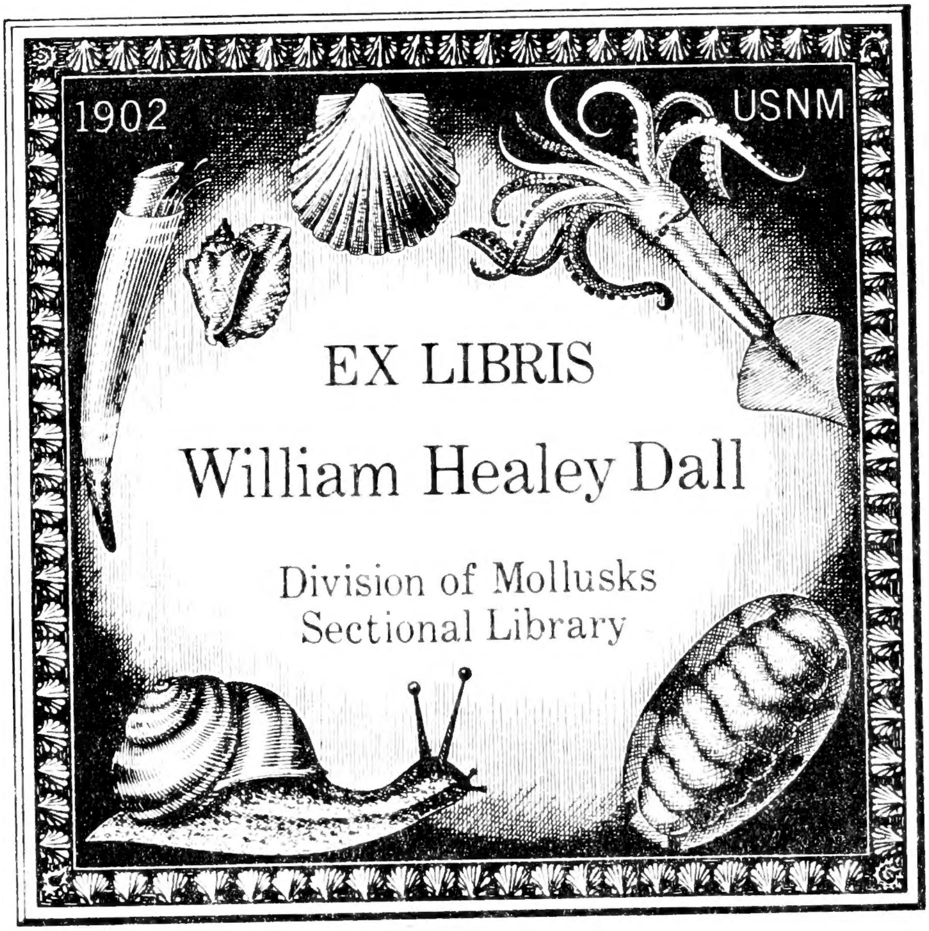
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OUTLINES OF GEOLOGIC HISTORY WITH ESPECIAL REFERENCE TO NORTH AMERICA

A SERIES OF ESSAYS INVOLVING A DISCUSSION OF GEOLOGIC CORRELATION PRESENTED BEFORE SECTION E OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE IN BALTIMORE, DECEMBER, 1908

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PREFATORY NOTE

The essays in this volume were presented before Section E, of the American Association for the Advancement of Science, at the meeting in Baltimore in December, 1908. The original plan of the papers involved the formulation of the principles of correlation, as applied to the formations of different periods. This plan was conceived by Bailey Willis, then vice-president of Section E, and was carried out with much success. The several chapters have appeared in the *Journal of Geology*, since their presentation at Baltimore. They present in broad outlines a summary of certain phases of existing knowledge of North American geology, and are now bound together in the belief that students of geology in this country and abroad will welcome them in this more convenient form. The paleogeographic maps by Mr. Willis form a valuable part of the volume.

JUNE, 1910

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CHAPTER I

PRINCIPLES OF CLASSIFICATION AND CORRELATION OF THE PRE-CAMBRIAN ROCKS

CHARLES RICHARD VAN HISE

A half-hour summary of the principles of classification and correlation of the pre-Cambrian rocks can give no more than the barest outline of the subject.

In the classification and correlation of the pre-Cambrian formations we lack the guide of fossils. While life existed in pre-Cambrian times, and a few fossils are found in several areas, they are not sufficiently abundant to serve either for the purposes of classification or correlation. How far-reaching this handicap is will be realized when this paper is contrasted with those that follow. In considering the questions of classification and correlation of the later formations, fossils occupy a paramount position. It is true that the faunal breaks are often and probably are generally dependent upon physical causes, and the latter are frequently considered; but when the determinations are made, the fauna rather than the physical factors are given first place.

