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THE CORRELATION OF GEOLOGICAL FAUNAS

A CONTRIBUTION TO DEVONIAN PALEONTOLOGY

BY

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THE CORRELATION OF GEOLOGICAL FAUNAS.

By Henry Shaler Williams.

INTRODUCTION.

In the year 1881 I began a series of investigations for the purpose of discovering the laws which determine the association of fossils in faunal aggregates and their modifications in relation to geographical distribution and to vertical succession, in order to apply those laws as guides to the correlation and classification of geological formations. While these investigations have been in progress many other workers have joined in the search. Many statistics have been gathered, and observations have been extended over a wide field. A few important results have been attained, and the nature of the problem is now more clearly understood than at the outset. It seems, therefore, that this is a fitting time to review the progress already made, and to point out the more prominent results achieved and the paths along which future investigations may be guided with most promise of success.

When the investigations were begun it was already known that geological formations were marked by species of fossils differing greatly for each succeeding formation. In the early days of geology this difference was supposed to be due to extinction of old and the appearance of new forms for the first time with the income of each new formation. With this conception was associated the idea of sharp distinction between formations, each of which had a characteristic set of "Leitfossilien." The prevalence of this latter view dominated all the literature; and the presence, in a newly exploited section of rocks, of a species supposed to be characteristic of a given formation was assumed to be sufficient evidence of the presence of the formation in the new section. On this basis of determination it had become a fact that under the name of each formation there was catalogued a group of species collected from widely separated regions and found in different kinds of rocks, all of them being thus lumped together as the characteristic species of the formation considered.

At the outset of the present inquiry it was evident that, in order to learn how the modification of species has actually taken place, the composition of the fauna of a formation must be critically examined, the actual association of species in each bed of rock must be analyzed, and the succession of species traced step by step through continuous sections.

My first experiments in this field of investigation were with the faunas exhibited in the rocks in the neighborhood of Ithaca, N. Y. In these rocks, which were classified as Portage and Chemung, a number of zones filled with separate faunules[a] were discovered, some of which were entirely different from others in the series, but the order of their succession was readily distinguished in each of the rock sections for miles about. This integrity of the faunules in geographical distribution, over at least the few miles of area at first explored, together with the sharp differences in the composition of successive faunules, suggested a clue to the solution of the larger problems involved.

When, again, on comparison of two sections running through the same portion of the geological column it was found that a formation which was clearly defined in one section was missing in the other, it was customary (in the absence of evidence of unconformity) to explain the absence of the missing member in the second section by the supposition that it had gradually thinned out until it disappeared. Its place in the second column was recognized, but the thickness of its sediments was reduced to nothing or to an inappreciable amount. Correlation of diverse formations being made on this basis, the general geological column was constructed of a single series of superimposed formations, diversity of fossil contents standing for difference of formations. Each formation was thus forced to take some particular place in a single geological column.

As knowledge of the faunas increased, the failure to establish the exact identity of a newly discovered fauna with any of the faunas of the standard column already described led to the intercalation of the formation containing it between the standard formations whose faunas most closely resembled it. That there might be living at the same time two entirely distinct faunas whose records were buried and preserved within a few miles of each other was a possibility that was not then seriously contemplated. I refer to marine faunas, for the distinction between marine, fresh-water, and land conditions was clearly recognized; but almost never were faunas from diverse envi-

[a] The term "faunule" is here and in the following pages used to distinguish an aggregate of fossils associated in a single stratum or zone from the total aggregate of species (the fauna) distributed through a greater or less thickness of strata, each faunule containing a considerable proportion of the same species, but not always in the same combination or proportionate abundance. The association in the faunule is supposed to be an expression of the temporary adjustment to environment and to each other of the living species—an adjustment determined by the relative vigor of each species; whereas the fauna is an aggregate of species determined by several quite divergent conditions and factors, the fauna living on so long as these conditions and factors remained sufficiently intact to permit it to preserve its general characteristics and the dominant species to maintain their relative place in the fauna, though for a time suffering more or less variation of composition, due to local and temporary conditions. (See page 131.)

ronments present in sections so nearly contiguous to one another as to occasion confusion in correlation.

The case of the Old Red sandstone and the marine Devonian was a conspicuous exception to the practice indicated. In this case the marine faunas of the Devonian limestone were recognized by Lonsdale as holding an intermediate place between the Silurian and Carboniferous marine faunas; and the Old Red sandstones were known to occupy the interval between these two systems; hence the equivalency of a series of marine beds with a series of estuary or fresh-water beds containing an entirely different fauna was established. But, in general, in the lesser cases, where faunas of the same kind of organisms are concerned, it has been the prevailing practice of geologists everywhere to assume that formations must be classified in a single column. Since the correlation and identification of formations has depended on their fossil contents, this practice has resulted virtually in the assumption that fossil faunas whose identity can not be established must be either older or younger than the standard faunas to which they are most closely related.

It was in the belief that this practice was erroneous and was leading to false conceptions of geological history that the investigations here described were begun. But the difficulties in the way of demonstrating the fallacy of the practice were great. Since the fossils are the only means by which the identity of two formations found at a distance from each other can be established, it seemed like a contradiction to say that two formations with unlike faunas may be identical in age. In order to test the question, it was necessary to take a region in which, for considerable distance, the structure of the rocks was so simple and so little disturbed that the stratigraphical equivalency of the beds could be traced with a high degree of certainty from one end to the other, independently of the fossil contents. Such a set of conditions appeared in the Devonian rocks of New York, Pennsylvania, and eastern Ohio. It was proposed to make a series of sections cutting through the same general part of the geological column, at intervals of about 50 miles, extending eastward as far as the Hudson River Valley and westward as far as the Cuyahoga Valley at Cleveland, the first trial section having been made along the meridian running through Ithaca, N. Y., in 1881–82. Minute study of each section was to be made; the fossils were to be collected from each fossiliferous zone, the position of which was to be carefully noted, and the faunules so collected were to be separately analyzed and listed. Intermediate traverses were to be made to tie together the sections by clearly recognized continuous strata, so that the stratigraphic equivalency of the parts of each section could be established with certainty. The work was begun privately in Cornell University, but the necessity of transgressing State lines led to the association of the university with the United States Geological Survey, by whose official sanction and financial assistance the necessarily slow process of accumulating the statistics has proceeded. At the outset Major Powell, then Director of the Survey, and Mr. Charles D. Walcott, then in charge of Paleozoic paleontology, gave their valued encouragement. The task was a large one, but its importance was also great. A single person could not expect in a lifetime to execute the whole work required to solve the problem, and therefore graduate students at Cornell University, and later at Yale, seeking practice in geological investigation, were interested in the work, and original research along these lines was intrusted to them. A large amount of statistics has been thus gathered.

These investigations have now been going on for twenty years, and numerous geologists have taken part in them. In the year 1885 a brief report of the general results attained up to that time was made before the American Association for the Advancement of Science.[a] At that time ten of the sections had been run, viz: Cuyahoga, Ohio; Painesville, Ohio; Girard, Pennsylvania; Chautauqua, New York-Pennsylvania; Genesee, New York-Pennsylvania; Canandaigua, New York; Cayuga, New York; Tioughnioga, New York; Chenango, New York; Unadilla, New York. The fossils were collected from the separate faunules, and certain general conclusions were then evident. Since then Messrs. Prosser, Clarke, Darton, and others have pushed the sections farther east, and they have been extended, with the aid of Messrs. Van Ingen, Weller, and Kindle, into Missouri, Arkansas, Kentucky, Indiana, Virginia, and West Virginia. Messrs. Geiger and Sayles have added collections from the Appalachian region. The Maryland geological survey is adding to the statistics for Maryland, and investigations are now going on in many other regions of the United States. Preliminary study of most of the collections has been made. The investigations for some part of the field have been carried much further than others, but the undertaking has now reached a stage in which it is possible to exhibit the general bearings of the results upon the whole field of stratigraphical geology and to state the principles upon which the investigations have proceeded, as well as to suggest at least what may be expected in the future, when the facts shall be fully elaborated.

In the preparation of this report I have been obliged to refer often to the statistics already gathered. Some of them, accumulated by myself or under my direction, have been published. Other statistics, in the form of unpublished notes, compiled in the course of elaborating the collections, have also been freely consulted. In addition to these sources, the reports of others working in the same field have been used, and for all such statistics I am deeply grateful to the contributing authors. The bibliographic list is large, and may be

[a] On the classification of the Upper Devonian: Proc. Am. Assoc. Adv. Sci., Vol. XXXIV, 1886, pp. 222-234.

referred to for the names of those to whom I am chiefly so indebted. Works not mentioned in that list, such as standard reports on the paleontology of groups and State and Government reports on the geology and paleontology have also been consulted for such facts as bear upon the questions discussed. I wish also to acknowledge my indebtedness, on the theoretical side of the subject, to the suggestions of others, though the influence of these may not always be directly traceable. Barrande's theory of colonies; Newberry's theory of cycles of sedimentation; the principle of separate facies for each formation elaborated by Renevier; Chamberlin's theories regarding the relationship of restriction of faunal occupation of sea-bottom to continental oscillation and the base-leveling of continents—these have all been taken in and digested in elaborating the hypotheses here advanced.

Finally, with high appreciation of valuable assistance rendered, I wish to acknowledge my special indebtedness to Messrs. Prosser, Harris, Van Ingen, Weller, Kindle, and Cleland, who, as graduate students at Cornell and Yale, have entered with enthusiasm into the investigations, and who are still engaged in prosecuting them with vigor and success in different parts of the field.

CHAPTER I.

THE PRINCIPLES OF CORRELATION.

IMPORTANCE OF CORRELATION.

In the Ninth Annual Report of the United States Geological Survey (1889), the Director called attention to the importance of correlation in the work of the Survey. His words are:

> In order to develop the geological history of the United States as a consistent whole, it is necessary to correlate the various local elements. . . It is especially important to determine the synchrony of deposits. So far as the outcrops of strata can be continuously traced, or can be observed at short intervals, correlation can be effected by the study of stratigraphy alone. The correlation of strata separated by wide intervals of discontinuity can be effected only through the study of their contained fossils. This is not always easy, and it is now generally recognized that it is possible only within restricted limits. As distance increases the refinement in detail of correlation diminishes.
>
> Recent discussions in connection with the work of the International Congress of Geologists have shown that different students assign different limits to the possibilities of correlation and give different weights to the various kinds of paleontologic evidence employed.
>
> The study of the data and principles of correlation is thus seen to be a necessary part of the work of the Geological Survey.[a]

CORRELATION DIVISION OF THE U. S. GEOLOGICAL SURVEY.

A division of the Survey was thereupon established for the purpose of preparing essays on correlation, and summarizing existing knowledge bearing on the correlation of American strata. A number of essays were subsequently prepared by specialists and published as bulletins of the Survey. Those now published are as follows:

No. 80. Devonian and Carboniferous, H. S. Williams, 1891.
No. 81. Cambrian, C. D. Walcott, 1891.
No. 82. Cretaceous, C. A. White, 1891.
No. 83. Eocene, W. B. Clark, 1891.
No. 84. Neocene, Dall and Harris, 1892.
No. 85. Newark, I. C. Russell, 1892.
No. 86. Archean and Algonkian, C. R. Van Hise, 1892.

This attempt to bring together the facts available for the correlation of American formations was a direct consequence of the work of the International Congress of Geologists, and particularly of the American committee of the congress whose report was made to the London session of the congress in the year 1888.

[a] Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 16.

DUAL NOMENCLATURE.

It was while acting as a member of the American committee which was engaged in preparing reports on the American systems for the International Congress that I became impressed with the necessity of a dual nomenclature. The common usage abroad, as here, was to name and classify geological formations only. Fossils were a means of their identification, but no attempt had been made to distinguish the limits of the life range of the fossil faunas from the formational boundaries which were established on lithological and stratigraphical grounds.

The principle of distinguishing the faunal from the formational classification and nomenclature was thus summarized in the Compte Rendu of the Fourth Congress.

Prof. H. S. Williams at the Albany meeting [1887] suggested an important fundamental idea, and one which may influence materially the final distribution of terms in stratigraphic nomenclature, viz, the adoption of a dual set of designations—one set, that referring to the lithological character of the rock masses and based on geographic names, will be liable to vary as the strata change from place to place; and the other, based on some great and persistent life characters, shall refer to the faunas of those rock masses and be substantially constant over large areas, and perhaps over the world. It is very evident that great confusion has resulted in the past, among geologists, by confounding these distinctions, and much controversy has arisen in attempting to maintain one or the other of these different zonal designations. Stratigraphic work has been ignored, or at least neglected, by paleontologists, and the practical field geologist has been tempted, in some instances, to ignore, if not to deny, the assertions of the paleontologist. Instead of this confusion there should be introduced some new departure. The confusion results from a confusion of nomenclature. Faunal characters have been made to have the force and the usage of stratigraphic designations and have been extended as stratigraphic features over strata where the faunal characters are wanting. Again, stratigraphy, based on natural and great lithological distinctions, having been defined in one region by its faunal associations, is extended over other States by one geologist so far as he finds the lithology to warrant, and by another so far as he finds the paleontology to warrant.

There are, hence, two laws by which we must be governed in framing a scheme of nomenclature which shall allow the freest rein both to the stratigraphic geologist and to the paleontologist. One relates to the work of the stratigrapher, who takes account of the great physical changes to which the earth's surface has been subjected, and the other refers to the work of the paleontologist, who strives to delineate the organic changes which the surface of the earth has witnessed. These changes have been supposed to be coeval and coextensive; but our investigations show they have not been so entirely. But we sometimes have the same fauna, or nearly the same, living under different circumstances, and, perhaps, also at different dates, in different parts of the world.

So long as the geology of the United States, for instance, was known accurately in only one part (New York State) the faunal characters which the formations were found to exhibit were seen to be coincident with the stratigraphic to so great an extent that there was no reason to dissociate them under separate schemes; but since the whole area of the United States is being brought under careful examination, it is found that the close connection which these two classes of characters have in New York State is broken up and they begin to diverge gradually in various places and in different ways. The same experience is found, to a greater or less extent, as any local terms are extended from any of the States into those contiguous. This plainly shows that unless there be allowed great freedom to vary from the scheme adopted for stratigraphic designations, any nomenclature which the committee or the International Congress may adopt will be but a short-lived experiment.

It will obviate all this confusion if * * * one set of names be chosen for the lithological characters and another for the faunal.

The stratigraphic terms should be wholly geographic and should be allowed to change as often as local geologists deem it is necessary. The faunal terms should be very broad in their scope at the outset, and subdivisions should be introduced as fast as the special subfaunas are discovered and defined.[a]

This was stated more explicitly in a paper published in 1894.[b]

As surveys have advanced, and as the field of geological correlation has gone beyond local and national boundaries, the task of establishing correlations has made the necessity of a dual nomenclature more imperative. Correlations between widely separated regions are now established on the basis of fossils alone. Correlations on the basis of continuity of lithological peculiarities are already known to be valid for only limited areas. Thus geologists throughout the world are already adopting the principle of a dual method of correlation, although the nomenclature and classification of correlation are still primarily conjoined with lithological formations, the names of which furnish the only means of distinguishing the faunas and floras which they contain.

This lack of a nomenclature by which to distinguish the lithologically defined formation from the biologically defined fauna (which may or may not be limited in its range by the boundaries of the formation) can be supplied only through discrimination of the characteristics of actual fossil faunas and a demonstration of their independence of the limiting conditions by which the formations are defined. If it can be shown that fossil faunas and floras can be discriminated, defined, and discussed separately from the formations, which now constitute the only elements of geological classification, not only will the separate nomenclature naturally follow, but the fossil fauna will then become, as it is now partially recognized to be, the definite means of determining the time relations of geological formations. Such a discrimination is attempted in the following pages.

In order to exhibit the characteristics of faunas a concrete case is selected from among the faunas of the Devonian system, the choice having been determined by the abundance of the facts already gathered regarding Devonian faunas. Abundance of fossils, frequency of exposures, and wideness of distribution distinguish the Hamilton formation of the New York section above all other formations in the country. The large number of workers, the degree of refinement in analysis, and the fullness of publication of the statistics regarding

[a] Compte Rendu Congrès Géologique International, fourth session, 1888, A 91.

[b] On dual nomenclature in geological classification, by H. S. Williams: Jour. Geol., Vol. II, p. 145.

the Hamilton formation have made it possible to treat the facts concerning it with a degree of precision that would not be possible in considering a formation which is less perfectly known or one the facts concerning which are scattered and but imperfectly classified.

For the discussion of a geological fauna it is also important to have some conception of the environmental conditions under which it lived and the succession of conditions which have preceded and led up to them. Thus, to understand the fossil fauna preserved in the Hamilton formation, it is needful to reconstruct the physical conditions of the Devonian sea in which the fauna lived, and to look backward over the history of that sea for some considerable period of geological time. In order to describe a fossil fauna it must be traced back to a time when it was not, and onward till it has ceased, and thus the history of the basin in which the evolution has taken place is incidental to the description of the fauna itself.

DEFINITIONS AND NOMENCLATURE OF FAUNAL PALEONTOLOGY.

The primary fact that fossils may be used in identifying formations and tracing them from place to place was announced and demonstrated by William Smith. Many other laws regarding the order and succession of fossils have been formulated by d'Archiac, Bronn, Pictet, Lyell, Brongniart, Zittel, and other writers on paleontology. But in addition to these fundamental and established laws of the relations of fossils to formations, there are some special facts or principles pertaining to the relations which living organisms bear to their environment and to each other, brought out by the study of organic evolution, which require definitions and lead to the adoption of terms differing somewhat from those in common use, at least with special application to correlation and the expression of time relations in geology.

The question here raised is not, Can geologic formations be correlated by their contained fossils? The fact of correlation is taken for granted; but the questions are, Wherein does correlation consist? What is done in correlation? Upon what principle are correlations made?

Thus the discriminations to be made pertain to the relations which fossils bear to one another, to the geological conditions of preservation, to the conditions of their living and continuing to live in the past, and, finally, to the value of fossils as means of distinguishing different periods of geological time as well as of identifying like periods of time represented by them.

ANIMAL AND PLANT AGGREGATES.

To discuss organisms in their relations to time, it becomes necessary to treat of them in aggregates and to discriminate the reasons for which the particular aggregations are made.

The zoologist associates organisms on the basis of their morphological affinities, and calls the aggregates species, genera, orders, etc. Two specimens belong to the same species because the morphological characters which the zoologist regards as of specific rank are alike in the two specimens. The members of the same order are thus classified together because they exhibit the same ordinal characters. The members of the same species were formally supposed to be so associated because of their genetic affinity—i. e., descent from common parents; but we are now accustomed to recognize community of characters, of whatever rank, as an indication of the genetic affinity of the organisms exhibiting them. The difference between ordinal affinity and specific affinity is one of degree, not of kind; the members of the same order are genetically related, but the relationship is more distant than that of members of the same species. Thus the terms species, genus, order, and class are applied to aggregates of plants and animals on the basis of their genetic affinity, and the several terms indicate the degree of nearness of affinity. The individuals associated to form a particular aggregate of this kind may be fossils or living beings, and they may come from opposite sides of the earth, but they are associated on the basis of the likeness of the morphological characters they possess, and they are classified on the basis of the theoretical relative degrees of kinship they bear to one another. A species or a genus is therefore an ideal aggregate. No one ever sees the whole of a species, and only as its relationship to place and time are indicated can the aggregate called a species be defined. Furthermore, the terms species, genus, etc., are arbitrarily applied in every particular case. In other words, there is no standard except common practice to determine what characters are of varietal, specific, or generic rank. But the law is well established that the aggregate shall be named in the order of degree of affinity by the terms species, genus, family, order, class, etc., terms implying, progressively, near to more distant kinship.

A second mode of classifying organic aggregates is on the basis of their relationship to environment, or to the conditions of life. Thus we find Walther, in his "Bionomie des Meeres" (1873), adopting and applying Haeckel's terms: *Halobios*, the total aggregate of living beings inhabiting the sea, as distinguished from *Limnobios*, the inhabitants of fresh water, and from *Geobios*, the organisms inhabiting the land. The marine organisms (*Halobios*) are subdivided into *Benthos*, those living on the bottom, as distinguished from *Necton* and *Plankton*, the inhabitants of the open seas. Depth of range of faunas or floras is indicated by such terms as *littoral* or *abyssal*. Such aggregates are made without consideration of genetic affinity or likeness of form; all kinds of animals and plants living together are included. The general basis of the classification is coincident with area of geographical distribution, and the relationship determining the classification is the adaptation of the organisms to the common conditions of environment.

A third kind of aggregates of organisms is defined by the geologist.

He speaks of Paleozoic faunas, Carboniferous floras, the fauna of the Trenton or of the Cambrian or of the Eocene. The basis of aggregation in these cases is the fact of living at the same time, or period of time, in the earth's history; or, to speak more abstractly, the *geological range* of the organisms. The Eocene fauna includes all the animals, of whatever descent or of whatever zoological rank, existing in all kinds of environments, of which fossil remains are known occurring in the Eocene formations of the whole world. As at present defined the term Eocene is applied to formations of different lithological kinds, outcropping in various parts of the world, the only final test of the Eocene age of which is the uniformity of the faunas. Hence it is evident that the assumption is made that the whole life of the globe for each period of time is in a marked degree alike for like conditions of environment. But this conclusion is true only when the qualifying phrase *in a marked degree* is kept in mind, for a comparison of the faunas and floras from different parts of the earth now living shows them to differ, though living under like conditions of environment.

Students of geographical distribution have shown that in distant parts of the same ocean the species are widely divergent, as much difference existing between the marine faunas of the southern and northern temperate zones as between the faunas of two successive formations of a continuous geological section. It is evident from this observation that discussions of the time relations of fossils must treat not only of the genetic affinity of the forms making up a fauna, but of the geographical distribution and of the geological range of the species concerned.

While *species*, *genus*, etc., have been adopted as terms to express *genetic affinity* of the organic aggregates under consideration, *fauna* and *flora* are general terms used to indicate aggregates of animals or plants associated on the basis of their *geographical distribution* (or adaptation to similar conditions of environment) and their *geological range* (or place in the evolutional history of the total life of the globe). It is no longer internal structure but external conditions which determine these latter aggregations

In discussing fossil aggregates of organisms we have to consider, therefore, this threefold relationship they bear, viz, (a) to zoological and botanical classification, (b) to geographical distribution, and (c) to geological range.

ZOOLOGICAL AND BOTANICAL CLASSIFICATION.

The first kind of relationship is expressed by the internal structure possessed by the organisms themselves; hence the definition of an aggregate of this kind is in terms of morphological characters, and its classification is based upon the rank (the taxonomic rank) of these characters, which is indicated by the technical name of the species or genus or order to which the individual organism is said to belong.

What is actually meant in such classification is that the individual specimen to which a particular specific name is applied exhibits in its morphological structure the characters which have been described under the specific name used. In the same way, to say that a certain animal or plant belongs to a particular genus means that it possesses the characters to which the generic name used has been scientifically applied.

The specific and generic name given to a fossil applies to the peculiar morphological characters recognized in the scientific definition of the species or genus, and in giving it we are not dealing with the individual as a whole or with aggregates of individuals, but only with the particular characters exhibited by the individuals implied by the name. When, for instance, it is stated that *Phacops bufo* lived as long as a third of the time represented by the Devonian system, it is not meant that any individual specimen continued to live so long, but that in genetic succession the specific characters of the species *Phacops bufo* were repeated without noticeable and permanent modifications during that period of time. We are not dealing with the biological aggregate, a taxonomic species, but with the geological aggregate, a living succession of individuals—the race.

The terms of zoological and botanical classification are constructed, primarily, to apply to *living* organisms—animals and plants. A *fauna* has thus come to mean, in scientific usage, an aggregate of animals of different kinds structurally, associated on the basis of some conditions existing outside the animals themselves. These conditions may be kind of element, as air, water, or land inhabited; place, as country, mountain, sea; altitude, as plain, plateau, or mountain, or zones of depth in water, or geological formation, or kind of sediments in which the remains are preserved as fossils. *Flora* is a term for the aggregate of plants under like conditions.

DISTRIBUTION AND RANGE.

When the conditions determining the classification of the fauna or flora are geographical, the boundaries and their measurement are spoken of as *geographical distribution.* Thus the fauna is said to be distributed over a country or through a number of degrees of latitude, or through a number of feet in altitude above the sea, or through a number of fathoms of depth below sea surface. Geographical distribution is concerned with the relation of organisms in faunal or floral aggregates to the *position* of their living, if living forms, or of their burial if fossils.

Range and *geological range* are terms which signify that the criterion of association is geological rather than geographical, and refer to the association of organisms with geological formations. Thus a genus is said to *range* from the Cambrian to the Devonian systems; or the *geological range* of a species or fauna may be said to extend from one formation to another. This use of the term *range* is illustrated by the phrase "*Atrypa reticularis* has a long geological range in Paleozoic time." The range of fish must be carried below the Devonian and Silurian (where it was previously supposed to begin) because of the discovery of the wonderful fish remains in the Harding sandstone of Canyon, Colo., associated with a Trenton limestone invertebrate fauna.

In order to discuss the problems of the time relations of organisms it is necessary to use the terms *range* and *distribution* to refer respectively to geological and geographical space, and to note that the facts concerning the range of species and genera are stated in terms signifying position in and thickness of formations. Range *in time*, often referred to, must be determined by relationship of the faunas or species to one another, and this is another method of the discrimination of the faunas, a method which is neither geographical nor geological, but, as we shall see, *organic*, and which is strictly a measure of the life history of organisms in evolutional succession one to another.

The importance of the distinction between range and distribution, as applied to fossils, is apparent when it is considered that the evolution or modification of the form of organisms may be coincident either with change of place during the same epoch of time or with passage of time in the same area of space. Fossils can be used as indicators of uniformity of geological horizon only within the limits of their modification by conditions of geographical distribution. If the form of a fossil varies according to the nature of the sediments in which it is buried, indicating different conditions of life, the extent of that variation and the relation of the change of form to the particular nature of the sediments must be observed before the characters of the fossils can be accurately applied in discriminating their age.

It has been ascertained, as will be illustrated beyond, that a fossil species may recur at successive zones for a thousand or more feet of thickness of strata without showing greater modification of form than is expressed in specimens of the same species obtained from the same stratum. It can also be shown that the species making up the fauna of rocks not over 100 miles distant from each other, which by other means are proved to be at the same geological horizon, may present greater differences than the successive faunas of a single section extending over a range of many hundreds of feet. These facts lead to the discrimination of the idea of *variation* and to the application of that term to indicate *differences* expressed by specimens of the same species—*differences arising coincidently with extension of geographical distribution and change in conditions of environment;* while the term *mutation* is technically applied to those *changes of form that are coincident with passage of time, and hence to generational succession under conditions of life so nearly the same that extinction of the race does not result.*

In treating of the relations of organisms to time and of their evolutional history, it becomes necessary to notice the fact that each individual organism expresses the characters by which the taxonomic divisions of all ranks are defined. When one speaks of a species living in a certain locality or at a particular period of time, the expression is not strictly true; the species (or the genus) is a category, not a living body.

The fact in the case is that individuals live, developing the characters of some species, or of the specific category. Each individual is no more a species than it is a genus or order or class; and whenever one is speaking of the time range of a genus or species, it is necessary to understand that what is meant is the time range of the particular specific or generic characters, as the case may be. By forgetting this point one is liable to think that the species cited as characteristic of a particular epoch of geological time suddenly became extinct when the formation holding it is succeeded by another containing different species.

So long as representatives of a genus continue to appear it is necessary to assume that there has been a continuous succession of living individuals arising by direct generation one from another. Whenever a new species appears in the rocks it is not to be supposed that it had no immediate ancestors living at the time of sedimentation of the subjacent formations. So long as a family exists in the world, it is also necessary to assume that genera and species have continuously existed, and their absence from the formations does not indicate that they did not live in the zones of sedimentation which lack their remains.

These observations make plain the reason for the introduction of the ideas expressed by the terms *migration* and *shifting* of faunas, to account for absence of faunas, in the place of the idea of extinction held by the earlier geologists. Not only must we conceive of whole faunas, as well as individual species, migrating, but it is necessary to assume that, coexistent with thick formations that are barren of fossils there were living, in probably not very distant localities, faunas made up of abundant individuals of many kinds of different species and genera. This fact will explain also why it is necessary to take into consideration the question of migration in order to make correlations with precision. Other problems, which will be discussed farther on, are suggested by the fact that the evolutional accounting for divergence of characters implies always *a continuous, unbroken series of generations for each race of organisms until it becomes extinct.* The characters which are of specific rank at one time in the history of a race can not take generic rank in another part of the history. The passage from varietal to specific rank, advocated by Darwin in the "Origin" as the mode by which species originate, does not apply to *specific characters*, since the reason for the distinction between variety and species is, so far as the characters are concerned, purely a question of permanency. The evanescence of the varietal character in generation is the reason for calling it varietal; when it becomes fixed and is repeated without change its rank in the vital economy determines whether it be classed as a specific, generic, ordinal, or class character. The changing of the characters of all ranks of taxonomic value and the length of the reproduction of the several characters without change are chiefly the measures of that taxonomic rank, since the classification of the organisms into the taxonomic groups, species, genus, order, etc., is regarded as natural only when the groups of higher rank are strictly inclusive of those of next lower rank; and this could happen only when the higher characters were present before the distinctions of lower rank were produced. For instance, it would be impossible to conceive of the distinctions between two genera arising by evolution before the ordinal characters had been evolved—i. e., in a natural classification. Hence, *the higher the rank of the zoölogical character of an animal the more ancient the history of that character.* The application of the principle may be expressed by saying that in identification of fossil specimens for purposes of correlation it is imperatively necessary to know the taxonomic rank of the characters by which the identification is made. If a generic character be interpreted as evidence of a particular species, the correlation inferred from the fact may be false, since the range of the specific character in most cases must be far shorter than that of a generic character of the same group of organisms.

From the preceding remarks it follows that fossils, either as taxonomic aggregates based on genetic affinities or as aggregates associated on the basis of living together, can not be considered simply by morphological features, but that their chronological relations must be distinctly noted. *In considering a species, the paleontologist must not only consider all the descendants of a common parent and those differing from them no more than they differ from one another, but must consider the descendants which do differ, and the length of time during which generation continues in the race with retention of the specific characters.* The idea of continuity of race is an element in the geological study of species.

In like manner a fauna at any particular instant of time includes all the species of animals living together under a particular, though very complex, combination of environmental conditions. The paleontologist has to extend this idea to include also the *length of time through which the fauna persists without loss of the characters essential to the fauna.*

Thus the paleontologist is not only forced to consider the time relations of species and faunas, but it is by means of the relations of fossils to one another that periods and epochs of geological time are distinguished.

A living species may be classified by its taxonomic characters and be identified with forms living within a particular geographical area of distribution; but this is not a sufficient discrimination of a fossil species. The life period through which successive generations reproduce the same characters is an important part of the paleontological discrimination of a species. In order to so discriminate fossil species, their time relations must not be obscured by making them coordinate with the formations in which the fossils are preserved. The time relations of a fauna are so obscured so long as we have, for instance, no means of naming the fauna of the Hamilton formation except by calling it the Hamilton fauna. So long as we have but a formational name to apply to the fauna, any question as to the continuance of the fauna later in one region than in another can not be stated, since the presence of the fauna is the only certain evidence of the upward extension of the formation.

In order, therefore, to deal with the fauna separately, it must be designated by a biological name.

GEOLOGICAL FAUNAS AND THEIR NOMENCLATURE.

In order to demonstrate the independence of faunal history from the history of formations, as commonly defined, on a lithological basis, it has been found necessary to study a fossil fauna as an aggregate of species living together, and not as an aggregate of fossil remains occurring in and characterizing some particular geological formation. As commonly understood and as represented in the collections of museums, fossils are tabulated and arranged by formations. Whatever specimens have come from rocks classified as the Hamilton formation, for instance, are put together as constituting the fauna of the Hamilton formation, and, as has been previously noted, this makes it rarely possible from the lists (or from the collections so gathered) to determine with precision the range of the species. Again, rarely in the older lists is the abundance or rarity of species of a fauna noted, and the collections are often deceptive in this respect, since the collector is, for economical reasons alone, apt to neglect common forms, while rare forms are selected with great care and every trace of a newly discovered species is retained.

In order, therefore, to exhibit the full time value of fossil faunas, it becomes necessary to observe all those relations which the individual fossils bear to the environment in which they lived and to each other as they were associated as living individuals of a composite fauna. In thus analyzing fossil faunas the most conspicuous fact presented to the collector is the different degrees of abundance in the general distribution of fossils in the rocks. *Fossiliferous zones* are thus set off from unfossilliferous or *barren zones*. Such zones, distinguished on purely paleontological grounds, are entirely distinct from the geological formations of our maps and geological reports. A fossiliferous zone may be coextensive with a formation vertically in one section, while another exposure of the same formation may be broken up into several fossiliferous and barren zones; and still another exposure of the same stratigraphical formation may be barren of fossils from bottom to top.

In order to define such zones it becomes necessary to note and record their *place in the vertical section* of strata making the formation. This is indicated most conveniently by measuring distance from bottom or top of the formation. This stratigraphical position of the fossiliferous zone in the section of the geological formation is its *horizon*.

A fossiliferous zone may occupy the same horizon, a higher horizon, or a lower horizon in two exposures of the same formation, according as its position relative to the top or bottom limits of the formation is the same, higher, or lower.

A fossiliferous zone may increase in thickness on following it in one direction, and decrease in the opposite direction, in proportion as the thickness of strata through which the fossils prevail increases or decreases in the section.

A fossiliferous zone may appear gradually on following the strata upward, or it may appear abruptly, being sharply contrasted with a subjacent nonfossiliferous zone. It is often the case that the central portion of a fossiliferous zone is richer in kinds of fossils than are its lower or upper portions. Species which are proportionately dominant at the first appearance of the fauna may disappear when the full expression of the fauna is seen, but reappear as the species become rare in the upper strata of the zone.

Thus, for instance, *Leiorhynchus* is apt to occur on the borders of a fossiliferous zone, and is less frequently met with in the center of a richly fossiliferous zone; *Lingula* and *Discina* are more frequently found in sparsely fossiliferous zones than in association with many other species or genera.

When it is necessary to speak of a portion of a zone, be it fossiliferous or not, the terms *bed* or *band* or *stratum* are used.

In this connection it is important to note that in ordinary sedimentary rocks, limestone (or the calcareous element of the sediments) is reasonable evidence of fossils, although present in a pulverized condition; and for purposes of discrimination between fossiliferous and nonfossiliferous zones, limestone should be classified among the fossiliferous zones although the forms of its fossils are obliterated. In like manner a coal bed is a mass of fossil plant remains.

The kinds of strata in which the forms of fossils are in general best preserved are those ranging between coarse sandstone and pure limestone. In the former the roughness of the original conditions under which the formations were made was ill adapted for marine organisms, while the pure limestones were formed under conditions favorable for such organisms; but, on account of the absence of sands and muds to cover the shells and other hard parts of the fossils, these were ground up by the action of waves and currents, and their substance, though not their forms, was preserved.

A zone may be traced from place to place, as may the formation itself, and whenever a zone runs out or thickens, or breaks up into alternate barren and fossiliferous zones, the facts relate to the *continuity* or *discontinuity of the zone*. *Continuity* and *discontinuity* are, therefore, terms describing physical conditions, and are applicable in describing the persistence or reappearance of the same or parts of the same zone in different localities. But a zone is a part of a physical formation and is not a fauna or a flora; the term connotes the geological position occupied by the fauna, as the term *province* connotes the geographical area of distribution of a fauna.

Just as it is presumable that the separate observed localities of a living fauna are continuous, and that all of them together make up the geographical area or province of the distribution of the fauna, so it is presumable that all the outcrops of the same fossiliferous zone were originally connected, and thus that there has been a continuous zone representing the *geological range* of each particular fauna whose remains characterize the zone.

