatidæ.
		Viviparidæ.
	Assiminiidæ	Assiminiidæ.
Rissoellidæ		
		Pomatiopsidæ.

Diœca—Continued.

ORDER PECTINIBRANCHIATA—Continued.

Marine.	Brackish.	Fresh.
Rissoidæ	Rissoidæ	Rissoidæ.
Skeneidæ		
		Bythiniidæ.
Fossaridæ		
Littorinidæ	Littorinidæ	
Pyramidellidæ		
Eulimidæ		
Styliferidæ		
		Ceriphasiidæ.
	Melanopsidæ	Melanopsidæ.
		Melaniidæ.
Cerithiopsidæ		
Cerithiidæ	Cerithiidæ	Cerithiidæ.
Planaxidæ		
Cæcidæ		
Vermetidæ		
Tenagodidæ		
Turritellidæ		
Trichotropidæ		
Hipponicidæ		
Capulidæ		
Calyptreidæ		
Neritopsidæ		
Onustidæ		
Strombidæ		
Aporrhaidæ		
Pedicularidæ		
Amphiperasidæ		
Cypræidæ		
Triviidæ		
Marseniidæ		
Velutinidæ		
Naticidæ		
Pyrulidæ		
Doliidæ		
Cassididæ		
Ranellidæ		
Tritonidæ		
Ianthinidæ		
Solariidæ		
Scalariidæ		

ORDER HETEROPODA.

Atlantidæ		
Carinariidæ		
Pterotrachæidæ		

ORDER RHIPIDOGLOSSA.

Neritidæ	Neritidæ	Neritidæ.
Rotellidæ		
Rotellidæ		

Diœca—Continued.

ORDER RHIPHIDOGLOSSA—Continued.

Marine.	Brackish.	Fresh
Turbinidæ		
Liotiidæ		
Trochidæ		
Stomatellidæ		
Pleurotomariidæ		
Scissurellidæ		
Haliotidæ		
Fissurellidæ		
Emarginulidæ		

ORDER DOCOGLOSSA.

Acmæidæ	Acmæidæ	Acmæidæ.
Patellidæ		
Lepetidæ		

ORDER POLYPLACOPHORA.

Chitonidæ		
Chitonellidæ		

Pulmonifera.

ORDER PULMONATA.

		Chilinidæ.
		Physidæ.
		Ancylidæ.
		Limnæidæ.
Otinidæ	Otinidæ	
Auriculidæ	Auriculidæ	
Siphonariidæ	Siphonariidæ	
Gadiniidæ	Gadiniidæ	
Amphibolidæ	Amphibolidæ	

Opisthobranchiata.

ORDER TECTIBRANCHIATA.

Philinidæ		
Amphyspiridæ		
Ringiculidæ		
Actæonidæ		
Cylinchnidæ		
Bullidæ		
Amplustridæ		
Lophocercidæ		
Aplysiidæ		
Runcinidæ		
Tylodinidæ		
Umbrellidæ		
Pleurobranchiidæ		

Pteropoda.

ORDER THECOSOMATA.

Marine.	Brackish.	Fresh.
Limacinidæ		
Hyalidæ		
Cymbuliidæ		

Prosocephala.

ORDER SOLENOCONCHÆ.

Marine.	Brackish.	Fresh.
Dentaliidæ		

The foregoing table of the families of living Gasteropoda is, as already stated, constructed upon the same plan as that of the fishes, an explanation of which plan and its significance is given on page 336. The list includes the names of only those families at least some members of which possess shelly or skeletal parts that are likely to resist decomposition after the death of the animal. Other families are not included, because it is only by means of those hard parts that the living can be compared with fossil forms. The significance of placing the name of a family in only one of the three columns of the table is so apparent as to need little, if any, explanation, but there are certain facts relating to members of others of these families which such a table can not distinctly show. Mention of such of these and kindred facts as is deemed necessary for the present purpose is made in the following supplementary notes.

The greater part of the Buccinidæ inhabit marine waters, but they not unfrequently range into estuaries, and certain species are sometimes found in waters that are nearly or quite fresh.

While a majority of the species of the Assiminiidæ find a fresh-water habitat congenial, some live upon the borders of saline water, at river mouths or in estuaries.

Of the living forms referable to the Rissoidæ some inhabit marine, some brackish, and others fresh waters, but no species is known to range from one of these kinds of habitat into another, although it is probable that some may do so. Because the fossil species referable to this family may, as a rule, be regarded as distinct from all living species, the presence of fossil shells referable to this family in any formation does not necessarily give any definite indication as to whether it was of marine, brackish, or fresh water origin. In such cases the character of the habitat must be determined by means of their faunal associates.

The Littorinidæ usually inhabit the margins of marine waters, but some species have a brackish-water habitat.

The Melanopsidæ usually inhabit fresh waters, but some of them are ound in waters that are more or less saline.

All living forms of the Melaniidæ are regarded as fresh-water mollusks, but a few species appear to be able to live in waters which are in some degree saline. Certain fossil members of this family have been found in such association with other molluscan remains as to indicate that they were capable of living in saline waters.

Much the greater part of the Cerithiidæ inhabit marine waters, but some species are known to find a congenial habitat in brackish waters, and a few are known to range into adjacent fresh waters.

As a rule, the Neritidæ are found in either marine or brackish waters, but a few species are known to live in fresh water.

The Trochus-like shells which have been found in Lake Tanganyika probably do not belong to the Trochidæ. The trochids are therefore regarded as distinctly marine.

A few of the Acmæid limpets found in Borneo are reported to pass from saline waters into fresh. The Acmæidæ are not uncommon in brackish waters, but members of the family are most abundant in marine waters.