In the classification and correlation of the pre-Cambrian our sole criteria are physical. Therefore we have for the discriminations only those guides which for the fossiliferous rocks are commonly regarded as subordinate. It follows that with the pre-Cambrian rocks we are on less certain ground than with the later formations. However, the very fact that fossils are not available in studying the pre-Cambrian has led the workers in this field to a careful consideration of the physical criteria and their relative value.

Among the physical factors which have been used in the classification and correlation of the pre-Cambrian, the following are the more important: (1) Lithological character; (2) Continuity of formations; (3) Likeness of formations; (4) Like sequence of formations; (5) Subaerial or subaqueous deposits; (6) Unconformities; (7) Relations to series of known age; (8) Relations with intrusive rocks; (9) Amount of deformation; (10) Degree of metamorphism.

1. *Lithological character.*—The first step in the study of rocks from a physical point of view is to determine the character of the formations, series, and groups—whether igneous or sedimentary; if igneous, whether plutonic or volcanic, acid or basic; if sedimentary, whether psephite, psammite, pelite, limestone. While according to definition a formation is essentially a lithological unit, usually this unit is more or less composite, consisting of many somewhat variable beds and often of several members of different character. Because of the variability of the elements constituting a formation, there are an indefinite number of permutations and combinations of these factors. This results in giving a given formation, series, or group special peculiarities which often enable one to recognize it even when actual connections of the various outcrops have not been observed.

Accepting any of the current theories as to the history of the earth, the rocks of the earliest time are dominantly of igneous origin, and those of later time dominantly sedimentary. Since the earliest Cambrian rocks contain remains of all the great types of life, it is certain that antecedent to this time the more fundamental and the greater part of organic evolution took place. Hence in a full pre-Cambrian succession we should expect the rocks of the early pre-Cambrian to be dominantly igneous and those of the later pre-Cambrian to be dominantly sedimentary. In accordance with the natural expectation, in practically all of the great regions of the world in which the pre-Cambrian have very extensive exposures, and in which close studies have been made, we find that the basal series of rocks is dominantly igneous, and the superior series dominantly sedimentary.

2. *Continuity of formations.*—Where formations in different districts are found to be continuous, they are supposed to be of the same age. It is realized that this conclusion is not absolute, for in the case of a great slanting transgression of the sea, the basal clastic deposits of the early part of the transgression may be considerably earlier than those in the later part, although the formations may be continuous. However, as yet given pre-Cambrian formations have

not been traced to sufficiently great distances to introduce important errors upon this account.

3. *Likeness of formations.*—Where in different districts there are like formations, this is of assistance in correlation. Thus, if in several districts of a geological province but a single limestone formation is observed in any one, and the limestone of the different districts has the same peculiarities, there is a natural tendency to suppose all the limestone to be part of a single formation. However, the criterion of lithological likeness alone is not sufficient to establish identity. This is illustrated by the three iron-bearing formations of the Lake Superior region. Because these formations were of such an exceptional and peculiar character, and were so remarkably alike, it was supposed for a long time that they were of the same age. For a number of years this mistaken belief was a serious hindrance to an understanding of the succession and structure in this region. The weakness of lithological likeness in correlation is due to the fact that the same set of physical conditions has frequently occurred during geological time, and thus formations practically identical even in the combinations of their variations, including color, banding, nature of beds, etc., have been produced again and again.

4. *Like sequence of formations.*—Similar sets of formations in the same order furnish a criterion for correlation, of much greater consequence than the likeness of a single formation. But even this criterion has severe limitations, for similar sets of formations in the same order may have been deposited a number of times during a geological era; for instance, when a sea transgresses over a land area there are normally formed in order a psephite, a psammite, a pelite, and a non-clastic formation, and frequently over this, another pelite. Several such similar sets of formations are known in the pre-Cambrian in a single geological province.

5. *Subaerial or subaqueous deposits.*—Closely connected with the third and fourth criteria is the question as to whether the deposits were laid down under air or under water. It is clear that the conditions of deposition of these two classes of rocks are so different and the nature of the formations which may be contemporaneous so variable, that there is great difficulty in correlating the two. Also it is plain that the difficulties in correlating disconnected continental deposits

are scarcely less great. Only recently has serious study been undertaken to discriminate subaerial and subaqueous deposits. This subject will not be gone into here, since it is one which has been recently discussed in several extended papers. I may, however, speak of one point. So far as we can yet determine the subaerial deposits are in general not so well assorted nor so likely to be sharply separated into distinct formations as the subaqueous deposits. This statement is believed to hold although it appears that under exceptionally favorable conditions the aerial deposits may be pure quartzose sands. Consequently cleanly assorted quartzose sands, pure limestones, and series composed of sharply contrasted formations are regarded as strongly favoring the idea of subaqueous deposition. As yet there is no evidence that air has the discriminating capacity which water has in producing cleanly assorted sands. If it is difficult to discriminate subaerial or subaqueous deposits, it is much more difficult to discriminate subaqueous deposits of the inland lakes and seas from those of the ocean.