If no changes in geological conditions were to take place the *geographical distribution* of any fauna at any particular time, recent or geological, would constitute its geographical province, and thus define the geographical limits of the fauna. It is, however, evident that geological changes have been and are constantly going on, resulting in the *migration of faunas* from place to place. It is quite conceivable, therefore, that *the lapse of time represented by the presence in the strata of the species of the same continuous fauna may be nonsynchronous for two sections not many miles apart and belonging to the same geological province.*

This fact would be explained as a case of migration of the fauna as a whole over the bottom of the ocean. Such a case may be stated in the following way: The fauna was a littoral fauna, living along a shore facing an ocean to the west; the land in relation to ocean level was gradually sinking during the life period of the fauna, causing the littoral conditions of the water to transgress toward the east. As the sinking progressed we may suppose the fauna as a whole to creep along eastward, retaining its relationship to the littoral conditions of environment without modification of its species or loss of its faunal integrity. After a long time of such movement in the same direction it is quite conceivable that the whole area of bottom originally occupied by the special fauna might be deserted, and that too within the life period of the fauna, which, in the case of the Hamilton formation in central New York, was a time long enough for the accumulation of over a thousand feet of argillaceous shale strata.

The record of such a migration would be left in the strata of the whole region occupied by the sediment-receiving sea; but the place in the geological section of the more eastern part of the area marked by the presence of the fauna would represent a different period or moment of time from the place in the more western section containing the same fauna. The difference in time could easily represent half the period of the existence of the fauna in the province.

The fauna in such a case may be supposed to slowly adjust itself to its evironment *by migration instead of by modification*, keeping the center of its distribution within the limits of the favorable conditions of depth, pressure, salinity, etc. Instead of accepting an unfavorable environment which has invaded its original habitation, it keeps its relation to the favorable conditions by changing its place of habitation, and thus by slow migration maintains uniform conditions of environment.

If, now, we adopt the term *equivalency* to express the fact that the faunas are alike, and *continuity* to mean that the stratigraphical horizon of a zone or formation is the same, the conclusion which has been reached may be expressed by saying that *faunal equivalency does not necessarily conform to formational continuity, except for areas that are narrow in relation to the extent of the distribution of the fauna.*

This same principle of *transgression of a fossiliferous zone* to a lower or higher horizon in a formation on passing from place to place, applies as well to the limestone beds as to the other lithological characteristics of a formation. On account of the transgression it will be evident that *formational continuity can not be interpreted into exact time equivalency, except for very limited geographical areas*, the limits of which must be determined also upon other evidence. Not only may the same fossiliferous zone occupy different horizons in separate outcrops of the same formation, but the same formation whose stratigraphical continuity can be clearly traced is presumably of diverse age at the extremes of its geographical distribution rather than of the same age. Thus *area*, *locality*, *distance apart*, are geographical terms for which *zone*, *horizon*, and *thickness* vertically in a section are the corresponding geological terms.

Systematic position in a geological section is, like geographical position on a map, a means of locating the *place* in which a formation is situated, and has no necessary connection with the *time* at which the original formation of the sedimentary deposit was made.

Age, *contemporaneity*, *equivalency*, and *correlation* are terms of a different order, and rest for their discrimination upon the evidence of fossils whose preserved forms testify of the time when particular species of organisms lived, and thus become a distinct indication of time relations.

Particular fossil species are not confined to single fossiliferous zones, but may recur again and again in successive zones, irregularly separated by barren or nearly barren zones. This fact is itself an evidence of *migration;* since a recurrence of the same fossils in successive zones can be rationally interpreted only on the supposition that during the sedimentation of the barren strata the successors of the lower fossils and the ancestors of those that followed must have lived in some other locality.

The successive zones thus become evidence of successive occupation of the locality at which the stratigraphic section was made, and of an oscillation in the movements of the shifting faunas. In order to ascertain whether the shiftings are in one direction, or back and forth, the successive zones must be examined and the fossils compared. The paleontologist is therefore obliged to examine every foot of the section exposed, and wherever fossils can be discovered examination must be made and record of the facts be preserved.

When a fossiliferous stratum is discovered on ascending a stratigraphical section, the paleontological observer stops and samples the stratum. The fossils thus gathered constitute a *faunule.* The faunule may be found to extend upward for several inches, or possibly several feet, without apparent change. But the collector should observe carefully to discover the least sign of change in the fossil content of the faunule.

In recording the contents of the faunule, care is needed to observe the *proportionate abundance* of the species. If collections are made with this idea in mind the species may stand in the collection in the same relation to one another as in the natural faunule. In addition to the collection, notes should be taken of the abundant and common species—the rarer forms will be discovered as such during the study of the collection in the laboratory.

Each fossiliferous zone should be examined, and particular attention should be given to any intercalated bands of rock not like the prevailing rock of the section, which may bear faunules of a different fauna from the one prevailing in the general fossiliferous zone of the region. It has been ascertained that these slight temporary incursions of a fauna, which may be conspicuous not many miles distant, are valuable guides to the *direction of the migration*, and they are often forerunners of a fauna belonging normally at a higher horizon in the formations.

The faunule is a sample of the faunal contents of a fossiliferous zone, and, as a sample, care should be taken to keep together in their true relations all the species of the individual faunule, so as to permit no doubt as to the natural association of the species when the collections come to be more minutely studied in the laboratory. The position of the faunule in relation to other faunules in the local section should be observed and recorded with precision, note being taken of its relative position in the fossiliferous zone, as well as its position in the formation as officially mapped and described in Survey reports of the region.

As the order of *succession of the faunules* is of great importance, the section should be examined from bottom to top and each fossiliferous zone noted, and faunules obtained and recorded as frequently as may be practicable. In practice it has been found that sections in the Devonian of New York and Pennsylvania are sufficiently alike for a radius of 5 or 10 miles to make the separate fossiliferous zones recognizable in the separate sections examined. As an actually continuous section vertically is more satisfactory in faunal studies for the establishment of sequence than several short sections whose zones at top or bottom have to be correlated across a covered interval, it is desirable to make a thoroughly exhaustive section, extending through the formations examined, for at least every 15 or 20 miles. The local shorter sections will then fall into their places in relation to the general sections and prevent confusion of *geological mutation* with *geographical variation.*

In reporting the faunules the identification of species is of first importance, but for study of the biological relations of the faunas as such the *relative abundance* and evident *dominance* of the species is of almost as great importance. Only thus are the intimate relations of the faunas to be established and their time values brought to light. After these two sets of facts are recorded, note should also be taken of the *variability* expressed by the species, and particularly those which are the *dominant* species of the faunule. It is by catching the particular characters of specific form which express variability, and the direction of the changes taking place in the form of the fossils, that genetic kinship of faunules is traced.

By taking note of these characteristics of the faunules over territories several hundred miles in extent, and ranging through the middle and upper formations of the Devonian system, it has been possible to formulate several valuable rules for the discrimination and interpretation of fossil faunas.

Faunules of the same formation, located together in the same general region, are more closely alike in constitution and proportionate abundance than those of widely separate regions. Hence it follows that a fauna has a local expression. The details and exact description of this local faunal expression can be stated in terms of relative abundance of the species constituting the faunules.

Although over wide areas some of the species of a general fauna are recognized, the *limited area* within which *the dominant species hold the same relative dominance in numbers* over the other species may be clearly distinguished by the statistics of the faunules.

By comparison of the species of the faunules in their relation of relative abundance a *standard list of dominant species* is formed, and the region over which this standard is preserved may be called the *metropolis of the fauna.*

By the same method the faunules express for several numbers in succession the same dominant species. So long as this is the case it may be assumed that the same fauna is under examination. When the dominant species become replaced by others *a change in the fauna* is taking place, though it may be shown that a large majority of the species are identical.

This maintenance by a fauna of the same relations of abundance and rarity among the component species may be called the *bionic equilibrium of the fauna*, since we can not assume that the whole fauna dies out and a new one comes in, but rather must believe that the fauna changes by an adjustment of equilibrium among its species. Some of the species may become extinct, some of them may be modified, and some may be left behind or become separated from the main fauna in the course of its migration.

The term *bionic* refers to the quality of *persistence in transmitting the same characters from generation to generation*, a quality that is recognized by the presence of the same species in the same relative abundance in the successive faunules. This relative abundance of individuals of the same species is thus taken as the evidence of the bionic rank of the species in the faunule at the particular time in which it lived.

It has been observed that species having a high bionic rank are more variable than those with low bionic rank; therefore it is to be expected that the varietal forms which are destined to become the new species of later stages of the fauna will be found among the varietal forms of dominant species. On the other hand, the dominant species of a new fauna are likely to be the rare forms of an antecedent fauna which in the revolution of the conditions have gained in bionic vigor and replaced the old species which have lost their bionic dominance. It is to catch this replacement of the old fauna by a new one that the observer should watch with care the thin occasional intercalated beds containing species either wholly or in part different from the prevailing fauna.

It has been often observed that the first traces of the new overlying fauna are to be detected almost pure in such little zones occurring in the midst of the normal rocks of a formation several feet or even tens of feet below its actual top. Much light is thrown upon the time relations of faunas and upon the shifting of sediments and faunas (to be ultimately interpreted into elevation and depression of parts of the earth's surface in relation to other parts) by noting precisely the sequence of faunules, and particularly the first evidence of change in the faunal contents of the zones of a continuous section.

The question of bionic values may be discussed more satisfactorily farther on in this paper, after the presentation of concrete examples to be used as illustrations. The general conception of bionic relations and values is given in a paper first read before the Geological Society of Washington in 1901.[a] In this paper definitions tending to clarify thinking in these directions are given. In another paper,[b] read before the Connecticut Academy, February 12, 1902, a brief synopsis of the results of the investigations given at length in this bulletin are stated, and some laws not specifically formulated in this paper are there given.

In order to call attention to the distinctions which are made by a separation of the discussion of fossil faunas from that of the geological formations in which record of them is preserved, it may prove useful to mention in this place the terms in common use as well as those here introduced, classified according to their application to formations or faunas.

NOMENCLATURE OF FORMATIONS.

Formations are portions of the rocky crust of the globe. They may be called igneous, sedimentary, or metamorphic, according to their mode of origin. They may receive lithological names, as granite, limestone, or sandstone, according to their lithological constitution.

The terms sheets, intrusive or extrusive strata, lenses or lentils, apply to formations on the basis of their geological structure.

They are called crystalline, schistose, stratified, or oolitic, on the basis of their texture.

They are described and mapped as occupying particular geographical areas on the basis of their present outcroppings to the surface of the earth. Their thickness is determined by measuring them from bottom to top in a line vertical to the plane of their supposed original deposition, and they are said to be older or younger according to their order of succession.

They are named on the basis of their local, prominent, or first-described geographical outcrops. These names are generally geographical terms.

They are classified primarily on the basis of their observed order of succession, and secondarily on the basis of their supposed equivalence in stratigraphical position with other formations whose order of succession has been established. Such terms as system, series, groups, stages, zones, and beds are thus applied to geological formations; station, section, geological column, outcrop, conformity and unconformity, province, region, and like terms also apply to geological formations.

The terms correlation, contemporaneity, and equivalency apply to formations, and may be used on the basis of structural, lithological, or stratigraphical evidence; but in general it is only on the basis of evidence furnished by the fossils within them that they become widely applicable.

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[a] The discrimination of time values in geology: Jour. Geol., Vol. IX, pp. 570-585.

[b] Fossil faunas and their use in correlating geological formations: Am. Jour. Sci., 4th series, Vol. XIII, pp. 417-432.

The geologist is liable to regard fossils, in determination of correlation, as of the same order as minerals (viz, chondrodite) or petrographical characters (limestone, sandstone), and then to associate them with other diagnostic characters of the formations, but a closer consideration of the facts will show that the quality of the fossil by which it becomes evidence of a particular point of geological time, and from which it derives its value in correlation, is biological, and is due to the fact that in biology incessant change is taking place.

While a formation has a bottom and a top and thickness, which, to be sure, must have started and ended at particular points of time, those particular points of time can not be determined in the general history of the earth except upon evidence which changed with the passage of time. The validity of this statement will become apparent by attempting to ascertain the geological age of an igneous rock without noting its relation to some fossil-bearing rock.

In dealing with formations, therefore, whenever fossils are brought in, a new body of evidence is introduced, and a number of terms not applicable to formations are required for the scientific discrimination of this evidence.

FAUNAL AGGREGATES.

Fossils when spoken of in aggregates are faunas or floras. Faunas are particularly spoken of in this paper, not to the exclusion of floras, but because in most respects the remarks which apply to the geological relations of faunas apply also to floras. The term fauna, however, will be used in its strict sense of an aggregate of animals. The first reason for making the distinction between formation and faunas is that the aggregation of the species which makes up a fauna is not determined by the formation. The generally accepted practice, which was formulated in Dewalque's report[a] for the committee on uniformity of nomenclature at the International Geological Congress at Berlin—by which the chronological divisions (era, period, epoch, and age) are adopted as names for the duration of time *corresponding to* the stratigraphical divisions called group, system, series, and stage—does not deal with faunas as such but only with the nomenclature and classification of geological formations.

Professor Renevier took a step toward the recognition of fossil faunas, as distinct from formations, in his "Chronographe Géologique,"[b] by distinguishing separate "*faciès*" of the same formation deposited at the same time with other facies.

In 1884 Renevier defined "faciès" as follows:

"*Les faciès sont donc en définitive les différentes sortes de formations, sédimentaires ou autres, qui peuvent s'être produites simultané-*

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[a] Compte Rendu Congrès Géol. Internat., third session, Berlin, 1888, p. 322.
[b] Compte Rendu Congrès Géol. Internat., sixth session, Zurich, 1894, p. 519.

ment, à un moment quelconque des temps géologiques, comme cela se passe encore au temps actuel."[a]

Renevier, although distinguishing between *the duration of time* of the formation and the means of recognizing that duration, viz, *the different faunas* which are found in the different kinds of deposits, still makes the time division synonymous with the duration of the work of producing the formation, not the duration of the living of the organisms whose remains are seen in the fossils.

A fossil fauna may characterize a formation without having its limits (chronological) determined by the beginning or cessation of deposition of sediments making up the formation. In fact, a fauna which appears in full force at the base of a formation must have existed somewhere for a long geological period of time before the specimen of it (the faunule) which occupies the lower layers of the formation was buried, or else we are forced to assume that it was suddenly created on the spot.

If this proposition be true, and I think no modern paleontologist will question it, the common methods of correlating the time equivalency of formations by the likeness of their fossil faunas is inaccurate at least by such a length of time as would be required for the establishment of that coadaptation of the species which characterizes the fauna during its whole expression in the given formation. The change of faunas in successive formations which on other grounds may reasonably be supposed to represent continuous sedimentation, frequently is very abrupt and complete. It is only occasionally that a gradual transition of the species is actually recorded in the successive beds of a continous rock section. And within the limits of a stratified formation, as generally recognized, the same species prevail, not always presenting the same relations of abundance throughout, but the same species, and each one with less amount of variation than is expressed by the representatives across the line by which the formations are distinguished.

What takes place with the living organisms during the transition of one formation to another has not been thoroughly observed or discussed. This failure of knowledge is certainly in some measure due to the practice of assuming that the time duration of the fauna is synonymous with the time duration of the formation which in some particular locality contains it.

In order to differentiate the fauna from the formation, it is needful to observe the characters which pertain to faunas and not to formations.

A fauna is an association of species which for some reasons naturally live together. It is described in terms of species, genera, orders, etc., and not by formations or localities in which it temporarily lived. A faunule is a local sample of the fauna. The fauna at a particular

[a] Loc. cit., p. 528.

period of time may have a metropolis or center of distribution. The species of the fauna may migrate, and the whole fauna with its metropolis may shift. The composition of the fauna may be described in terms of the species, to each one of which degrees of relative and actual abundance or rarity of individuals, and smallness or largeness of size of specimens, may be applied.

The integrity of the fauna may be defined as the preservation of equilibrium of dominance of some species over others, and the life period of the fauna may be recognized by the corporate integrity of the fauna. Geographical distribution and geological range are terms applying to the species of a fauna.

Adaptation to conditions of environment, plasticity, variability, permanency of characters, and evolutional mutation are qualities of species of the same or successive faunas, and may be detected by comparison of specimens from different geographical or geological positions.

From such analyses of species and aggregates of species in corporate faunas may be framed conceptions of their chronological relations; and thus evidence of time duration may be gathered in terms of geographical area or thickness of strata occupied by the fossil remains of the once living races of organisms. An individual specimen of a species does not express an appreciable length of time duration, but only a point of time during the life period of the species. Species vary greatly in the lengths of their life periods. The life period of a large number of known fossil species is greater than the average duration of most of the named formational divisions of smaller size.

The life period of genera is in many cases greater than the duration represented by formational systems. Nevertheless, an approximation to those formational divisions which have been found convenient in actual usage is presented by the life periods of species, genera, and orders of marine organisms, as has been shown by a tentative scheme of classification on a bionic basis,[a] already published. In the paper presenting this scheme it was pointed out that in the Paleozoic is recorded the total life period of trilobites and that such genera as *Olenellus*, *Asaphus*, *Phacops*, have a life endurance at least of the same order of length as the grander subdivisions called systems or series in common usage. Again, it may be pointed out that the life history of such species as *Spirifer radiatus*, *arenosus*, *disjunctus*, or *cameratus* is of the same order of magnitude as the geological divisions of the formation scale called Niagara, Oriskany, Chemung, and Coal Measures. In the paper just cited it was shown that these portions of time duration are the measure of an actual power of endurance expressed by the organisms themselves.

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[a] Jour. Geol., Vol. IX, p. 587. See also p. 133 of this bulletin.

This power of endurance is undoubtedly an exceedingly complex fact, but it is recorded simply by the continued appearance of fossils with the same morphological characters. If the characters are of specific rank their endurance is of relatively short geological time; if the characters are generic they are repeated for a longer period of time, etc. These endurance values of the characters of organisms were spoken of as bionic. The general term *chron* was proposed as a designation for a division of geological time, and thus one is enabled to speak of *geochron* as the time duration expressed by formations, and *biochron* as the duration expressed by the life history of organisms.

A definite and independent value (i. e., independent of the formation scale) was given to the chronological terms hemera, epoch, period, era, eon by using the bionic or endurance quality of organisms as the measure of them. Thus *hemera* was to be measured by the endurance of the bionic equilibrium of a local faunule; *epoch*, by the endurance of species; *period*, by the endurance of genera; *era*, by the endurance of families; *eon*, by the endurance of orders.

One other set of terms applies peculiarly to faunas. Fossil faunas express evidence of a certain amount of migration or shifting of place of habitation during their life history. Barrande spoke of colonies. Recurrence of faunas has been described. In case a marine fauna shifts upon the sea bottom during differential movements of the crust of the earth two results are possible—either the bionic equilibrium of the fauna will be disturbed and thus the faunal composition will be modified, with more or less mutation of the species, or the faunal equilibrium will be retained and the fauna in its integrity will appear at a higher stratigraphical position in the region to which it migrates than in the region from which it has shifted. This will be expressed by a transgression of the fauna in relation to the formation. It may be expressed by a mingling of the species of two faunas; then it is defined as transitional. It is possible to have such oscillation of orogenic movements that a region may be reoccupied by a fauna which has shifted out of it temporarily. In such cases there will appear in the stratigraphical section evidence of recurrence of faunas, and the "colonies" of Barrande may be thus explained, in so far as they are not explained by disturbance of the strata after sedimentation.

As orogenic movements presumably cover long periods of time in one direction for a given area, the direction of the induced migrations of organisms would also be in one general direction, thus furnishing no occasion for recurrence of faunas. In such cases the order of the faunas would be correctly expressed, though in two sections the time represented would differ at top and bottom.

Mingling of faunas would also be expressed by the arrival of migrating species into the midst of a native fauna before the shifting was general.

Such movements of faunas may be assumed to have been more frequent and more apparent in such portions of the ocean bed as were near the shore, and thus where the sediments were in process of rapid accumulation and were expressed by varying classes of sediments. The Devonian formations of the upper portion of the Appalachian Basin were on this account particularly fitted to tell the story of shifting of faunas, and in the following pages evidence of the shifting, recurrence, and modification of faunas is reported, and it will be shown that the movement or migration of a fauna may occur with only slight evolutional mutation of the species.

CHAPTER II.

THE GEOLOGICAL EXPRESSION OF FAUNAL MIGRATIONS.

The association of specific difference in plants and animals with geographical distribution, involving difference in climate, altitude, and general difference in environment, has been noticed by naturalists for centuries. It was a problem of geographical distribution, more than anything else, which suggested to Darwin the accounting for difference in organisms by evolution through the agency of natural selection. In a letter to Moritz Wagner, Darwin wrote, in 1876, "It was such cases as that of the Galapagos Archipelago which chiefly led me to study the origin of species."[a]

The geologist, however, for whom the record of change in fossils is more sharply apparent on passing vertically through successive strata, is accustomed to associate change with sequence of time, neglecting the part which migration and associated change of environmental conditions may play in the modification of the specific composition of fossil faunas.

It is commonly known that great thicknesses of limestone, representing immense periods of geological time, are dominated from bottom to top by the same fauna; while shales and sandstones, indicating rapid accumulation of sediment and change in conditions of the sea bottom, present series of faunas in which not only species but genera differ. If the rate of evolution during the long periods of time represented by the limestone indicates the steadiness with which organisms reproduce their kind under uniform conditions of environment, then either the changes of environment coincident with change of sediments must be the occasion of the modification of the organisms observed in the successive faunas of the second case, or else the faunas have shifted with the change, and the observed difference is due to migration of new species into the region whose conditions have changed, with only slight immediate change in the character of the species.

If we adopt the first assumption, viz, that the rapid changes of environment are coincident with rapid evolution, the irregularity in rate of evolution in different parts of the globe must have resulted in great diversity of organisms, and Huxley's view, that likeness of fossils in widely distant portions of the globe does not indicate time equivalency, must be accepted as substantially correct. If, on the other hand, we adopt the second inference, viz, that coincident with

[a] Life and Letters, Vol. II, p. 338, New York, D. Appleton & Co., 1898.

the rapid changes of environment faunas have shifted their habitation, the conclusion would be that there was a slight acceleration in evolution with the readjustment of the faunas, and that the shiftings, when of a general nature, would result in modifications of the faunas which would serve as means of a closer correlation of the time relations of geological events, not only in one quarter, but quite around the globe. While the first of these inferences is not inconsistent with the second, the first does not furnish an explanation of the constant considerable change of genera as well as species seen on comparing the successive faunas of any continuous section if followed through several hundred feet of diverse sediments. In either case the observing and the recording of the differences expressed by fossil faunas of the same horizon coincident with geographical distribution promise to throw some light on the problems of time measurement of organic evolution and to test the value of fossils as means of geological correlation.

The possibility that a fauna may preserve its integrity by shifting its habitation with the slow changes of environmental conditions was suggested by Barrande's theory of colonies. He believed that a fauna characteristic of one epoch of time, by isolation, could be preserved in a restricted basin, while all the general faunas were destroyed and replaced by others, and that later, in a second or third epoch, the representatives of the preserved "colony" might migrate into the general seas and reappear (out of stratigraphical place) in the midst of the succeeding faunas. The theory as a whole did not commend itself to general acceptance. But "recurrence of fossils," the fact at the basis of his theory, has been frequently recorded; and the theory that a fauna may be preserved in one region later than in another appears to have much evidence to support it. Barrande was, however, not an evolutionist; uniformity and continuity of species was a part of his creed; hence he did not consider the positive aspect of the case, nor did he conceive change of environment to be a cause of modification; he saw only the negative side, viz, the association of uniformity of conditions with preservation of characters among the inhabitants. This conception of the unchanging character of the species still continues to influence general notions of correlation, although we are theoretically all evolutionists.

Correlation by identity of species implies that the rocks containing the same species of fossils were formed at the same period of time, and on this basis it is inferred that formations belong to the same geological horizon so long as their species are found to be the same. While in a general way this is correct, since the evolution of forms goes on at a very slow rate, the converse is not true, viz, that unlikeness of species is evidence of a different age for the formations holding them. Sufficient facts are now gathered to prove that in each great province different faunas, adjusted to the different conditions of environment in the province, have been living at the same time, as is clearly known to be the fact in the case of geographical distribution of living faunas at the present time on the face of the earth.

The term *facies* has been applied to the peculiar combination of species of a fauna characteristic of particular, restricted conditions of environment. So that two sets of species, living simply under different conditions of enviroment, are said to express different facies of the fauna of the period in which they lived. In attempting to make correlations and classifications of stratigraphical formations, geologists have found difficulty in distinguishing between the different *facies* of the fauna of the same period and the successive *mutations* of the fauna consequent upon geological succession. To put this in a word, *difference in faunas may be due either to geographical distribution or to geological range.*

Geographical distribution furnishes the basis of classifying living faunas existing on the earth at the same time, and the facts concerning it are so well known that no one need hesitate to explain difference of living faunas by difference of geographical distribution. The principal fact in the case is that environments of different kinds are occupied by different species. This is a matter of fact, irrespective of any theory as to how such relation of the faunas to their environment has come about.

When, however, we are led to ask how the adjustments came about in geological time, we have to choose an answer from these two possibilities, viz, either (a) slowly progressing and relatively constant evolution has taken place among organisms constantly struggling together and varying, or (b) faunas become rapidly adjusted to new conditions, attaining a biological equilibrium, and then maintain that equilibrium with extremely slight variation for great periods of time, under like conditions, but quickly and rapidly suffer specific modification whenever the environment changes and the equilibrium is thus disturbed. Such a disturbance, it is assumed, has taken place whenever a sudden change occurs in the sequence of sediments from one formation to another with change of sediments and corresponding change of fossils.

Instead of assuming that the fossils were destroyed at such points and recreated in the following period, the theory here proposed is that the faunas have shifted over the ocean bottom. The uppermost of two successive faunules in a single continuous section is presumed to have lived synchronously with the underlying faunule, but in a separate region; and at the point where the faunal change occurred the second fauna migrated into the region, expelling and replacing the first. Such cases are not universal, but it is assumed that the shifting of faunas is more or less common. In other words, the elevation or depression of continents in relation to ocean level, which involves the shifting of the position of deep or shallow or shore conditions, does not necessarily involve the institution of a new combination of conditions, but rather causes a transfer from place to place of existing conditions of environment. Such movement of the earth's surface, resulting in the geographical changing of the conditions of environment for each particular spot on the surface, would necessitate the movement of the faunas living under particular conditions or else their destruction. They must either shift their place of habitation as the conditions favorable to their existence are changed, or, if they attempt to stay on the same spot, they must adjust themselves to new conditions of environment. This principle of migration necessarily involves a change in the geographical distribution of the living faunas; that the species should be modified as such migration takes place is a natural conclusion to be drawn from the facts.

The other kind of change which organisms undergo during the lapse of geological time may occur without any disturbance of the physical conditions of the province in which they live, and is coincident with the passage of time alone. The ordinary theory of evolution contemplates a modification of species under such conditions, a gradual variation of form coincident with the continuance of the species under like conditions during their "struggle for existence." The modification they suffer is then due to "natural selection" and the "survival of the fittest." I say this is the prevalent hypothesis to account for the modification of species by evolution. It is altogether probable that both these methods of modification have been effective to a greater or less extent in producing the total results which go under the name of evolution of species.

But the paleontologist, as he studies the succession of species, will have his attention more closely called to the modifications which are coordinate with the geological movements of the surface and are expressed in changes of local conditions within the whole province in which the organisms live. This modification by forced migration has to do with the breaking up and reinstituting of biological equilibrium of the faunas, and in less measure and with less effect with the principle of struggle for existence among common competitors.

In order to discuss the subject of the migration of species and the effects of forced migration upon faunas, it is necessary to discriminate two distinct sets of facts as under discussion at the same time. In the first place, there are the geological *formations* in which the fossils are preserved, which are made of fragmental particles of sand or mud or limestone, massed together into sheets called strata, piled one upon another, forming geological columns. These are the formations of the geological "time scale." These are local, from the fact that the materials of which they are composed are sediments which have been deposited under water and have necessarily been brought from some contiguous lands to the place of their deposit. Geological formations are thus, from the nature of things, local deposits, having local origin, their materials having been brought together and formed under conditions which were more or less local in extent. In dealing with the classification of such formations the question of their sequence, their thickness, and the composition of their materials must first be taken into account. In correlating two formations of this kind the first question is as to their geographical continuity. If we find that a stratum of limestone occupies a similar place in the sections of two regions separated by 50 miles of distance, and the sequence for both regions is the same, it is safe to assume that we are dealing with the same part of the earth's crust. The second question, as to whether the two parts of the earth's crust thus correlated were formed at exactly the same *time*, does not interfere with the conclusion that the formations are the same and may be classified as equivalent. In other words, it is possible (and there are examples which show that it is a fact) that the conditions at one particular geographical spot have been repeated in the same order at a distance removed from that spot, although each episode of the second region occurred later in time than its corresponding episode of the first region. Such phenomena are generally explained by the supposition of the rising of the shores or the sinking of the same in relation to sea level, with "transgression of the sea."

The second set of facts is described by the term *faunas*. The faunas are biological quantities, the term fauna meaning the aggregate of organisms living together in a region at a particular period of time. Such a fauna lived during the formation of the sediments of a particular formation, and on account of this fact is said to characterize that formation.

It does not necessarily follow, however, that another formation, far removed geographically from the first, which contains approximately the same species, is, on that account, the same formation; but in order even to understand what such a proposition means it is necessary to differentiate the fauna from the formation and to conceive of the two as different entities and as not either intimately or necessarily combined. The discovery that the limestones of two separate regions were not formed during exactly the same interval of time would not be sufficient to prove them to be different formations, for the deposition of the sediments making up a particular formation may have continued at one point after it had ceased and was replaced by the deposition of sediment constituting another formation in a separate region, or deposition may have begun earlier at one spot than at another. Such a state of facts follows necessarily from the principle of regarding a formation as a unit mass of rock instead of a unit division of time.

On the principle of migration of faunas it is quite possible that two distinct faunules living contemporaneously in two adjacent districts of one basin might be arranged consecutively in a third (also adjacent) district. In such a case the formation holding the two faunas would be identified, by their fossils, as belonging to two separate epochs; and the stratigrapher would take the third example as proof positive that the one fauna followed the other and therefore that the two epochs were successive and not contemporaneous.

An example of such a case is discussed in detail beyond. The Chemung formation is known to follow (to lie above) the Hamilton formation in western New York by the fact that normal faunas of the former are some thousand feet higher up in the section. But that the faunas are actually contemporaneous in a part of their existence is shown by the recurrence of a faunule of Hamilton species at Owego, N. Y., in the midst of strata containing below as well as above characteristic Chemung fossils.

These two sets of facts—the formations and the faunas—must therefore be dealt with separately. While the presence of the fossils of a particular fauna does stand for something in a column of sedimentary rocks, it does not stand for the whole of any particular period or interval of time. It represents some portion of the life period of the fauna, but the limits observed in a local column between one fauna and a succeeding one may not be the horizons of the beginning or of the close of the life history of the fauna; they may be the limits of the formation for that section.

There seems to be necessity of considering also a third element, which Mr. Bailey Willis has recently emphasized. I refer to the time element of geological classification. Formations are lithological and physical. Faunas are biological and must be treated of as living. Time divisions are conceptions, and their use depends upon the accuracy and reliability with which they may be represented by visible formations or faunas.

The primary basis of distinguishing the time relation of formations is stratigraphical sequence. But the formation itself is a lithological aggregate, and the lithological characters by which one formation is distinguished from another have no regular order of stratigraphical sequence, hence stratigraphical sequence has no positive time value; it is only the element of sequence of time which is recorded by the observed facts.

When faunas are considered separately from formations, in this way, we are ready to notice that faunas may have shifted geographically, and may thus cause confusion in the classification and correlation of the formations of contiguous basins. When we consider the confusion which has already arisen in the classification of the geology of the various counties of Pennsylvania, which is probably to be accounted for in this way, the necessity for more light on the subject is apparent. The consideration of a possible shifting of faunas may therefore be necessary to the proper interpretation of facts which otherwise greatly confuse the geologist. Classification based upon succession of formations often differs from classification based upon the succession of species, and the paleontologist is often found practically differing from the stratigrapher in his interpretation of the correlation of the rocks in any particular region.

Although the matter of shifting of faunas has been, in a general way, involved in what is called geographical distribution, I am not aware that, in this country, it was deliberately announced as a fact until about 1883 or 1884, when such announcement became necessary in order to explain certain facts in the geology of New York State which I then had under investigation. The most conspicuous case which came under my notice was reported in Bulletin 41 of the United States Geological Survey, On the Fossil Faunas of the Upper Devonian—the Genesee Section, New York. The investigations which led to the publishing of that report were carried on for the direct purpose of ascertaining what kind of modification actually occurred in the same formation when it was minutely and comparatively studied for a few hundred miles across the field of its distribution. The Upper Devonian was taken because of its possession of several successive faunas, the lack of disturbance of the strata, and the wide region over which its outcrops could be studied without any doubt as to their stratigraphical correlations. The investigation showed unmistakably that the constituent faunas which make up the sequence of any particular section had shifted back and forth over the region. It was ascertained, for instance, that the place of the fauna belonging to the Ithaca group corresponded stratigraphically to the lower part of the Portage formation of the western part of the State; whereas to the east the Hamilton faunas crept up with some of their species into the same stratigraphical zone; while still farther east the same horizon, geologically speaking, was filled by sediments of the Oneonta group, which seem to be equivalent, in every respect but position, to portions of the typical Catskill formation. Again, in 1897 a study of the faunas of the southern Appalachian province, in the southernmost point of Virginia, brought to light the fact that actual traces of the Carboniferous fauna were found in a position in the sequence which, a little to the north, was found to be dominated by Chemung species.[a] Such facts can be explained at present only by supposing that there was a shifting of the faunas geographically within the common basin in which they lived.

The theory of the migration of faunas, then, assumes to be true the proposition that two faunas, one of which generally succeeds the other, may be actually contemporaneous in their life periods, at least during the end of one and the beginning of the other. By the theory of shifting of species and migration of faunas it is easy to understand how a fauna which immediately succeeds any other particular fauna of a given region (if the faunas be actually different, or if one be

[a] See On the Southern Devonian formations: Am. Jour. Sci., 4th series, Vol. III, 1897, pp. 393-403.

strongly contrasted with the other) has come from outside the particular region in which it is introduced and is not the immediate evolutional successor of the underlying fauna.

The supposition that two faunas will evolve separately if placed in two different regions implies simply the fact that no two actually distinct regions can be supposed to have exactly the same conditions of environment or the same actual set of species. Such conditions are frequently observed, as on two sides of an ocean, or, again, along the same coast, where we may find northern and southern faunas. When we cross from one ocean to another, under similar climates, it is familiarly observed that the composition of faunas living under similar physical conditions is different. Supposing, in this way, that we have a set of similar conditions in different parts of a basin which are separated one from another by barriers sufficient to prevent easy intercourse between the two parts, although not necessarily prohibiting migration, here we have all the conditions for the development of special faunas. With the breaking up of the geological conditions of such a general basin—as, for instance, by the rising of the bottom in relation to the surface of the ocean, or by the sinking of another part of the basin so as to bring deeper and purer waters where had been prevailing the accumulation of shore sediment—we may suppose the conditions of environment so completely changed for a particular part as to force the organisms to shift their position. In shifting, those which are able to shift and migrate would migrate, whereas those which are less capable of migration must necessarily be cut off, or at least be removed from the migrating fauna to such an extent as to change the equilibrium of the species. Coincident with such movement of the fauna due to geological changes in the province, it is assumed that the evolution of the species finding favorable conditions for life would be more rapid than it was during their existence in the conditions from which they came, the biological equilibrium of which had for a long period of time been approximately fixed and rigid.

Migration as a stimulus to variation.—It is inferred from what has been already said that the more rapid changes in the contents of a geological fauna have been caused, or certainly stimulated, by the forced geographical change of place of residence of the fauna itself. This may be formulated under the term *modification by migration.* When it is attempted to explain how such effects are produced it becomes evident that the principle of variation must be conceived of as affecting the species of the fauna more intensely when the environmental conditions are forcibly modified than during the periods, however long, in which the biological equilibrium of the fauna maintains its integrity. Throughout the whole geological column there are illustrations of this fact which will occur to paleontologists. It is a common observation that so long as that integrity of the fauna sufficient to lead to regarding the stage as the same continues through a series of sediments, the individual species suffer but slight change, and this has been observed through hundreds of feet of limestones, running up into the thousands, and not confined to only a single case. The interpretation of this fact is that so long as the equilibrium of the species composing a fauna is preserved they may continue to reproduce and live on without any considerable modification of their specific characteristics. Interpreting this into the principles of evolution, it means that natural selection having attained a relative equilibrium, evolution will stand still, in so far as the modification of organisms is concerned, for great periods of time. On the theory of modification by migration it is assumed that this equilibrium is an equilibrium of active forces residing in the organism, which are held in the state of equilibrium by the combination of circumstances going under the name of "natural selection." There is also implied, however, the idea that the species are in a plastic state, ready for modification, and that those which survive vigorously are in a more plastic state than those which succumb and are lost in the fight.