The Otinidæ, Auriculidæ, Siphonariidæ, and Gadinidæ, are air-breathing mollusks living upon the margins of both marine and brackish waters. The Amphibolidæ also usually inhabit the sea margin, but some of them appear to find waters of less than marine saltness not uncongenial.

Although the Bullidæ are, as a rule, strictly marine, two genera, namely, Haminea and Tornatella, have been found in the mud of brackish water lagoons.

As indicated in the paragraph preceding this table, all the members of the Gasteropod order Nudibranchiata, together with all those of the Pteropod order Gymnosomata are omitted from it because none of the species possess more than a minute embryonic shell, and therefore no identifiable fossil remains of any members of these orders are likely to be discovered. All the Tunicata and land Pulmonata also are omitted, the former because the character of the body is always such that remains of it are not likely to be found fossilized, and the latter, because they have no direct relation to an aquatic habitat.

Of the twelve families mentioned in the foregoing notes as having representatives in more than one of the three kinds of habitat indicated in the table, fully one-half of them are so generally found only in marine waters that geologists usually are inclined, in the absence of contrary evidence, to regard fossil representatives of them as indicating a marine origin for the strata in which they may occur. Three of the other families are so generally found only in fresh waters that the converse of the foregoing remarks would apply to them. Representatives of the others are so often found in both marine and nonmarine waters that in the case of fossil representatives it is always necessary to have corroborative evidence as to the probable character of the water in which they lived.

Conchifera.—The following table of the families of the Conchifera is constructed in the same form as that of the Gasteropoda, and the general remarks preceding that table are applicable to this:

ORDER DIMYARIA.

Marine.	Brackish.	Fresh.
Aspergillidæ		
Gastrochænidæ		
Teredinidæ	Teredinidæ	Teredinidæ.
Pholadidæ		
Solenidæ		
Solecurtidæ	Solecurtidæ	Solecurtidæ.
Saxicavidæ		
Myidæ		
Corbulidæ	Corbulidæ	Corbulidæ.
Pandoridæ		
Anatinidæ		
Myochamidæ		
Pholadomyidæ		
Mactridæ		
Mesodesmidæ		
Amphidesmidæ		
Tellinidæ		
Psammobiidæ	Psammobiidæ	
Donacidæ		
Petricolidæ		
Veneridæ		
Glauconomidæ	Glauconomidæ	
Cyrenidæ	Cyrenidæ	Cyrenidæ.
		Pisidiidæ.
Cyrenoididæ	Cyrenoididæ	Cyrenoididæ.
Dreissenidæ	Dreissenidæ	Dreissenidæ.
Veniliidæ		
Glossidæ		
Cardiidæ		
	Adacnidæ	Adacnidæ.
Chamidæ		
Lucinidæ		
Ungulinidæ		
Erycinidæ		
Cyamiidæ		
Leptonidæ		
Galeommidæ		
Solemyidæ		
Crassatellidæ		
Carditidæ		
		Unionidæ.
		Iridinidæ.
		Mycetopodidæ.
		Ætheriidæ.
		Muelleriidæ.
Trigonidiæ		
Nuculidæ		
Ledidæ		
Arcidæ	Arcidæ	Arcidæ

ORDER METARRHIPTÆ.

Marine.	Brackish.	Fresh.
Tridacnidæ		

ORDER HETEROMYARIA.

Marine.	Brackish.	Fresh.
Mytilidæ	Mytilidæ	

ORDER MONOMYARIA.

Marine.	Brackish.	Fresh.
Pinnidæ		
Pteriidæ		
Vulsellidæ		
Spondylidæ		
Limidæ		
Pectinidæ		
Placunidæ		
Anomiidæ	Anomiidæ	
Ostreidæ	Ostreidæ	

The following remarks are confined to those families which are known to have representatives in more than one of the three kinds of aquatic habitat indicated in the foregoing table.

The Teredinidæ are properly regarded as a marine family, but at least one living species is known in a fresh-water habitat, namely, in the lower Ganges. Therefore the discovery of a fossil member of this family is not of itself positive, although presumptive, proof ot the marine origin of the formation containing it.

A similar remark may be made concerning the Solecurtidæ, a few species of which have been found in brackish waters, and in rare cases some have been known to range into fresh waters.

The Corbulidæ are common in both marine and brackish waters, and they are occasionally found to have passed into adjacent fresh waters or to have survived the freshening of the saline waters in which they formerly lived. Fossil members of this family are often found with only marine associates, quite as often with brackish water associates, and in rare cases all associated species are fresh-water forms.

Some species of both the Psammobiidæ and Glauconomidæ have been found in estuarine waters of considerably less than marine saltness. Therefore fossil species referable to either of these families are likely to be found associated with an estuarine fauna.

The Cyrenidæ like the Corbulidæ, are represented in marine, brackish, and purely fresh waters, and the paleontological significance of both families is similar.

The range of habitat of the Cyrenoididæ is similar to that of the Cyrenidæ, except that none of them are known to inhabit purely fresh waters.

The Dreissenidæ as a family appear to find marine, brackish, and fresh waters equally congenial, and some species appear to range into both brackish and fresh water. This family, however, is represented by a greater number of species in nonmarine than in marine waters.

The Adacnidæ are seldom or never found in waters of full marine saltness, but they are found in such waters as those of the fresher portions of the Black sea, in estuarine waters, and in those which are quite fresh. Therefore fossil members of this family are regarded as indicating a nonmarine origin for the deposits containing them.

One feels so fully warranted in regarding the living Arcidæ as a marine family that he expects to find no exception among its fossil members, but the case of the living fresh-water *Scaphula gangetica* shows that this rule is not absolute. Therefore it is possible, if not probable, that fossil members of this family may be discovered in nonmarine formations.