6. *Unconformities.*—Unconformities are of great assistance in classification and correlation. It has been intimated that the great physical movements producing unconformities are frequently the real causes of faunal changes. Irving was the first fully to realize the importance of unconformities in correlation. The criteria by which unconformities are determined and their magnitude and significance analyzed cannot be discussed in a short paper. Those interested in this aspect of the subject must be referred to the original discussions.[1]

It should be remarked, however, that unconformities may have a very variable extent and significance. It is now realized that a sharp orogenic movement may take place resulting in uplift, erosion, subsidence, and therefore discordance of strata, which may not affect an adjacent area. Thus it should clearly be understood that it cannot be assumed that unconformities due to orogenic movements are more than of district extent. There are, however, great movements of uplift and subsidence which are continental and may be even inter-

[1] Roland Duer Irving, "On the Classification of the Early Cambrian and Pre-Cambrian Formations," *Seventh Annual Report*, U. S. G. S., pp. 365–454; Charles Richard Van Hise, "Principles of North American Pre-Cambrian Geology," *Sixteenth Annual Report*, U. S. G. S., pp. 724–34.

continental. Unconformities due to movements of this kind may have a very wide extent, and may thus be used for correlation from province to province, or possibly even from continent to continent. But in order that this may be fully done, it is necessary to show that the unconformity upon which correlation is based is an extensive one.

As yet insufficient careful study has been made of known unconformities from this point of view. Here is a great and fundamental field for investigation. If the known unconformities of the world were broadly studied, it is probable that many can be determined to be local, others to be provincial, others continental, and a few intercontinental. No more important determination than this remains to be made in geology. So far as I can see until this work is done there will be no very close correlation of pre-Cambrian formations from province to province and from continent to continent.

7. *Relations to series of known age.*—The relations of a formation, series, or group, to other formations, series, and groups of known age are of very great assistance in correlation. Frequently a formation, series, or group may be continuous or recognizable in the different districts of a geological province when other formations, series, or groups are not continuous. The position of the latter with relation to the former, whether above or below, and if above or below, conformable or unconformable, are valuable helps in correlation. Thus the Keweenawan is practically continuous about the entire Lake Superior basin. This is the only series of which this is true. The position of the series called Upper Huronian immediately but unconformably below the Keweenawan in different districts in connection with other facts is of great significance.

8. *Relations with intrusive rocks.*—The older is a series the more intricately is it likely to be cut by intrusive rocks, and this relation is of assistance in correlation in connection with other criteria. If a series is intricately cut by igneous rocks, all of which stop at a definite horizon, this is strong evidence that the adjacent rocks free from such intrusives are later and probably belong to a different series.

9. *Amount of deformation.*—The amount and nature of the deformation are of assistance in correlation within limited areas. Upon the whole, the older a series the greater and more intricate the deformation. The difference in the amount of deformation in the

pre-Cambrian series wherever there is a somewhat full succession of formations is sufficiently great to make this an important factor in the classification and correlation of the formation.

10. *Degree of metamorphism.*—The amount of metamorphism is a factor in correlation. Upon the whole, the older a series the more likely it is to be metamorphosed, but this criterion has severe limitations, since within comparatively short distances the closeness of folding and the quantity of intrusives may greatly vary, and these are very important factors in metamorphism. The worker among the pre-Cambrian rocks must have a very thorough understanding of the principles of metamorphism and the nature of the transformations through which rocks go. For, in working out the stratigraphy of the pre-Cambrian, if the criterion of the original character is to be used, it is necessary to know the rocks which the now greatly metamorphosed varieties represent.

GENERAL STATEMENT

In actually working out the succession of formations, series, and groups in the different districts of a geological province and in correlating them, all of the above criteria must be used. It is in judgment in appreciating the value of each of these criteria and their combinations that the skill of the pre-Cambrian stratigraphical geologist appears.