That species vary so soon as they are subjected to new conditions of environment implies that the variation is an expression of special vigor in the organism and not a sign of weakness—that variation is the expression of vitality (if we may use that term in a general sense) and is not a consequence of competition among the individuals themselves. Darwin has spoken of such variation as "spontaneous variation;" that is, variation which is not accounted for on the principle of natural selection, but which is presumed to be present before natural selection is capable of acting upon the morphological characters of the organisms.

This interpretation also explains another fact which paleontologists have frequently observed—the fact that succession of faunas of the same general facies is rarely traceable to gradual modification of a subjacent fauna. In such a case the metropolis, or center of distribution, of the new fauna is generally (and it may be universally) found in a different geographical area from that of the old fauna which it replaces.

CHAPTER III.

FAUNAL DISSECTION OF MIDDLE AND UPPER DEVONIAN OF THE NEW YORK PROVINCE.

The collecting of statistics to illustrate the laws of faunal history has been carried to a higher degree of perfection for the Devonian faunas than for any other fossil faunas of North America.

This is partly because a great amount of information regarding the individual species of the faunas had been acquired before these particular investigations were begun, and partly because for a number of years definite attention has been given to gathering and recording the exact statistics needed for the purpose of solving practical difficulties in this particular field of correlation.

The method of investigation which has brought out these facts is formally stated in Bulletin 41 of the U. S. Geological Survey, under the head of "Geographic and chronologic relations of the faunas," as follows:

It is necessary to recognize the effect of geographical conditions upon faunas as well as the changes incident to chronological sequence if we would interpret the confusion existing in the Devono-Carboniferous deposits of the eastern portion of our continent. But the assigning of the Marshall fauna to the period of the Catskill group does not settle it. Neither does the expansion of the Chemung formation to receive the Waverly fauna nor the pulling down of the Carboniferous system to cover the Portage formation relieve us from the main perplexities.

It is only by disentangling these faunas and ascertaining the true geographical and chronological relations which they bear to one another that the difficulty is to be met. This is to be attained, not by clinging to any sharp limits of a stratigraphical or a lithological nature, or to any absolute division between one formation and the following, but each fauna must be traced upward and downward and its modifications noted until it is replaced by another, and whatever on the way is interpolated or is added to it must be traced to its origin or to its center of occurrence. By this method a scale marking the chronological sequence in the life history of the organisms and faunas may be prepared which may serve as a definite standard for determining the relative age of formations quite independent of the lithological characters of the sediments which were being continuously thrown down, these being in main part determined by local conditions of the disintegrating shores and distance away from them. By themselves the rocks, as rocks, present no features which may serve as indications of the particular stage in geological time at which they were deposited.[a]

Previous work in correlation had been conducted on the fundamental assumption that identity of fossils is sufficient evidence of

[a] On the fossil faunas of the Upper Devonian—the Genesee section, New York, by Henry S. Williams: Bull. U. S. Geol. Survey No. 41, 1887, p. 21.

identity of the formations containing them. In other words, it had been assumed that for purposes of classification in the time scale the formation and the fauna are identical. The way in which fossils have been customarily labeled has prevented a testing of the truth of this assumption. If there be any distinction in time value between the formation and its fauna, it is difficult to demonstrate it so long as the only name and designation of the fauna is that of the formation in which it was originally found.

If the "Chemung formation" be extended below the fossiliferous strata of Ithaca, as it was in the literature before 1880, then the fossils in the "Ithaca group" belong to the Chemung fauna. When the Ithaca fauna was dissected and it was shown that the species were not those of the Chemung fauna above, but were rather modified successors of the Hamilton fauna,[a] it became clear that, faunally, the Ithaca group was not a part of the Chemung formation. Nevertheless, the term "Chemung" was still retained in general literature for the "period" which included both the "Ithaca" and "Chemung" epochs, so that the real issue was still obscured by the imperfection of the nomenclature which used "Chemung" with two meanings.[b]

The terms "Portage," "Hamilton," "Trenton," and "Niagara" are also applied in this double sense in the classification of formations, making it almost impossible to frame a statement which will express the thought that formations and faunas are discriminated upon different bases and that their limitations may not be identical.

In order to demonstrate the actual facts in the case, it has been found necessary to collect a large number of statistics regarding the actual faunal contents of each zone in some well-known formation, and also regarding the separate faunules taken from outcrops of the same formation over an extended area.

This work of dissecting and analyzing the faunas of the Devonian, begun in 1881, has been carried on continuously since that time. Students in the laboratory, at both Cornell and Yale, have been trained to discriminate, collect, and analyze the faunules, and to observe accurately the range and distribution of every fossil coming to their notice. Others outside have adopted the method, and, thanks to the painstaking and energetic labors of many workers, it is now possible to demonstrate from the statistics already gathered at least the distinction between a lithological formation and a fossil fauna.

It is now possible to state that the *Tropidoleptus* fauna of the Hamilton formation persists in its integrity above the top of the Hamilton formation; that in eastern New York it occupies a place in the column which is occupied in central New York by the Ithaca formation and in the Genesee Valley by a portion of the Portage formation.

[a] On the fossil faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, N. Y., to Bradford County, Pa., by Henry S. Williams: Bull. U. S. Geol. Survey No. 3, 1884.

[b] See Manual of Geology, by James D. Dana, 4th edition, 1894, p. 603.

This state of things has been already partially demonstrated in respect to the position of the Catskill formation in the geological column.[a] But the significance of the facts was obscured in that case by the fact that the Catskill as a pure formation is distinguished by its red sedimentation, which, therefore, was easily discerned in the field by the stratigraphical geologist; but the fossil evidence of the Chemung, though constantly annoying him, had not in his mind the distinct stratigraphical significance which he attached to the color ingredient in the Catskill. The evidence of the Catskill was clear, and if the fossils told another story, so much the worse for the fossils. This was his attitude.

In the present case the faunas are of the same kind, made up of marine invertebrate fossils. They are distinctly marine in all cases, and the demonstration may be expressed in mathematical values. The statistics are sufficient and are gathered from a field that is wide enough to make possible the comparison of the faunules in terms of composition, frequency, and abundance. The variation of species, though not yet demonstrated by the statistics, is strongly indicated by the increasing uncertainty in identification of the species in one direction, while the species are always positively identified in the central region. Great promises of future discoveries in this direction are offered by the facts, and in the future we may expect to see the laws of variation associated with transgression of the faunas clearly demonstrated.

Enough evidence is already in sight to show that at any particular point of time, as represented by a common geological horizon or zone in a given formation, the inhabitants of one sea differed in species within a relatively small distance (50 miles); and within 200 miles the faunas may be entirely different, having not a single species in common.

The facts also give clear evidence of the *shifting* of the fauna with the accumulation of the sediments, so that the center of distribution of each fauna changes as we ascend in the formation. The evidence points to this shifting of the total fauna as the occasion of rapid *modification* and *variation* of the species, and the inference is drawn that great changes of conditions were coincident with great shiftings of the fauna. During the prevalence of a fauna in a common center of distribution, very little evolution took place for long periods of time, as measured by thickness of sediments, but slight shifting in the geographical position of the fauna is coincident with the appearance of new varieties and, in general, with disturbance of the faunal equilibrium.

The work of dissecting the contents of a fauna into its constituent faunules, and then of the analysis of these faunules into their specific composition, was begun at Ithaca, in the midst of the abundant

[a] Dual nomenclature in geological classification: Jour. Geol., Vol. II, 1894, pp. 145-160.

Devonian fossils of the formations outcropping in that region. The first attempts to define the separate faunules and to apply names to them were imperfect on account of the absence then of any knowledge as to the range, distribution, and relative abundance or rarity of the component species. These statistics were gathered as the investigations progressed. Although those first attempts at classification on the new basis are now superseded by classification based on the full appreciation of the laws of shifting of faunas, the record of the steps by which the progress has been made will indicate how from the study of conspicuous local phenomena broad general laws have been developed.

INTRODUCTION OF A FAUNAL CLASSIFICATION OF THE DEVONIAN SYSTEM.

Bulletin No. 3 of the U. S. Geological Survey, On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, etc. (Cayuga Lake meridian), was issued in 1884. In it is given an analysis of the faunas of the section, from the Genesee shale near the head of the lake to the Barclay coal in Bradford County, Pa.

The classification of the formations was based upon the changes exhibited in the faunas, and the following faunas were recognized, in ascending order, viz:

1. Genesee slate fauna.
2. Portage group; 1,300 feet, including the Ithaca fauna and several faunules.
3. Chemung; 1,200 feet, with separate faunules.
4. Catskill rocks.

The Portage included the lower beds with the *Cardiola* fauna, and the upper part was observed to be nearly or wholly barren. Secondary faunas of the Portage group were recognized and named as follows:

1. Cladochonus fauna (No. 48, sec. 1113, p. 11).
2. Spirifer lævis fauna (sec. 1101, p. 12).
   (Both of these were traced eastward as to origin.)
3. Lingula fauna (Ithaca shale, No. 6, sec. 1106, p. 14).
4. Hamilton recurrent fauna (No. 14 N, sec. 1102 N, p. 15).
5. Cryptonella fauna (sec. 1105, p. 17).
6. Ithaca fauna proper, Spirifer mesicostalis zone (1102 B, 1107, p. 18 and p. 20).
   (This was traced to the eastward.)

6a. Recurrent Portage (Cardiola speciosa fauna; 1168, p. 20).

7. Discina fauna, a recurrent Genesee shale fauna (mentioned on pp. 20 and 30).
   (This was traced westward for its origin.)
8. Spirifer lævis recurrent fauna (pp. 20 and 30).
9. Lingula fauna (1162 A and B).
10. Orthis tioga; typical Chemung fauna (1172 D, 1165-67, p. 23).
11. Heliophyllum halli zone (coral zone; 1167 E, H, p. 24).
12. Catskill.

The investigation was described as the first of a series of articles on the comparative paleontology of the Devonian and Carboniferous faunas. The manuscript of the bulletin was prepared and sent to the Survey in 1883, before the field work of that year was begun. The field work of 1883 and 1884 was planned as a continuation of this earlier work in and south of Ithaca which had been conducted privately as a part of the work of a professor of Cornell University, and it was carried on under the auspices of the U. S. Geological Survey in the Genesee Valley. The report on this work was published as Bulletin 41 of the U. S. Geological Survey, the manuscript of which had been sent in on August 2, 1886. A preliminary report of the results of the summer's work along the Genesee Valley was prepared at some length and sent to the Director. This paper was received by the Director July 27, 1884, and is numbered 1398 of correspondence of 1884. An abstract of it is published in Science, Vol. II, pp. 836, 837, dated December 28, 1883.

At first the report was intended for publication in the annual report of the Director, but was returned for enlargement into a bulletin and formed a basis of the report finally published as Bulletin No. 41. The paper sent to the Director in 1884 contained a classification of the successive faunas observed on passing across the State from Wyoming County, N. Y., the examination extending as far as the southern part of McKean County, Pa.

Bulletin No. 41, on the Genesee section, was published in the year 1887. It was written after two more years of field work had carried the studies westward, as well as eastward, from the initial section at Cayuga Lake. In 1884 the sections from Chautauqua County, N. Y., to Cleveland, Ohio, were investigated, and in the following summer (1885) sections across the corresponding part of the formations were run from Chenango County to Delaware and Otsego counties.

In the report as published in Bulletin No. 41 the faunal zones recognized were as follows:

1. Lingula fauna (sec. 468, p. 31). Genesee formation.
2. Cardiola fauna (sec. 472). Portage formation.
3. Early Leiorhynchus fauna (sec. 476 G). Green shale of Chemung.
4. Spirifer mesicostalis fauna (sec. 476, p. 58). Rushford shale.
5. Streptorhynchus and Spirifer disjunctus fauna proper (sec. 477, p. 65). Cuba sandstone.
6. Lingula fauna (second; sec. 477 A 2, p. 64).
7. Lamellibranch fauna (sec. 477 A 3, p. 64).
8. Athyris angelica fauna (sec. 477 H, p. 67).
9. Flat-pebble conglomerate; Palæanatina typa (sec. 486).
10. Ferruginous sandstones; Rhynchonella allegania (sec. 484, p. 87).

Two important subfaunas, local in extent, were also recognized, viz, the *Centronella julia* fauna of Rushford, in the midst of the zone covered by the *Spirifer disjunctus* fauna, and the *Orthis leonensis* zone south of Cuba (p. 34). On the same page it was stated that the several faunas do not indicate particular geological horizons, but particular conditions of environment or habitat, which, locally, had definite place in the column. Each of the faunas was dissected as it occurred in its own section of the formations (p. 38).

In 1886, in a paper On the Classification of the Upper Devonian,[a] this classification of the faunas was further elaborated in a report of investigations based on the examination of ten sections across the same formation, made at intervals of about 50 miles, and reaching from Newberry's typical Cuyahoga section at Cleveland, Ohio, to the Unadilla section of Otsego and Delaware counties, N. Y. In the list there given the different faunas were spoken of as *faunas*, distinguished by the general content of species, and *stages* was the name applied to the faunules into which the dominant fauna was divided. On this basis the following successive faunas were recognized:

A. Hamilton fauna and its direct successors.
B. Black shale fauna.
C. Portage fauna.
D. Chemung fauna.
E. Flat pebble conglomerate fauna.
F. Catskill fauna and flora.
G. Waverly fauna.
H. Olean conglomerate fauna and flora.
J. Barclay coal fauna.

In the life range of each of these faunas temporary stages were noted. These temporary and local expressions of the fauna are called *faunules* in the present paper. Although they do express halting places or stages in the evolution of the fauna, they are not full, but rather partial, expressions of the general fauna, reflecting particularly the influence of local conditions of environment; and, as the statistics show, rarely holding any peculiar species, but holding the common species of the fauna in particular proportions of rarity and abundance of individuals. The name applied to each is derived from some particularly abundant species. Thus, in the series of local temporary faunules of the Hamilton fauna, eight stages were recognized, as first reported in 1886, as follows:

A 1. Paracyclas lirata stage or faunule.
A 2. Spirifera lævis stage or faunule.
A 3. Stropheodonta mucronata stage or faunule.
A 4. Atrypa reticularis stage or faunule.
A 5. Leiorhynchus globuliforme stage or faunule.
A 6. Tropidoleptus carinatus stage or faunule.
A 7. Spirifer mesistrialis stage or faunule.
A 6+. Second recurrence of Tropidoleptus stage or faunule.

In the same way the Black shale fauna (B) was expressed in the following five local temporary faunules, successive to each other in time:

B. Lingula spatulata stage or faunule; Genesee shale.
B 1. Second Lingula spatulata stage; Portage shale.
B 2. Lingula complanata stage; "Ithaca group."
B 3. Lingula spatulata, third stage; Cleveland shale.
B 4. Lingula complanata, second stage; Chemung shale.

[a] Proc. Am. Assoc. Adv. Sci., Vol. XXXIV, pp. 222-234.

The Portage fauna (C) was analyzed into the following faunules:

C 1. Cephalopod stage or faunule, Goniatites and large Cardiadæ.
C 2. Lamellibranch stage, Cardiola speciosa.
C 3. Portage sandstone, a generally barren zone.

The Chemung fauna (D), or *Spirifer disjunctus* fauna, was analyzed into:

D 1. Orthis tioga stage or faunule.
D 2. Stropheodonta (Cayuta) mucronata stage.
D 3. Athyris angelica stage.
D 4. Rhynchonella contracta stage.
D 5. Spirifer altus fauna.

The flat-pebble conglomerate (E), as illustrated by the Wolf Creek conglomerate (sec. 483 C, p. 86), contains:

E. Palæanatina typa fauna.

The Catskill (F) was recognized in the Oneonta sandstone (F 1) and the typical Catskill (F 2); but except by the presence of *Holoptychius* and other fish remains, characteristic plants, and the *Amnigenia catskillensis*, the fauna and flora were not then exactly defined.

The Waverly (G), with *Syringothyris*, is a still later fauna in which three faunules were observed:

G 1. Bedford shale stage or faunule.
G 2. Berea grit and sandstone.
G 3. Cuyahoga shale and sandstone.

No attempt was made in 1886 to elaborate these higher faunules of the Waverly, as the statistics were at that time too imperfect for drawing conclusions.

REVISED CLASSIFICATION OF FAUNAS.

Revising this classification now in the light of the fuller exhibition of the facts, some of the distinctions made in 1885 are believed to be too refined and local for perpetuation in a general classification, but a few of the points then made may be adopted for general use in discussing the faunas of the whole continent and in comparison with the faunas of the world.

The fauna of the typical Hamilton formation (A) may be appropriately called the *Tropidoleptus carinatus* fauna. That species is more characteristic of the fauna as it appears in its purity in the eastern New York province than is *Spirifer* (*mucronatus*) *pennatus* Atwater.

The second fauna of the Black shales (B) may be appropriately called the *Lingula spatulata* fauna, as that species is characteristic of it far and wide when in its purity, is rarely entirely absent, and may be found, if diligently searched for, in a typical black Devonian shale almost anywhere in the interior continental basin.

The third fauna of the Portage shales (C) may be called the *Cardiola speciosa* fauna. Although, as Hall has shown, this is not a

Cardiola, as strictly interpreted, and the name *Glyptocardia* was proposed as a new generic name in 1885[a] to take its place, the fact that in Europe as well as in this country this generic name has been applied to this species and its European representative makes it not inappropriate as a name for the fauna. As Hall observed in discussing this species (*Glyptocardia* (*Cardiola*) *speciosa* Hall):[b]

It is probably identical with the *Cardiola retrostriata* (von Buch) of various authors, and with *Cardium palmatum* of Goldfuss. Its citation by numerous authors shows its wide distribution in Europe.

The fourth fauna of the list (D)—that of the Chemung formation of the east—is the *Spirifer disjunctus* fauna. The species *Spirifer disjunctus* is undoubtedly identical, specifically, with the form which is more commonly called *Spirifer verneuili* by European geologists. There are several varieties of it which are present in some regions in which the typical form *Sp. disjunctus* is wanting.

These four faunas may now be named and distinguished. In the discussions that follow, the relation to these of other faunas, which may eventually be classified as distinct, will also be considered.

THE STATISTICS AND THE PLAN OF DISCUSSION.

After the publication of the classification set forth in the paper of 1886[c] a large number of investigations were undertaken, not only in New York, but in other parts of the country, which throw new light upon the questions then raised. But nowhere have the statistics been so well gathered as in New York State. Particularly valuable have been the researches of Prof. C. S. Prosser. Other contributions have been made by N. H. Darton, J. M. Clarke, S. G. Williams, G. D. Harris, C. E. Beecher, J. J. Stevenson, E. M. Kindle, Stuart Weller, A. W. Grabau, and H. F. Cleland. Many others have taken part in accumulating the statistics, dissecting the faunas into faunules, and analyzing the faunules, more or less perfectly, into their specific values, as expressed by abundance or rarity and in terms of frequency of appearance in successive stratigraphical zones or at distributed geographical stations. The particular part of the geological column about which the fuller statistics are gathered is also that part of it which was selected in 1881 for special investigation—i. e., the middle and upper formations of the Devonian system.

In order to illustrate the method, and to demonstrate the few generalizations which at the present state of the investigation are fairly well established, these statistics of the Devonian will be digested and interpreted in the following ways, viz:

The order of discussion will be: First, a presentation of the facts regarding the faunas; second, the dominant and characteristic spe-

[a] Palæontology New York, Vol. V, Pt. I, Lamellibranchiata, II, text, p. xxxv.
[b] Ibid., pp. 426-427.
[c] Classification of Upper Devonian: Proc. Am. Assoc. Adv. Sci., Vol. XXXIV.

cies of each fauna as determined by study of the statistics; third, the general laws regarding the history of faunas and their use in interpreting the correlation of formations and the structure and development of the continent.

The faunas specifically examined are:

1. Fauna of the Hamilton formation, which may be called the *Tropidoleptus carinatus* fauna.

2. Fauna of the Ithaca formation, which may be called the *Productella speciosa* fauna.

3. Fauna of the Chemung formation, designated the *Spirifer disjunctus* fauna.

Other faunas and subfaunas will be named as they are taken up, but the statistics of these three faunas are ample and they are of a like facies,[a] so that their comparison will make evident the laws of shifting of faunas and their modification coincident with this shifting, with geographical distribution and with stratigraphical succession.

HAMILTON FORMATION AND TROPIDOLEPTUS CARINATUS FAUNA.

In the final report on the geology of the Fourth district of New York (1843) the Hamilton group was defined as the twenty-fourth group of the New York system, and with others was included in the Erie division. In the later classification, of which Dana's Manual of Geology, fourth edition, 1894, may stand as an exponent, the Hamilton group includes the Marcellus shale, the Goniatite beds, the Encrinal beds, the Hamilton shales, and the Moscow shales. The Tully limestone is also included by some authors; for the present discussion, however, this local formation may be treated faunally as a separate formation. Faunally, the series of sediments, as they are exhibited in central New York (beginning at the top of the Onondaga (Corniferous) limestone and terminating at the base of the Tully limestone), presents a continuity which leaves no doubt as to the genetic succession of a common fauna from the base to the top. In dealing with this fauna, only the species between the limits of the top of the Onondaga limestone and the base of the Tully limestone, when these are present, will be considered as belonging typically to the *Tropidoleptus* fauna. But the published lists are, on the one hand, too full, because they contain all the species which have been reported from the Hamilton group or formation, however that formation has been identified; and, on the other hand, they are not sufficient for the purposes of this paper, because locality and place in the formation are not always recorded or known. It has been necessary, therefore, to use specially prepared statistics.

In order to ascertain the average characteristics of the fauna, a

[a] In a paper read before the Geological Society of America after the present bulletin had gone to press I proposed the term *homeotopic* to express this likeness of facies of these faunas. See Bull. Geol. Soc. Am., Vol. XIV, 1903.

[illegible] and I think incorrect. It ought to be restricted to the Hamilton group of Hall + Vanuxem which is called the Hamilton [illegible] by Clarke + Schuchert.

large set of local faunules, prepared in determining, by the fossils, the areal distribution of the formation, has been examined, and only those faunules were taken which hold accredited Hamilton species. In order to obtain evidence as to the composition of the fauna in different parts of its history, a complete series of the faunules of each fossiliferous zone from bottom to top of a typical section of the formation was examined, and the proportionate abundance of species for each zone and the range of the species were thus ascertained.

TROPIDOLEPTUS CARINATUS FAUNA AS EXPRESSED IN EASTERN COUNTIES OF NEW YORK AND PENNSYLVANIA.

An examination of the faunal lists prepared by Prof. C. S. Prosser[a] for the eastern counties of New York and Pennsylvania furnishes 146 localities from which fossils of the Hamilton formation have been carefully collected and listed. In all 172 species were positively identified. The localities are distributed over the counties of Madison, Chenango, Broome, Otsego, Delaware, Schoharie, Albany, Greene, Ulster, and Orange, of New York; and Pike, Monroe, and Carbon, of Pennsylvania. The species listed in these tables have been tabulated so as to exhibit the number of times each species is recorded in the separate faunules. The abundance or rarity of each species in the particular faunule was also recorded.

From this complete tabulation of the statistics the following table has been prepared to show the species which stand highest in respect to *frequency of appearance in the faunules of the region studied.*

TABLE I.—*Tropidoleptus carinatus fauna: Species occurring most frequently in the Hamilton formation east of Cayuga Lake.*

[Dominant distributional frequency list for eastern New York.]

	Number of localities at which found.	Number of groups of localities.	Abundant.	Common.
1. Spirifer pennatus	113	30	26	33
2. Tropidoleptus carinatus	89	27	22	30
3. Spirifer granulosus	59	28	11	15
4. Chonetes coronatus	57	26	10	16
5. Palæoneilo constricta	56	27	2	5
6. Nucula bellistriata	42	23	4	8
7. Ambocœlia umbonata	40	22	4	8
8. Nuculites triqueter	38	22	1	7
9. N. oblongatus	35	21	1	3
10. Nucula corbuliformis	33	17	4	3
11. Athyris spiriferoides	32	24	2	5
12. Phacops rana	32	18	1	4

[a] The classification and distribution of the Hamilton and Chemung series of central and eastern New York: Fifteenth Ann. Rept. State Geologist New York, Part I, 1895, pp. 87-222.

The classification and distribution of the Hamilton and Chemung series of central and eastern New York: Seventeenth Ann. Rept. State Geologist New York, Part II, 1900, pp. 67-327.

The Devonian system of eastern Pennsylvania and New York: Bull. U. S. Geol. Survey No. 120, 1894, pp. 1-81.

The total number of species cited in faunule lists from 146 localities, divisible into 30 groups of localities, in eastern New York and Pennsylvania is 172. In addition to these positive identifications, 15 species are named with a query, and 11 genera not positively identified by species are cited. From these statements the lists must be regarded as approximate, not perfect, lists of the species of the fauna. We must await further investigations to perfect the conclusions drawn from them, which can be only outlined at the present time.

DISTRIBUTIONAL VALUES OF THE SPECIES.

In the first column, after the name of the species in Table I, is given the number of times each species is recorded in the 146 localities. In the second column the localities are grouped by fives, making 30 groups in all, and the number of such groups of localities in which the species occurs is given.

Analysis of these two sets of statistics shows that the 12 species of the list have all been reported from 32 or more of the 146 localities, nearly 22 per cent of the whole. When the distribution is based on groups of five localities the frequency reaches 17 out of 30 times, or nearly 59 per cent, showing that we have for all of them a common distribution, which would place them in 50 per cent or more of the localities examined in a cursory survey of the regions studied.

The best 6 of the list show a frequency of occurrence equal to nearly a third of the localities examined, and the same species all occur in as many as 23 of the 30 groups of five, and the best 5 out of the 12 occur in 26 out of 30, or nearly 90 per cent of the cases. It is safe to assume, therefore, that the first 12 species of this list give a fair representation of the dominant fauna of the Hamilton formation as it is expressed in eastern New York and Pennsylvania.

FREQUENCY VALUES OF THE SPECIES.

The dominance of the species in the fauna may be proved by noting the number of times each species is reported as *abundant* or *common* in the local faunule in which it occurs. This kind of value may be called the frequency value of the species in the particular faunule. The facts for this test are given in the third and fourth columns; the figures in the third column express the number of times the species is recorded as abundant, and those in the fourth column the number of times the species is reported as common. We note at once the prominence of the first four species of the list.

The first species is cited as abundant 26 times and common 33 times; or for 59 times out of the 113 records it is at least common. This species is *Spirifer* (*mucronatus*) *pennatus* of Atwater.

The second species in the list, *Tropidoleptus carinatus*, is abundant 22 times and common 30 times; or 52 times it is a common constituent of the fauna.

The next two species, *Spirifer granulosus* and *Chonetes coronatus*, are common 26 times out of 59 and 57 occurrences, respectively.

The remaining species of the list are occasionally abundant and common for from 4 to 12 times out of from 32 to 56 occurrences; or something like 20 per cent of the times they were observed they were common species in the faunule analyzed.

In matter of relative dominance among the species of the fauna the list is therefore representative, and since all the remaining 160 species of the Hamilton formation of this region (so far as reported in these statistics) are both less frequent and less abundant in the faunules examined, we may assume that we have here not only the dominant but the characteristic species of this *Tropidoleptus carinatus* fauna.

This set of statistics was chosen for first consideration for the following reasons:

(1) The localities are distributed over a considerable territory, so that in case there were local peculiarities in the samples of the fauna examined they might be detected and eliminated.

(2) Although the fauna can be traced upward in the strata above the place of the Genesee formation, in the greater part of this region the pure Chemung fauna does not appear in the series above the Hamilton fauna, but its place is represented by the sediments of the Catskill, without a strictly marine fauna.

(3) The faunas are all gathered and studied by a single person; hence the personal difference in estimating specific values and identifications is eliminated, and whatever may be the possible error in identification it is likely to be uniformly made, so that as bionic units the species may be regarded as fairly uniform in value, the same name standing for the same fossil form in each case reported.

(4) From the general distribution of the Hamilton formation, I have estimated that this northeast corner of the Appalachian province is likely to present its fauna in greater purity than it appears elsewhere in the interior continental basin.

(5) The statistics are gathered and studied with great care by one thoroughly familiar with the species and keenly aware of the importance of making accurate analyses of the faunas.

I believe, therefore, that the statistics are as reliable as any that are published, and that they represent, as accurately as can possibly be reported at the present stage of knowledge, the essential elements of the fauna of the Hamilton formation.

RANGE VALUES OF THE SPECIES.

In order to define a fossil fauna it is not sufficient to enumerate the list of species which have been described from the same geological formation, chiefly because in such a list will be found species from many different regions and from rocks of different stratigraphical horizon, and species which when living were adjusted to different conditions of environment.[a]

A fossil fauna is made up of the species which lived together under a common set of environmental conditions at the same time, and also of species which continued to be associated together for a greater or lesser length of time (they and their descendants), bearing the same relations to one another. It is this twofold extension which must be considered in dealing with the faunas of geological time, viz, their geographical distribution and their geological range. The geographical distribution will indicate the limits of expansion of the fauna, determined, it is to be presumed, chiefly by conditions of exterior environment. The geological range will indicate the power of endurance of the whole fauna, and of the constituent species, in preserving its integrity as a fauna, generation after generation, against the adverse changes of environment and against encroachment of other species.

In order to get a definite conception of a fossil fauna, it is necessary to ascertain what were the dominant species. Dominance is a relative term, and implies an equilibrium among the several constituent members of the community. So complex a combination of forces is represented by a fauna that it can not be imagined that the relative dominance of the species of a fauna could be retained through any serious disturbance of the general conditions of life. A fauna thus characterized may be conceived of as keeping the equilibrium (once established among its constituent species) only so far geographically as the same conditions of environment prevail, and only so long geologically as it is able to continue breeding and living, at least in a metropolis of distribution whose conditions remain approximately constant. A fauna once broken up in its biological equilibrium as a fauna must come to an end, however long thereafter individual species may persist.

In order to apply these principles to the determination of the essential characteristics of the *Tropidoleptus* fauna, two kinds of statistics were needed:

(1) Statistics to show the dominant species of the fauna in its geographical distribution over a considerable region of surface; and

(2) Statistics to show the dominant species of a series of successive zones ranging through a considerable thickness of rocks in a single geographical section.

CAYUGA LAKE SECTION.

In order to provide a standard list of the fauna of what is called the Hamilton formation, from a typical section of the formation, I persuaded Mr. H. F. Cleland, already well equipped by his previous biological training, to make an exhaustive analysis of the Hamilton

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[a] *Heterotopic* is proposed to express this adjustment to diverse conditions of environment. See Bull. Geol. Soc. Am., Vol. XIV, 1893.

formation as it is exposed along the shores of Cayuga Lake in central New York. Dr. Cleland accomplished the work successfully. The paper which he wrote, containing the results of the investigation, was first presented as a thesis for the doctorate degree conferred by Yale University in 1900, and was afterwards published as a bulletin of the U. S. Geological Survey,[a] wherein the statistics here used may be examined in detail.

A list was prepared, based upon a very thorough study and dissection of the formation from bottom to top. The faunules were collected from 76 zones of the 1,224 feet[b] of strata representing the Hamilton formation of this region. Upon examination of the collections it was decided that, faunally, there were but 25 separate faunal aggregates represented in the series. These were spoken of in his paper as zones, and marked by letters from A to Y. The species were distributed quite generally throughout the several zones; but each zone—sometimes a few feet thick and occasionally 10 or over 100 feet thick—held practically the same faunule from bottom to top; that is, the same species in the same relative abundance as compared numerically with each other. The investigation was made under my supervision, but the identifications were all made by Dr. Cleland, who gave very careful attention to the discrimination of the least departure from the described characteristics of the species cited.

In the use of fossils for the purpose of scientifically measuring geological time the *faunules* of such zones as Cleland has analyzed and listed may be called *bionic units* of the first order; the time represented by the continuance of the particular faunal equilibrium of such a unit may be called a *hemera*, applying the term nearly in the original sense of Buckman,[c] but giving it a definition. It may be described as the time during which the particular individuals of a given fauna and their descendants maintain their faunal equilibrium in relation to one another in a local and temporary faunule, as expressed by the retention of the same species in the same relative abundance in the faunal aggregate.

The analysis of Dr. Cleland's lists of *hemeral faunules* and the reduction of their statistics to averages gives an approximate conception of the constitution of the fauna as a whole, viewed in its relation of range through the whole Hamilton formation. It is in reality the dominant fauna of the region for the epoch of time through which it preserved its integrity as a fauna.

Table II presents the results of such an analysis.

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[a] A study of the Hamilton formation of the Cayuga Lake section in central New York, by H. F. Cleland: Bull. U. S. Geol. Survey No. 206, 1903.

[b] This is Prosser's estimate of thickness. Cleland estimates the total thickness of Hamilton to be 1,100 feet (Bull. 206, p. 90).

[c] S. S. Buckman, Quart. Jour. Geol. Soc., November, 1893, Vol. XLIX, p. 481.

That is probably for the Hamilton beds which were given as 1142 in my section. In Cleland's paper it is the 67' of Hamilton beds on Eighteen Mile Creek which he compared with the Cayuga

TABLE II.—*Tropidoleptus fauna: Fourteen species occurring most frequently in the Hamilton formation of Cayuga Lake.*

[Dominant range frequency list for Cayuga Lake meridian.]

	Number of zones in which found.		Number of zones in which found.
1. Tropidoleptus carinatus	21	8. Chonetes mucronatus	18
2. Ambocœlia umbonata	21	9. Athyris spiriferoides	17
3. Palæoneilo constricta	21	10. Nuculites triqueter	17
4. Spirifer pennatus	20	11. Modiella pygmæa	16
5. Phacops rana	20	12. Tellinopsis subemarginata	16
6. Cryphæus boothi	20	13. Stropheodonta perplana	16
7. Nucula corbuliformis	19	14. Nuculites oblongatus	16

The list here compiled (Table II) exhibits the 14 species occurring most frequently in the 25 zones into which the formation was divided at Cayuga Lake exposures. It will be noticed that these 14 species occur in 16 or more of the 25 zones, and that 6 of them occur in 20 or more of the 25 zones. The first 5 in the list are also in the list of 12 characteristic species of the eastern Hamilton (Table I, p. 51). These are *Tropidoleptus carinatus*, *Ambocœlia umbonata*, *Palæoneilo constricta*, *Spirifer* (*mucronatus*) *pennatus*, and *Phacops rana;* the remaining 7 of the dominant list are found in the Cayuga Lake section, but they are not among the more widely ranging species of that section.

Chonetes coronatus is represented in 13 of the zones, in both the lowest and highest, and is fairly common in several of the zones in which it appears.

Nucula bellistriata does not appear in the 6 lower zones at Cayuga Lake, but is seen in 8 of the zones above.

Cryphæus boothi, which appears in 20 of the 25 zones of the Cayuga Lake section, is not common in the eastern sections. It was discovered in several sections about Smyrna and Sherburne, once at Summit, and from Kingston southward the species is again occasionally reported, 13 times out of 36 stations.

Chonetes mucronatus is among the long-ranging species of Cayuga Lake. It is fairly common in the eastern faunas, but not among the first 12.

Modiella pygmæa and *Stropheodonta perplana* are long-ranging species in the formation, and are frequent in the localities as far as Chenango Valley, and again from Kingston southward, but are rare in the intermediate region.

Tellinopsis subemarginata and *Nuculites oblongatus* are frequently noted in the zones at Cayuga Lake, and are also fairly common eastward, but fail to appear in the first 12 of the typical list.

Looking over the range of the species in the zones of the Hamilton formation at Cayuga Lake, the dominant list already selected presents the most characteristic species on the basis of frequency of appearance vertically in the zones; but, allowing for imperfection in the collecting, the list as given in Table I may still stand as the list of dominant species of the fauna, considered geologically as well as geographically.

EIGHTEENMILE CREEK SECTION.