While the Mytilidæ all thrive in waters of full marine saltness, some of them also thrive in brackish waters. Entirely fresh waters, however, seem to be uncongenial to all of them.

All the Ostreidæ thrive in waters of full marine saltness. They thrive equally well in the less saline waters of estuaries and bays, but never in entirely fresh waters. Therefore the presence of fossil representatives of this family in any formation is taken to indicate that the water in which it was deposited was at least in some degree saline.

The Anomiidæ are far more abundant in marine than in any other waters, but they are frequently found in the less saline waters of bays and lagoons. They are not known to occur in fresh waters, and it is therefore inferred that no fossil members of this family had a fresh-water habitat.

Brachiopoda.—Every known member of all the families of this class is exclusively marine. Therefore geologists regard the presence in any formation of Brachiopod remains as sufficient evidence of its marine origin, in case there is no indication of its accidental presence.

Polyzoa.—With the exception of the three fresh-water families, Pectinatellidæ, Cristatellidæ, and Plumatellidæ, all the Polyzoa inhabit saline waters, most of them living in those of full marine saltness. A few of them range into brackish waters, but as a class they are so generally marine in their habits that the geologist rarely hesitates to conclude that any formation is of marine origin which contains fossil polyzoan remains. This conclusion is supported by the fact that the living fresh-water representatives of the class are rarely provided with skeletal, protective, or supporting parts which resist decomposition after the death of the colonies of minute animals.

ANNULOIDA.

The Annuloida are divisible into two classes, the Scolecida and Echinodermata. All the Scolecida are omitted from this review because the remains of no representative of any of its families is likely to be discovered in a fossil state.

Every known member of all the families of the class Echinodermata is a denizen of marine waters. Therefore the discovery in any formation of fossil remains referable to this class is accepted as proof of its marine origin.

ANNULOSA.

The classes Myriapoda and Arachnida are omitted from this review because they are all land animals except the few that find a congenial habitat in more or less direct contact with water.

In their adult state the Insecta are generally land animals, but some of them resort to at least a partially aquatic habitat. In their larval state, however, many insects are true aquatic animals, usually living in fresh waters. In this state some of them possess no such skeletal or protective parts as are likely to resist decomposition, but many of them, like the adult Insecta, Arachnida and Myriapoda, are provided with a chitinous covering which retains more or less completely the bodily form of the animal after its death and decomposition. Therefore such forms are not unfrequently found preserved in a fossil state, but because all, or nearly all the members of those three classes had either a land or fresh-water habitat their remains are much more likely to find intombment in the sediments of fresh waters than in those of either brackish or marine waters. Indeed no such remains are known to have been found in any deposits which are unmistakably of marine origin.

Crustacea.—All the Crustacea being provided with gills or other organs suited to aqueous respiration have a peculiarly direct relation to the subject of these discussions. All of them also being provided with a more or less complete dermal skeleton or outer covering which resists decomposition and retains the form of the animal after its death, necessarily are of great paleontological importance. It is, however, true that their practical value in the present discussion is much less than that of the Mollusca not because of any inferiority, but because crustacean remains are comparatively very rare, especially in all North American strata which represent that portion of geological time during which were deposited the principal unmistakably nonmarine formations. For this and other reasons a tabulation of the families of the living Crustacea like that of the fishes and mollusks on preceding pages has been omitted. Some of the more important facts concerning the range of habitat of certain of the various groups which constitute this class are, however, recorded in the following paragraphs.

This review of the Crustacea is, therefore, somewhat more general than that of the fishes and mollusks. That is, no regular classification of the Crustacea is attempted, but the remarks are ranged under the head of the general divisions of the class, and direct reference is made only to those families or other subdivisions representatives of which are found in either fresh or brackish waters or both. All those subdivisions, which are not specially mentioned, are not known to live in other than marine waters.

Members of many of the families of the large subclass Malacostraca range beyond the limits of marine waters, but most of them are confined to a marine habitat.

The living Brachyurans are so generally of marine habitat that in the absence of any conflicting evidence geologists are usually disposed to regard all those strata as of marine origin which contain fossil remains referable to this division of the Crustacea, but the following facts show that this exclusive view is not admissible. The greater part, if not all of one subfamily, the Thelphusinia, are either denizens of fresh waters or live a large part of the time upon the land in the vicinity of fresh waters. Some species of the Grapsoidea, although most of them are marine, also have a similar range and peculiarity of habitat while others are apparently confined to brackish waters. Many of the marine as well as of the fresh-water species of the Grapsoidea range more or less upon the land.

Although it is well to emphasize the fact that most of the species and genera of the Brachyurans are typically marine animals, many of them besides those already referred to, such, for example, as the genera Callinectes and Panopeus, range into estuaries and bays, some of them going into adjacent fresh waters without apparent inconvenience. It is also a significant fact that of the Brachyurans, as well as of the Macrurans which inhabit fresh waters, many more are found in fluviatile and palustral than in lacustrine waters.

The range of habitat of the Anomoura is similar to that of the Brachyura. Most of them live in waters of full marine saltness, some inhabit brackish waters, some wander inland, and one genus, Æglea, is nearly or quite confined to fresh waters. It is thus apparent that the discovery of fossil remains of a representative of this group of Crustaceans in a given formation would not necessarily be proof of its marine origin.

The Macrura as a whole have a wide range of aquatic habitat, most of them living in marine waters, many in fresh waters, and some of them venturing occasionally upon the land.