Another test of the correctness of the list of dominant species of the *Tropidoleptus carinatus* fauna is derived from a study of the lists of species reported by faunules as they occur in the section of the Hamilton rocks at Eighteenmile Creek.[a]

Mr. Grabau made an exhaustive study of the zonal succession of faunules throughout the Hamilton of Eighteenmile Creek. In his list 35 zones are recognized. The total number of species named by Mr. Grabau in his list is 163, but 10 of these are not positively identified with any known species. Hence there are only 153 species positively recognized in the collections studied by him. Of these the following 12 are the more frequently represented in the zones, the first 9 of them appearing in at least 17 out of the 35 zones, or in 50 per cent of the zones.

TABLE III.—*Tropidoleptus fauna: Twelve species occurring most frequently in the Hamilton formation at Eighteenmile Creek.*

[Dominant range frequency list for Eighteenmile Creek.]

	Number of zones in which found.		Number of zones in which found.
1. Spirifer pennatus	28	7. Primitiopsis punctilifera	18
2. Phacops rana	26	8. Stropheodonta perplana	17
3. Chonetes lepidus	21	9. Orthothetes arctistriatus	17
4. Athyris spiriferoides	20	10. Rhipidomella vanuxemi	14
5. Ambocœlia umbonata	18	11. Productella spinulicosta	14
6. Chonetes scitulus	18	12. Cryphaeus boothi	14

It will be noticed that 4 of the species of this list belong to the dominant list of eastern New York (page 51), and these 4 are among the first 5 showing most frequent occurrence in the zones of the formation in western New York, appearing in 18 or more of the 35 zones. It is to be noted, however, that several of the species of the list for eastern New York (Table I) are rare or wanting in the Eighteenmile Creek section, and are there restricted to a few zones. They are the following species, the number of zones in which they appear in the Eighteenmile Creek section being expressed by the figures to the right of the name. The total number of zones is 35.

[a] The faunas of the Hamilton group of Eighteenmile Creek and vicinity in western New York, by A. W. Grabau: Sixteenth Ann. Rept. State Geologist New York, 1898, pp. 231-339.

TABLE IIIa.—*Dominant eastern species not dominant in the Eighteenmile Creek section.*

Spirifer granulosus	10
Chonetes coronatus	6
Palæoneilo constricta	4
Nuculites triqueter	1
Nucula bellistriata	0
Nucula corbuliformis	0

There are also several species in the range list of Eighteenmile Creek not in the dominant distributional list of eastern New York. They are:

TABLE IIIb.—*Dominant Eighteenmile Creek species not dominant in the eastern New York region.*

	146 faunules.		146 faunules.
Chonetes lepidus	11	Orthothetes arctistriatus	12
C. scitulus	17	Rhipidomella vanuxemi	17
Primitiopsis punctilifera	0	Productella spinulicosta	0
Stropheodonta perplana	15	Cryphaeus boothi	17

The numbers in this list indicate the number of times the species is recorded among the 146 faunules of the eastern distribution recorded by Prosser; these numbers indicate that the species are rare in the East.

It is evident, therefore, that the Hamilton fauna of western New York is considerably modified from the standard presented in eastern New York.

CONSTRUCTION OF A STANDARD LIST OF THE DOMINANT SPECIES OF THE TROPIDOLEPTUS FAUNA.

These several local lists already presented may be assumed to give a fair representation of the dominant characteristics of the *Tropidoleptus* fauna, derived in two ways—first, on the basis of frequency of occurrence in geographical distribution for a region in which the formation is typically expressed; second, on the basis of frequency of recurrence of the species in vertical range through the successive zones of a continuous section, passing from the bottom to the top of the formation.

The statistics in all cases were prepared with special attention to the discovery of the facts used in the present discussion, and by men who were well acquainted with the fauna they were analyzing.

Difference of opinion regarding the identification of species is not alone due to difference in knowledge. The same person is more likely to use specific names alike in successive papers, but the habit is not uniform, as statistics show. Nevertheless, for determining values of species in terms of abundance or frequency of occurrence, lists made by the same man are, naturally, more likely to furnish correct comparative statistics than lists made by different men.

These three selected cases may be taken as offering a fair basis of reckoning, the results derived from which may constitute a fairly satisfactory standard, though they can not be regarded as final in any of the lists, since the statistics of the faunules are decidedly incomplete. This incompleteness of the fundamental statistics of this investigation, while important, does not invalidate the general conclusions which are drawn from them, for, although the exact degree of dominance is not mathematically expressed by the figures, or by the order of the species in the lists, the fact of dominance is clearly expressed for the species mentioned.

In order to reduce to a minimum the errors pertaining to the several modes of measuring the bionic values of the species the average may be struck, and thus dominance of both kinds may be expressed in a final list which may stand as a standard and representative list of the dominant species of the *Tropidoleptus carinatus* fauna.

In order to add together the statistics of various kinds regarding the same species the several fractions may be reduced to percentages (Table IV). The statistics are in three sets and are expressed in figures at the right of the species tabulated in the preceding tables (I, II, III). The figures express the following facts:

(1) The geographic frequency of occurrence of the species in the 146 sample collections made in eastern New York and Pennsylvania.

(2) The frequency of recurrence in the 25 zones making up the vertical column of the Cayuga Lake section.

(3) The frequency of the vertical recurrence of the species in the 35 zones of the Eighteenmile Creek section.

The total number of stations in the first group is 146; the total number of zones in the second group is 25; the total number of zones in the third group is 35.

By reducing the fractions to approximate percentage values we get the following table:

TABLE IV.—*Tropidoleptus fauna: Preliminary dominant list.*

	1. Eastern New York.	2. Cayuga Lake.	3. Eighteen-mile Creek.	4. Ontario, Canada.	5. Total.	6. Rank of species.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	
Spirifer pennatus	78	80	80	*	238	1
Tropidoleptus carinatus	60	84	23	*	167	3
Spirifer granulosus	40	40	29	*	109	7
Chonetes coronatus	40	52	17	*	109	8
Palæoneilo constricta	40	84	12	....	136	6
Nucula bellistriata	29	32	0	....	61	12
Ambocœlia umbonata	28	84	51	*	163	4
Nuculites triqueter	28	68	3	*	99	9
N. oblongatus	24	64	6	....	94	11
Nucula corbuliformis	23	76	0	....	99	10
Athyris spiriferoides	22	68	60	*	150	5
Phacops rana	22	80	74	*	176	2

In this table columns 1, 2, 3 express, approximately, in percentages, the facts shown in Tables I, II, and III; column 4 indicates the species which are recorded in the fauna of Ontario, Canada;[a] column 5 gives the sum of the percentages in the first three columns, and column 6 shows the relative order of the species, according to the results thus reached.

Tabulating the species in this order the following table is obtained:

TABLE V.—*Tropidoleptus fauna: Standard list of dominant species for the New York-Ontario province.*

	Per cent of bionic value.		Per cent of bionic value.
1. Spirifer pennatus	79	7. Spirifer granulosus	36
2. Phacops rana	58	8. Chonetes coronatus	36
3. Tropidoleptus carinatus	56	9. Nuculites triqueter	33
4. Ambocœlia umbonata	54	10. Nucula corbuliformis	33
5. Athyris spiriferoides	47	11. Nuculites oblongatus	31
6. Palæoneilo constricta	45	12. Nucula bellistriata	20

The figures to the right in this list express in percentage the approximate bionic value for each of the species as obtained from the statistics before us. It will be seen that there are 10 species which have a bionic value in this fauna of 33 per cent and over, and no other species attain this bionic value when tested by the several modes of estimating them which have been here defined.

The first 10 species in this list (Table V) may be regarded as the 10 most characteristic species of the fauna of the Hamilton formation as it is seen in New York State, as determined by the evidence already presented.

The geographical distribution of the fauna may be recognized by the distribution of these species. A fauna which fails to contain any of them can not be said to be the *Tropidoleptus* fauna, although it may be called equivalent (on some basis) to it.

When the vertical range of the fauna is under consideration, so long as a majority of these 10 species continue to appear in the rocks, although lithologically or stratigraphically they lie above the Hamilton formation, it will be correct to state that the fauna still lives and preserves its bionic integrity in the measure of dominance of these species. When, therefore, the question as to upward range of the *Tropidoleptus* fauna is discussed, these species should be considered as the standards by which the fauna is to be recognized, irrespective of the stratigraphical evidence of continuance or noncontinuance of the Hamilton formation.

The effect of checking up the eastern list, on the basis of the vertical-

[a] On some additional or imperfectly understood fossils from the Hamilton formation of Ontario, with a revised list of the species therefrom, by J. F. Whiteaves: Contributions to Canadian Palæontology, 1885-1898, Vol. I, Part V, pp. 361-436, Pls. XLVIII-L.

recurrence frequency, is to exalt the rank of the species *Ambocœlia umbonata*, *Athyris spiriferoides* and *Phacops rana*, and this throws *Nucula* and *Nuculites* to the end of the list. This result may be attributed to the influence of environmental conditions upon the species, for the conditions are more favorable for lamellibranchs in the eastern region, and more favorable for trilobites in the western. It is, secondly, traceable to the rarity of these species in the localities in the counties of Otsego, Delaware, Schoharie, and Albany, which lowers their frequency percentage for the whole area. Their frequency in Madison and Chenango counties, and again in Greene, Ulster, and Orange counties, and across the State line in Pennsylvania, would entitle them to the prominence they hold in the list as furnished by the other evidence.

I conclude from the balancing up of the various kinds of evidence now in hand that the last list (Table V) contains the twelve most characteristic species of this fauna as it appears in the New York province, and shows the order of approximate rank they occupy in the fauna as a whole.

Examination of the faunas in the formations succeeding the Hamilton formation of the eastern division of New York reveals the fact that this typical *Tropidoleptus* fauna continued to appear above the strict limits of the formation, though associated with new forms distinct from those of the *Tropidoleptus* fauna.

The Hamilton formation is regarded as terminating where the Tully limestone comes in, when it is present, and where the Genesee shale appears, when the former is wanting. When neither of these lithological formations is present, the position in the strata was traced from place to place with great care by the lithological character of the strata with the aid of structure and minute discrimination of the faunal contents. The faunas confirm the accuracy of the geological work of Professor Prosser, and of the dissection of the local sections made by him. I have examined his reports with critical scrutiny, and have great confidence in the interpretation of the equivalency of the species and faunas made by him. The evidence of change in the faunas is clear, and the relative order of the succession of the faunas is always the same, and the gradual departure of the less conspicuous elements of the earlier fauna is apparent as the faunas are traced upward in each section.

The Ithaca formation is succeeded by the Oneonta, and above the Oneonta a considerable number of the typical species of the *Tropidoleptus* fauna still appear. These species continue after the introduction of *Spirifer mesicostalis* and after the *Spirifer mesistrialis* fauna was well established in the province. The *Tropidoleptus* fauna was not entirely dispersed till the characteristic *Spirifer disjunctus* of the Chemung had arrived in central New York. In the extreme eastern counties this species is not certainly reported, but many of its associates in the western part of the basin are introduced before the entire disappearance of the *Tropidoleptus* fauna from the eastern corner of the basin.

On following these faunas westward it is found that the *Tropidoleptus* fauna lies entirely below the Genesee shale in the Genesee Valley and farther westward. The formations called Sherburne, Ithaca, Oneonta, and, I am inclined to think, a considerable part of what is classified as Chemung in the eastern half of the State, lying above the Oneonta, must be regarded, on stratigraphical grounds, as equivalent to the Portage formation of the Genesee Valley.

EFFECT OF ADDITIONAL STATISTICS.

In order to demonstrate the way in which such a standard list as Table V is affected by additional statistics, a few cases are left for analysis after the estimate has been deliberately made.

The faunules of the Unadilla region of Otsego and Delaware counties, in eastern New York, were gathered by Prof. C. S. Prosser and reported in 1893.[a] In his report 37 faunules are analyzed and the species tabulated. The number of species positively determined is 66; 18 more species are named, but marked with a query, and 13 generic names are cited without identification of the species observed. The 12 more common species of the 37 faunules are named in Table VI.

TABLE VI.—*Tropidoleptus fauna: Dominant species of the Hamilton formation of the Unadilla region.*

*1. Ambocœlia umbonata	23	* 7. N. triqueter	9
*2. Tropidoleptus carinatus	20	* 8. Chonetes coronatus	9
*3. Spirifer pennatus	17	* 9. Spirifer granulosus	7
4. Paracyclas lirata	11	*10. Palæoneilo constricta	7
5. Leiorhynchus laura	10	11. Spirifer medialis	7
*6. Nuculites oblongatus	13	12. Chonetes scitulus	7

It will be noted that 8 of these 12 species belong to the standard dominant list of 12 (Table V), compiled from the various statistics of the State. They are marked with asterisks before the names.

The species of the standard list which are not among the first 12 species of the Unadilla list are—

Phacops rana.
Athyris spiriferoides.
Nucula corbuliformis.
N. bellistriata.

The dominant list for the Unadilla district contains four species not in the general dominant list, which are—

Paracyclas lirata.
Leiorhynchus laura.
Spirifer medialis.
Chonetes scitulus.

[a] Forty-sixth Ann. Rept. New York State Museum, 1893, pp. 256-288.

If now we make a revised list by adding to the standard list based on the 146 faunules the new distributional values of all the species as they appear in the 37 Unadilla faunules, they will then stand as in Table VII, the numbers at the right expressing the distributional values of the species in the 146+37=183 faunules.

TABLE VII.—*Tropidoleptus fauna: Revised list of dominant species of the Hamilton formation of eastern New York and Pennsylvania, as expressed in 183 faunules.*

1. Spirifer pennatus	130	9. Nucula bellistriata	47
2. Tropidoleptus carinatus	109	10. Phacops rana	38
3. Spirifer granulosus	66	11. Athyris spiriferoides	36
4. Chonetes coronatus	65	12. Nucula corbuliformis	33
5. Ambocœlia umbonata	63	13. Leiorhynchus laura	30
6. Palæoneilo constricta	63	14. Paracyclas lirata	29
7. Nuculites oblongatus	48	15. Chonetes scitulus	24
8. N. triqueter	47	16. Stropheodonta perplana	21

It will be observed that the first 12 species of this table are the same as the 12 species in the standard list (Table V), and that none of the 4 species which were specially dominant *only* in the Unadilla list reach as high distributional value as do all of those of the standard list. The new facts brought in by the additional statistics derived from the same general region do not disturb the general results obtained by consideration of the smaller number of faunules.

STATISTICS BASED ON ANALYSIS OF THE ZONES OF THE LIVONIA SALT SHAFT.

The faunules discussed by Prosser in his paper on eastern New York and Pennsylvania under the designation of Hamilton do not definitely include the Marcellus. The list of faunules reported by Cleland from Cayuga Lake begins with the Marcellus. Mr. Grabau's analyses of the Hamilton group of Eighteenmile Creek take in the transition zone of the top of the Marcellus. The conclusions, therefore, reached from study of the statistics reported by these men deal with the pure Hamilton fauna.

Dr. Clarke has given an analysis of the species discovered in the Livonia salt shaft,[a] which runs lower than the other records, taking in the Marcellus and Onondaga faunas. In his list for the part of the record covering the Hamilton formation, all the abundant species of the other lists are reported, with the exception of *Nucula corbuliformis*, but the frequency of records in the separate faunule lists is not so emphatically expressed as in the lists formed with the definite purpose of recording frequency values with precision. Dr. Clarke separates the series above the Marcellus into 16 zones, but the recorded species reach, in the highest case, only 10/16 of frequency value. This is the case of *Phacops rana*, which is recorded ten times.

[a] The succession of the fossil faunas in the section of the Livonia salt shaft, by John M. Clarke: Thirteenth Ann. Rept. State Geologist New York, 1893, Vol. I, Geology, pp. 131-158.

The species occurring the greater number of times in the 16 faunules reported are as follows:

TABLE VIII.—*Tropidoleptus fauna: List of species appearing most frequently in the 16 zones of the Hamilton formation of the Livonia salt shaft.*

*1.	Phacops rana	10	8.	Bellerophon leda	6
2.	Diaphorostoma lineatum	8	9.	Actinopteria decussata	6
3.	Orthoceras nuntium	7	10.	Streptelasma rectum	5
4.	Chonetes scitulus	7	*11.	Spirifer pennatus	5
5.	Orthis vanuxemi	7	12.	Orbiculoidea media	5
6.	Orthothetes arctistriatus	6	*13.	Chonetes coronatus	5
7.	Productella spinulicosta	6	*14.	Ambocœlia umbonata	5

Those of the standard list are marked with asterisks, and constitute only 4 of the list of 14, and only 1 of those among the first 10. The other species of the Livonia list (with the exception of the second) are, however, all reported from rocks of the Hamilton formation in the East. The high range value assigned to species in the Livonia section, which take a relatively less conspicuous place in both the Cayuga Lake and the Eighteenmile Creek sections, may be explained on the supposition that the author gave closer attention to the species by which the several zones can be distinguished than to those common species which appear most frequently throughout the series. Otherwise it is necessary to assume from the records that the common species appear less frequently in the zones of the Livonia section than would be expected from all the other statistics which were gathered specially to ascertain the range and distributional values.

HAMILTON FORMATION IN ONTARIO, CANADA.

The species of the Hamilton formation of Ontario, Canada, as reported by Dr. Whiteaves,[a] include 8 of the standard list of 12 dominant species of the *Tropidoleptus* fauna, and several of those quoted as more or less dominant not among the first 12.

The list of species is given in Table IX. They are arranged alphabetically, because the statistics regarding range or distributional frequency are not reported.

TABLE IX.—*Tropidoleptus fauna: Species of the standard lists of the Hamilton formation of New York State which are also reported from the Hamilton formation of Ontario, Canada.*

* Ambocœlia umbonata.	Orthothetes arctistriatus.
* Athyris spiriferoides.	* Phacops rana.
* Chonetes coronatus.	Primitiopsis punctilifera.
C. lepidus.	Rhipidomella vanuxemi.
C. scitulus.	* Spirifer granulosus.
Cryphæus boothi.	* S. (mucronatus) pennatus.
* Nuculites triqueter.	* Tropidoleptus carinatus.

[a] On some additional or imperfectly understood fossils from the Hamilton formation of Ontario, with a revised list of the species therefrom, by J. F. Whiteaves: Contributions to Canadian Palæontology, 1885-1898, Vol. I, Part V, pp. 361-436, Pls. XLVIII-L.

The four species absent are—

Nucula bellistriata.
N. corbuliformis.
Nuculites oblongatus.
Palæoneilo constricta.

The naming of these species at once calls attention to the fact that these species and the genera to which they belong hold conspicuously a more important place in the fauna of the Hamilton formation of the eastern portion of the State of New York than in the western half. This remark applies also to the Pelecypoda in general. On the other hand, the fauna is richer in Cœlenterata in Ontario than in its more eastern expression.

HAMILTON FORMATION IN MICHIGAN.

The faunal lists for the Hamilton formation of the Michigan area are still imperfect, but some idea of the common species may be gathered from the lists prepared by C. Rominger.[a]

The occurrence of the following species is mentioned:

Spirifer (mucronatus) pennatus.
S. granulosus.
Chonetes coronatus.
(Spirigera concentrica=) Athyris spiriferoides.
(Phacops bufo=) P. rana.

Other species of the *Tropidoleptus* fauna are recorded, but the above mentioned constitute 5 of the 10 species of the standard list.

The recent investigation of the faunas in northern Michigan made by Mr. Grabau[b] does not increase the number of species of the dominant list.

HAMILTON FORMATION IN WISCONSIN.

The Milwaukee fauna analyzed by Messrs. Teller and Monroe[c] contains the following species:

Phacops rana.
Palæoneilo constricta.
Nucula corbuliformis.
Spirifer pennatus.

Several other species of the common fauna of the Hamilton formation of eastern New York are also reported.

Here are enough of the representatives of the standard *Tropidoleptus carinatus* fauna to lead to the inference that the typical fauna is not far distant, but whether the separation is geographical or strati-

[a] Geological Survey of Michigan, 1873-1876, Vol. III, pp. 38-63.

[b] Stratigraphy of the Traverse group of Michigan, by A. W. Grabau; Rept. State Board of Geol. Surv. Mich., for 1901-2.

[c] The fauna of the Devonian formation at Milwaukee, Wis.: Jour. Geol., Vol. VII, 1899, pp. 272-283.

graphical is not evident from the citation of these species alone. The presumption is that the strata at Milwaukee constitute an extension of the Hamilton formation of the lower peninsula of Michigan. The problem of determining the correlation of the fauna can be discussed more satisfactorily after the facts regarding the relations of the various faunas in the New York-Pennsylvania subprovince to one another are elaborated.

HAMILTON FORMATION IN SOUTHERN ILLINOIS.

In southern Illinois occurs a fauna, analyzed by Prof. Stuart Weller,[a] which contains three of the standard representatives of the *Tropidoleptus* fauna, viz:

Chonetes coronatus.
Phacops rana.
Tropidoleptus.

Some of the less common species of the New York Hamilton formation are also reported in the list.

The species enumerated constitute characteristic species of the *Tropidoleptus carinatus* fauna, and, although few, they seem to leave no doubt as to the presence of the fauna. But we are still left in doubt whether this faunule may not represent actually an earlier geological horizon than the base of the typical Hamilton formation in New York.

The association of these species with species which do not appear in the typical Hamilton formation in New York confirms the opinion, derived from a comparison of the fauna with those outside the basin, that the *Tropidoleptus* fauna as a whole came into this intercontinental basin from the south, and probably by a passage on the south side of the Ozark island of Missouri. If this hypothesis be correct, the association of the more typical species of the fauna with Onondaga species in the southwest corner of the basin is not unexpected. The facts regarding the association of species in the faunules along the western side of the Cincinnati-Nashville axis, in Kentucky, Indiana, and Ohio, point the same way.

SELLERSBURG FORMATION IN INDIANA.

Recent investigation made by Dr. E. M. Kindle is revealing traces of the *Tropidoleptus* fauna to the west of the Cincinnati-Nashville ridge in central Indiana.

In a report now preparing for the press, Dr. Kindle gives the following list of species occurring in a Sellersburg faunule from a section in the town of Lexington, Scott County, a few miles north of Louisville, Ky.

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[a] Correlation of the Devonian faunas in southern Illinois: Jour. Geol., Vol. V, 1897, pp. 625-635.

Sellersburg faunule, Lexington, Scott County, Ind.

Chonetes yandellanus (abundant).
Tropidoleptus carinatus (abundant).
Spirifer granulosus (common).
Stropheodonta demissa (common).
Roemerella grandis (rare).
Phacops rana (rare).
Proetus canaliculatus.
Stictopora sp. ?
Cystiphyllum sp. ?

Other sections of the same formation (Sellersburg) contain *Spirifer pennatus*, *Spirifer granulosus*, *Stropheodonta perplana*, and other species of the *Tropidoleptus* fauna. Several other faunules reported from the southern part of the district contain *Tropidoleptus;* in this faunule it is abundant.

As far north as Cass County traces of the same fauna are detected in the beds overlying the Jeffersonville limestone and underlying the New Albany black shales.

Although these facts point to the presence of representatives of the *Tropidoleptus carinatus* fauna in the formation west of the ridge, it does not necessarily follow that the Sellersburg is the stratigraphical equivalent of the Hamilton formation of New York, since, as will be shown, the dominant as well as a large number of the ordinary species of that fauna appear in the Ithaca formation, known to be, geologically, of later age than the Hamilton formation.

The fuller discussion of the questions here raised will appropriately come after the main problem is presented and elaborated, and the laws of shifting of faunas established by evidence.

There will be no objection, I think, to the claim that these several local faunules belong to the same general *Tropidoleptus* fauna; but the formational equivalency may be questioned, as will be brought out as we proceed to the discussion of the fauna of the formations following the Hamilton in the eastern New York area.

ROMNEY FORMATION IN WESTERN MARYLAND.

Through the courtesy of the State geologist of Maryland, Prof. W. B. Clark, and of Prof. C. S. Prosser, the paleontologist, I am able to consult the faunule list of species from the Romney formation of western Maryland, recently secured under the auspices of the Maryland geological survey.

In the list furnished me by Professor Prosser there appear 132 entries, 91 of which are positive specific identifications. Among the latter are found all of the dominant species of the *Tropidoleptus carinatus* fauna, as estimated from the New York statistics (see Table V). This is sufficient to establish the extension of the *Tropidoleptus* fauna, in its integrity, as far south in the Appalachian trough as Maryland.

ABSENCE OF TROPIDOLEPTUS FAUNA IN OTHER REGIONS.

That the *Tropidoleptus* fauna is not represented in the Iowa formations is signified by the fact that only *Phacops rana* of the standard list—a species of very wide geographical range—appears in the lists consulted.

The Manitoba, Saskatchewan, and Mackenzie River lists prepared by Dr. Whiteaves do not record a single species of the standard *Tropidoleptus carinatus* faunal list.

We are thus led to the separation of the Devonian faunas of Iowa and the Northwest (outside the intercontinental basin) from those of the Appalachian province and its extensions, both into the Tennessee province and into the Michigan province, with the latter of which, faunally, the Milwaukee locality must be regarded as directly connected.

POST-HAMILTON FORMATIONS AND THEIR FAUNAS IN NEW YORK PROVINCE.

Having demonstrated the dominant characteristics of the fauna which is contained in the Hamilton formation in its central position and where the facts are most fully known, we have next to consider the faunal characteristics of the overlying formations. The upper termination of the Hamilton was, for the purposes of this investigation, assumed to be at the bottom of the Tully limestone, where that is present; at the bottom of the black Genesee shale, where that is clear and the Tully is not evident; and, where the evidence of those ordinarily overlying formations is indistinct, at the place in the sequence of strata which can be definitely traced, by either stratigraphical or paleontological evidence, as the stratigraphical extension of that plane.

It is also taken for granted that the list of species given in Table V may be relied upon as positive evidence of the *Tropidoleptus carinatus* fauna as it is expressed in the northeastern corner of the continental basin of North America. The entire absence from any fossil faunule of the 12 species there enumerated may be regarded as presumptive evidence that the *Tropidoleptus* fauna is absent, although other species among the 200 or more thereof known to be and found associated with them might be present.

On the other hand, the presence of the majority of these dominant species is not proof positive that we are dealing with the stratigraphical equivalent of the Hamilton formation, for the two following reasons: First, the fauna may have migrated into the region in which the Hamilton formation was deposited, in which case the fauna existed prior to the beginning of that formation; second, unless evidence can be furnished of the destruction of the fauna at the time of the deposition of the Tully limestone or the Genesee shale, there is no reason to believe that its integrity as a fauna was there suddenly lost. But we may assume that evidence of lessening bionic value of these species, as indicated by their loss of dominance in the local or temporary faunules in which they occur, may be interpreted as indicating modification of the fauna as a whole, due either to lapse of time in the same region, resulting in the loss of supremacy of these species, or to shifting of the fauna as a whole, resulting in loss of life and change in the equilibrium of the species owing to change of conditions of life.

It will be remembered that in the section running through Cayuga Lake and Ithaca, which was elaborated in 1883,[a] both the Tully limestone and the Genesee shales are distinct formations and form a definite termination for the Hamilton formation.

It was pointed out in a later paper[b] that this zone was indicated by the first appearance in the New York section of *Rhynchonella* (*Hypothyris*) *cuboides* (=*R. venustula* Hall) and other species not found below in the Hamilton, but widely distributed in other parts of the world. The inference was drawn that there had been modification of the local fauna by immigration of foreign elements. The fauna to which these immigrants belonged in other regions was observed to be more intimately associated with the later faunas of the New York region (the *Spirifer disjunctus* fauna) than with the *Tropidoleptus* fauna, and the conclusion was therefore reached that the Tully limestone was more naturally associated faunally with the formations that stratigraphically follow it than with the *Tropidoleptus carinatus* fauna of the Hamilton, and so, in spite of the survival of many species of the underlying formation, the fauna of the Tully limestone was appropriately called the *cuboides* fauna, from the dominance of this new form, *Rhynchonella cuboides*.

In the more exact nomenclature adopted in writing this paper the *cuboides* fauna may be regarded as only a faunule—that is, only a local and temporary representative of a fauna which, though not widely represented in the interior continental basin of North America, probably had its fuller characteristics expressed in the outer Manitoba-Mackenzie River seas of Devonian time.

In the Cayuga Lake-Ithaca section, above the Tully came the black Genesee shale with its *Lingula spatulata* faunule.[c] This faunule contains *Ambocœlia umbonata*, but no other one of the 12 dominant species of the *Tropidoleptus* fauna. Following this was a small faunule which is related to the Portage fauna of the Genesee Valley, as seen by the continued presence of *Cardiola speciosa*;[d] and above that came the *Spirifer lævis* faunule, still a modification of the western *Cardiola* (Portage) fauna,[e] but mingled with some of the species of the *Tropidoleptus* fauna. Still a third modification of the *Cardiola* fauna is seen in some black or dark shales above the *Spirifer lævis*

[a] On the fossil faunas of the Upper Devonian along the meridian of 76° 30′ from Tompkins County, N. Y., to Bradford County, Pa., by H. S. Williams: Bull. U. S. Geol. Survey No. 3.

[b] The Cuboides zone and its fauna; a discussion of methods of correlation, by H. S. Williams: Bull. Geol. Soc. Am., Vol. I, pp. 481-501, Pls. XI-XIII.

[c] Bull. U. S. Geol. Survey No. 3, p. 9.

[d] Ibid., p. 11.

[e] Ibid., p. 12.

zone.[a] A few feet higher, in the lower part of the rocks outcropping in the Cascadilla Creek gorge,[b] a faunule was discovered in which occurred several well-known Hamilton species, among them—

Spirifer fimbriatus.
Pleurotomaria capillaria.
Ambocœlia umbonata.
Modiomorpha complanata.

Of these only *Ambocœlia* belongs to the dominant *Tropidoleptus* faunal list.

Above all these appears the typical Ithaca fauna, which now may be called the *Productella speciosa* fauna, from the species of *Productella* which is characteristic of this horizon in a number of stations examined and does not appear to have occurred earlier, while higher up it is represented by such forms as *Productella lachrymosa* and its varieties. The "*Spirifer mesicostalis*" associated with it in the fauna at Ithaca[c] was, at the time of writing the report, regarded as an early form of the species so named, then regarded as a Chemung species. This common Ithaca form is now called *Spirifer pennatus* var. *posterus.*[d]

In the report[e] quoted I called attention to the fact that the Ithaca fauna, with this *Spirifer* as a characteristic, occurred below the Chemung and was a fauna more closely related to the Hamilton than to the Chemung:

> This fauna is the regular successor of the Hamilton fauna, and is intermediate between it and that of the Chemung group. It appears to have come in from the east. It prevailed during the deposition of two to three hundred feet of arenaceous shales; the coral sandstone fauna came in before its maximum development. At the close of its occupation of this area a dark, fissile shale with a *Discina* fauna came in. This I believe to be another outlier of the Genesee shale conditions, whose center at this time must have been toward the western part of the State.

Since writing that report the new facts regarding the range of species east of the Cayuga Lake meridian have led to a recognition of the actual presence of a large part of the *Tropidoleptus carinatus* fauna in the sediments farther east, which are shown to be the stratigraphical equivalents of these beds at Ithaca. This fact establishes the variational nature of the differences marking many of the Ithaca forms when compared with typical Hamilton species. Sufficient facts are present to show a gradation from typical *Spirifer* (*mucronatus*) *pennatus* of the eastern counties to *Spirifer pennatus* var. *posterus*[f] of this western extension, and many of the species going under the same names show some local peculiarities which are sufficient to

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[a] Bull. U. S. Geol. Survey No. 3, p. 14.
[b] Ibid., p. 15.
[c] Ibid., p. 17.
[d] Palæontology New York, Vol. VIII, Part II, p. 361, pl. 34, 1895.
[e] Bull. U. S. Geol. Survey No. 3, p. 30.
[f] Palæontology New York, Vol. VIII, Part II, p. 361, figs. 27-31, Pl. XXXIV.

enable one familiar with the fossils to distinguish the Ithaca varieties from the typical Hamilton species.

FAUNA OF EASTERN EXTENSION OF PORTAGE FORMATION.

The identification of the Portage formation in eastern New York and Pennsylvania is fairly satisfactory in case the identification refers to a recognition of the *formation* in its eastern extension, irrespective of exact equivalency of faunas or likeness of sediments. But in the eastern counties neither is it stratigraphically clearly to be distinguished from lower or higher strata, nor does it contain in its fauna any characteristic species of the Ithaca expression of the lower Portage formation. Nevertheless, the identification of the strata as the outcroppings of the same rocks which farther west are distinguished, both lithologically and paleontologically, as lower Portage is well demonstrated; and the assignment on a geological map of the Portage color to the region from which the 15 reported faunules came is defensible, if it be granted that the same formation name may be applied to strata of which the contemporaneous sedimentation can be established, although their lithological and paleontological characters are different.

I take this case from the region holding the typical Hamilton formation, with its *Tropidoleptus carinatus* fauna, to illustrate a phase of a fauna which is, without question, directly descended from the typical *Tropidoleptus* fauna, but is certainly younger.

How is such a fauna distinguished?

(1) The great majority of its species are the same as those of the typical *Tropidoleptus carinatus* fauna below.

(2) The few distinctive species never appear at the lower horizon, but they are frequent above, and first appear at a like horizon over considerable area; and

(3) They are more prominent in frequency of individuals where the characteristic species of the *Tropidoleptus carinatus* fauna are deficient.

In the 15 faunule lists of this group given by Prosser, 41 species are positively identified.

Of these 41 species, 34 are recurrent species, and among the dominant species of the Portage fauna occur five species and two varieties of the *Tropidoleptus* fauna.

Of the standard *Tropidoleptus carinatus* list, six species are reported the number of times, out of a possible 15 localities, indicated by the figures in the following list:

Sherburne

TABLE X.—*Recurrent species of the Tropidoleptus fauna in the Portage formation.*

Tropidoleptus carinatus	8
Nucula corbuliformis	3
Palæoneilo constricta	3
Nuculites oblongatus	3
Phacops rana	1
Spirifer (mucronatus) pennatus	1

The form *Spirifer pennatus* var. *posterus* is reported eight times, thus indicating the unmistakable mutation of "*pennatus*" into the new variety.

Below is the list of forms characteristic of the Portage formation:

TABLE XI.—*Characteristic Portage species.*

1. Spirifer pennatus var. posterus (=S. mesicostalis, first var.)	8
2. Spirifer mesistrialis	7
3. Modiomorpha subalata var. chemungensis	6
4. Leiorhynchus mesicostale	6
5. Rhynchonella stephani	4
6. Prothyris lanceolata	2
7. Palæoneilo filosa	1

Putting these two lists together, it will be seen that the characteristic Portage species dominate over the recurrent Hamilton species of the older fauna. *Tropidoleptus* still retains its conspicuous place in the fauna, its bionic value being eight-fifteenths, or 50 per cent. In the Ithaca region this species does not occur in the Portage formation, but all the above characteristic species are present, and have high bionic values, with the exception of *Prothyris lanceolata*, which is a rare form.

The dominant species of the fauna of the Portage zone in the eastern counties at 15 localities, with their approximate bionic values, are shown in the following table:

TABLE XII.—*Dominant species of the Portage zone in eastern New York.*

1. Paracyclas lirata	12
2. Tropidoleptus carinatus	8
3. Spirifer pennatus var. posterus	8
4. Actinopteria boydi	8
5. Spirifer mesistrialis	7
6. Palæoneilo emarginata	7
7. Leiorhynchus mesicostale	6
8. Modiomorpha subalata var. chemungensis	6
9. Leda diversa	6
10. Chonetes setigerus	5
11. Rhynchonella stephani	4

Study of these lists shows that this fauna of the Portage zone in the eastern counties is still strong in recurrent species of the typical Hamilton formation of that region, viz, the *Tropidoleptus* fauna, so that the former might be called the *Posterus* subfauna of the *Tropidoleptus* fauna; still it has characteristics of its own, clearly indicating its later age and its equivalency with the more distinct lower Portage fauna of Ithaca.

These characteristics may be formulated in the following way:

(1) The majority of the species (34 out of a total 41 listed) are recurrent species.

(2) Its dominant list of 11 species includes but one of the dominant list of the Hamilton formation.

(3) In the dominant list occur five characteristic species not found in the formations below, and two of the five are recognized mutants of earlier species.

FAUNA OF ITHACA FORMATION AS EXPRESSED IN THE TYPICAL LOCALITY AT ITHACA, N. Y.

In the bulletin referred to[a] the faunas directly following the Genesee shale in the Ithaca region were fully analyzed into distinct subfaunas, and in later papers the extension of these subfaunas to their prevalent common faunas to the east and west was traced. The recurrence of Hamilton species was also there distinctly recognized in a small faunule occurring in the lower part of the Cascadilla Creek gorge (station No. 14 N.). The University quarry (station 5) and the "inclined plane" section on South Hill and outcrops in Fall Creek and Cascadilla Creek were examined, and the lists of species were reported at that time as containing the typical "Ithaca fauna." After the publication (1884) of the bulletin many additional species were collected by my students and myself, which were added to the collections in Cornell University. Some twelve years later Dr. E. M. Kindle (then a student in Cornell University) made an exhaustive study of the Ithaca fauna, and to illustrate this particular fauna put together in a valuable memoir all the statistics then in hand. This was published in 1896,[b] and for the purpose of the present discussion this paper by Dr. Kindle contains by far the best set of statistics in sight.

Ten sections within a few miles of the head of Cayuga Lake, situated in the town of Ithaca and in the immediate neighborhood, furnish the statistics. The number of stations is 54. These range through a thickness of 260 feet stratigraphically. I have tabulated the species for the purpose of determining their relative values in relation to frequency of discovery in the 54 stations examined.

In all the collections gathered, 84 species were positively identified, specifically, by Dr. Kindle. Of the species so recognized, 33 are reported also from the Hamilton of the eastern counties (Prosser), and 31 from the underlying Hamilton of the Cayuga Lake section (Cleland).

The stations are not uniformly distributed through the sections, and some of the sections contain over ten stations, while others contain but two or three. They are the chief fossiliferous outcrops of the region, presented by ravines, quarries, and occasional outcrops on the steep hillsides about Ithaca. They do not, however, present as com-

[a] Bull. U. S. Geol. Survey No. 3.

[b] The relation of the fauna of the Ithaca group to the fauna of the Portage and Chemung, by Edward M. Kindle: Bull. Am. Pal., No. 6, Dec. 25, 1896. Ithaca.

plete and thorough an analysis of the faunal contents of the Ithaca formation as we have of the Hamilton formation in Mr. Grabau's analysis of Eighteenmile Creek, or in Dr. Cleland's analysis of the Cayuga Lake section. In both of the latter cases the rocks are exposed in continuous sections from bottom to top, and each zone is open for inspection over considerable horizontal space. Nevertheless, Dr. Kindle's analysis of the faunal contents of the Ithaca formation is more complete than anything else published, and it presents statistics from which a fair idea of the bionic values of the species composing the faunas may be estimated.

The dominant species of the fauna are the following, the figures indicating the frequency of occurrence of the species in the 54 faunules analyzed:

TABLE XIII.—*Productella speciosa fauna: Dominant species of the Ithaca formation at Ithaca, N. Y.*

1.	Spirifer pennatus var. posterus	35
2.	Productella speciosa	25
3.	Modiomorpha subalata var. chemungensis	25
4.	Chonetes scitulus	24
5.	Cyrtina hamiltonensis	23
6.	Palæoneilo filosa	21
7.	Camarotœchia eximia and stephani	21
8.	Atrypa reticularis	20
9.	Stropheodonta mucronata	19
10.	Actinopteria boydi	19
11.	Pleurotomaria capillaria	19
12.	Stictopora meeki	17
13.	Palæoneilo constricta	17
14.	Cypricardella bellistriata	15
15.	Spirifer mesistrialis	14
16.	Leiorhynchus mesicostale	14
17.	Grammysia subarcuata	14
18.	Orthoceras bebryx var. cayuga	14
19.	Ambocœlia umbonata	13

This may be considered as a standard list of the fauna of the Ithaca formation. Three points must be noted, however: (1) Several *characteristic* species of the Ithaca formation are not in this list, because they do not occur as frequently as all these other species; (2) a large proportion of this standard list is made up of common Hamilton species (i. e., species of the standard *Tropidoleptus carinatus* fauna); (3) the species which are peculiar and dominant are closely related to species of the *Tropidoleptus carinatus* fauna. It will be noticed, however, that not a single one of the *dominant species* of the *Tropidoleptus carinatus* fauna appears until we reach the thirteenth species in this list; and among these 19 dominant species of the typical Ithaca formation only two species of the dominant *Tropidoleptus* fauna are present, i. e., *Palæoneilo constricta* and *Ambocœlia umbonata*.

Before further discussing this list it may be well to present the list of dominant species of the eastern region where the underlying Hamilton formation contains the standard *Tropidoleptus carinatus* fauna, above which the sedimentation was continuous. It may be inferred that the latter fauna was not driven out from this eastern region, but lived on continuously, suffering only genetic evolution, uncomplicated by the effects of shifting its habitation. The distributional values of the species will be furnished by the statistics of the eastern faunules.

Analysis of the statistics gathered by Professor Prosser in the eastern counties of New York[a] shows a larger number of species in the formation than is reported by Kindle. This increase is probably due to the wider area examined, presenting, undoubtedly, local differences in original environmental conditions. The localities from which the faunas of the Ithaca formation are reported by Prosser are 67 in number, and are distributed from Smyrna, Chenango County, through Chenango, Otsego, Delaware, and Schoharie counties.

The faunules contain 100 species. Of these, 78, or over three-quarters, occur also in the standard *Tropidoleptus* fauna. All the 12 species of the dominant list of the *Tropidoleptus* fauna occur also in the faunules of the Ithaca formation. These 12 species, arranged in the order of their distributional dominance in the Ithaca formation, are shown in Table XIV, the first column representing collections from 67 localities, the second, collections from 14 localities.

TABLE XIV.—*Productella speciosa fauna: Twelve dominant species of the Tropidoleptus fauna found also in the Ithaca formation of the eastern counties of New York.*

[The starred species occur also in the Portage formation.]

1. Spirifer pennatus	31	13
*2. Tropidoleptus carinatus	31	13
3. Nucula bellistriata	7	4
*4. Palæoneilo constricta	7	4
*5. Nuculites oblongatus	6	5
*6. Phacops rana	6	5
*7. Nucula corbuliformis	6	4
8. Ambocœlia umbonata	2	3
9. Athyris spiriferoides	2	2
10. Nuculites triqueter	2	2
*11. Spirifer granulosus	2	2
12. Chonetes coronatus	2	1

[a] Classification and distribution of the Hamilton and Chemung series of central and eastern New York, Part 1, by C. S. Prosser: Fifteenth Ann. Rept. State Geologist New York, 1895, pp. 87-225.

Idem, Part 2: Seventeenth Ann. Rept. State Geologist New York, 1900, pp. 67-327.

The first 2 species of Table XIV are still dominant in the faunule aggregate, but the other 10 species of the list have lost their preeminence and are replaced by other species.

This fact will be better appreciated by examination of the list of species having highest distributional and abundance values in the Ithaca faunules. Table XV, representing collections from 67 localities, shows the dominant species of the eastern extension of the Ithaca formation. Comparison of Tables XIV and XV will show how completely the dominant species of the *Tropidoleptus carinatus* fauna (excepting the two chief species) have lost their supremacy in the fauna, the highest frequency value of the last 10 species of Table XIV appearing far below the twelfth in rank of the dominant list:

TABLE XV.—*Productella speciosa fauna: Dominant species of the eastern extension of the Ithaca formation.*

1. Spirifer mesistrialis	36	6	24
2. S. pennatus	31	4	19
3. Tropidoleptus carinatus	31	0	10
4. Camarotœchia eximia	19	6	12
5. Chonetes setigerus	20	0	9
6. Paracyclas lirata	18	0	4
7. Chonetes scitulus	15	0	9
8. Leiorhynchus mesicostale	12	2	7
9. Actinopteria boydi	12	1	7
10. Camarotœchia stephani	9	3	7
11. Palæoneilo emarginata	12	0	0
12. Cypricardella gregaria	9	1	4

In the first column of Table XV is given the number of positively identified occurrences in 67 analyzed faunules. In the second column are the additional times in which the identifications are marked as doubtful. The figures in the third column indicate the number of cases in which the species is marked abundant or common in the faunule analyzed.

In the case of *Spirifer mesistrialis* the species most readily confused with it is *S. granulosus.* That species is recorded twice positively, with 4 questionable identifications.

Spirifer pennatus may be confused with *S. pennatus* var. *posterus*, of which 1 doubtful case is recorded, and with *S. mesicostalis*, of which 2 positive and 4 doubtful identifications occur. In 4 of the faunules in which the latter species is mentioned it is common or abundant.

PRODUCTELLA SPECIOSA FAUNA.

In the 67 faunules examined in this eastern region *Productella speciosa* occurs but once positively, and four times it is reported with doubtful specific identification, and only one other case of a *Productella* is reported. This suggests, in connection with its standing second in dominance in the list for the Ithaca formation at Ithaca, that the immigration of the fauna was from the west, and that it had not so strongly occupied the eastern area as that of central New York at this horizon.

Analysis of this list shows that two of the dominant species of the *Tropidoleptus* fauna are still dominant, but the other species of the list have dropped out. Among the species of the list which occur in the *Tropidoleptus* fauna, but are there rare, are *Actinopteria boydi* and *Paracyclas lirata*. These, though frequent in the faunules occurring east of Fulton, Schoharie County, are rare in the Hamilton formation west of that point. *Cypricardella gregaria*, though occasional, is very rare in the eastern Hamilton faunules. Another species of the genus, *C. bellistriata*, is common in the Hamilton formation.

It is evident, therefore, upon purely paleontological grounds, that this fauna, classified as of the Ithaca formation, is distinct from and later than the *Tropidoleptus* fauna of the Hamilton formation, and this is evident in spite of the fact that it contains all of the 12 dominant species of the latter fauna. The discrimination between the two is based upon a change in the bionic values of the dominant species and upon the introduction of new species or varieties which are either rare or wanting in the typical *Tropidoleptus* fauna.

The correctness of this interpretation is further supported by the presence of species entirely wanting in the underlying Hamilton formation of the region, but present in the Ithaca formation at its typical expression in Tompkins County.

Table XVI is compiled from the statistics reported by Prosser in the papers already referred to:

TABLE XVI.—*Productella speciosa fauna: Twenty-one species characteristic of the Ithaca formation of eastern New York and Pennsylvania not occurring in the Tropidoleptus fauna.*

[The starred species are dominant at Ithaca.]

* 1. Camarotœchia stephani.	12. Grammysia elliptica.
* 2. C. eximia.	13. G. globosa.
3. Cryptonella eudora.	14. G. nodocostata.
* 4. Leiorhynchus mesicostale.	15. Leda brevirostris.
5. Orbiculoidea media.	16. Lunulicardium ornatus.
6. O. neglecta.	*17. Modiomorpha subalata var. chemungensis.
* 7. Productella speciosa.	18. Prothyris lanceolata.
* 8. Spirifer mesistrialis.	19. Pterinopecten suborbicularis.
* 9. S. pennatus var. posterus.	20. Schizodus ellipticus.
10. Actinopteria perstrialis.	21. Coleolus aciculum.
11. A. theta.	

Of these 21 species not in the *Tropidoleptus* fauna 6 appear also in the Portage list.

All the 12 most dominant species of the *Tropidoleptus* fauna are present, as has already been mentioned, and besides more than three-quarters ($\frac{78}{100}$) of the total listed species are of the *Tropidoleptus* fauna. Seven of the 21 species not in the Hamilton below are among the dominant species of the fauna of the typical Ithaca formation at Ithaca. They are starred in Table XVI. Three other species, together with the 7 just mentioned, occur in the typical Ithaca and in the formation identified as Ithaca in the eastern counties. These three species are:

Cryptonella eudora.
Grammysia elliptica.
Actinopteria perstrialis.

IMMIGRANT SPECIES OF ITHACA FORMATION.

Among the species appearing for the first time in the strata of this region, distinct affinities with the Iowan and related faunas are evident. Examples are:

Productella hallana,
Pugnax pugnus, and
Spirifer (Reticularia) lævis.

The common *Productella speciosa* may belong to the same group, though it is possible that this is a case of direct evolution from *Productella spinulicosta* of the Hamilton formation. *Rhynchonella venustula* (=*Hypothyris cuboides*) of the Tully limestone is a still earlier immigrant, as was shown in a paper on the Cuboides zone.[a]

Orthis (*Schizophoria*) *tulliensis* is another closely related to *Orthis impressa* of the Ithaca zone, and believed to be a variety of *Schizophoria striatula* (Schlotheim). The *Goniatites* are associated with the western typical Portage fauna, rather than with the Hamilton fauna, which was restricted farther east at the time of deposition of the Ithaca beds. This may indicate immigration, but the case is not clear from the evidence now before us. The *Cardiolas* of the Portage group at Ithaca and farther west in the Genesee Valley are immigrants, and represent the wider fauna of Europe, but, so far as known, the present faunas of Iowa do not contain this genus (i. e., *Glyptocardia*).

The High Point fauna (as given in full by Dr. J. M. Clarke)[b] contains still further traces of the western Iowa Devonian fauna.

The lower appearance of this fauna is indicated about Ithaca in the Ithaca formation, in which no trace of *Spirifer disjunctus* has been discovered; but in the High Point station at Naples that characteristic Chemung species is reported by Dr. Clarke, although I had not seen it when writing up the list reported in 1883.

The faunule of the High Point station exhibits its characteristics, but

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[a] The Cuboides zone and its fauna: a discussion of methods of correlation: Bull. Geol. Soc. Am., Vol. I, 1890, pp. 481-501.

[b] On the higher Devonian faunas of Ontario County, N. Y., by J. M. Clarke (chapter on fauna of Chemung beds at High Point, pp. 72, etc.): Bull. U. S. Geol. Survey No. 16, 1885; see also Am. Jour. Sci., 3d series, Vol. XXV, Feb., 1883.

as traces of the species occur at several points in the strata earlier and farther eastward, it is evident that the eastern migration began as early as the Tully limestone depression, which, for the region in which it is represented by a limestone, terminated the pure *Tropidoleptus* fauna.

The full list of High Point is given in Dr. Clarke's paper (see foregoing footnote), and the following species there listed are also reported from the Iowa Devonian.

TABLE XVII.—*The Pugnax pugnus fauna of High Point, New York.*

Camarotœchia contracta var. saxatilis.	Schizophoria iowensis.
Pugnax pugnus.	Dalmanella infera.
Atrypa reticularis.	Orthothetes chemungensis.
A. hystrix.	Strophonella reversa.
Spirifer orestes.	Stropheodonta calvini.
S. hungerfordi.	S. variabilis.
S. bimesialis.	S. canace.
S. subattenuatus.	S. arcuata.
Productella (dissimilis) hallana.	Fistulipora occidens.

These facts leave no doubt as to an intimate affinity existing between the High Point and associated faunas of New York and the Iowa Devonian fauna, as was claimed when I first called attention to the High Point fauna in 1883.[a]

These species, common to the Iowa and New York faunule, may be regarded as characteristic species of this *Pugnax pugnus* fauna. The fauna is mingled with the *Tropidoleptus carinatus* fauna to form the aggregate of the Ithaca formation. But at Ithaca it is not so strongly represented as at the High Point locality at the south end of Canandaigua Lake, in Ontario County.

The study of the relations of the *Cuboides* fauna to a world-wide distribution led to the conception that affinities expressed by faunas may be due to migration rather than to direct evolution of the prevalent fauna living in the region. This idea was set forth in the paper on the *Cuboides* fauna.[b]

The observation that the Devonian faunas of Iowa are more closely akin to those of the Mackenzie River Valley and of Europe, and the fact that the faunas reported from South America are more closely akin to the faunas of the New York Hamilton than to the European Devonian faunas, furnished the third clue to the interpretation of faunal history, viz, long periods of uniformity in the general geographical condition of the earth's surface have determined the local characteristics of the marine faunas, and a change in the fauna of a local province may indicate important geological changes involv-

[a] On a remarkable fauna at the base of the Chemung group in New York: Am. Jour. Sci., 3d series, Vol. XXV, 1883, p. 97.

[b] The Cuboides zone and its fauna; a discussion of methods of correlation: Bull. Geol. Soc. Am., Vol. I, 1890, pp. 481-500.

ing the geography of wide areas of surface. This was indicated in the paper written in 1892.[a]

The list made by Dr. Kindle from the typical Ithaca formation contains 84 species, specifically identified. Of these, 47 are not recorded for the eastern Hamilton stations reported by Prosser, and 2 only of these 47 species are in the Cleland list of Cayuga Lake Hamilton, or in the Eighteenmile Creek Hamilton faunal list given by Grabau. Thus there are 45 species, or more than half of the species listed, which are specifically distinct from the species of the *Tropidoleptus* fauna.

The other half of the Ithaca faunal list is composed of species belonging to the *Tropidoleptus carinatus* fauna of the Hamilton formation of the general region. About half of the peculiar species is represented by closely related species in the *Tropidoleptus* fauna, and therefore it may be assumed that three-quarters of the fauna of the Ithaca formation is derived by evolution directly from the *Tropidoleptus* fauna. The other quarter may be derived by migration from a more distant source.

In both cases of origin, however, it will be noted that varietal modifications have taken place. Enough mutation occurred to furnish a list of over 40 species to characterize the Ithaca formation, as it occurs in the column of central New York.

Of the species peculiar to the fauna of the Ithaca formation, only 13 are reported in the eastern counties at any horizon, from the Hamilton proper up to the departure of the marine species with the sediments of the red Catskill shales and sandstones.

It will be noted also, by examination of the lists already given that 5 out of the 10 most dominant species of the Ithaca list are Hamilton species—i. e., they belong to the *Tropidoleptus* fauna, and 10 of the most abundant 18 species are Hamilton, all of which are recorded from 13 to 24 times among the 54 lots analyzed.

It is evident from this last observation that the old fauna which had spread over the Ithaca region during the sedimentation of the Ithaca formation has a preponderance of species belonging to the *Tropidoleptus* fauna, both in the number of species and in dominance of the species in the fauna. If it were far enough removed from the Hamilton formation to make correlation by stratigraphical evidence impossible, the faunal characteristics would lead to its association with the Hamilton, as a stratigraphically equivalent formation whose fauna was modified by change of conditions of environment, whereas the facts now before us leave no doubt as to its actual succession above the other formation.

The comparison of the Ithaca fauna with the fauna belonging to the eastern extension of the same formation shows that the *Tropido-*

[a] The scope of paleontology and its value to geologists: Proc. Am. Assoc. Adv. Sci., Vol. XLI, pp. 149-170.

leptus fauna is dominant to a greater degree in the eastern counties than at Ithaca, not only for the particular part of the column in which the Ithaca fauna is abundant, but all the way upward so long as a marine fauna is present in the rocks of the region. On the other hand, very few species characteristic of the Ithaca formation (though enough to mark the horizon), reach into the extreme eastern part of the New York area. Following the strata farther westward it is found that in the Genesee River Valley the fauna so abundant in the Ithaca formation is entirely wanting, and is there replaced by the sparse *Cardiola* fauna of the Portage formation of that region.

MUTATION AND CORRELATION OF THE FAUNAS.

This critical examination of the typical fauna of the Ithaca formation at Ithaca and its representatives at corresponding horizons east of Ithaca demonstrates some important facts regarding the mutation and correlation of fossil faunas.

(1) The *Tropidoleptus* fauna, belonging, typically, to the Hamilton formation, and in western New York known to cease entirely with the Genesee shale or at a corresponding horizon, appears in eastern New York with its dominant species still prominent at a horizon much higher stratigraphically.

(2) Above the Genesee shale, in the meridian of Cayuga Lake, a fauna (the *Productella speciosa* fauna) appears with many of the dominant species of the *Tropidoleptus* fauna, but with other species characteristic of the Ithaca formation.

(3) Eastward from Cayuga Lake, at the stratigraphical place in the sections corresponding to the Ithaca formation, the characteristic species of the *Productella speciosa* fauna become more infrequent, while at the same time the *Tropidoleptus* fauna increases in dominance.

(4) Westward from Ithaca the *Productella speciosa* fauna is traceable a few miles only, and disappears before reaching the Genesee Valley, where it is replaced by the *Cardiola* fauna of the Portage.

This series of facts demonstrates another general law of the history of organisms, as expressed by the range of species, viz:

(5) The stratigraphical horizon of the incursion of new species into a region may be sharply recognized long before the common fauna of the region is dispersed or dies out.

(6) The characteristic species of the *Productella speciosa* fauna of the Ithaca formation as it occurs at Ithaca are present and dominant in these eastern counties of the State, although the *Tropidoleptus* fauna still constitutes 75 per cent of the fauna and is represented by all its most characteristic species.

(7) If the composition of the faunules still higher up in the eastern counties be examined, it will be found that this same *Tropidoleptus*

fauna dominates in the rocks above the Oneonta sandstone and on upward until it is finally extinguished by the deposit of red Catskill sediments.

(8) Nevertheless, on tracing the strata westward, the *Productella speciosa* fauna is still dominant as the Cayuga Lake meridian is reached, with very little trace, in the higher zones, of the *Tropidoleptus* fauna; but that the latter fauna is still living late in the sequence is shown by a recurrent faunule in the midst of the *disjunctus* fauna of Owego, with its *Phacops rana*, *Tropidoleptus carinatus*, and *Cypricardella bellistriata*.

(9) Following the strata westward to the Genesee River section, it is found that the *Cardiola* fauna of the Portage formation has entirely replaced the *Productella speciosa* fauna of Ithaca and its eastern equivalents.

If now we were to interpret this into the dual nomenclature, we would say that the Portage formation of the Genesee Valley, with its *Cardiola* fauna, is equivalent, in the Ithaca region, to the Portage formation with its *Spirifer lævis* fauna together with the Ithaca formation with its *Productella speciosa* fauna, and that these latter two are equivalent, stratigraphically, to the so-called Ithaca and Oneonta formations of Chenango and Otsego counties, and to the upper part of what has been called the "Hamilton formation" in the extreme eastern counties of New York, holding the *Spirifer mesistrialis* fauna of that region which there extends upward to the base of the Catskill formation.

CHEMUNG FORMATION AND ITS FAUNA.

The case of the Ithaca formation and its fauna, composed of a majority of species of the *Tropidoleptus carinatus* fauna and but a few relatively characteristic species, leads to the inquiry: What is the Chemung fauna, and is it to be recognized in the eastern half of New York State prior to the sedimentation of the Catskill formation? These questions are not to be answered by examination only of those species of the fauna which are exhibited in the sections within the eastern region. We must first ascertain the content of the fauna where it is typically and fully represented in the western part of the State.

In the western half of New York and across the State line in Pennsylvania the Chemung formation is sharply differentiated, stratigraphically, from the Hamilton formation. Between the two are found several hundred feet of sediments containing no trace of either the preceding or the following faunas. These sediments are divisible into two easily distinguished parts—the black Genesee shale and the Portage group. The lower part of the latter is typically a greenish argillaceous shale; its upper part is a flaggy sandstone with some massive sandstone beds at the top.

The beds following the Portage sandstone contain a characteristic set of marine fossils which may be taken as the type of the *Spirifer* *disjunctus* fauna, and the formation through which this fauna prevails is the Chemung formation.

SPIRIFER DISJUNCTUS FAUNA.

The fauna of this typical Chemung formation, as it appears in the southern tier of counties in the western half of New York State, may be appropriately called the *Spirifer disjunctus* fauna from the brachiopod species of that name which is abundantly represented in the rocks of the formation and is widely distributed elsewhere.

In 1884, in Bulletin No. 3, the fauna was critically separated from the fauna occuring below it, south of Ithaca, and the name *disjunctus* fauna was applied to it. The original list of species of the faunules examined in the counties directly south of Cayuga Lake (as then identified) included 46 species.

In a preliminary "Catalogue of the fossils of the Chemung period of North America,"[a] published two years before, in November, 1882, a list was given containing 94 genera with 268 species and varieties. Since then the New York State paleontologist has published revisions of the Lamellibranchiata, the Brachiopoda, and the Crustacea of the Devonian formations of the State, and it is quite probable that now the number of genera may have increased to 150 and the species to 400, or perhaps 500; but the literature in which the species are described gives very little evidence upon which to base a definite estimate of the bionic values of these species—either the bionic value as expressed in terms of frequency of individuals in the local composition of the faunas, or that expressed in terms of frequency of appearance in geographical distribution.[b]

The first attempt to form a list of the dominant species of the *disjunctus* fauna, purely on the basis of what I have, in the present paper, denominated bionic values of the species, was made in 1884, in a paper on the Ithaca faunas.[c]

The following list was prepared on that basis, as roughly estimated in the field, without, however, recording the exact statistics of abundance and frequency, statistics which have been insisted on in later investigations.

TABLE XVIII.—*Spirifer disjunctus fauna: Dominant species of the Chemung formation south of Ithaca, N. Y. (roughly estimated in the field).*

1. Schizophoria tioga.	7. Spirifer mesistrialis.
2. S. carinata.	8. Ambocœlia gregaria.
3. Stropheodonta mucronata.	9. Spirifer (Delthyris) mesicostalis.
4. Productella lachrymosa.	10. Orthothetes chemungensis.
5. Spirifer disjunctus.	11. Pterinea chemungensis.
6. Atrypa spinosa hystrix.	12. Camarotœchia contracta.

The twelfth species is not mentioned in my list from station 72, near Park station of the Utica, Ithaca and Elmira Railroad (p. 22),

[a] University Press, Cornell University, Ithaca, N. Y.
[b] See the discussion of bionic values of fossils, p. 124.
[c] Bull. U. S. Geol. Survey No. 3, 1884, pp. 22-23.

but it is reported in the typical Chemung fauna on the following page, as found at Chemung Narrows, and is conspicuous in the more characteristic Chemung faunules of the western part of the State.

Another basis for estimating the dominant characteristics of the fauna of the Chemung formation is found in the statistics published in Bulletin 41, U. S. Geological Survey.[a]

In this bulletin lists of the species were tabulated primarily to indicate the composition of the local and temporary faunules. Thirty-seven such Chemung faunules are analyzed. The value of clearly distinguishing the geographical from the geological modification of the faunules was not fully appreciated when the bulletin was written. As the investigations have progressed, however, it has become clear that modification of a general fauna, coincident with a few miles of separation in space, geographically, may be as great as, or even greater than, the modification coincident with passage upward stratigraphically through tens or even hundreds of feet of sediments. These two kinds of bionic value (geographical and geological) are not so sharply distinguished in Bulletin 41 as they might be, but the statistics there given will serve for estimating the general bionic values of the constituent species of the fauna. These values are not generally evident in the descriptive reports of the individual species concerned, and particular attention to collecting the evidence must be given, both in the field and when the collections of fossils are analysed in the laboratory, in order to exhibit the bionic values of the species of the fauna.

Difficulties in the way of preparing an exact list of the dominant species of the *Spirifer disjunctus* fauna arise from still another source. Many of the species of this fauna are in a variable condition, and the separate faunules present strong contrasts in the particular aggregation of species making up the faunules, which call for still fuller investigation. This plasticity of the fauna is what might be expected on the theory of its origin in the New York province by immigration. The various elements of the fauna were occupying new territory (or *aquitory*, we might more properly say), and were struggling into a new adjustment of equilibrium among themselves and in their new environment. The more vigorous the species were the more plastic we may suppose them to have been. However the facts may be theoretically explained, it is noticeable that many of the species of both the Ithaca and Chemung formations are in a remarkably variable condition.

The spirifers, the productellas, the orthids, the rhynchonellas, the pterineas, and aviculoids in general, which constitute the larger part of any good sample of the *Spirifer disjunctus* fauna, are so variable that two authors will almost certainly disagree in naming the species of any particular lot of fossils, and even the ablest paleontologist will differ in his own distribution of the specimens among the

[a] On the fossil faunas of the Upper Devonian—the Genesee section, New York.

species at different times, according to the order in which he happens to take them up for study. In Schuchert's list[a] there are 15 species of *Productella* recognized as belonging to the Chemung fauna. Spirifers of the three types—*disjunctus*, *mesicostalis*, and *mesistrialis*—are present and each type is widely variable. The rhynchonellas of the *contracta*, *sappho*, and *eximia* types are all very variable, the last appearing more conspicuously below and the others higher; but between the several species named frequent intermediate forms are found which it is difficult to determine specifically. *Chonetes scitulus* and *Chonetes setigera* are extremely difficult to discriminate. A footnote to Plate VI, *A*, of Hall and Clarke's revision of the Brachiopoda, contains the following statement about the orthids:

> The species of *Orthis=Schizophoria*, described as *O. propinqua*, *O. tulliensis*, *O. impressa*, *O. iowensis*, and *O. macfarlanii*, present so many features in common that further study and comparison should be given them to determine the actual value of the characters on which the specific distinction has been based, and whether these differences coincide with their geological relations.

These remarks will suggest an explanation for some of the differences observed in the lists of Chemung fossils reported by different authors. Nevertheless, it seems reasonable to rely on the value of frequency of appearance in recorded lists (made by the same author) of the species of separate faunules as evidence of a corresponding frequency of the species in the actual faunules.

In the following table the statistics reported for the Genesee Valley faunules are given. In this case the failure to mention the less common species in every faunule list arose from the fact that the chief purpose of the report as made was to distinguish the successive zones into which the fauna was divisible. The lists are sufficient, however, to indicate the dominant species.

TABLE XIX.—*Spirifer disjunctus fauna: Dominant species of the fauna as it occurs in the Genesee Valley section.*

Species.	Thirty-seven localities.	Species.	Thirty-seven localities.
1. Spirifer disjunctus	24	7. Productella lachrymosa and vars	21
2. Camarotœchia contracta and var	16	8. Ambocœlia umbonata	7
3. Athyris angelica	12	9. Sphenotus contractus	7
4. Orthothetes chemungensis	10	10. Chonetes scitulus	7
5. Delthyris mesicostalis	9	11. Mytilarca chemungensis	6
6. Schizophoria striatula impressa	7	12. Grammysia communis	4

A list of the species of the Chemung formation of Chautauqua County (prepared by G. D. Harris in 1887), indicating the dominant

[a] A synopsis of American fossil Brachiopoda, including bibliography and synonymy: Bull. U. S. Geol. Survey No. 87, 1897, pp. 1-464.

species in each faunule, shows the following species to be dominant in approximately the order in which they are listed below:

TABLE XX.—*Spirifer disjunctus fauna: Dominant species of the Chautauqua County faunules.*

1. Camarotœchia contracta.	7. Productella hystricula.
2. Spirifer disjunctus.	8. Athyris angelica.
3. Ambocœlia gregaria.	9. A. polita.
4. Camarotœchia duplicata.	10. Productella lachrymosa.
5. Dalmanella leonensis.	11. Palæoneilo constricta.
6. Chonetes scitulus.	12. Orthothetes chemungensis.

Examination of these lists in respect to the less common but characteristic species brings out some peculiarities in geographical distribution which should be here indicated. Orthids of the *Schizophoria* type, like *impressa* and *tioga*, are more conspicuous in the eastern than in the western faunules of the State, and in range they are conspicuous in the lower rather than in the higher portions of the sections. *Spirifer mesistrialis* is less conspicuous in the western than in the middle and eastern part of the State, where it appears as low as the Ithaca formation. *Delthyris mesicostalis* of the characteristic form is conspicuous in the Genesee Valley faunules of the Chemung, but is infrequent in the Chautauqua County sections. *Camarotœchia contracta* and *C. duplicata* and *Athyris angelica* and *A. polita* are of frequent occurrence in the purer Chemung faunas of the western part of the State and become less conspicuous in the eastern faunules.

When the attempt is made to construct a standard list of dominant species of the *Spirifer disjunctus* fauna, after the first half dozen common species, there is a much larger number of species which are dominant in some part of the region, or in some part of the formation, though not characteristic of all the formation or of the whole area of western New York alone.

From the statistics now in hand we may form the following standard list of dominant species of the fauna, which may be divided into three parts: (1) The first six species are dominant throughout western New York localities, and, stratigraphically, throughout the successive zones of the formation; (2) the species numbered 7 to 11 are more dominant in the eastern localities in middle New York; while (3) the remaining species numbered 12–20 are more common in the western counties of the State.

TABLE XXI.—*Spirifer disjunctus fauna: Standard list of dominant species of the Spirifer disjunctus fauna for the New York province.*

1. Spirifer disjunctus.	11. Atrypa spinosa hystrix.
2. Camarotœchia contracta.	12. Orthis (Schizophoria) impressa.
3. Ambocœlia umbonata.	13. Athyris angelica and polita.
4. Orthothetes chemungensis.	14. Sphenotus contractus.
5. Productella lachrymosa and vars.	15. Mytilarca chemungensis.
6. Delthyris mesicostalis.	16. Grammysia communis.
7. Spirifer mesistrialis.	17. Chonetes scitulus.
8. Orthis (Schizophoria) tioga.	18. Camarotœchia duplicata.
9. O. (S.) carinata.	19. Dalmanella leonensis.
10. Pterinea chemungensis.	20. Palæoneilo constricta.

Another method of determining the constitution of the *Spirifer disjunctus* fauna from statistics already gathered is that of analyzing a set of faunal lists, all of which contain *Spirifer disjunctus*. In this way the strict associates of that species will be given.

As a convenient set of statistics (for this purpose) the fauna as reported in Bulletin 41, for the Genesee section in western New York may be taken.

Of these faunules there are 16 containing *Spirifer disjunctus*. In the following table are listed the more frequent associates of that species. The number in the right-hand column indicates the number of times each species is reported in the 16 faunules.

TABLE XXII.—*The Spirifer disjunctus fauna, with its more dominant associates, as represented in the Genesee section.*

1. Spirifer disjunctus	16	7. Mytilarca chemungensis	6
2. Camarotœchia contracta	13	8. Sphenotus contractus	5
3. Orthothetes chemungensis	8	9. Orthis (Dalmanella) leonensis	4
4. Athyris angelica	8	10. Orthis (Schizophoria) impressa	4
5. Chonetes scitulus	7	11. Ambocœlia umbonata	4
6. Productella hirsuta	7	12. Productella costatula	4

The first 7 species of this list are among the standard forms determined by the first method and listed in Table XXI, and all of them except the eighth are actually in that group of 20 species, but several species obtained by the other method are not mentioned in this list simply because, though common species, they did not appear conspicuously in faunules actually containing *Spirifer disjunctus*, though present in the same general fauna to which that species belongs.

In the original volume describing the brachiopods of the Devonian of New York[a] the following localities are mentioned in which *Spirifer disjunctus* occurs, viz: Elmira, Leon, Painted Post, Factoryville, Cayuta Creek, Chemung Narrows, Conewango, Great Valley, Randolph, Napoli, New Albion, Chemung, Bath, Angelica, Troupsburg, Meadville, Pa., Twentymile Creek, Ellington, Olean, Covington, Pa.

From these localities the following species are recorded for the number of localities indicated:

TABLE XXIIa.—*Species listed from same localities with Spirifer disjunctus in New York reports.*

Camarotœchia contracta	10
Orthothetes chemungensis	3
Athyris angelica	3
Productella hirsuta and var	17
Sphenotus contractus	2

There are other species mentioned in the published lists, but from each locality the number of species is limited, rarely over 20 and generally under 10. The collections show in themselves that the conspicuous species were gathered, or perhaps the fine specimens only

[a] Palæontology New York, Vol. IV, 1867.

were selected and recorded, the imperfect ones being left and not mentioned in the catalogues. Nevertheless, the statistics give a slight indication of the prominent associates of *Spirifer disjunctus*. Among the prominent members of the dominant list of the species of the fauna it is safe to say that the following species frequently appear, viz:

TABLE XXIIb.—*Conspicuous species of the Spirifer disjunctus fauna.*

Spirifer disjunctus.
Camarotœchia contracta.
Productella—some one of the forms of the lachrymosa or hirsuta forms and markings.
Orthothetes chemungensis.
Athyris angelica.

Among the spirifers the typical *Spirifer* (*Delthyris*) *mesicostalis* with coarse plications and distinct septum does not appear in the Ithaca zone, but is common in the Upper Chemung zone. *Spirifer mesistrialis* is common in the lower Ithaca zone; and in the zone dominated by the *Spirifer disjunctus* fauna it is represented by *Spirifer* (*Cyrtia*) *alta* or *Spirifer marcyi* var., but is rarely associated with a pure *Spirifer disjunctus* faunule.

The common Ithaca spirifer is *S. pennatus* var. *posterus*. It is often called "*mesicostalis*," but generally has finer plications and is always without distinct septum in the Ithaca zone, thus separating it from *Delthyris mesicostalis* of the typical *Spirifer disjunctus* fauna.