The family Astacidæ proper, or crayfish, are all denizens of fresh water, while those similar genera which were formerly referred to this family are confined to a marine habitat, with the probable exception that some of them range into brackish waters. Although many of the Astacidæ burrow in wet earth at considerable distances from any body of water, few or none of them wander so far upon the land as do some of the Brachyura or even some of the Anomoura.

The Crangonidæ are generally of marine habitat, but some range into brackish waters.

Most if not all the Atyidæ inhabit fresh waters.

Many of the Palæmonidæ are restricted to marine waters, many live in brackish waters, and several genera are confined to fresh waters, some of them living in rivers far from the sea.

As a rule the Penæidæ inhabit marine waters, but some of the species are known to range into fluviatile waters.

The Stomatopoda have considerable range of habitat. Some of the Mysidæ range from marine into brackish waters, and at least one species is found in inland fresh waters.

The Squillidæ are, as a rule, marine forms, but some of them range into brackish waters.

The greater part of the Isopoda inhabit marine waters, but many genera are confined to fresh waters, while all the members of one family, the Oniscidæ, are of terrestrial habitat. A considerable number of genera also range into brackish water.

All known members of the Anisopoda are denizens of marine waters.

A considerable proportion of the species and many genera of the Amphipoda are denizens of fresh water while most of the others are confined to a marine habitat, many ranging into brackish waters.

The subclass Entomostraca embraces a greater proportion of denizens of nonmarine waters than does the subclass Malacostraca. They are also of special interest to the geologist because representatives of at least one suborder are found in much earlier formations than are any members of the other subclass.

The Cirripedia are so generally regarded by geologists as being exclusively denizens of marine waters, or of those which are of nearly full marine saltness, that they rarely hesitate to accept the presence of fossil remains of any crustacean referable to this order in any formation as evidence of its marine origin. One species of Balanus, however, has been found in comparative abundance ranging from marine waters far up the St. John's river in Florida, and thriving there in fresh water. This case is apparently as exceptional as that, for example, of the Teredinoid and Arcoid mollusks in the lower Ganges and of Selachian fishes in Lake Nicaragua, but it may be that other similar cases will be found among the Cirripedia. Still, in the absence of conflicting evidence geologists are probably justified in regarding Cirriped remains as indicating marine conditions.

The Copepoda are mostly minute animals, and inhabit both fresh and salt waters. They are usually provided with a chitinous or membranous covering which, with few exceptions, is too delicate to be well preserved in sediments after the death of the animal. It is probable, therefore, that few fossil remains of these animals have ever become fossilized, and these are likely to escape discovery because of their minuteness and delicacy.

Various forms of the bivalve Crustacea constituting the Ostracoda are found in both fresh and marine waters, and also in the brackish water of estuaries. They are often gregarious, immense numbers being often found together. Their former abundance was also great, as is shown by the multitudes of fossil forms that are sometimes found in the sedimentary rocks of various ages.

Most of the Phyllopoda inhabit fresh waters, but some live in marine, and some in brackish waters. They are mostly small or minute Crustaceans but being gregarious they are often found together in great numbers. Their paleontological value is similar to that of the Ostracoda except that the latter are more prevalent in the paleozoic formations.

Nearly or quite all the Crustacea of the earlier geological ages are referable to the subclass Gigantostraca, but its living representatives are only the Xiphosura, and these are confined to two species of the genus Limulus. Although the Malacostraca are more conspicuously abundant than all other living Crustaceans, fossil remains referable to any divisions of this subclass are comparatively rare in strata of any age and none have been found in rocks of earlier than Carboniferous age. On the contrary, the Gigantostraca, which are represented by only two known living species, existed in great abundance in the Cambrian, Silurian and Devonian ages, when they were represented by numerous genera and families, especially of the trilobites.

It is therefore evident that a knowledge of the different kinds of aquatic habitat of living crustaceans affords little direct information concerning that of those which lived during the three earlier geological ages just mentioned. Consequently all the obtainable evidence of this kind is derived from the remains of their faunal associates. Much the greater proportion of all those ancient crustaceans, including all of the trilobites, are thus assumed to have lived in marine waters, but the usual absence of immediately associated forms that can be with certainty assigned to either a marine or nonmarine origin has left in doubt the question as to the character of the water in which others of the Gigantostraca lived.

Annelida.—The members of this class which possess such skeletal or protective parts as are most likely to resist decomposition are the Tubicola, all of which secrete a shell, usually calcareous, much resembling the shells of gasteropod mollusks. They are all denizens of saline waters, mostly those of the open ocean. By means of the partly chitinous covering of certain of the Errantia or roving worms, their bodily form may occasionally be preserved after the death of the animal in the sediments which formed its habitat while living; and their presence in such sediments is often indicated by their burrows when the animals themselves are not discovered.

So generally are the Annelida denizens of marine waters that the presence of the remains or burrows of any of them in a geological formation is regarded by geologists as indicating its marine orig n.

CŒLENTERATA.

The Hydrozoa only of the somewhat numerous orders embraced in this subkingdom are represented in fresh waters. These fresh-water representatives are all minute, and are not furnished with skeletal parts such as would be likely to be preserved in a fossil state. Therefore it is not to be expected that fossil remains referable to the Cœlenterata will be found in any formation of fresh-water origin.

The marine subclasses Siphonophora, Discophora, and Lucernarida, as well as many members of the class Actinozoa, are also all destitute of such skeletal parts as are likely to long resist decomposition after the death of the animal. It is an interesting fact that unmistakable imprints of the bodies of Cœlenterata belonging or related to the jelly-fishes have been found in certain geological strata composed of extremely fine sediments; but, as a rule, the geologists can not hope to discover any fossil traces of animals which in life were not furnished with such skeletal or integumentary parts as would resist the decomposition of their soft parts after death. While the bodies of many of the Cœlenterata are wholly of this soft character, a large proportion of them are furnished with stony skeletal parts, the most conspicuous examples of which are the numerous kinds of corals. Others are furnished with corneous or chitinous coverings or supports which are sometimes found fossilized. So characteristic are these Actinozoa of marine waters that the geologist does not hesitate to accept as of marine origin any formation containing fossil corals, which are the skeletal parts of such animals.