The rhynchonellas (*Camarotœchia*) show a definite succession of species. The Ithaca zone carries *C. eximia* and *stephani*, and occasionally forms identified as *C. contracta;* but typical *C. contracta*, with the small number of plications, is confined to the higher horizon, and runs into the forms called *C. orbicularis* and *C. sappho* or *C. alleghenia* in the typical higher Chemung. *R.* (*Pugnax*) *pugnus* is not found associated with the *Spirifer disjunctus* fauna, but is a species of the lower Ithaca zone.

Among the productellas the forms called *P. lachrymosa* and its varieties do not appear in the faunules till the *disjunctus* stage is reached. They are distinguished by their coarse, large, evenly rounded gibbous form. Although these are associated with the finely hirsute forms and others marked on the surface like *P. speciosa*, the form which is generally identified as *P. speciosa* is an earlier form.

The Ithaca form is characteristically *Productella speciosa*, though showing some variation; the small rounded spine bases not drawn out so as to be oblong, and the low and pinched or narrow beak, with more or less rounded cardinal angles, are conspicuous distinguishing features.

Although the original specimens named *P. speciosa* appear to have come from the western part of the State and a locality holding a typical Chemung fauna, the Ithaca form is characteristic and much more common and has in the later literatures become the type of that species.

These remarks will serve to express the present knowledge regarding the actual distinguishing features of the fauna of the typical Chemung formation. The difficulty found in making the definition more accurate comes from the great uncertainty as to the precision with which the limits of the fauna have been discriminated.

In many reported Chemung lists of species uncertainty is presented, both as to the identification of *Spirifer disjunctus* and as to the exact stratigraphical horizon from which the species came.

The present paper can therefore go no further in precision of definition of this fauna; and attention is here directed to the great need of more accurate statistics regarding the individual faunules of the upper extension of the marine Devonian faunas. These statistics can be obtained by local collectors living in regions of outcrops of Chemung rocks, who will render a service to science by furnishing accurate lists of the species, with statistics as to the exact locality and zone and the relative abundance of the species in each faunule.

RECURRENCE OF THE TROPIDOLEPTUS FAUNA IN THE EPOCH OF THE SPIRIFER DISJUNCTUS FAUNA.

Report of a recurrent Hamilton fauna in the midst of the rocks of the Ithaca formation was made in Bulletin No. 3 of the U. S. Geological Survey, p. 15.

Mention was made also of *Tropidoleptus* and other Hamilton species occurring in Owego at a horizon high up in the Chemung. The full importance of these cases was not appreciated at the time of their first announcement. Recently the facts have been stated in detail and may be restated here:

> We have positive evidence of a colony of the *Tropidoleptus* fauna within at least 50 feet of the typical horizon of the Chemung formation in Chemung County, and also in the midst of the Chemung, or *Spirifer disjunctus*, fauna at Owego, as I announced in 1884.[a]
>
> These evidences of the *Tropidoleptus* fauna are so clear that if we were to find them in an isolated region, we should have no hesitation in calling the formation holding them Hamilton, except that a few species of much later age are associated with them.

The typical species of the *Tropidoleptus* fauna are such as—

Tropidoleptus carinatus (abundant).
Ambocœlia umbonata (abundant).
Phacops rana (rare, but with several specimens).

[a] Bull. U. S. Geol. Survey No. 3, 1884, p. 24; also Proc. Am. Assoc. Adv. Sci., Vol. XXXIV, 1886, p. 226. This is the stage A^{6}+ of the *Tropidoleptus* fauna, called in that paper Middle Devonian fauna A; also p. 230.

It also contains such characteristic species as—

Spirifer marcyi, and probably S. granulosus.
Cypricardella bellistriata.
Goniophora hamiltonensis.
Macrodon hamiltoniæ.
Loxonema delphicola.
Modiomorpha mytiloides.

The faunule from Owego, to which I made reference in my papers of 1884 and 1886, was so characteristically Hamiltonian in its species that at that time it was difficult to believe that the zone in which it occurred was not out of place. But the recent rediscovery of the zone at Waverly by Dr. Kindle, and a comparison of the forms, leaves no doubt as to the actual position of the recurrent Hamilton faunule in the midst of the Chemung formation. The species of this faunule are given in the following list:

TABLE XXIII.—*Recurrent Tropidoleptus fauna from Cemetery Hill, Owego, Tioga County, on side hill above and southeast of the old Erie station, collected by H. S. Williams (U. S. Geological Survey station 1130 A).*

1.	Spirifer marcyi var.	*aa* [a]	Hamilton.
2.	Ambocœlia umbonata	*aa*	Marcellus-Chemung.
3.	Cypricardella bellistriata	*aa*	Hamilton.
4.	Tropidoleptus carinatus	*c*	Hamilton.
5.	Leiopteria bigsbyi	*c*	Hamilton.
6.	Phacops rana	*r*	Hamilton.
7.	Productella speciosa	*r*	Portage-Chemung-Kinderhook.
8.	Coleolus acicula	*r*	Genesee.
9.	Loxonema delphicola	*r*	Hamilton.
10.	Camarotœchia cf. prolifica	*r*	Marcellus-Hamilton.
11.	Goniophora hamiltonensis	*r*	Hamilton.
12.	Modiomorpha mytiloides	*r*	Hamilton.
13.	Spirifer cf. granulosus	*rr*	Hamilton.
14.	Chonetes setigerus	*rr*	Marcellus-Waverly.
15.	C. lepidus	*rr*	Marcellus-Chemung.
16.	Macrodon hamiltoniæ	*rr*	Hamilton.
17.	Lingula sp.	*rr*	
18.	Pterinea sp.	*rr*	
19.	Grammysia sp.	*rr*	
20.	Palæoneilo sp.	*rr*	
21.	Aviculopecten sp.	*rr*	

It will be observed that of the 16 species specifically identified, all but 2 are Hamilton species. One of the exceptions is *Productella speciosa*, which has been reported from Portage, Chemung, and Kinderhook formations, and the other, *Coleolus acicula*, is a Genesee species. Eleven of the 16 have not been hitherto reported from above the Hamilton formation, while the other 4 range both below and above that formation.

On the principle of specific identification, therefore, this faunule belongs to the genuine *Tropidoleptus carinatus* fauna, of which it contains four of the dominant species of the standard list.

[a] *a*, abundant; *aa*, very abundant; *c*, common; *r*, rare; *rr*, very rare.

The species of the Waverly fauna collected and identified by Dr. Kindle are as follows:

TABLE XXIV.—*Tropidoleptus faunule as a colony in Chemung formation, Waverly, N. Y. (1462 B, U. S. Geological Survey), identified by E. M. Kindle (1902).*

1.	Tropidoleptus carinatus	*a* [a]	Hamilton.
2.	Ambocœlia umbonata	*a*	Marcellus-Chemumg.
3.	Rhipidomella vanuxemi	*c*	Corniferous [Onondaga]-Hamilton.
4.	Spirifer marcyi	*c*	Hamilton.
5.	Cypricardella bellistriata	*c*	Hamilton.
6.	Productella lachrymosa	*c*	Chemung.
7.	Delthyris mesicostalis	*c*	Ithaca-Chemung.
8.	Camarotœchia contracta	*r*	Portage-Waverly.
9.	Schizophoria cf. tioga	*rr*	Portage-Chemung.
10.	Leptodesma matheri	*rr*	Chemung.
11.	Glyptodesma erectum	*rr*	Hamilton.
12.	Pterinopecten sp.	*rr*	
13.	P. crenicostatus	*rr*	Chemung.
14.	Modiomorpha cf. concentrica	*rr*	Hamilton.
15.	Cyrtina hamiltonensis	*rr*	Up. Held., Ham., Portage, Chemung.

The commonly reported range by formations is given in the column on the right.

In this faunule, it will be observed, the abundant and common forms are, with the exception of *Productella*, chiefly found in the Hamilton formation.

Nevertheless, the faunule occurs in the rocks after the *Spirifer disjunctus* fauna has occupied the region in force with its typical development; thus showing that in time the two faunas were coexistent in separate areas in their normal bionic strength. That is to say, in the areas of their geographic metropolis, each fauna maintained its bionic equilibrium as expressed in frequency and dominance of species.

The importance of this case of recurrence of the *Tropidoleptus* fauna is so great as to call for every precaution as to its verity. The intrinsic evidence of its Chemung horizon was not present in the Owego faunule.[b] There are no species there which might not occur as low as the Ithaca group. But the faunule collected at Waverly contains *Delthyris mesicostalis* with a distinctly strong median septum, which is wanting or very slightly developed in the specimens of the Ithaca formation; also a single specimen of *Schizophoria tioga*, nothing like which is known in the typical fauna of the Ithaca formation. The *Productella lachrymosa* is not so strongly of the true *lachrymosa* type as to make it certain that it may not be an extreme variation of *Productella speciosa*. The leptodesmas are so variable that the form *L. matheri* is not conclusive of post-Ithaca stage.

In my collections from the Waverly-Chemung cliffs, however, *Tropidoleptus* was discovered above the first appearance of *Spirifer disjunctus* and other typical members of the *Spirifer disjunctus* fauna. These facts are intrinsic evidence, therefore, that the combination of species, so much like the typical *Tropidoleptus carinatus* fauna of the Hamilton, is here present in a part of the rock section occupied in general by a typical *Spirifer disjunctus* fauna.

The fact that the combination of species is the normal combination seen in the undisputed Hamilton formation shows that its equilibrium had not been disturbed, and therefore that the life history of the fauna of the Hamilton forma-

[a] *a*, abundant; *c*, common; *r*, rare; *rr*, very rare.

[b] Since the above was written I have examined the Owego locality and another locality west of Waverly, and have proved beyond controversy that this recurrent Hamilton fauna occurs not only well above *Spirifer disjunctus*, but several hundred feet above the base of the rocks along Chemung Narrows, constituting the typical exposure of the Chemung formation of Hall's Report of 1843. (Part IV, Geology New York State, p. 252.).—H. S. W.

tion had not ceased, while the faunas above and below in the cliffs in Chemung Narrows is evidence that the geological horizon is that of the typical Chemung formation. The lapping of faunas of the same kind seems to be established by evidence beyond dispute, and correlations must be made with recognition of such a possibility in cases where the direct evidence of the fact may be wanting.

When we attempt to correlate formations with this knowledge before us it is evident that the life period of a fauna is not what it appears to be in any particular section. Whenever the succession is sharply defined by the stopping of one fauna and the abrupt beginning of another, in full or decided strength, the evidence should be interpreted as positive that the boundary between the two consecutive formations does not make the end of one fauna and the beginning of the succeeding one. It is to be interpreted rather as only a well-advanced stage into the later one and the vigorous period of persistence of the other. This, interpreted into comparative terms, would result in showing that the two faunas lap over each other in time.

My studies convince me that this is frequently the case in respect to the boundary lines of our formations. The abrupt transition from one formation to another with a different fauna is convincing evidence that the abruptness of the change in fossils is due either to absence of strata (i. e., an apparent or concealed unconformity) or else to migration of the faunas across the area.

This principle must be recognized in making correlation, if we would reach correct interpretation of the facts.[a]

MARINE FAUNA ABOVE ONEONTA SANDSTONE OF EASTERN NEW YORK.

Accepting Table XXI as an approximately correct list of the dominant species of the *Spirifer disjunctus* fauna, as it existed in the typical area of its distribution, what relation does the fauna occurring above the Ithaca fauna in the eastern part of the State bear to it?

In opening the discussion of this question it may be noted that among the 20 dominant species listed in Table XXI (the *Spirifer disjunctus* fauna), three are reported by Grabau from the Hamilton formation of Eighteenmile Creek. These are *Ambocœlia umbonata*, *Chonetes scitulus*, and *Palæoneilo constricta*. The same species, and the variety *arctistriatus* of *Orthothetes chemungensis* are reported from the Hamilton faunules of the Cayuga Lake section by Cleland. All four of these species are specifically identified by Prosser in the Hamilton faunules of eastern New York and Pennsylvania.

Removing from the list these recurrent species (viz., *Ambocœlia umbonata*, *Orthothetes chemungensis*, *Chonetes scitulus*, and *Palæoneilo constricta*), as occurring also in the fauna of the Hamilton formation below, the remaining 16 will stand as characteristic species as well as dominant representatives of the typical fauna of the Chemung formation.

In the sections in Chenango and Otsego counties above the Oneonta sandstone occasionally a few species occur which have led to classifying the beds holding them in the Chemung formation.

In the recent revision of the geological mapping of that part of the State the State paleontologist appears to have adopted the Oneonta

[a] Am. Jour. Sci., 4th series, Vol. XIII, 1902, pp. 428-431.

formation as the formational plane of division between the Ithaca and Chemung formations. But an examination of the faunas concerned makes it clear that the classification is more strongly influenced by the lithological than the paleontological evidence.[a]

Regarding this point Prosser[b] says:

After reviewing the results obtained by different investigators of this problem of the separation of the Chemung and Portage and the Chemung and Oneonta formations in the central part of southern New York, the facts seem to justify the conclusion that the Chemung begins with the *Orthis impressa* fauna overlying the Oneonta formation. The thickness of the formation composing the Chenango Valley section, ranging from the base of the Marcellus shale in Sangerfield Township, Oneida County, up into the Chemung, on top of the hill in Fenton and Kirkwood townships, Broome County, to the northeast of Binghamton, is approximately as follows: Estimating the dip for the northern part of the Chenango Valley to be 60 feet to the mile, we would have a thickness of about 1,500 feet for the Marcellus and Hamilton formations. To the east of Smyrna there are perhaps 25 feet, representing the Tully limestone and Genesee slate. The Sherburne formation is 250 feet, the Ithaca 500 feet or more, and the Oneonta 500 feet thick, while for the Chemung, from Greene to the top of the hill south of Port Crane, calling the dip 60 feet per mile, there are 1,225 feet, which result agrees quite well with the record of the well drilled at Binghamton.

Generalized section giving thickness of the Chenango Valley formations.

	Feet.		Feet.
Chemung	1,225	Sherburne	250
Oneonta	550	Genesee and Tully	25
Ithaca	500+	Hamilton and Marcellus	1,500 (?)

This solution is a practical one for the particular region. For the purpose of mapping the middle eastern part of New York the Oneonta sandstones may no doubt be recognized as a formation, and they form a convenient separating line for formations.

When, however, the statement is made that "in the vicinity of Greene * * * the Oneonta beds are overlaid by a typical and highly developed Chemung fauna,"[c] the necessity for using some other term for the name of a fauna than the geographical name of a formation becomes apparent, for the fauna in Greene County referred to does not represent the *Spirifer disjunctus* fauna, which is characteristic of the Chemung formation in its typical geographical area. Statistics regarding the composition of the fauna following the Oneonta formation in eastern New York are given by Prosser in two papers,[d] an examination of which will illustrate this fact.

[a] See Report of field work in Chenango County, by J. M. Clarke: Thirteenth Ann. Rept. New York State Geologist, 1893. Vol. I.

[b] The classification and distribution of the Hamilton and Chemung series of central and eastern New York, Part I, by C. S. Prosser: Fifteenth Ann. Rept. New York State Geologist, pp. 165-166.

[c] Clarke, loc. cit., p. 557.

[d] Classification and distribution of the Hamilton and Chemung series of central and eastern New York, Part II, by Charles S. Prosser: Fifteenth Ann. Rept. New York State Geologist, 1895, pp. 87-222. Classification and distribution of the Hamilton and Chemung series of central and eastern New York, Part II, by Charles S. Prosser: Seventeenth Ann. Rept. New York State Geologist, 1899, pp. 67-327.

There are 29 faunules occurring above the horizon of the Oneonta formation, whose specific composition is analyzed. The faunules are from the counties of Chenango, Broome, and Delaware, New York State. The species of the characteristic Chemung fauna reported as present in these 29 faunules of this region are given in Table XXV.

TABLE XXV.—*Spirifer disjunctus fauna: Characteristic representatives of the fauna reported in the eastern counties of New York and Pennsylvania.*

1. Spirifer mesistrialis	6	4. Camarotœchia contracta	1
2. Productella lachrymosa	8	5. Spirifer disjunctus	1
3. Delthyris mesicostalis	[a]9		

As to the occurrence of *Productella lachrymosa*, it was also reported by Clarke from the Juliand Hill locality in Greene Township, Chenango County.[b]

Prosser, referring to the identification of the same species in a faunule from the extreme southwestern corner of the township (his station XXXVI A 1), says:

Probably some of these specimens should be cf. *P. speciosa* of Ithaca, but the pustules are coarser than in this species. So identified by Clarke in Thirteenth Annual Report, page 543.[c]

Dr. Clarke, referring to the Juliand Hill faunule, says:

Fossils are abundant throughout these shales and are of typical Chemung expression.[d]

In no other faunule of the Chenango localities reported by Dr. Clarke in the paper cited is this species mentioned, and in none of his faunule lists are any species of the characteristic Chemung list reported, not already mentioned in the list above.[e]

The one record of *Camarotœchia contracta* made by Prosser is from the Pixley Mill faunule north of Afton. The only identification of *Spirifer disjunctus* by Prosser is in a faunule (XLII B 5) in the section southwest of Port Crane near the top of the hill. This observation led him to remark:

The occurrence of this characteristic Chemung species conclusively proves that the rocks near the top of the high hill south of Port Crane are in the Chemung formation.[f]

In order to test the equivalency of this fauna it will be necessary to make a more deliberate examination of its content, and to study the bionic values which the several species hold in the general corporate fauna as a whole.

We have the carefully collected statistics of 29 faunules reported by Prosser from this so-called Chemung formation of the eastern counties. The total number of species positively identified is 65,

[a] Three times positively.

[b] The stratigraphic and faunal relations of the Oneonta sandstones and shales, the Ithaca and the Portage groups in central New York, by John M. Clarke: Fifteenth Ann. Rept. State Geologist New York, 1895, pp. 27-81.

[c] Fifteenth Ann. Rept. State Geologist New York, p. 152.

[d] Thirteenth Ann. Rept. State Geologist New York, p. 543.

[e] Table XXV, above.

[f] Fifteenth Ann. Rept. State Geologist New York, p. 160.

there are 23 more named with a query, and 31 entries in which only generic or more general identification was made. Of this total of 65 species 27 species are also listed in the faunules of the Hamilton formation; they are given in Table XXVI.

TABLE XXVI.—*Species of the Tropidoleptus carinatus fauna occurring above the Oneonta sandstone in eastern New York.*

1. Ambocœlia umbonata.	15. Lunulicardium fragile.
2. Atrypa reticularis.	16. Cypricardella bellistriata.
3. Camarotœchia congregata.	17. C. complanata.
4. Chonetes scitulus.	18. C. gregaria.
5. C. setigerus.	19. Nuculites cuneiformis.
6. Coleolus tenuicinctum.	20. N. oblongatus.
7. Cyrtina hamiltonensis.	21. Orthis (Schizophoria) impressa.
8. Grammysia bisulcata.	22. O. undulata.
9. G. circularis.	23. Palæoneilo plana.
10. G. subarcuata.	24. P. constricta.
11. Leda diversa.	25. Spirifer granulosus.
12. Leiopteria bigsbyi.	26. Stropheodonta demissa.
13. Loxonema delphicola.	27. Tropidoleptus carinatus.
14. L. hamiltoniæ.	

Five of these (Nos. 1, 20, 24, 25, 27) are found in the list of the 12 most dominant species of the typical Hamilton formation of eastern New York (p. 51).

Of this list, 23 are also reported from the underlying Ithaca formation. The 5 not listed by Prosser in the Ithaca are—

Grammysia circularis.	Stropheodonta demissa.
Loxonema delphicola.	Orthis (Schizophoria) impressa.
L. hamiltoniæ.	

Both *Stropheodonta demissa* and *Schizophoria impressa* are in the Ithaca formation of Ithaca. Their omission from the Ithaca formation in the eastern counties may be only accidental, but they certainly do not furnish means of discrimination between the Ithaca and Chemung formations.

There are also eight species which are not recorded in the Hamilton, but are recorded in both the Ithaca and Chemung lists of the same region. They are recorded in Table XXVII.

TABLE XXVII.—*Species in "Chemung" list which are also in the Ithaca, but not in the Hamilton formation.*

1. Camarotœchia stephani.	5. Leiorhynchus mesicostale.
2. Cyclonema multilara.	6. Delthyris mesicostalis.
3. Grammysia elliptica.	7. Spirifer mesistrialis.
4. G. nodocostata.	8. S. pennatus posterus.

Palæoneilo filosa might be added to the above table. It occurs in the "Chemung" list and in the Portage, but not in the Ithaca or Hamilton lists.

Two of the species in Table XXVII—*Spirifer mesistrialis* and *Delthyris mesicostalis*—are among the characteristic and dominant species of the standard *Spirifer disjunctus* fauna (see Table XXI). So far as their evidence bears upon the case, their appearance in the

Ithaca formation, which has been demonstrated to lie below the Chemung in the Ithaca section,[a] is opposed to the supposition that the horizon now under investigation is as high as the typical Chemung formation of western New York.

Finally, there are 25 species which have not been recorded in the region below the base of what is there called the Chemung formation. These are tabulated in Table XXVIII.

TABLE XXVIII.—*Species which occur above the Oneonta formation but not in the Ithaca formation of the eastern counties.*

* 1. Bellerophon mæra	2	3	
2. Camarotœchia contracta.			
3. Edmondia philipi.			
4. Ectenodesma birostratum.			
* 5. Goniophora subrecta	2		
6. Grammysia communis.			
7. Holonema rugosa.			
8. Leiopteria rafinesquii.			
* 9. Leiorhynchus globuliforme	9	1	
*10. Leptodesma sociale	4	3	
*11. Lyriopecten priamus	3		
*12. L. tricostatus	4	2	
*13. Modiomorpha quadrula	4		
14. Mytilarca carinata.			
15. Onychodus hopkinsi.			
16. Palæoneilo brevis var. quadrangularis.			
*17. P. brevis	3	3	
18. Pleurotomaria itys.			
*19. Productella lachrymosa	8		
*20. Pugnax pugnus	3		
21. Schizodus gregarius.			
22. S. chemungensis.			
*23. S. chemungensis var. quadrangularis	3		
24. Sphenotus contractus.			
25. Spirifer disjunctus.			

The species starred are mentioned in more than one faunule; those not starred were positively identified but a single time in all the faunules analyzed. On the right of the starred species are numbers indicating, first, the number of positive identifications, then the number of doubtful specific identifications. When the number of doubtful identifications is large, variation is probably great.

Only 3 of these 25 species belong to the standard list of dominant species of the western Chemung (see Table XXI). These are:

Spirifer disjunctus.
Productella lachrymosa.
Camarotœchia contracta.

As has already been said, the first and last of these are reported but once. On the other hand, the fauna contains *Pugnax pugnus*, which is characteristic of the typical Ithaca fauna, but does not belong to the typical Chemung fauna of western New York.

On the other hand, the following table (Table XXIX) shows a prominence of species which in the western New York Devonian are characteristic of an earlier stage in faunal development than that of the *Spirifer disjunctus* fauna.

TABLE XXIX.—*Dominant species above the Oneonta not confined to the horizon of the Chemung formation in western New York.*

Spirifer pennatus posterus.	Delthyris mesicostalis.
S. mesistrialis.	Pugnax pugnus.
Camarotœchia stephani.	Chonetes setigerus.
Cypricardella gregaria.	Camarotœchia eximia.
Tropidoleptus carinatus.	Palæoneilo constricta.

[a] Bull. U. S. Geol. Survey No. 3, 1884, p. 28.

CHAPTER IV.

SHIFTING OF FAUNAS.

EVIDENCE OF SHIFTING OF FAUNAS ASSOCIATED WITH DEPOSITION OF ONEONTA SANDSTONE.

In considering the evidence contained in the tables of statistics already presented, it is important to note the following points: The strata lying above the Oneonta sandstone and below the Catskill, in the eastern counties of New York, contain a fauna in which there are 27 species of the *Tropidoleptus carinatus* fauna, 5 of which are among its most characteristic 12, and 25 of which are reported from genuine Ithaca formation strata. The fauna contains 8 species which are found in the underlying Ithaca formation, but have not been recorded for the Hamilton of this region; 3 of these are in the list of dominant species of the *Productella speciosa* fauna. Finally, there are 25 species not recorded from the formations below in the same region, 4 of which are among the dominant species of the *Spirifer disjunctus* fauna, but only one of these forms is at all dominant in the eastern fauna under investigation.[a]

The evidence points clearly to a position intermediate between the typical faunas of the Hamilton and Chemung formations. That the rocks are younger than the Hamilton formation is shown both by stratigraphical evidence and by the occurrence of species that have never been discovered in the Hamilton formation. That they are not of the same horizon as the Chemung formation containing the pure *Spirifer disjunctus* fauna is shown by the absence of most of the dominant species of that fauna, as well as by the strong representatives of typical species of the *Tropidoleptus carinatus* fauna; and that they are later than the typical Ithaca formation is shown by the presence of a few forms not occurring so low as the Ithaca formation of the central and western parts of the State.

The paleontological statistics are thus conclusive in demonstrating the intermediate place of the post-Oneonta fauna between the typical *Productella speciosa* fauna of the Ithaca formation, and the *Spirifer disjunctus* fauna of the Chemung; but it does not follow that the rocks are intermediate, and therefore not represented in either the Portage or Chemung formations farther west. The exact stratigraphical equivalency may be shown by a close study of the particular local characteristics of the faunules themselves.

This temporary phase of the general fauna of the zone following

[a] See Tables XXV to XXIX.

the Oneonta sandstone was recognized and named in 1886[a] as the "*Leiorhynchus globuliformis* stage of the Middle Devonian fauna." The gibbous form of *Leiorhynchus*, under the name *Atrypa globuliformis*, was noted by Vanuxem as existing in myriads in the "Chemung group" of the third district, "numerous localities abounding with it."[b]

The close relationship between the species so abundant in the arenaceous strata overlying the Oneonta sandstones of Chenango and Otsego counties and the common flattened form *Leiorhynchus mesicostale* was recognized by Hall.[c]

The presence of the species in the Ithaca formation was noted in 1884,[d] also the fact that in the rocks about Ithaca the form called *Leiorhynchus mesicostale* was found in the softer argillaceous shales, "while in the more arenaceous beds the convex forms *L. globuliforme* and *L. kellogi* appear." The great variability of the specimens in any handful led to the belief there expressed—

that the representatives of the genus *Leiorhynchus*, found in the Devonian of New York at least, offer no better claim to specific distinction than do the various forms of *Atrypa reticularis*, although the variations of form and the relative prevalence of certain variations are valuable and, we believe, sensitive indications of changed conditions of environment.

The association of gibbosity of form with sandy sediments gave occasion for expecting the species to appear in the sediments following the Oneonta sandstone in the Chenango Valley, and that this species should appear there in place of *Leiorhynchus mesicostale* was looked upon not as indicative of a new species, but as evidence of changed conditions of environment modifying varietally the common Ithaca form.

Another fact has been observed in the course of these studies—*Leiorhynchus* occurs very often in the rocks among the first species of brachiopods to appear in running up a section after a barren place in the strata. This was interpreted as an indication that the genus was adapted to live in conditions unfavorable to the life of most of the brachiopods. It was noticed in the Chenango Valley region that *Leiorhynchus globuliforme* was among the earlier species to appear above the sands and flags (nearly barren of marine invertebrates) above the horizon of the Oneonta sandstone. The fact that the species appeared in the Ithaca formation associated with the characteristic species of that formation, and was particularly associated with the hard sandstone beds, which were distinctly purple in color, led to the suspicion that this *Leiorhynchus globuliforme* fauna was a representative of the *Productella speciosa* fauna of the Ithaca formation, but a little later in age.

This theory of a *shifting of the fauna* across central New York from

[a] Proc. Am. Assoc. Adv. Sci., Vol. XXXIV, p. 226.
[b] Geology of Third District of New York, p. 182.
[c] Paleontology New York, Vol. IV, p. 364.
[d] Bull. U. S. Geol. Survey No. 3, p. 16.

the east toward the west during the time of the sedimentation of the Portage and Ithaca formations of the Cayuga Lake meridian was suggested by the fact that in the neighborhood of Ithaca, on passing upward from the Genesee shale, there is an increase of species of the *Tropidoleptus* fauna with the withdrawal of the Portage species. The shifting was reversed after the center of the Ithaca formation was passed, as was shown by the reappearance of the species of the Portage formation (in reverse order) on ascending the strata, until above the Ithaca formation, with its dominant marine invertebrate fauna, came several hundred feet of sediments quite similar to the typical Portage of western New York and holding the *Cardiola speciosa* fauna.

This shifting of the fauna first westward and then eastward was such as to make the true succession of the faunas take a wedge-shaped position in the sediments rather than make a continuous superposition of formations in one column. The Oneonta formation pushed westward into the midst of the Ithaca formation of Ithaca, and as it ceased as a formation, by the withdrawal eastward again of the peculiar kind of sedimentation, the Ithaca formation also pushed eastward, but the fauna in the latter expressed a later stage of evolution in Chenango County than in Tompkins County.

Taking this view of the case the Oneonta formation is, stratigraphically, at the same horizon as the middle of the Ithaca formation of the Ithaca section, which is also at the same horizon as the midst of the Portage formation of the Genesee Valley section. The fossiliferous zone above the Oneonta, in Chenango and Otsego counties, is the stratigraphical equivalent of the barren 300 or 400 feet of the Ithaca section and the fossiliferous beds of Caroline, which lie between the fossiliferous Ithaca formation with the *Productella speciosa* fauna and the Chemung formation with the *Spirifer disjunctus* fauna.

The geographical shifting of faunas coincidently with the accumulation of sediments not only is consistent with all the facts which have so far come to light, but there is no other theory advanced by which the bewildering confusion in the relations of the faunas of this region is satisfactorily accounted for.

The place of the Oneonta sedimentation is recognized in the sandstones and flags in the midst of the Ithaca formation, and the Oneonta, by its becoming thicker and more strongly marked on passing eastward in Chenango and Otsego counties, is seen to have its origin from that direction.

The black shales of the Genesee and the following fine mud shales of the Portage of western New York containing the *Cardiola* fauna (*Glyptocardia speciosa*) thin out eastward; but the proposition that they occupy the place of the Portage and Ithaca formations of the central part of the State, in which is a fauna rich in species of the *Tropidoleptus* fauna, is proved by the statistics collected by Messrs. Prosser and Clarke.

The difficulty found in discussing this problem has been due in large measure to the lack in common usage of any way to deal with the *fauna* independently of the name and classification of the geological *formation* to which it is said to belong.

In the present case, in order to treat of the subject in hand with the nomenclature already in use, it is necessary to say that the rocks and their fossils appearing in the section of Chenango and adjacent counties, *above* the Oneonta sandstone, are either Ithaca, Oneonta, or Chemung. There seems to be no other way of designating them; the use of the word transition is only an avoidance of decision. But if one speak of the formation as Chemung, the necessity arises of assuming the fauna to be equivalent to some part of the fauna of the Chemung formation where typically exhibited. This, as has been shown, is not correct, if by the "typical exhibition" be meant a case in which the separation between the Ithaca and Chemung faunas is sharply defined. If a case be taken in which the mingling of the two faunas is evident, it is not properly a typical exhibition. But in the list of species from these rocks in Greene Township, Chenango County, there is an undisputed mingling of a large number of species of the standard *Tropidoleptus* fauna with a considerable number of species of the standard *Spirifer disjunctus* fauna, and a still larger number of species whose most central stratigraphical position is in the standard Ithaca formation.

If now we are to deal with the formations as such, the evidence seems to be very strong for the opinion that the part of the actual column of the Genesee section of western New York, called the Portage formation in the reports, when followed stratigraphically eastward is represented not only by the Oneonta formation of Otsego and adjacent counties in the eastern part of the State, but by the fossiliferous beds lower down, and by some, at least, of the fossiliferous beds following the Oneonta.

Even if we were to suppose, with Dr. Clarke, that the Oneonta sandstone is the formational equivalent of the "Portage sandstone,"[a] this does not dispose of the essential problem; because the equivalency does not include likeness of species in the two formations.

The fauna in the beds below the Oneonta sandstone is more diverse from the fauna immediately preceding the Portage sandstone of western New York than it is from the fauna preceding the Genesee shale of the same column. The fauna following it is also less like the fauna following the Portage sandstone than it is like the fauna of the Ithaca formation, which is known to be stratigraphically below it. If the formational equivalency were in fact as Clarke supposed it to be, the term *equivalency* would not carry with it the meaning that the beds were deposited at the same epoch of geological time.[b]

The actual tracing of the beds step by step across from Otsego to Allegany County would settle the question as to time equivalency,

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[a] Thirteenth Ann. Rept. State Geologist New York, 1893. p. 557. [b] See p. 117.

but so far as such work has already been carried the evidence is all against the supposition that the sandstone of the Otsego section would be a sandstone in the Allegany County section. This is borne out in the special case of the Oneonta, which is lost as a red sandstone mass before reaching Tompkins County.

We are therefore forced, by the evidence before us, to conclude that *lithological characters, which constitute the basis of discrimination of the geological formations as units, not only can not be relied upon to discriminate time equivalency, but uniformity of lithological constitution must be regarded, in some cases at least, as positive evidence of non-equivalency in time.* This rule is applicable whenever the formation is traced at right angles to the original shore line along which the sediments were deposited. The exception to the working of the rule is in those cases where the formation is traced in a line parallel to the original shore line. In such a case sedimentation may have been approximately uniform for long distances.

It is necessary, therefore, not only to use the fossils as an aid to stratigraphy in determining equivalency, but the fossil evidence must be so separated from inferences drawn from formation names that its real value in time discrimination can be independently estimated.

To make such separation of the two sources of evidence of time relations (viz: formations and faunas), it is necessary to deal with the fauna independently of its particular place in any geological column of formations. So considered the fauna is an aggregate of organisms combined in such number of genera, species, and individuals as to express the bionic values of each in their relations to the total corporate fauna of each epoch of time for the area covered.

The presence of a few species which are common in the typical series of rocks called the Hamilton formation (as currently defined by geologists) is not evidence of contemporaneity of formation for the rocks containing them in some other region. In fact, we have shown that the 12 most dominant and characteristic species of the formation actually do all occur in the Ithaca formation, which, at Ithaca, is separated from the Hamilton formation by two well-defined geological formations (the Tully limestone and the Genesee shale) and by still another series of rocks with a distinct fauna (the "lower Portage" so-called, with the *Spirifer lævis* fauna)—in all about 400 feet of strata. Nor does the mingling of species of one fauna with those of another invalidate the value of the faunas as time indicators.

Again, in order to use the fauna as a time indicator, the changes in the fauna coincident with passage of time must be observed and noted. The study of the details of these Devonian faunas, as has been already stated, brought out the fact that a fauna may retain for a considerable thickness of sediments its integrity as a general fauna—viz, its corporate integrity. Illustrations are given in Grabau's and Cleland's analyses of the successive faunules of the Hamilton formation. In such range of a fauna through hundreds of feet of sediments the corporate integrity of the fauna is ascertained by observing the continuance of dominance of the dominant species.

It was found that at any particular stage of the fauna certain species were dominant, as indicated by their abundance in the particular faunule. The relative abundance of the species gave a means of estimating the particular adjustment of the species to one another at the particular time and in the particular environment of the faunule. The temporal equilibrium was not found to be preserved for much thickness of strata, nor, when studied geographically, for much distance of distribution; such a faunule with its exact combination and proportion is both temporary and local, and constitutes the type of a single faunal unit—i. e., a monobion, and its time limit is the hemera.

Slight change of conditions, not sufficient to effect permanent change in the specific characters of the species, either coincident with passage of time or with change of position, may disturb the equilibrium, and the effect of the change is exhibited primarily in the different relations of abundance or rarity of the constituent species.

The difference in these respects observed upon comparing the successive faunules is found to consist in a change in their relative dominance as constituent species, and rarely in the entire absence of any of the more common species, when imperfection of the collection is fairly taken into account. Certainly the facts indicate that there was no extinction of the species, for they came in again at successive places higher up in the column of strata.

To ascertain, then, the real character of the fauna as a corporate whole, in terms of species, it is necessary to ascertain what species are sufficiently dominant to overcome the lesser changes of conditions, and to hold their preeminence, continuously, coincident with succession of faunules as recorded in the geological column of a single section, and coincident with changes of conditions as indicated by the faunules taken from separate geographical localities.

The species which appear most frequently in sample faunules, representing geological succession and geographical distribution, may hence be regarded as the most characteristic representatives of the fauna for the total period of time during which it has preserved its faunal integrity and over the region in which it was normally adjusted to live. The presence of any large number of such dominant species of a fauna may be safely regarded as indicative of the epoch in which the fauna was dominant, and which may be appropriately designated as the epoch of that fauna.

This would be a reasonable conclusion even in case species of a fauna which in general succeeds it were present and associated with it in force. The argument for this conclusion is that the fauna can not be regarded as having ceased its existence as a fauna, so long as in a single faunule, anywhere, the species which have all along proved their dominance in the fauna are not replaced by other species.

Upon reading on this basis the time value of the *Leiorhynchus globuliforme* faunule of Chenango County, we are able to say, from the study of the faunas, that the dominance of the *Tropidoleptus* fauna is already passed, although 27 of its species are present. The epoch of the *Productella speciosa* fauna of the Ithaca formation is also far advanced, but the *Spirifer disjunctus* stage has not been reached in force, as only a slight representation of its species is seen. The dominant species are those of the *Productella speciosa* fauna of the Ithaca formation.

So long as the majority of the species, including a majority of the dominant species, belong to the faunas characteristic of the Hamilton and Ithaca formations, the evidence is strong for its contemporaneity with some part of the Portage formation of the Genesee River section.

The mingling of species of two adjacent faunas by slight and repeated shiftings is well illustrated in a paper by Dr. J. M. Clarke.[a] He has shown how the species of the "Portage (Ithaca) fauna" are mingled with the species of the "Portage (Naples) fauna," as he calls them, in central New York.[b] In this paper is brought out the evidence of the great difference in composition between the fauna of western New York in the Portage rocks and the faunas occupying the same horizon in central New York. The method of accounting for the presence of both faunas in the same section is that advocated in this paper. Dr. Clarke speaks of the fauna of the western extension of the Portage group as an "exotic fauna," and describes the faunas of the central and eastern sections as "indigenous." Confirmation of the interpretation given in the present discussion appears in the statement that the Ithaca group fauna is a modified Hamilton fauna, with the following: "It contains a more abundant representation of unmodified Hamilton species in the meridional section along the Chenango River." If we had passed the time in which the "Hamilton," i. e., *Tropidoleptus carinatus*, fauna was living in its integrity the species would show modification. The greater abundance of these "unmodified" species in the eastern outcrops points to the metropolis of this fauna, in which the fauna itself has maintained its bionic integrity. Although outside, only a hundred miles westward, a new fauna, exotic in origin, has occupied this ground with partial replacement there of the indigenous species of the region.

PRINCIPLES INVOLVED IN SHIFTING OF GEOLOGICAL FAUNAS.

This brings us to a consideration of the fundamental principles involved in the shifting of faunas, announced in 1883, the outlines of which were further set forth in 1892 in the vice-presidential address

[a] The stratigraphic and faunal relations of the Oneonta sandstones and shales, the Ithaca and the Portage groups in central New York: Fifteenth Ann. Rept. State Geologist New York, 1897, pp. 31-81.

[b] Ibid.; see p. 53, etc., for the lists, and fig. 5, p. 51, for the diagram.

before Section E of the American Association for the Advancement of Science.

In a paper read before the American Association in August, 1885, the fact of shifting of faunas was illustrated by a chart based on the detailed examination of the faunules of ten sections cutting across the strata of the Devonian, extending from Cuyahoga County, Ohio, eastward to Unadilla, in Otsego County, New York. A brief report of the paper was published in the proceedings, and the formulated expression of the law was given in the following words:

> The actual order of faunas met with in a vertical section is not necessarily expressive of biologic sequence, but signifies the sequence of the occupants of that particular area.
>
> The change in the species from one stratum to the next may express the shifting for miles of the actual inhabitants, and if the change, within a few feet of strata, is to an entirely distinct group of species, the evidence should be taken as pointing to a considerable shifting of conditions of the bottom. If in such case each fauna is kept distinct, the means of tracing the geographic distribution and modification are at hand. If mingled, then the collection, though made at the same locality, will only confuse. Two such faunas meet at Owego, Tioga County, in distinct strata, but in rocks which are of similar lithologic character; one is a remnant of a prevailing western fauna, the other is an eastern and late stage of a new fauna.

It was there shown how, by the shifting of faunas and formations, the lower part of the Catskill formation of the Hudson River section was actually equivalent to the Oneonta formation of the Delaware County section, to the Ithaca formation of the Cayuga Lake section, and to the Portage formation of the Genesee River section.

From the established fact that the Catskill (a formation discriminated on a lithological basis) did not occupy the same horizon, when the horizons were determined on a paleontological basis in sections not over 50 miles apart, it was argued that there is need of differentiating by nomenclature the vertical divisions discriminated by fossils from the lithological divisions called formations.

The same subject was further elaborated in a discussion before the Geological Society at Boston in 1893, the immediate topic then under examination being the place of the Catskill formation in the geological time scale. In that discussion I proposed the use of dual nomenclature in geological classification, and again showed how the shifting of faunas from place to place necessitates their appearance at different horizons in separate sections, using horizon in the sense of synchrony in time. By this interpretation of the facts the Catskill formation was shown to occupy in eastern New York the actual horizon of the Oneonta of Delaware County, of the Ithaca formation of the Cayuga Lake section, and of the Portage of the Genesee River section.

The lack of statistics for the discussion of migration of faunas was greatly felt in all those early studies of the subject.

The deep interest taken in the question by numerous investigators has been shown by the many papers which have been published since then, giving the much needed statistics. With these statistics in hand it is possible now to express more clearly the laws involved in this shifting of the corporate faunas, as wholes, and their coincident modification.

BIOLOGICAL CONSEQUENCES OF SHIFTING OF FAUNAS.

The principles assumed to account for the change in the character of faunas are of two kinds, viz., (i) the *geographical shifting* of the faunas, and (ii) the *evolution* of organisms independent of change of environment. Only so long as the conditions of a marine basin remain constant, or differ so slightly and so slowly that the faunas living under them can preserve their integrity as a whole and preserve that balance of adjustment to each other which may be called biological equilibrium—only so long as these conditions remain can the fauna be supposed to retain its integrity as a fauna. This state of things is represented in many geological formations for a great period of time. Throughout strata of limestone, in some places reaching 1,000 feet or more in thickness, this integrity of the fauna is preserved. It is to be interpreted as due in some measure to the conditions of environment remaining constant, whether evolution takes place under such conditions or not. Attention is called in the present statement to the fact that the fauna as a whole does maintain a relative integrity, which permits the assumption of at least very slight evolution of the types. Some of the species may drop out, and occasionally a few new ones may come in during the course of this life period—if we might so call it—of the fauna. At the same time the variations, pure and simple, which are observed are very slight, and not to be compared with the differences which are often noted on passing across a very limited distance of sediments where the conditions have changed and the fauna is broken up. It is not necessary to assume that a very great length of time has intervened between the embedding of the old and the appearance of the new fauna as we follow upward a stratigraphical section. Throughout the geological column many cases are known where one fauna is immediately followed by another, without greater break of sedimentation than the passage between two strata and with perfect parallelism of the contiguous strata, yet the species are almost completely changed. The species of the same genera are often found to be quite different.

The student of paleontology is not required to assume that in such cases the second fauna has been evolved directly from the species which underlie it in the strata below. The more natural assumption, and the one which is borne out by further investigations in other regions, is that the new fauna has come to be deposited in the second series of beds lying above the first fauna by the shifting of the faunas upon the ocean bottom itself. A migration from some other region into the region where it is recorded is made by the species. This proposition requires us to assume that our second fauna lived contemporaneously with the one immediately underlying it, but in some other region separate from the one in which it is recorded. Examples of such shifting of faunas have occasionally been met with in the investigations of deep seas. Professor Verrill,[a] in his studies of the faunas of the Atlantic edge of the New England shores, has pointed out a remarkable case of this kind. About 80 miles off Woods Hole one season a unique fauna appeared—the tile-fish fauna—with a new and abundant set of species, a great proportion of them new and representing altogether a new fauna. This fauna afterwards was lost sight of, and the dredgers found no traces of it in the region where it was first found. The explanation of the sudden appearance of such a fauna is that the shifting of currents, or some other movements of conditions in the ocean, led to the temporary migration of the fauna over the banks it occupied, and to its later retreat and resumption of its old conditions.

The tile-fish fauna may belong to the deeper seas under the Gulf Stream, or it may be connected with other currents that at present we are unfamiliar with. However, this immigration may be taken as an example of what has unmistakably taken place over and over again in the sea basins whose life records are preserved in the fossils of our stratified rocks. Of course the modification of species in the course of time would affect such species as lived in a continuous series of reproductions for millions of years; such modifications, however, might be spoken of as purely evolutional. Paleontology gives us evidence of such modifications of a general kind in the character of the species of a genus coincident with the passage of time; i. e., a young stage, a vigorous middle stage of the life history, and a final decadent stage of the life of the genus. Facts of this kind may be gathered from the study of faunas which have preserved their integrity through a great thickness of sediments in a single basin; but the conditions more important to the paleontologist, and more necessary to be observed in making correlations, are those directly coincident with the movement of faunas from place to place; i. e., the shifting of faunas. This shifting of faunas is well illustrated in the history of the latter part of the Paleozoic formations in the central basin of North America. The general proposition assumed to explain such shifting of the geographical position of faunas and their containing formations, as we follow them successively through a geological section, is as follows:

It is assumed, first, that the evolutional process of change is geologically very slow in its effects; that so long as the same conditions prevail with sufficient exactness to prevent the disturbance of the biological equilibrium of a fauna, so long the individual species will retain their distinctive characters and relative abundance in a general fauna.

[a] Am. Jour. Sci., 3d series, Vol. XXIV, p. 366.

On the other hand, it is assumed that changes of conditions of environment, which may have been very slight but which necessitate a shifting or migration of the faunas, may produce some and even considerable changes in a short time in the faunas concerned. The changes may be produced in the following ways: If the forced migration be sudden, the ability of the different species to migrate will, in the first place, be very unequal; some species can migrate and some can not; some can migrate easily and others with difficulty, and the sudden necessity of migrating, as a fauna, must necessarily break up what I have called the *biological equilibrium* of the fauna. In every shift some species will be forced to drop out, because they can not migrate or because they can not adjust themselves to the new conditions. If such a dropping out of species from the faunas takes place, there results at once a new condition of affairs in the faunal life. Competition is different; the means of livelihood have changed; the necessity of new habits of life is forced upon the remaining species. In the process of adjustment of one to another, irrespective of the changing conditions, we may suppose that the species which remain in the fauna will, some of them, be reduced in rank and some of them increased, which will be indicated by change in abundance or rarity. The increased or decreased abundance of species in the fauna is one of the evidences of this shifting process. Where a species is abundant, I have frequently observed that variability also is increased.

Relatively speaking, the variability is almost in proportion to the vigor and abundance of reproduction of the individuals. Here at once we see a means of rapid evolution. If a species varies and the variation is augmented by favorable conditions of livelihood, the change from one environment to another necessitates the modification of some of the species almost immediately, and the variability of the fauna will be strongly expressed when migration of the species takes place. The adjustment of the fauna to its changed conditions is a matter of slower accomplishment, but it may be supposed that migration from one region to another will result in more or less modification and readjustment of the proportionate fertility and abundance of the species, unless the change of environmental conditions be so slow as to enable the whole fauna to move its center of distribution without disturbance of its bionic equilibrium. Such cases would be rare and the distances not great.

The investigations of Grabau and Cleland, already referred to, illustrate this principle. The study of the Cayuga Lake section was made for the purpose of furnishing a minute comparison with the Eighteen-mile Creek section, as well as to determine the exact composition of the temporary combination of species found in each stratum. The result was very clear. The general fauna was found to be very much alike from the bottom of the Hamilton up to its top in both sections. The difference between the several zones was constantly fluctuating, and the fluctuations are not expressed so much by an incursion of new species or a disappearance of some of the old species entirely from the fauna, but the differences between the temporary faunules of each successive zone are found to consist chiefly in relative abundance of specimens and in relative size of those which do appear in the faunules.

Other cases have been investigated, and from their study I conclude that the ordinary changes which take place in the life inhabitants of the seas on passing from one stratum to the next are chiefly differences in abundance and vigor of the several species. When it is found, on passing from one zone in a section upward to the next, that the genera change with each new set of species the inference is at once that the change is due to migration. When, therefore, according to the above interpretation, it is observed that the faunas occupying the formations of the geological scale are not the same in two neighboring regions, the interpretation may be one of two: Either we have a succession of several faunas which may be contemporaneous, but represent different conditions of environment at the same time, or we have the modification of a single fauna into numerous local faunules—local and temporary—as it has been forced to migrate. Interpreting Paleozoic history on this basis, it becomes necessary to assume that the faunas must be distinguished geographically as well as vertically.

EFFECT OF SHIFTING OF FAUNAS ON CLASSIFICATION OF GEOLOGICAL FORMATIONS.

If we trace the sediments of the Devonian for several hundred miles in one direction, from the west in Ohio eastward across the States of New York and Pennsylvania to their eastern limits, a remarkable series of changes is observed in the character of the sediments as a whole, which is interpretable by this study of the faunas contained in them. The facts developed by the minute analysis of the Devonian faunas already presented show that formational equivalency is not in accordance with faunal equivalency for the different parts of the region examined. In other words, if we attempt to trace a common geological horizon across the country by means of the evidence of formational uniformity, we will reach a different conclusion as to equivalent formations than if the means of determination be the evidence of faunal integrity.

This fact may be expressed in the case of the Catskill sedimentation by saying that the Catskill formation occupies a lower place in the geological column in eastern New York and Pennsylvania than it does a hundred miles to the northwest. In this statement higher and lower are terms the estimation of which is based upon evidence of place of marine faunas in the rocks.

The case of the Oneonta sandstone and its place in the midst of the faunas, described in detail on previous pages of this report, is another vivid illustration of the fact. As a formation the Oneonta is a well-defined body of rock in Otsego County, New York, occupying a definite place in the geological column of the Devonian.

The evidence we have been examining, however, leads to the belief that the particular part of the geological column which was being formed in eastern Ohio at the time of the deposition of the Oneonta formation in eastern New York is not a sandstone but a soft sand shale called the Ohio shale. If we follow these Ohio shales eastward we find that they become coarser, and when we reach the Genesee Valley the sediments are still fine shales with some sandstones, laid down in even-bedded, sometimes flaggy, layers, with few fossils, and the fossils belong to a fauna quite different from that of either the Hamilton below or the Chemung above. The rocks here are known as the Portage formation. Following the rocks occupying the same geological horizon still eastward, by the time we reach the meridian of Cayuga Lake and Ithaca the same part of the column is represented by argillaceous and sandy shales alternating for several hundred feet. Many of the layers are rich in fossils and contain species of both the lower Hamilton and the higher Chemung formations, together with certain peculiar and characteristic species which have come in from elsewhere or have been evolved from the faunas prevailing at the lower horizons. In the midst of these sediments there are beds of flagstones and, locally, of massive sandstones. In this region the rocks are known as the Ithaca group or formation. Following the sections still eastward as far as Chenango Valley, the flagstone quarries of Norwich, Oxford, and Greene townships are found occupying the place of the more fossiliferous Ithaca zones farther west.

Still farther east, the Oneonta sandstones, including red sandstones and even conglomerates, with fish remains and some plants, but holding very slight traces of any marine fauna, occur in considerable thickness. From the evidence at present in sight I conclude that this series of sandstones is continued eastward without interruption and is probably a portion only of what is called the Catskill formation of the Catskill mountain region. Theoretically this is assumed to be the fact.

If now we analyze the distribution of these sediments, which are supposed to have been laid down during the same epoch of time, we find that four distinguishable classes of sediments may be recognized as in process of deposit at different areas of the bottom at the same time. These may be spoken of as (*a*) the black shale, (*b*) the relatively barren Portage shale, (*c*) the fossiliferous argillaceous shales, and (*d*) the red sandstones.

BLACK SHALE SEDIMENTS.

The Ohio shales are a continuation upward of what is called the black Genesee shale in other regions, and consist of a series of fine-grained somewhat arenaceous sediments which have the peculiarity of being made up of very thin and even laminæ and are very uniform for a thickness of several hundred feet. Where they are found in the black stage, this uniformity in the size of the grains, the evenness of the surfaces of lamination, and the uniformity of the sediments from top to bottom are striking characteristics. Faunally they are distinguished by a marine fauna containing a few, generally minute, invertebrates, many traces of plants, and often the spore cases of rhizocarps, together with the bones of large fish, distributed irregularly among the sediments. These peculiarities indicate quiet conditions of sedimentation—conditions not enough disturbed by currents or even wave action to affect the smoothness of the sediments on the bottom—and show that the sources of the sediments were at a considerable distance. The indications also point strongly to some kind of Sargasso sea, as suggested by Newberry; and it is possible that this coating of the surface of the sea by a living vegetation may account both for the black character of the sediments and for the absence of any considerable marine population.

PORTAGE FORMATION SEDIMENTS.

The second group of sediments still shows a sparsity of invertebrate life, but exhibits alternations of sediments ranging from the fine, evenly laminated layers of the black shale to the coarser arenaceous shales and sandstones, with occasional indications of shore action in the form of ripple marks, worm tracks, and pebbles. This set of sediments is well represented in the typical Portage formation of west-central New York.

FOSSILIFEROUS SHALY SEDIMENTS OF ITHACA GROUP.

A third class of sediments is found to be typical of the sections south of Cayuga Lake, in the formations described by me,[a] whose fauna is more fully elaborated in Mr. Kindle's paper on The Faunas of the Ithaca Group. These are composed of alternating sediments of sands and shales, richly fossiliferous, much more roughly deposited, and rarely showing the peculiar, evenly laminated character of the typical Genesee seen in the lighter-colored shales of the Portage of the Genesee Valley, and in the Erie shale of Ohio.

RED SANDSTONE SEDIMENTS.

The fourth set of sediments is found in the East, and is represented by the Oneonta sandstones and the flagstones—purple and red—which reach as far west as the Chenango Valley, and traces of which appear in the midst of the Ithaca group of the Cayuga Lake meridian. These more eastern sediments are generally tinged with red. They are often coarse-grained with interspersed pebbles, and sometimes

[a] Bulletin U. S. Geol. Survey No. 3.

have layers of clearly defined conglomerate. They rarely contain any purely marine life, except lingulas. The organisms they do contain are generally fish and a few large lamellibranchs (*Amnigenia*) which possibly were fresh-water mollusks, and may have occupied a place similar to the unios of the present time. Plant remains of unmistakable land origin are frequently found in the sediments.

Thus in this fourth class of sediments the indications of nearness of shore are very clear, not only in the nature of the sediments themselves, but in the organic remains buried in them. Bearing in mind this fourfold classification of the sediments, geographically arranged, it may be assumed that the relationship they bear to each other is in general coincident with distance from a shore outside of which they were laid down. The fourth represents the deposits nearest the shore; the third the zone of littoral sediments, rich in organic marine life. Going still farther outward from the shore line the more or less barren sedimentation is found beyond the zone of the littoral fossils, but still near enough to the surface to be influenced by wave action and by local and temporary disturbance of the currents and supply of sediments; still beyond this are the sediments of the first class, above enumerated, which are beyond the reach of movements of currents, or oscillation of supply and distribution of the sediments derived from the shore.

We have here, then, a set of formations which are associated with different faunal populations, and, although they may be supposed to be synchronously deposited, the several formations, discriminated for particular regions where each one is typically expressed, possess almost nothing in common. The stratigraphical, the lithological, and the paleontological characters are distinct for each one of the four classes of formations.

The relation which these four classes of sediments bear to one another, and the way in which they stand related in the stratigraphical succession of a single section, lead one to the hypothesis that they represent approximately relative distances from the original shore line. With this as a working hypothesis, it is evident that a shifting which might be observed in one of the zones of sedimentation should be recognized by a corresponding shifting, in the same direction, of the other zones of sediments.

When it is observed that the *Tropidoleptus* fauna stops in the sections of western New York with the deposit of the Genesee shale, while in eastern New York the dominant species of the fauna continue on for several hundred feet of strata above the horizon of the Genesee shale, the inference is justified that not only has the *Tropidoleptus* fauna shifted eastward, but that the Genesee shale of the western New York section shifted eastward to cut it off, and that a place may be evident in the eastern extension of the Genesee sedimentation corresponding to the Portage phase of sedimentation.

This phase may be recognized in the Sherburne formation of Chenango County.[a] In the same way the Portage of western New York should, on this hypothesis, be represented by a black shale laid down farther west, such as the Ohio shale, and to the east it actually blends into the Ithaca and then into the Oneonta, in accordance with the theory. Still higher in the series the Catskill formation of the eastern part of New York is at the same horizon as the fossiliferous Chemung of the central part of the State and the Erie shale of the sections of western Pennsylvania and Ohio.

Thus the shifting of faunas furnishes a key by which the chronological relations of the formations which hold the fossils may be determined with a degree of accuracy not possible on any other basis, and reduces to order facts which on the ordinary interpretation are not only without apparent order but seem, at least, to be unrelated to each other.

The sequence of the faunas themselves, in each section, furnishes a clue to the direction in which the shifting has moved. If, for instance, the passage upward is from richly fossiliferous shales into black, nearly barren, even-bedded shale, the locality where the sediments occur was sinking, and the shore line was becoming more distant; and, on the assumption that at the time the general shore lines were to the east and north of central New York, the inference is that the pushing in of the black Genesee shale over the Hamilton was from the southwest. All the facts bear out this conclusion.

Again, if the succession of beds is from fossiliferous shales into red, flaggy, and coarse sandstones, the interpretation is that the region was rising. In central New York rising would cause the shore lines to encroach upon the sea advancing toward the west. This is the fact in the case of the Oneonta sandstone; and all the facts bear out this interpretation.

FAUNAL SHIFTING AND CORRELATION.

Thus a minute study of the faunules in their relation to the sediments and their distribution and succession furnish a means of correlation far better than continuity of like sediments, a safe method when the transgression is parallel to shore lines but fallacious when the formation is traced at right angles to the shore line of origin of the sediments. It is a surer method of correlation than reliance upon identity of fossils alone, for we have ascertained that a prevalent fauna retains a general integrity of its specific composition for a time of great length, measured by the sedimentation of many hundred feet of ordinary shale and sandstone rocks, and through a thickness of limestones which may reach several hundred feet.

The relation of limestones to the other classes of sediments has not been indicated in the above analysis. It is more difficult to determine

[a] See section at "Nigger Hollow," Prosser, p. 134, XIX C 2.

the precise relation of limestone sediments to the shores, for there are no terrigenous materials in the sediments. The limestone, when pure, does not necessarily indicate great distance from land erosion, and it may not indicate distance from actual shore.

In the discussion of the *Cuboides* zone and its fauna[a] I adopted, as a working hypothesis, the view that limestone sedimentation constitutes a fifth class lying beyond the black shale end of the series. I think, in general, this is borne out by the facts; still it must be observed that limestones form near coasts, and, under favorable conditions, in water not deep.

Where limestones continue to form for long periods, during which some oscillation is evident, the associated fragmental material is fine grained, and the passage from limestone into terrigenous deposits is generally, if not always, through fine-grained sediments to coarse; often black shales are among the transition beds. As a working hypothesis it would appear still to be safe to regard limestones as at least in the same class with black shales on a basis of relative distance from shore, and as a means of determining the direction of the shifting of the faunas.

This particular order of distribution of the conditions of sedimentation in relation to distance from shore line may require modification as the facts are more thoroughly elaborated, but that the several contemporaneous faunas associated with distinct types of sedimentation have shifted together laterally seems to be established beyond question. The following facts seem to favor this view:

(1) *Fossil faunas give indication of their normal association with particular classes of sediments.*

Unless we suppose that the fauna has shifted its local habitat the abrupt termination of a class of sediments in a given section requires the assumption that the fauna ceased to live, whereas, the actual continuity of life of species associated in faunal aggregates is theoretically an established fact.

(2) *Sediments of each class are of limited geographical distribution.*

This fact taken with No. 1 makes the following a rational conclusion, viz:

(3) *A fauna in its purity is restricted in its geographical distribution.*

If a fauna in its purity has a limited geographical distribution, the recurrence of the same fauna in a continuous section, after the occupation of the region by an entirely distinct fauna, can be explained only on the assumption that the fauna moved away from the region during the interval of occupation by the latter.

(4) *Such recurrences of faunas are established facts, as shown on the previous pages of this discussion.*

(5) *A formation (when understood to be a continuous series of*

[a] Bull. Geol. Soc. Am., Vol. I, 1890, p. 481.

superimposed strata, composed of the same class of lithological sediments) may contain a large number of zones, each with a faunule differing in particular from the others; but all the faunules from bottom to top may be made up of varying combinations of a common list of species, i. e., the common fauna of the formation.

The absence or presence of the individual species in the separate zones of faunules is more rationally explained on the assumption of this temporary shifting of the species than by the hypothesis that either the species temporarily ceased to live or they were simply not recorded in the sediments. So long as the species continued to live there must have been some locality in which favorable conditions for their living were found. The conclusion is reasonable, therefore, that they shifted their place of habitation—in the case of faunules, not far enough in distance to disturb the normal equilibrium of species in the general fauna.

This difference in the relative abundance of the component faunules of a continuous fauna leads to the conclusion that we are dealing with parts of the fauna at varying distances from its center, or metropolis, rather than with fluctuations of the composition of the whole fossil contents. This actual fact of (6) *frequent difference in relative abundance of the species of the faunules of a continuous fauna is established by the statistics already given.*

By the hypothesis proposed the shiftings are adjustments of the species to constantly but in general slowly shifting conditions of environment of the life of the species.

It is believed that these zones of different sedimentation might be recognized (if we had the whole record before us) all around the shores of such a marine basin as we have now under investigation.

It is supposed, second, that the difficulties arising from correlation of the sediments which are cut through by sections in different parts of such a basin are due in great measure to neglect of this fact of utter difference, as far as adaptation to species is concerned, in the sediments synchronously forming. Across the central part of New York State the shifting of these sediments was recognized early in the eighties, and it is represented in the region about Ithaca and immediately eastward in the following way:

The Hamilton formation is found underlying the whole State, reaching from eastern New York across the State and into Ontario, Canada. It contains a rich marine fauna, and for that reason is clearly traceable wherever it appears.

This formation, as an arenaceous, sometimes argillaceous, shale, occupied a large area of near-shore bottom of a sea which extended over what is now New York State. The sediments became more calcareous on passing southwestward, and in Ohio and Indiana the calcareous beds increase, the limestone conditions of the Onondaga continuing upward after the time of occupation of the region by the *Tropidoleptus carinatus* fauna. Taking the presence of this fauna as the basis of discrimination of the Hamilton formation, the latter in central New York is followed directly by the Tully limestone, and that by the Genesee shale, in which there is no trace of the *Tropidoleptus* fauna. Farther westward this cutting off of the fauna takes place lower down, and by the time we reach Ohio the *Tropidoleptus* fauna is almost entirely wanting. Still farther on, the highest of this particular series of marine faunas is that of the Onondaga.

In the other direction, when the Genesee shale once comes in it is expressive of the departure of the *Tropidoleptus* fauna from the region. Following the Genesee shale eastward we find it gradually ceases as a formation, and east of the Chenango Valley very slight traces of the sedimentation of the Genesee formation are evident. In that region, as soon as the thinning and insignificance of the Genesee and Tully become evident in the column, the *Tropidoleptus* fauna is found to extend upward in full strength. In this eastern region there is evidence, for several hundred feet of the succession—the direct succession—of the *Tropidoleptus carinatus* fauna, and its continuance on until the very base of the Oneonta sandstone. This is evidence of shifting of the faunas eastward. As the sedimentation of the black shale character pushed farther eastward the *Tropidoleptus* fauna was also crowded farther eastward, and in the later part of the life of the *Tropidoleptus* fauna its geographical distribution was restricted to this eastern half of New York State, the *Cardiola speciosa* fauna prevailing through the corresponding strata in western New York.

Now the next clear evidence of shifting of the faunas is found when the red shales and sandstones, which are characterized as Oneonta sandstones, came in in Otsego County. Coincident with this shoving in of the shore deposits westward we find the forcing of the *Tropidoleptus* fauna also westward after the zone of the Genesee shale was passed. This is represented in the Cayuga Lake section by the Ithaca group and its fauna, which is called the *Productella speciosa* fauna. This fauna penetrates somewhat westward of Seneca Lake. At High Point the dominant species are of another fauna. I have thought that traces of the *Productella speciosa* fauna appear as far west as Hornellsville, but in the section of Genesee Valley no trace of the fauna has been discovered.

The shifting in the other direction, toward the east, is evident at the *Leiorhynchus globuliforme* zone, which follows in the stratigraphical succession above the horizon at which the Oneonta sandstones cease in the Chenango Valley. Here is indicated a shifting backward of the faunas which were so dominant in the region of the Cayuga Lake section about Ithaca and for 50 miles eastward. The shifting is indicated by the withdrawal of the red sediments, also, farther eastward, and in the Ithaca section it is indicated by the cessation there of the *Productella speciosa* fauna, followed by a return of the species of the *Cardiola speciosa* fauna of the Portage formation of the Genesee Valley in a long stretch of about 500 feet of sediments above the fossiliferous Ithaca zone in the hills south of Ithaca.

The final return shifting of the faunas westward is seen in the occupation of eastern New York by the red sediments of the Catskill formation. This incursion of the red sediments took place before the complete extinction of the *Tropidoleptus carinatus* fauna, and it was, probably, in great measure the cause of the extinction of that fauna. The species which lived on shifted westward, and in the eastern counties of Pennsylvania and adjoining borders of New York we find them represented and mixed with the typical *Spirifer disjunctus* faunas, which occasionally came in, intercalated between red layers of the Catskill. As this set of sediments is followed farther westward, the red sediments also pushed farther and farther westward, until they reached the position of Olean and corresponding positions in Pennsylvania. But during the Catskill occupation of eastern New York and Pennsylvania, the *Spirifer disjunctus* fauna prevailed over most of the western half of these States, in a thousand or more feet of sediments, from which the red sediments of the Catskill are almost entirely, and for the more western sections entirely, absent.

With each shifting of the sediments or faunas it is not simply a single kind of sediment that changes its position, but all of the sediments change their geographical position of accumulation; and the sequence of faunas (represented in any particular section cut through them) presents contrasts which have led to much confusion in making the correlations. There is, throughout the region, a gradual succession of faunas and species constituting the faunas. The species are modified, chiefly, at the periods when the shifting took place. The shifting does not result, in most cases, in the extinction of the fauna, as is clearly indicated by the recurrence of the species in the successive stages.

From an analysis of the faunas living in the New York province during Devonian time, we are led to believe that along with the oscillation of the depth of the bottom below the surface of the ocean there occurred shifting of the faunas as corporate wholes. The changes were gradual, but, with the change of condition of the bottom, the species of the whole fauna moved together in the direction their favorable conditions of environment was taking. Coincident with such forced migration there was modification of some of the species, noticed most distinctly at first in change in the dominance of individuals, and followed by modification of those which maintained their strength and vigor, and a selection of those varieties best adapted to endure the new conditions.

CHAPTER V.

EQUIVALENCY AS INTERPRETED BY GEOLOGISTS.

DIVERSITY OF INTERPRETATION.

There is no problem in geology which occasions more controversy than that of determining the equivalency between the rocks or formations of regions separate from one another. In stratigraphical geology this may be said to be the great problem with which everyone is concerned until it is settled; and when it is settled it is the one thing which every new investigator is wont to think he has a right to criticise and modify, in the light of his own newly discovered facts. If I mistake not, the chief cause for this disagreement regarding geological equivalency is the unconscious confusion of different standards of measurement in estimating the values which are balanced, and regarding which equality of value is predicated.

One man, when he speaks of the same formation (e. g., the Medina sandstone) as appearing in different States of the Union, is referring to the kind of lithological material of which the rock is composed; it is a case of *lithological equivalency*. Another man is thinking of the geological time—the time when the formation was made—in the two regions; this is *contemporaneity of formations*. A third is thinking of the likeness of the fossil forms contained in the rocks—*faunal equivalency*. But in ordinary discussion it is rarely considered that lithological equivalency, contemporaneity of formation, and faunal equivalency are not necessarily the same, and that they may conflict with each other.

In order to make clear the reason for such confusion, the standards of equivalency in the case of geography may be examined. In dealing with geographical facts, there are three ways of measuring and defining them. A particular geographical feature may be defined in each of three ways. In order to define the geographical position of West Rock, for example—an elongated hill of trap rock rising to an elevation of about 400 feet above tide level—either of the following statements may be made:

1. It is situated about 2 miles north of the head of New Haven Bay, on the edge of the New England coast, opposite the central part of Long Island Sound.

2. It is situated in the town of Westville, New Haven County, Conn.

3. It is situated on the meridian of 41° 20′ north latitude and on the parallel of 72° 57′+ west longitude.

From this illustration it is evident that any geographical feature on the face of the earth may be defined as to its geographical position in three distinct ways—distinct, because the locality scale may be any one of the three kinds signified in the foregoing definitions.

These three locality scales are:

1. *A geographical locality scale*, in which the facts are the present configuration of the surface of the earth, chiefly in respect to altitude, or distance in feet above or below sea level.

2. *A political locality scale*, in which the facts are the political divisions of territory as defined by human ownership or occupation.

3. *An astronomical locality scale*, in which the facts are distances in angular degrees or minutes, north or south from the equator of the earth and east or west from an arbitrary standard meridian (that of Greenwich).

It will be observed that the only one of these standard scales which is permanent, fixed, and capable of use with precision is the astronomical scale, which can not be seen on the surface and has no regard whatever to facts upon which the other two scales are constructed.

I have referred to the locality scales of geography in order to illustrate more vividly the differences which are confused when a time-scale is under consideration for the definition of geological facts.

The geologist is using three time-scales in his attempt to define the chronological relations of geological events.

1. When an American geologist speaks of a formation in Ohio as the Trenton limestone, or in the Appalachian region speaks of the Medina sandstone, or the Catskill, or Pocono, he is using a time-scale in which the basis of classification is the fact that a rock of a particular kind in the section at Trenton, Medina, or in the Catskill or Pocono Mountains is assigned to a definite place in the stratigraphical sequence of formations. In applying the name to a formation in Ohio or in the Appalachians, he is attempting to affirm equivalency of position in a stratigraphical series of formations. It is a time classification by formations; he is dealing with a *formational time-scale.*

2. Again, in describing the Niagara of America as equivalent to the Wenlock, and then classifying it as therefore belonging to the Silurian age, the geologist is using an entirely distinct basis of classification. The basis of his determination now is equivalency of the faunal combination of fossil species found in the rocks of the two formations. In this case stratigraphical or lithological characters are not in evidence, but only the organisms which were living when the sediments composing the rocks were laid down. It is now a *faunal time-scale.*

3. There is still a third method of defining geological events chronologically. The question arises in mapping the rocks of a region, where, in the column of formations, shall the boundary be drawn between two systems, viz, between the Silurian and Devonian? This question

was settled in the case of the Appalachian sheets of the U. S. Geological Survey by drawing the line in the midst of the Monterey sandstone. In the legend of the map the Monterey sandstone is called neither Silurian nor Devonian, but transitional. In the text, the formation is defined as containing Oriskany fossils. Without entering into the merits of the case, this is an illustration of using a scale which is neither formational nor faunal. A formation is a distinct lithological unit, but its base, as thus defined, is placed below the boundary line between the two systems, and its top is above the boundary line. This boundary line is therefore a theoretical one, which does not occur in the stratigraphical series as mapped on the sheet, and the scale to which it is referred is the *standard geological time-scale.*

This particular standard is based upon a single section in Wales, where the earliest recognized boundary was drawn between the Silurian and overlying Old Red sandstone, and however differently the sequence of formations or faunas may occur in any other regions, the grand divisions of time—Cambrian, Silurian, Devonian, Carboniferous, etc.—are arbitrarily drawn, determined as near as may be by comparing all the points of geological history for the two separate regions.

In the previous pages the facts are presented by which the application of the rules for establishing equivalency may be illustrated.

In the case of the Devonian formations and faunas of the New York province the different kinds of equivalency may be stated with some degree of precision.