PROTOZOA.

Of the Protozoa only the orders Foraminifera, Radiolaria, and Spongida need be mentioned in this review, because only representatives of these orders secrete such hard parts as are likely to be preserved in a fossil state. Much the greater portion of the Protozoa are microscopically minute, but the sponges and some other forms are frequently of large size. The Protozoa live in both fresh and marine waters, but they are so very much more abundant in the latter that the discovery of their remains in a geological formation is usually taken as indicating its marine origin.

PLANTS.

Compared with the fossil remains of animals very little direct information can be obtained from those of plants as to the character of the water in which the formations containing them were deposited.

The siliceous remains of diatoms often constitute layers of considerable thickness among the sedimentary rocks, but because they are found in both marine and nonmarine deposits, and because of the special character of their classification, they are not definitely referred to in these discussions.

All seaweeds or marine plants are far more simple in structure than land plants and their composition is such as to insure their rapid decomposition. This character has prevented their fossilization in the sediments of formerly existing seas in such a condition as to be of any considerable value in paleontological study. The case is somewhat different as regards palustral plants, the character of most of which may usually be accepted as trustworthy evidence of their nonmarine habitat. Still, the remains of land plants, like those of land animals, are far more likely to have found the quiet entombment necessary to their preservation in the sediments of nonmarine than in those of marine waters, because the former waters were surrounded by the land upon which the plants grew, and because the nonmarine sediments receiving such remains are, as a rule, not subject to the destructive littoral wash which usually prevails along sea borders.

The following facts and assumptions have a direct bearing upon the foregoing statements and discussions and upon their practical application to geological investigation.

The various bodies of water which existed during geological time, and which constituted the habitat of aquatic animals, were of the same kinds that now exist, namely, marine and fresh, together with those of the various intervening grades of saltness. Although it is probable that the marine waters of early geological time were not so salt as those of the present oceans, it is believed that this difference in saltness has not been so great as to make any appreciable difference as to legitimate conclusions of the kind that have been indicated on preceding pages. It seems to be especially evident that this difference has been thus inappreciable since the close of paleozoic time, since which time the greater part of the known unmistakably nonmarine formations were deposited.

Existing bodies of water are constantly depositing materials similar to those of which the sedimentary rocks are composed.

In past geological epochs the habits of animals of a given character and structure were the same as those of similar now living animals, and they lived under conditions similar to those which are congenial and necessary to their now living congeners. Also in those epochs plants of a given character lived under conditions similar to those which are necessary to the corresponding kinds of now living plants.

Those animals alone which are furnished with organs for aqueous respiration can be confidently relied upon as indicating the character of the water in which they respectively lived.

Thus, if all the known now living members of a given family are confined to marine, or to fresh waters, as the case may be, it is assumed that the habitat of the extinct members of such families were similarly restricted, and that the presence of fossil remains of such animals in a given formation is, in the absence of conflicting facts, sufficient evidence of its marine origin on the one hand or of its fresh-water origin on the other. Again, if a given family is known to have representatives now living in marine, brackish, and fresh waters, respectively, it is assumed that it had a similar range of habitat during past geological epochs. Therefore, the discovery in a given formation of fossil remains of a single representative of a family having such a varied range of habitat is not of itself sufficient to enable one to decide whether it was of marine, brackish, or fresh water origin, and other evidence must be sought.

The evidence upon which criteria of the character of formerly existing bodies of water are based is usually more or less direct, but it is sometimes cumulative and concurrent in its character. Still, when properly applied, the latter kind of evidence is usually nearly or quite as valuable as if it were absolute and direct.

The criteria of past aqueous conditions which are discussed in this essay are of course only such as may be derived from sedimentary formations and their contents. It can not be said that there are any fully trustworthy physical criteria because a nonmarine formation rarely presents any condition of stratification, or any lithological character, which is not observable in some marine formations. Still, there are many more or less valuable indications which may be observed and to some degree relied upon in the absence of fossil remains.

For example, although considerable accumulations of calcareous strata are sometimes found among the generally arenaceous strata of fresh-water formations they have never been found to contain any important accumulations of regularly bedded limestones. Furthermore, estuarine deposits are often still more of a detrital character than are fresh-water formations and also they more rarely contain calcareous layers. Therefore if one should encounter a series of regularly bedded limestones, either magnesian or fully calcareous, he will rarely, if ever, be at fault in regarding them as of marine origin even without biological evidence.

In a large proportion of the nonmarine formations the stratification is less regular than is usually the case with marine formations. Still, this by no means is a certain criterion, and in some cases nonmarine formations are found to rest so conformably upon the marine and to be so conformably overlain by them as to give little indication of the great difference in the condition of their origin.

The foregoing examples show how indefinite is the character of physical evidence as to the past aqueous conditions under which the various sedimentary formations have been produced, but they serve to emphasize a statement of the fact that almost entire reliance must be placed upon the evidence furnished by fossil remains.

With reference to general indications of difference between marine and nonmarine formations which are furnished by their fossil remains we observe that a conspicuous difference lies in the comparative abundance and variety of forms of life which the fossil faunas of the formations respectively represent. Marine waters have always teemed with life in a wonderful variety of forms, and their fossil remains are proportionally abundant. The variety is less in brackish waters and least of all in lacustrine waters. It is true that ichthyic life is abundant in some fresh waters, but never so generally abundant or so various as in marine waters. It is also true that molluscan life is often locally abundant in shallow fresh waters, but, as already several times mentioned, the variety is extremely meager. All these peculiarities are distinctly observable among the fossil faunas of the nonmarine formations.

Other general indications of difference between marine and nonmarine formations are furnished by remains of land plants and animals. Open-sea formations are naturally free from any vegetal remains derived from the land, although coal and other materials of vegetal origin are not unfrequently found alternating with layers containing marine fossil remains. These, however, as explained on a preceding page, are regarded as cases of emergence of the bottom of shallow sea waters and the subsequent subsidence of the same as plant laden marshy land. It is a matter of fact, the reason for which has been suggested in preceding essays, that plant remains of any kind, especially such as are in a classifiable condition, have so rarely been found associated with remains of denizens of marine waters that the discovery of fossil plants in any formation is of itself presumptive evidence of its nonmarine origin.

It has already been shown on preceding pages that the remains of land animals have so seldom reached marine waters or, having reached them, they were probably so generally destroyed by the triturating action of coast waves that the discovery of any of this kind of fossil remains in any formation may also be regarded as presumptive evidence of its nonmarine origin.

The foregoing statements have been made with reference to indications which are either of a general character or without direct relation to the quality of the waters in which sedimentary formations have been deposited. All the direct evidence, as already has been fully stated, is derivable from the fossil remains of the denizens, especially the gill-bearing kinds, of the waters in which were deposited the formations under investigation.

Referring to the foregoing review of the animal kingdom, including the tables which it embraces, it will be seen that a large number of families of both fishes and invertebrates are confined to a marine habitat, and that every member of even some of the higher divisions is similarly restricted. For example, every known member of the classes Cephalopoda and Brachiopoda is confined to a marine habitat. It will also be seen that a certain small number of families, especially of the mollusca, are equally restricted to fresh waters. The significance of such cases as these has already been pointed out, but it is desirable to refer to them again.

Fossil remains representing any one of these kinds of animals may be taken as positive evidence of the quality of the water in which was deposited the formation containing them, provided there shall be no room for reasonable doubt that the animals were really denizens of that water. That is, caution is necessary even in these more positive cases, especially when the amount of discovered fossil material is meagre.

Not only caution but the exercise of careful judgment is necessary in other cases. For example, it will also be seen by referring to the foregoing review that certain families, while most of its members are confined to one kind of water, may have one or more representatives in other kinds, and again that certain families may have representatives in all the known kinds of habitable waters. In such cases as these it is plain that all evidence afforded by fossil remains to be of any value must be corroborated by other evidence.

Still, the cases are very few in which serious doubt need be entertained as to the true character of the water in which a given formation was deposited. This is especially true if the fossil remains are sufficient in quantity and perfection to approximately represent the whole fauna that lived in those waters. Indeed, if the facts which are recorded on the preceding pages are borne in mind there need be no more doubt as to what was the quality of the water in which any given formation was deposited than might arise concerning any other geological observation.

VIII. THE CLAIMS OF GEOLOGICAL SCIENCE UPON INVESTIGATORS, MUSEUMS, ETC.

With reference to the ordinary pursuits of life it can hardly be said that, aside from a natural demand for respectable emulation, one's occupation has any claims upon him other than those which are either conventionally or legally imposed by society upon every one of its members. The geological investigator, however. is not only amenable to all such claims but to others of a different nature which, although not enforceable by legal, and unfortunately not yet by conventional, penalties are not less imperative in their character.

These claims upon the investigator will be presented in the following paragraphs, but it is well to remark here that they are by no means an abridgement of his rights as an individual, because he has no rights with relation to science which the latter does not confer. It is true that the legal right of personal ownership of scientific material and the abstract right of independent investigation can not be questioned from the standpoint of the ordinary affairs of life, but it is my purpose to show that the individual investigator owes an allegiance to science which demands at least a modification of the privilege of asserting those rights. That is, I propose to show that because the general advancement of geological science must be accomplished and its integrity maintained by the coöperation of a multitude of workers in the various branches of investigation, its claims are superior to those of the individual, and that he can not exclusively assert the rights referred to without material disadvantage to science. Indeed, he can not do so without lessening, and to some extent destroying, the value of his own labors.

Much might be said in favor of the demands which may be made in the name of science upon the individual on the ground of justice and of moral and social ethics, but I shall omit all considerations of this kind and refer only to those claims which are supported by the urgent necessities of science itself. Claims of the kind referred to might be made in favor of all the various divisions of science, but I shall on the present occasion confine my discussions to those which pertain to biological geology, including both its structural and systematic branches. With reference to the manner in which the subject of this essay is presented it is proper to say that the homilitic form has not been adopted merely from personal preference, but because I believe it to be in the present case a proper and effective, if an indirect, method of calling attention to prevalent errors, and of suggesting necessary improvements in certain prevalent methods.

These claims of science will be considered not only with reference to the individual investigator, but to associations, museums, and geological organizations. Those which may be made upon the individual investigator relate to the manner of prosecuting his work and of publishing its results, and also to his final disposition of the evidence upon which his conclusions are based. Claims upon associations or societies relate to the character and methods of publication; those upon museums, to the conservation and installation of fossil remains and of the records pertaining to them; and those upon organizations, to the preservation of the integrity of geological science.