In a formational time scale the units compared are lithological units. Examples of such units are the black Genesee shale, the Huron shales of Ohio, the Tully limestone, the Catskill, the Oneonta, and the Hamilton formations. The questions of formational equivalency involve two points—lithological and stratigraphical equivalency. In two neighboring sections there may occur 50 feet of red sandstones in one, which are equivalent to 75 feet of red sandstone in the other section; this is a case of lithological equivalency. In two other sections 50 feet of red sandstones in one may be equivalent to 30 feet of greenish shales and flags in the other; this is a case of stratigraphical equivalency. From the examples given in discussing the Devonian faunas it is evident that the lithological and stratigraphical equivalency may coincide or may be discordant.

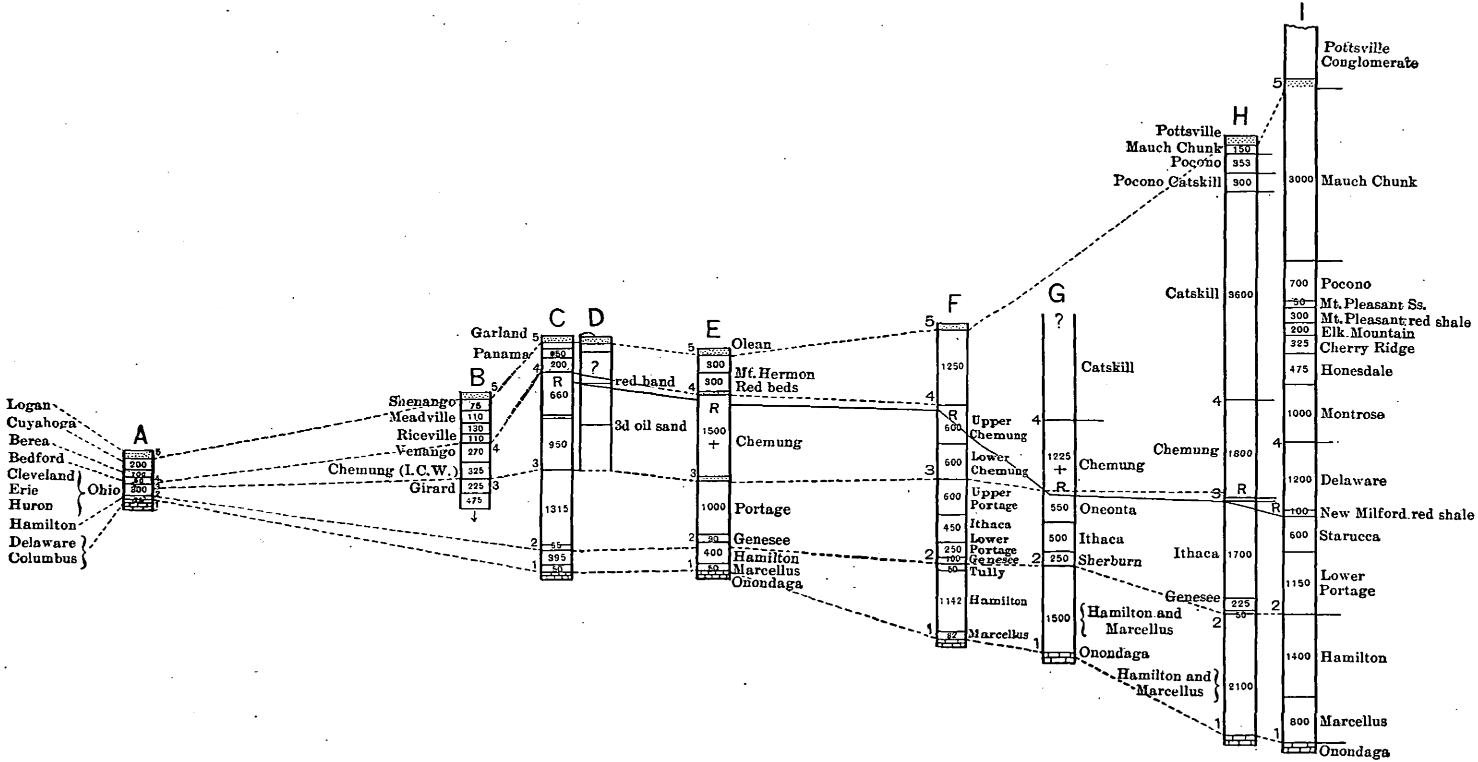
In ordinary cases it is presumed that lithological and stratigraphical equivalency coincide. Such is the case when the Tully limestone is followed along the line of its outcrops. When its calcareous character becomes so faint as to be indistinguishable in the series of strata, the formation is said to cease. According to the older habits of treatment of such cases the Tully limestone is supposed to thin and run out to a feather edge, thus finding its equivalency in the column between the subjacent and superimposed formations. According to the interpretation here proposed the change would be described as a lithological change—a change in the character of the sediments by increase of the argillaceous and arenaceous over the calcareous elements—until the former prevailed to the exclusion of the latter. The equivalent strata of the limestone would in the second locality appear as shales and sandstones; and, for instance, the actual stratigraphical equivalent of the Tully limestone in Chenango and Otsego counties may be supposed to be twice as thick as the Tully itself and not distinguishable lithologically from what lies below or above it. Such a formation is, strictly speaking, but a member, and the reason for separating it from the Hamilton formation is the appearance in it of diagnostic species not belonging to the general *Tropidoleptus carinatus* fauna, but which immigrated into the region from another fauna. Prosser described such a case in Otsego County, in section 21, east of Noblesville. The rocks are described as "smooth, greenish sandstones, in the midst of which are blocky shales in which *Rhynchonella venustula* Hall is common;"[a] i. e., a characteristic species of the Tully limestone. Associated with this species are *Spirifer* (*mucronatus*) *pennatus* and *Tropidoleptus carinatus*, two characteristic species of the Hamilton formation. The rocks below are bluish shales; those above are arenaceous shales. The thin "blocky shales with *Rhynchonella venustula* (*Hypothyris cuboides*)" may be regarded as the attenuated stratigraphical equivalent of the Tully limestone, but the facts favor the opinion that although this holds the attenuated representative of the fauna of the Tully limestone, the actual stratigraphical equivalent of the formation includes more or less of the blue shales below and the arenaceous shales above.

An example of the discordance between lithological and stratigraphical equivalency is given by the Oneonta formation. The Oneonta sandstone of Otsego County is shown to occupy the same position in the column which the Ithaca formation holds in the section at Ithaca. The Oneonta formation is, therefore, the stratigraphical equivalent of part of the Ithaca formation, but, lithologically, it is the equivalent of the lower Catskill. In the same way the Chemung formation of the Genesee Valley section is stratigraphically equivalent to the Catskill formation of eastern Pennsylvania, in part, to the Erie shales of Ohio. But lithologically the Ohio shales are equivalent to the Portage formation of New York. A formation, therefore, may be stratigraphically equivalent to one portion, while lithologically it is equivalent to another portion (either higher or lower) of the geological column.

CORRELATION OF THE DEVONIAN FORMATIONS OF OHIO, WESTERN NEW YORK, AND EASTERN NEW YORK.

The foregoing proposition may be illustrated by tabulating the formations of Ohio, western New York, middle New York, and eastern New York, along a west-east series of outcrops, as shown in Pl. I.

[a] Classification and distribution of the Hamilton and Chemung series of central and eastern New York: Fifteenth Ann. Rept. State Geologist New York, 1895, Part I, p. 183.



COMPARATIVE CHART OF THE MIDDLE AND UPPER DEVONIAN FORMATIONS OF OHIO, PENNSYLVANIA, AND NEW YORK.

The sections, A to I, are arranged in order along a curved line extending from Licking County, Ohio, northeastward toward Jamestown, N. Y.; thence eastward to Ithaca; thence nearly eastward to Norwich; thence southeastward to the Delaware Water Gap near Stroudsburg, Pa. These sections are placed in approximately the relative distances apart which the natural sections occupy along such a line. Such a line theoretically represents a section at right angles across the successive zones of conditions of sea bottom out from a shore which had a general trend parallel to the present Atlantic coast and the general Appalachian axis. The total distance represented is about 500 miles.

The several sections are, for thickness and classification of formations, based upon official survey reports, revised in some cases by special surveys; and the range of the fossil faunas has been determined by special detailed investigations, accomplished chiefly by the persons named below, viz:

A. Licking County, Ohio, revised by Orton, Herrick, and Prosser.

B. Meadville, Crawford County, Pa., and across Erie County, Pa.; Second Pennsylvania survey (I. C. White), Q 4; revision by E. M. Kindle and H. S. Williams.

C. Jamestown, Chautauqua County, N. Y., and Garland, Warren County, Pa.; Second Pennsylvania survey (Carll) I 4, and G. D. Harris; range of faunas, E. M. Kindle.

D. Warren, Warren County, Pa.; Second Pennsylvania survey (Carll) I 4, range of faunas, E. M. Kindle and H. S. Williams.

E. Genesee Valley and Olean, N. Y.; H. S. Williams; section revised by E. M. Kindle and M. L. Fuller.

F. Ithaca and Cayuga Lake, N. Y.; H. S. Williams, E. M. Kindle, and H. F. Cleland.

G. Chenango River Valley, New York; C. S. Prosser and H. S. Williams.

H. Catawissa, Columbia County, Pa.; Second Pennsylvania survey (I. C. White) G 7; range revised by E. M. Kindle.

I. Monroe and Pike counties, along Delaware River, Pennsylvania; Second Pennsylvania survey (I. C. White) G 6; range revised by C. S. Prosser.

The range of the faunas is expressed by the cross lines marked 1 to 5 and the letter R.

The line marked 1 represents the upper limit of range of the typical fauna of the Onondaga limestone.

Line 2 is the upper limit of the pure Hamilton fauna.[a]

Line 3 is the lower limit of the Chemung fauna.

Line 4 is, for the western sections, the lower limit of the Waverly fauna; in the Ithaca section (F) and the sections farther east, it is the highest level at which definite traces of the Chemung fauna have been detected.

Line 5 is the base of the Olean conglomerate (E) and of other conglomerates regarded by stratigraphers to be its equivalents. In the easternmost section (I) it is called Pottsville conglomerate series.

[a] In section F this line, by mistake, is drawn to cross the section at top instead of at bottom of the Tully limestone.

The line marked R is the horizon at which the first well-marked red beds appear in the sections on going up, above which the so-called Catskill fauna appears. In general, the figures in the columns express the thickness in feet assigned to each formation, the names of which are placed opposite them as applied in the several regions through which the sections pass.

These facts may be expressed in terms of equivalency, as follows: At the base of this particular series, the calcareous Delaware formation, in its upper measures, contains traces of the *Tropidoleptus* fauna. In western New York the Hamilton formation is composed of argillaceous, calcareous shales, and in eastern New York it is arenaceous, but not so strongly so as to change the fauna. The black Huron shales of Ohio, following the Delaware limestone and shading off gradually into the green shales of the Erie, occupy the interval which, in western New York, is made up of the Marcellus shale, Hamilton, Tully, Genesee, Portage, and some of the Chemung of western and central New York. In central New York these find their equivalent in the Marcellus, Hamilton, Tully, Genesee. Farther east the Tully and Genesee are wanting, as formations, or are represented by Hamilton and Sherburne formations. The Ithaca is in part represented by the Oneonta, and its upper part is represented by the so-called Chemung of Otsego and neighboring counties. The Chemung is represented in that region by the Catskill. Still higher up, the space from the black Cleveland shale of Ohio up to the Logan conglomerate is represented in western New York and Pennsylvania by the upper Chemung, Panama conglomerate, flat-pebble conglomerate, and beds at Olean holding *Spirifer disjunctus*, running up to the base of the Olean conglomerate. Farther east this interval is made up of the Catskill, and the probabilities are (though the facts to support the opinion are not positively in sight, fossils being out of evidence) that the Pocono and Mauch Chunk are also the representatives of this same Waverly group (or a portion of it) of Ohio.

The second kind of equivalency has regard to the faunal time scale. Equivalency of faunas may be illustrated in a definite case by saying that the *Tropidoleptus* fauna may be recognized over a wide territory by its dominant species, but this alone is not sufficient to identify the formation. For instance, in the case of the *Tropidoleptus* fauna of eastern New York we have already noted a list of 12 species which are dominant throughout the fauna, as exhibited in the different parts of the State. These are dominant on the basis of geographical distribution, and therefore may be regarded as representative species of the *Tropidoleptus* fauna, not necessarily of the Hamilton formation. Nevertheless, when in central and western New York we pass above the formation, which is sharply defined in the sections, both lithologically and faunally—so there is no possible doubt as to the termination of the formation in these western sections—we find that the fauna which appears in the Ithaca formation contains all of these representative species of the Hamilton formation, thus making a faunal equivalency with known discordance as to formational equivalency. It is known that stratigraphically the Ithaca formation is not equivalent to the Hamilton formation. However, if we were to detect the species named in the dominant Hamilton list in a section in Indiana, the inference would be drawn at once that the Hamilton fauna was present. The truth is that the *Tropidoleptus* fauna is present, but that the Hamilton formation may or may not be represented in Indiana. The evidence of the equivalency of the Sellersburg formation with the Hamilton formation in Indiana, furnished by the presence of the few specimens of the *Tropidoleptus* fauna, is not so great as the evidence of equivalency of the Ithaca formation with the Hamilton in New York. This case brings out the distinction between faunal and formational equivalencies. It also illustrates the importance of the recognition of some other basis than simple presence of species in order to certify the fauna to which they belong. The facts are not present for carrying correlations by this careful method through the whole series of formations known to occur within the boundaries of the intercontinental basin, but sufficient is known to make it certain that the general faunas prevailing in one section of the basin during a period of time, the formational equivalency of which may be clearly established in another section, are faunally diverse in the two sets of sediments representing the same period of time.

CHAPTER VI.

THE BIONIC VALUE OF FOSSILS.

GENERAL STATEMENT.

The essential difference between the three classes of evidence upon which geologists base their determinations of equivalency of compared formations having been demonstrated, a few words may be said regarding the nature of the evidence by which fossils record definite epochs of geological time.

Uniformity in rock constitution we all understand, and it requires no special analysis. Stratigraphical equivalency is readily perceived to be based upon structural uniformity; and in describing two formations as stratigraphical equivalents we mean that they are the same structural parts of the earth's crust. In making determinations of faunal equivalency, however, the presence of one or several fossils is not sufficient to establish close correlation, for the reason that the same fossil species may occur throughout many feet of thickness of sediments, and anywhere in that range may exhibit the same fossil forms. It becomes necessary to deal with the aggregate fauna regarding which the modifications are constantly taking place. Not only must we treat of fossils as aggregates, but we must have some means of measuring the aggregates other than the scientific names of the fossils. While their names are essential and cover a great many particulars, in order to extract the evidences of time we must be able to deal specifically with those elements which are associated directly with the passage of time.

In the previous pages I have referred to the bionic values of fossils, and have arrayed a mass of statistics, gathered and formulated in such ways as to exhibit these bionic relations, and the reader will now be ready to consider more particularly what is the nature of this special method of treatment of fossils as evidence of passage of time.

Fossils, as morphological records of the living organisms of the past, are of inestimable value in reading the history not only of the organisms themselves, but of the conditions of the environment through which they struggled and to which they were adjusted. But form such as the fossil expresses, and in general such as is expressed by the hard parts of all organisms, is extremely complex. It is impossible to describe it in geometrical terms, as may be done in the case of minerals. Although descriptions of form may be given which will convey some idea of the important elements of form, it is actually necessary that either the original specimen or drawings illustrating the form be used to convey to the mind the meaning of the terms of the description.

It becomes important, therefore, for stating scientifically the historical relations of organisms, to find some method of measuring the difference between one fossil and another which shall have mathematical value and be capable of expression in mathematical terms.

In the crystal the relations of the faces to each other may be expressed in degrees and minutes of angle borne by the planes to each other, and their extent may be measured in millimeters. The chemical elements of which they are composed may be expressed in percentages of the total quantity of matter in the individual crystal, and these elements may be compared by their atomic weights or be expressed in terms of specific gravity. It is the form of a fossil which expresses the qualities of the organisms, but this form can not be expressed mathematically, nor is it coordinate with composition. Degree of complexity of organization is of prime importance in measuring the rank of the organisms in systematic classification. This degree of complexity, or amount of differentiation of structure, which is the basis of systematic classification, is evidence of the amount of evolution through which the ancestors of an individual have passed.

For instance, the complex structure of the crayfish presents the morphological evidence of its taxonomic rank. It holds a higher rank in classification than does the trilobite. While thus much is known and is distinguishable in terms of form and use of organs—or, to speak abstractly, in terms of morphological characters—it is very difficult to express in mathematical terms the degree of difference or the relative rank of the organisms. In seeking for some such terms the practice in physics and chemistry may be studied. Both physics and chemistry have reached some degree of mathematical precision in expressing values of their phenomena by the adoption of arbitrary units, such as pound and foot, of which there can be preserved visible standards for comparison. Another set of standards are measures of exertion of force which is not visible but is capable of record in terms of the visible standards, pound and foot, with the help of the measures of time, duration, and motion in space. Such standards are the dyne and the ohm. When it is sought to measure the relative values of organisms, although their bodies are composed of chemical elements, it is found that their values are more than atomic. Although they are mechanically constructed and act in accordance with physical laws of matter, their values can not be expressed in terms of physics.

The idea that the survival of organisms in competitive struggle is determined by the measure of vital energy exhibited by the several competitors furnishes a suggestion as to the kind of measure by which the values of organisms may be compared.

Since it takes an appreciable length of time for an organism to develop to maturity the structure by which it carries on its living processes, and as, secondly, every individual organism develops its form elements by passing from a formless stage into a more and more complex morphological stage, these two elements, *time* and *individual development*, offer promise of some satisfaction for the measurement of organic values, which may be considered mathematically.

Organisms are not to be measured by the amount or kind of matter of which their bodies are constructed, but by the disposition and use they make of the matter within the scope of their activities. It is the shape of the lobster's claw, not its chemical constitution, which is significant.

Following out this line of search, we notice that the vigor expressed by the coming to birth and the growing to maturity of a single organism is repeated when it reproduces itself in a second generation. Whatever value be imagined as the value of the life power, force, or energy by which a single germ goes on to maturity, the value is doubled when another generation follows, and trebled on the third generation. *Generation* becomes thus the measure of a certain fundamental ability of organic bodies, and each individual organism stands for the exertion of a unit of such force. A fossil individual is the measure of this unit of organic energy as much as a living individual.

Again, if each case of reproduction of an organic individual were an exact repetition of the preceding case, all organisms would be alike. We assume that difference in the forms of organisms is to be accounted for by a change in the processes by which the mature body is constructed in the course of individual development.

If the constructive form of the adult individual organism be an expression of a unit of vital force, it may be assumed that the diversion of the process of development, so as to modify the construction and form, is the expression of another unit of force of some proportionate relation to the first unit.

If organic generation goes on for 100 generations without noticeable deviation, this second mode of energy may be supposed to be less than if some deviation be noticed in the course of 10 generations. The evolutional energy expressed in the deviation from a given form in the course of repeated generations is of the same nature as that expressed by the development of the germ to adulthood, since it is morphologically an *acquirement of structure* or of difference of form. This form is visible and is preserved in the fossil as well as expressed in the living organism. Hence it is evident that *difference in form*, when it is combined with *numbers of generations* taken for producing the difference, becomes a means by which the relative values of organisms may be compared. Difference in form is the basis of classification of organisms in systematic zoology and systematic botany. In these sciences relative difference in form is expressed by the terms of taxonomic classification, viz, species, genus, family, order, class, branch.

Out of these several terms which have actual visible expression in nature (viz, *difference in form*, expressed in terms of species, genus, family, etc., in systematic classification; *difference in generation*, expressed by number of individuals of a kind; and *number of generations* following each other without specific modification) may be elaborated a means of expressing the relative values of living organisms in mathematical terms.

These values may be called *bionic*, implying the *energy* values of *living beings*, rather than the values of their mechanical powers or of their chemical constitution, since development from germ to adult and evolution from one to another specific form are phenomena associated only with *living* organisms; and the term *bion* may be used to express the idea of such a *unit of vital force.*

To distinguish this mode of expressing the energy peculiar to living organisms from the other modes of energy expressed by machines and in chemical reaction of nonliving bodies, the energy may be spoken of as *bionic energy.* It is evident that the bionic energy of organisms greatly differs for different organisms; but it is not yet known that the differences may not be actually an expression of the *number of generations* through which the ancestors have passed, and thus actually may indicate, mathematically, the true bionic value of the species or race at the stage in which it is examined.

THE TERMS "SPECIES," "RACE," AND "GENERATION."

In order to discuss this problem, we are forced to use the term species in a somewhat special sense. Species, when contrasted with individual and genus, refers to an aggregate of individuals possessing like morphological characters. But when we describe a fauna as composed of ten or twenty or a hundred species, species is used in a different sense. We are not dealing with the aggregate, but with the specific characters. Each individual is then a particular species or belongs to a particular species. Moreover, each individual in this latter sense is not only a species, but a genus, family, and class.

Bearing in mind this distinction, we find the individual to be an aggregate of cells, parts, and organs, and the particular way in which these cells, parts, and organs shape themselves in the adult determines to what species and genus the individual belongs. But the individual also starts as a germ and becomes an adult, and as an individual dies, i. e., loses its individuality. The individual, thus, is a temporary expression of the species, and in considering time values it is necessary to make distinction between the species as individuals and the species as a race.

The species continues to live after the individual representative of it has perished, and species as a time measure is better expressed by the term race. So it is particularly the single generation rather than the single individual that we have in mind when the time value of an individual is under consideration.

If we could actually know the number of generations it takes to accomplish changes sufficient to be marked by describing the two extreme individuals as of different species, then we could express by such a number the magnitude of difference between the time values of the individual and of the species. The best we can do is to state that the two measures are of a different order of value. We may state that the time length during which the average species reproduces its kind without appreciable deviation in its specific character is measured by thousands and possibly millions of generations, while a single generation measures the time length of the first order in littleness of value associated with the individual. If we could deal with it in geology, the life period of the individual would be the primary unit of the bionic system (monobiochron). But as this can not be ascertained by the study of fossils—dead remains of organisms—we must take for the lowest practical bionic unit some unit which is capable of expression by fossils (dibiochron). This shortest lapse of time, to which the fossils themselves may give expression, is associated with the continuous life of the species, and may be conceived of as directly determined by the relative vigor maintained by the individuals struggling with one another at the particular point of time recorded. So long as, at a particular spot (a), under what may be supposed to be unchanged, local, environmental conditions (b), the relative number of individuals of each species (c), with the same comparative size and proportions of form (d), continues unchanged, so long a certain small unit of time may be considered to have elapsed. This is called a dibiochron, because it is the measure of the second order of appreciable magnitude of the expression of the bionic, or endurance qualities of the organisms whose fossil remains are examined.

The definition of terms was given in a previous paper[a], an extract of which will explain the sense in which the terms are used:

In order to isolate this time quality I have proposed to speak of it as the *bionic* quality or value of the organism. *The bionic quality of an organism may, then, be defined as its quality of continuing, and repeating in successive generations, the same morphologic characters.* * * * And if we should adopt the name *chron* to apply to geological time-units in general, and *biochron* to the units whose measure is the endurance of organic characters, we have a means of constructing a system of nomenclature which will express what is now known of geological time relations, and (more important still), which will serve as an aid in accumulating the necessary statistics to perfect the geological time-scale.

Order of magnitude of bionic units.—In expanding this system of nomenclature the following table will indicate the principle upon which the fundamental units of time value will be discriminated and named. The time-unit of lowest rank will be based upon the life endurance of an individual organism; the amount of

[a] Jour. Geol., Vol. IX, p. 579.

organic vigor expressed by the preservation of the individual life constitutes a bionic unit of simplest or lowest rank; the individual, therefore, is an organic unit of monobionic rank. How many individual lives are possible in the life-history of a species we at present do not know, but we do know that the bionic value of the species (or, strictly speaking, of specific characters) is of an entirely higher order than that of the individual. To be more concrete the individual, the species, the genus, etc., constitute organic units of consecutively higher and higher order of bionic magnitude, which statement may be tabulated in the following way:

Bionic values of the several categories of classification of organisms.

Individual	a monobionic unit.
Species	a dibionic unit.
Genus	a tribionic unit.
Family	a tetrabionic unit.
Order	a pentabionic unit.
Class	a sexbionic unit.

This actual dibion may be compared with the molecule in the atomic theory, for the theoretically simplest unit of the series (the monobion) is expressed by the time equivalent of an individual life from germ to death—i. e., the life period of the individual.

In the fossil individual, therefore, we find no evidence of the time value of individual development. The vigor which is characteristic of each individual of the species at the time may be expressed by the numbers of individual fossils found buried together in the same rock layer.

Even this actual number of specimens in a rock layer is not a certain test of individual characteristics when taken alone, because the conditions of preservation, we must believe, very greatly modify the number of individual specimens preserved in the rocks. In order to use a number of specimens as an expression of bionic value, the number must be in relation to the number of other species preserved at the same time under the same conditions. It is the relative abundance or rarity of a species in the local faunule list alone that is of value, just as in the analysis of a mineral the percentages of the component elements are significant, not their amount.

So far as fossils are concerned, the individual is recorded only by its dead remains, and the number of individual fossils of the same kind found together in the same faunule may stand for a measure of the bionic value of that kind in the particular aggregate of species making up the faunule. The larger the number of individuals the higher the bionic value of the species relative to the other species in the combination. Those species, therefore, which are represented by the greater number of individuals in a faunule constitute the *dominant species* of the particular faunule. The adjustment of equilibrium among the species with each other and with the environment is such a complex and delicate matter that it is preserved for each faunule for a brief lapse of geological time. This brief time, represented by the preservation of the bionic equilibrium of a faunule aggregate, is taken as the measure of the unit of geological time—the *hemera*. The visible expression of the hemera is the temporary *faunule*, the analysis of which into its constituent species constitutes the *faunule list* of a particular locality (geographically) and particular zone (stratigraphically).

For the purpose of ascertaining the bionic value of fossils it is necessary to know the list of species occurring together in the same faunule, or temporary association of species, and the abundance or rarity of each in that combination; and second, it is necessary to obtain such faunules at frequent intervals separate from one another, in order to ascertain how constant is the appearance of the species in the general region over which the fauna is distributed.

The bionic values may be expressed mathematically by recording the number of times of appearance. These will then stand as numerators of fractions of which the denominator is the total number of faunules listed.

When the faunules are from the same formation, but from separate stations, the statistics will show the frequency of geographical distribution of the species. If the distribution is wide and general the numerator will be high, if the species is local in distribution the numerator will be low. The place of the species in the general fauna, based on such estimate of its bionic value, may be called its *distribution value*, by which will be meant the power of the species to spread itself geographically and to preserve its life under diverse conditions of environment.

In like manner, the frequency of occurence of a species in different faunules found at successive horizons throughout the strata of a single section will express bionic value of a different kind, viz, the power of the species to reproduce itself and maintain its place in the midst of the competing species with which it lives. This may be called its *range value*. It will be expressed by a high figure when the species appears at a large number of the horizons of the column examined, and when it is of rare occurrence in such faunules its numerator will be relatively small.

The third kind of bionic value will be expressed by the abundance or rarity of individuals of the species in the particular faunal combination of each faunule. This may be spoken of as *frequency value*.

To estimate the predominant characteristics of the fauna, then, three measures of bionic values for each species may be summed up, and the species whose bionic values of these three kinds (viz, distribution, range, and frequency values) reach the highest total average will constitute the *standard dominant list* of species of the particular fauna.

The application and illustration of these rules are given in the preceding pages of this bulletin.

REVISED DEFINITIONS OF THE TERMS FAUNA AND FAUNULE.

The term fauna is commonly used in paleontology to indicate the list of fossils contained in a single formation, but it is important to observe that the limits of the lithological formation do not determine the limits of the fauna. It will be seen from the discussions of faunas and faunules in this paper that a new definition of a fauna is required which shall not be dependent upon formation boundaries. The following points should be included in such a definition: For paleontology a fauna is an aggregate of local and temporary faunules in which is expressed a common, corporate aggregate of organic species. The corporate nature of the aggregation is indicated by the relative bionic values maintained by the species in the faunal aggregate. The dominant species of a fauna show their relation to the fauna by their higher bionic values, the less dominant species by their low bionic value, and the fauna shows its integrity by maintaining the normal equilibrium of the specific aggregates. The *Tropidoleptus carinatus* fauna is defined in this report as an example of such a fauna.

In the process of collecting fossils it is necessary to keep separate records of the specimens taken from each fossiliferous stratum of each separate outcrop. The group of specimens from such a unit stratum (or from several contiguous strata in which the same set of species are distributed) is called a *faunule.* It is a sample of the general fauna of the formation, coming from a definite horizon in the local section and from a definite geographical position. A faunule will exhibit the local and temporary aspects of the fauna, and in most cases it will contain only a small part of the species which properly belong to the general fauna. The faunule may be regarded as closely adjusted to a particular set of environmental conditions, which, though not known, may be to some degree inferred by the character of the sediment in which it is found. It is often observed, however, that successive faunules in a column of strata differ greatly, although very slight change in character of sediments is observed. Living faunas in modern ocean waters so differ on account of differences of temperature or other conditions of the water, and it may be supposed that such differences affected in a similar way the ancient geological faunas.

The particular part of the formation, be it a single stratum, or a few or many feet of thickness of rock throughout which the faunule is recognized is properly a *zone*, as defined on page 20; and the locality, number, and name may be applied to the specimens of the faunule, as well as to the stratum or strata from which they came. But the faunule is the faunule of such a zone, and its proper name should be derived from the name of some dominant species (as *Leiorhynchus globuliforme* faunule or *Paracyclas lirata* faunule) when the analysis has been made and the character of the faunule has been fully established.

In so designating the faunule the distinction between fauna and faunule is exhibited. We may speak of a *Tropidoleptus* faunule in the Chemung formation; this will indicate only a temporary recurrence of the species and its associates in the midst of the *Spirifer disjunctus* fauna. In this case the species are not supposed to have stopped their existence when we pass above or below the particular zone in which they occur. On the other hand, when the term *Tropidoleptus carinatus* fauna is used the term includes not only all the species normally associated with *Tropidoleptus carinatus* in its distributional metropolis, but all the adjustments and modifications through which the fauna passes in the course of both its migrations and its geological succession, so long as the dominant species, including *Tropidoleptus carinatus*, live.

A fauna, therefore, may be modified and have a history, and its integrity may be discriminated by a set of dominant species, the fauna preserving its integrity and identity so long (in succession) and so far (in distribution) as the dominant species retain their ascendency among their associates. On the other hand, a faunule is limited to a single set of conditions and to a locality of limited extent, and may not be modified in composition without losing its identity.

THE BIONIC TIME-SCALE.

At the close of the paper [a] in which this subject of the bionic means of measuring geological time was first announced I gave a sample table of classification and nomenclature constructed on this basis and stated the general terms to be used in constructing such a time-scale. They were as follows: [b]

Terms of the bionic time-scale.

Chron.—An indefinite division of geological time.

Geochron.—The time equivalent of a formation.

Biochron.—The time equivalent of a fauna or flora.

Hemera.—The technical name for a monobiochron, indicated by the preservation of the individual characteristics of all the species of a local faunule, as shown by the association in the rocks of the same species in the same relative abundance, size, and vigor. An example is the hemera of *Rhynchonella* (*Hypothyris*) *cuboides*.

Epoch.—The name of a dibiochron, indicating the time equivalent of the endurance of a particular species and of the integrity of the fauna of which it is the dominant characteristic. An example is the *Tropidoleptus carinatus* epoch, which corresponds closely to the limits of the Hamilton formation of eastern New York.

Period.—May be defined as a tribiochron. This is the time equivalent of the continuance of a genus. An example is the *Paradoxides* period, which corresponds to the Acadian formation of the Cambrian system.

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[a] The discrimination of time values in geology: Jour. Geol., Vol. IX, 1901, pp. 570-585.

[b] Loc. cit., pp. 583-584.

Era.—May be used to indicate a tetrabiochron; and *Olenide* era would indicate the life range of the family *Olenidæ*, corresponding in length, approximately, to the geochron of the Cambrian system, though not strictly so.

Eon.—May stand as the name for a pentabiochron; an example of which is the *Trilobite* eon, the time equivalent of the continuance of the order, or subclass, *Trilobita*, which closely approximates the length of the Paleozoic geochron.

Classification and nomenclature of the Trilobite eon (Paleozoic) on the basis of the bionic values of fossils.

Eon.	Period.	Epoch.	Formational equivalent (approximate).
Trilobite	7. Phillipsian	Cameratus	Coal Measures.
		Increbescens	Kaskaskia, St. Louis.
		Logani	Keokuk, Burlington.
		Marionensis	Kinderhook.
	6. Phacopsian	Disjunctus	Chemung.
		Mucronatus	Hamilton.
		Acuminatus	Corniferous.
		Arenosus	Oriskany.
		Macropleurus	Lower Helderberg
	5. Calymenean	Vanuxemi	Waterlime, etc.
		Radiatus	Niagara, etc.
	4. Asaphian	(?)	Ordovician.
	3. Olenian 2. Paradoxidean 1. Olenellian	(?)	Cambrian.

Upon reviewing the subject I am of the opinion that this table fairly expresses the difficulties to be encountered in applying the principles here set forth as well as the advantages. When the table was constructed the details of the present paper were not ready for presentation. I am able now to point out the method of application to the Devonian faunas which have been already subjected to analysis.

The several faunas under consideration are the measures of epochs according to this scheme. We have thus: *Tropidoleptus carinatus* epoch, *Glyptocardia speciosa* epoch, *Productella speciosa* epoch, *Spirifer disjunctus* epoch.

Regarding these faunas and the time epochs indicated by them, it has been demonstrated that the range of time indicated by each epoch is not restricted to the particular formational limits in which the fauna is typically confined.

The *Tropidoleptus* epoch laps over both of the following two and reaches to the beginning of the fourth. The epoch of the *Glyptocardia speciosa* fauna is prior to and follows the limits marked by the typical *Productella speciosa* fauna at Ithaca.

The *Spirifer disjunctus* fauna, though in general later than the other three faunas in the New York province, probably dates its origin from a much earlier stage outside that province, into which it most probably came by migration, and not as an evolution from the earlier inhabitants of the New York province.

We have thus demonstrated the lapping of the faunas. This is a perfectly legitimate conclusion on the presumption that each of the faunas is not the universally distributed marine life of a particular epoch, but the fauna of a particular environment of that epoch. We are perfectly familiar with this discordance in the limits of dynasties of different races of peoples in human history.

The facts have also shown that migration—not of single species, but of the whole fauna, a shifting of the metropolis with the limits of distribution of the fauna as a corporate whole—has taken place.

This has been expressed in relation to formations by a transgression of one fauna over another, thus calling for the assumption that the limits of a formation based upon sudden change in the fossil contents can not be regarded as synchronous for two parts of even the same province and, wherever they are thus sudden and sharp, can not be synchronous with the limits of either the earlier or later fauna in evidence.

Nevertheless, with all this lapping, shifting, and incomplete expression of the faunas, the statistics also demonstrate the intrinsic value of fossils for measuring and indicating time. The sediments, whether by their lithological constitution, their structural form, or their stratigraphical position, furnish no such positive evidence of points or durations of geological time.

The bionic method of measurement of time relations, though in the present state of knowledge it can not be used as a substitute for the more apparent structure scale, will serve to make the imperfections of the present methods apparent. Our ignorance of the actual as well as relative life periods of the great majority of species of paleontology makes it impossible to reduce life periods to actual years or centuries.

It is also to be said that for the practical purposes of geological mapping and the descriptions of geological structure the formations are the essential elements, and a chronological classification of them is a convenient rather than an essential one.

Nevertheless, whenever the attempt is made to become accurate in establishing time equivalencies or correlations, it is in this direction we must turn. The collection of statistics along the lines here proposed will facilitate the formation of a definite time-scale for geology.

It is by making our knowledge of the composition, the range, and the geographical distribution of fossil faunas more complete and more exact that our classification and correlation of geological formations is to be perfected.

At present we know too little about fossil faunas to be able to predict in what manner their actual time limits will be defined or discriminated, but enough light has already been thrown upon the matter to show that it will be by means of the history which organisms have expressed in their continuous life and evolution that we may expect ultimately to mark off the stages of geological time.

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