Among the necessities of geological science which require the enforcement of these claims are those which arise from its extensive range, the interrelation of its various branches, and the cumulative character of the evidence upon which it is based. Its extensive range makes it impossible that any one investigator should compass more than a small part of the whole field, the interrelation of its branches requires that each branch should be investigated with direct reference to all the others, and the cumulative character of the evidence which constitutes its foundation requires that every item of that evidence should be conventionally judged. These conditions show that it is the public and not the individual that must be the final arbiter of all questions pertaining to the results of investigation. It is, therefore, essential that the public should be furnished with all the evidence upon which the individual reaches his conclusions, and that this evidence should be so preserved as to be accessible to all investigators.

In all such arbitrations a clear distinction must necessarily be made between evidence and testimony. The former rests upon facts and is therefore intrinsically infallible. The latter rests only upon individual judgment and is in every case liable to be modified even by its authors, and to be questioned, if not opposed, by others. Facts observed and recorded, and material collected and preserved, constitute a perpetual source of evidence, but personal authority can have no permanently exclusive or dominant place with relation to geological science, and acceptable personal responsibility for published conclusions and announcements of discovery must be confined to those which are supported by tangible evidence and by reference to all obtainable fundamental and relevant facts.

In biological geology the principal evidence necessary to be obtained is of two kinds, biological material in the form of fossil remains, and stratigraphic conditions with relation to geological structure and general stratigraphic classification. The fossil remains must necessarily be collected for study, and science justly demands that they should be placed where they will ever after be accessible to all investigators. It is also essential that observations of stratigraphical conditions should be made in immediate connection with the collection of fossil remains, and that such observations and collections should in all cases be so recorded and published that every locality may be readily revisited and identified, and every observation repeated by any other observer.

In short, it is essential that the public should be furnished with the same means of judging of the significance of all the facts and conditions that may be reported by an original, or any other, observer that they have themselves employed. It is largely with reference to the collection and conservation of the kinds of evidence referred to that the claims of biological geology are here presented.

In considering the claims of science upon the individual it is desirable to make some reference to the amateur as well as to the special investigator. This recognition of nonprofessional work is desirable because the general subject of geology has acquired such a hold upon the popular mind and the opportunities for making observations with relation to it are everywhere so common that in every civilized country there is a multitude of persons who are in the habit of making more or less critical observations. Notwithstanding the usually limited and desultory character of such observations, they have often contributed materially to the general fund of geological knowledge, especially when accompanied by a faithful record and preservation of evidence. Indeed some of the most valuable facts in geology have been brought out by amateur observers, who themselves were hardly conscious that they had made their way alone to the frontier of acquired knowledge; and from the ranks of such observers have arisen many of the leaders in geological investigation.

Although only a small proportion of amateur observers can hope to accomplish so much as this, it is proper to assume that a very large proportion of them desire to contribute all they can to the advancement of science. These will therefore be included with other individual investigators in presenting the claims of science upon them, but for obvious reasons no reference need be made to those whose attention is directed to geology by mere curiosity or the desire for pecuniary gain. In the following remarks concerning the claims of science upon the individual the amateur will readily perceive what portions of them are applicable to himself.

It has been shown in the preceding essays that systematic geology could have no existence without the use of fossil remains, and also that without their use structural geology would be reduced to mere local and disconnected studies. It has also been shown that to arrive at a just estimate of the value of fossil remains in these branches of geology they must be thoroughly and systematically studied as representatives of faunas and floras as well as tokens of the formations in which they are found. The proper collection and preservation of fossil remains is therefore a subject of the greatest importance. In view of these facts it is the plain duty of every geologist upon beginning a piece of field work in structural geology to accompany every step of his examination of the strata by as full a collection as possible of the contained fossils and to preserve them, together with notes recording the results of his observations and a statement of all the facts relevant thereto.

If it were practicable to obtain from these fossils at sight all the information which they are capable of conveying, and if the judgment of every collector were so infallible that no coöperation by other observers and no final arbitration by the scientific public were necessary, it would not be essential to the successful prosecution of field work that fossils should be collected and preserved. But this is only a negative method of stating the imperative necessity of making full collections of fossils in the prosecution of investigations in structural geology and of preserving them for future reference.

Fossils thus collected and the facts concerning them recorded become invested with a value which differs materially from that which is possessed by ordinary property, and the claims of science upon them and upon the investigator with relation to them at once begin. These claims, as just intimated, require that a careful descriptive record be made of the stratigraphical conditions under which the fossils are found, including a directive record of the locality and designation of the stratum from which they were obtained. They also require that these records should be inviolably preserved and made inseparable from every specimen by indices that shall be as intelligible to other investigators as to the original observer.

Aside from the claims of science such precaution is necessary, because reliance upon memory alone is always unsafe in the most favorable cases, and it can at best give rise only to such oral traditions as are out of place in scientific work. The immediate preparation of the records and indices just mentioned is also necessary, because, while every specimen is at all times competent to impart to an investigator all obtainable knowledge of its own character, it can of itself convey no information as to its original locality and stratigraphic position. With this information secured for a collection of fossils they may be made at all times available as aids to scientific research not only by the collector, but by all other investigators.

The claims of science also require that immediately upon the completion of the original study of fossils thus collected and recorded they shall be placed where they will be freely accessible to the scientific public, and that reference to their place of deposit shall be made in connection with their publication. It is needless to say that the only suitable places for such deposit are public museums. It is only when this indispensable evidence is thus made accessible that the public can exercise that arbitration over the accumulated results of the labors of investigators which has been shown to be imperative.

The preparation and publication of complete records concerning the locality and strata from which fossil remains are obtained are necessary even from a biological point of view alone, especially when those remains are studied with reference to the range of organic forms in time, and without such records fossil remains are comparatively worthless as aids in geological investigation. It is unfortunately true that a not unimportant proportion of the paleontological material contained in our best museums is without these essential records, and that many of the publications containing descriptions and illustrations of fossil remains give no satisfactory information as to the localities and strata from which they were obtained or of the final disposition of the specimens. In such cases those authors and collectors have evidently assumed to decide for themselves and for science the exact taxonomic position in the geological scale of the strata from which their fossils came. In omitting such records as have been referred to they seem to have considered any information unnecessary that would enable the scientific public to repeat their observations upon their specimens or those which they may have made in the field, or to learn the biological characteristics of the formations from which their collections were obtained other than those which may be suggested by their own partial collections and their necessarily imperfect descriptions. It is doubtless true that such omissions have been largely due to an honest lack of appreciation on the part of authors and collectors of the importance of preserving such records, but it is to be feared that in some important cases the omissions or suppressions have been intentional. In the former class of cases the fact can only be deplored, but in the latter every geologist is justified in feeling that a crime has been committed against science.

The claims of geological science upon associations and societies are so generally and justly recognized that only the one which relates to the manner of publishing the results of investigation need be referred to in this connection, and this reference will be confined to the necessity of enforcing the claims upon individual investigators which have already been discussed. This claim may be sufficiently indicated by reference to those last mentioned, and by the remark that if it is the duty of individuals to publish records of their observations in the manner that has been stated, it is plainly the duty of those persons who may be in charge of the means of publication to refuse to publish the writings of those authors who do not conform to that requirement.

The facts and principles which have been stated in the preceding essays fully warrant the statements made on foregoing pages of this one, that individual authority can have no existence with relation to geological science, that the public must be the final arbiter of all questions concerning the value of proposed contributions to its advancement, and that a public exposition should be made of the evidence upon which any contribution to biological geology is based. In accordance with the last-named requirement it is necessary to consider the claims of this branch of science upon museums, the force of which is apparent when it is remembered that the material pertaining to it therein stored constitutes the vital evidence of the value of all contributions to its advancement, and that without such evidence this branch of science would be reduced to a mass of personal testimony.

In view of the great scientific value of fossil remains the following remarks are offered concerning the precautions which are necessary in their preservation. It is true that most if not all these precautions are observed in a large part of the principal scientific museums of the world, but it is also true that much remissness in this respect has occurred in others. Besides the propriety of referring to the latter fact, these remarks are necessary to complete my statement of the claims of science which constitute the subject of this essay.

Three general classes of specimens of fossil remains should be recognized in museum collections, namely, typical, authenticated, and unauthenticated. Under the head of typical or type specimens are included not only those which have been described and figured in any publication, whether original or otherwise, but those which have in any public manner been so used or referred to. While all such specimens as these should at all times be accessible to any competent investigator, the risk of loss or injury is so great that they should in no case be allowed to be taken from the museum building in which they are installed. Such specimens are in a peculiar sense unique, and there can be no substitution and no equivalent in value. Their loss greatly reduces the value of every publication any part of which is based upon them, and to that extent retards the advancement of science. It is not enough that other, and even better, specimens of presumably the same species may be discovered; the former constitute the original, the latter only supposititious evidence. Besides the risk of loss or injury to type specimens by removal from the place of their installment their absence is a disadvantage to science. That is, no one investigator should be allowed their use to the exclusion of any other.

The term "authenticated specimens" is here applied to such as have been studied and annotated by competent investigators and properly installed. Such material constitutes the bulk of every important museum collection, and next to the type specimens already mentioned they are most valuable. Their increased value is due to the scientific labor that has been bestowed upon them, and it needs only the additional labor of publication to constitute them type specimens and to make them of like value. Authenticated specimens when installed are ready aids to all investigators of such value that even the temporary removal of any of them from a public museum is, to say the least, of doubtful expediency.

Unauthenticated specimens are, of course, those which have not been studied and installed, and they constitute the great mass of material from which authenticated and type specimens are drawn. Among them are those which constitute the material evidence upon which original observations in biological geology are based. If these are accompanied by the records and descriptive notes which on a preceding page have been shown to be essential to their value, they constitute proper material for acceptance by museum authorities, but if not their installment should be refused, whatever their character may be. That is, to apply a statement made in another connection, no specimen of fossil remains should be admitted to permanent installation in any public museum which is not accompanied by such a record of the locality and stratum from which it was obtained as will enable any investigator to revisit the same. In every case of installment such records should be so connected with every specimen as to be readily accessible, and so arranged that the danger of loss or disconnection shall be reduced to a minimum.

The foregoing discussion of the claims of science upon museums is intended to embrace reference only to those which are devoted to the preservation of material pertaining to biological geology, but they are of more or less general applicability. These partial claims alone demonstrate the important relation that museums hold to science and to civilization as centers of learning and conservatories of the evidence concerning acquired knowledge. Museums should not only be made safe treasure-houses of science, but they should be what their name implies—temples of study—perpetually open to all investigators.

The claims of science upon geological organizations can not be discussed at length in this essay, but because the ratio of power for the advancement or retardation of science possessed by such organizations is so much greater than that of individuals working independently, it is desirable to make this brief reference to them. That power increases also with the ratio of the extent of the organization, and it is largely centered in the director. His responsibility, especially if his organization is a large one, is peculiar, and, to himself, of an unfortunate character. That is, while all or nearly all the advancement of science that may be accomplished by the organization is the work of his subordinates, retardation, if it should occur, is mainly due to his failure to require that each branch of investigation should be prosecuted in accord with all others, and the case would be little less than disastrous should he himself favor *ex parte* methods or fail to require a symmetrical development of the work in his charge. The claims of science upon geological organizations are therefore really claims upon their directors, and they are more responsible than any other class of persons for the preservation of the integrity of geological science.