To this time, from my point of view, the only divisions of the pre-Cambrian which have been proved to be general, if not world-wide, are those of the Archean and the Algonkian. This subject I shall not take up in detail, since I have recently discussed it in another address.[1]

However, it may be said in summary that the Archean is a group dominantly composed of igneous rocks largely volcanic and for extensive areas submarine. Sediments are subordinate. The Algonkian is a series of rocks which is mainly sedimentary. Volcanic rocks are subordinate. The Algonkian sediments where not too greatly metamorphosed are similar in all essential respects to those which occur in the Paleozoic and later periods. When the Algonkian

[1] Charles Richard Van Hise, "The Problems of the Pre-Cambrian," *Bulletin, Geological Society of America*, Vol. XIX, pp. 1–28.

rocks were laid down essentially the present conditions prevailed on the earth. The Archean rocks on the other hand indicate that during this era the dominant agencies were igneous. The physical conditions had not yet become such as to lead widely to the orderly succession of sedimentary rocks like those being formed today. On the whole the deformation and metamorphism of the Archean are much farther advanced than the Algonkian. The two groups are commonly separated by an unconformity which at many localities is of a kind indicating that the physical break is of the first order of importance. As evidence of this, at many places are the fundamental difference in the character of the rocks, the greater intricacy of intrusion, greater deformation and metamorphism of the older group, and deep intervening erosion. In some localities a part of these phenomena are lacking, but the significance of an unconformity is determined by the places where evidences of its magnitude occur rather than where lacking. So profound are the contrasts between the Archean and the Algonkian in each of the great regions of the world in which the pre-Cambrian has been studied, and so similar are each of these great groups with reference to the fundamental principles discussed that it has been regarded as safe to correlate these two groups even when in distant geological provinces. In making this correlation it is not supposed that the formations of one province are of exactly the same age as those of another province, but that the formations assigned to the Archean and Algonkian respectively in any given case belong to the two great eras of the pre-Cambrian represented by the rocks of these groups.

For extensive areas the Archean may be divided into Laurentian and Keewatin. These divisions are purely lithological, the former being mainly plutonic acid igneous rocks and the latter basic igneous rocks, largely volcanic. The Algonkian in many of the various geological provinces may be divided into two or more series separated by unconformities. The formations of these series are commonly sedimentary, although igneous rocks are often abundant. As a whole, to the Archean group ordinary stratigraphical methods do not apply. To the Algonkian such methods are as applicable as to the Paleozoic and later series.

While the subdivisions of the Archean and of the Algonkian can be frequently equated in the same geological province, as, for instance, in the case of the Upper Huronian in the different districts of the Lake Superior region, it has not been found practicable to equate them from province to province. That is to say, one cannot be certain as to the correspondence of individual Algonkian series of China, Scandinavia, and of the Cordilleran region. If, as above suggested, it becomes possible to work out the physical history of the continents so that it may be determined which of the unconformities are continental, and intercontinental, or if in the pre-Cambrian rocks distinctive faunas are found, then closer correlation of the pre-Cambrian in different geological provinces may be possible than the Archean and Algonkian. In the meantime we must be content with the classification of the pre-Cambrian rocks in different geological provinces into Archean and Algonkian, with the understanding that the formations placed in each of these groups belong in a general way to the two early eras of the earth, during the first of which the agencies were dominantly igneous, and during the second of which the conditions had become similar to those of today. Further, within each geological province the Archean and Algonkian may be divided into series and formations which for each province are given local names.

CHAPTER II

THE BASIS OF PRE-CAMBRIAN CORRELATION

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That was indeed a fair and sunlit earth which our predecessors, the first geologists, had presented to them for study. The uniform strata of the newer periods of our earth's history in their succession, well exposed, and following one another in due and regular order, everywhere contained abundant fossil remains which afforded a certain clue by which correlation could be made even in widely separated areas. We, their unfortunate successors, in pursuing our studies are obliged to descend into the deeper parts of the earth where the light begins to fail and when once we pass through that last grim portal into the drear pre-Cambrian world, we enter into what these earlier geologists regarded as a hopeless chaos. Here we lose the guiding thread of life, and the darkness deepens. At first we could dimly descry but the outlines of the vast indeterminate ruins of former worlds, but as our eyes become accustomed to the darkness these become somewhat more distinct and we recognize succession even in this ruined waste.

It may be that being a petrographer I overestimate the value of paleontology, but, like other things, we prize it most highly when it is lost and we are obliged to look for something to take its place. The working-out of the stratigraphical succession by detailed mapping in special areas teaches us much, but unfortunately the areas showing such succession are usually limited and isolated and the criteria for correlating the successions in separated areas, and especially in widely separated areas, are as yet undiscovered.

The vice-president of our section, Dr. Bailey Willis, in inviting me to take part in this symposium, has suggested that I should treat this subject of pre-Cambrian correlation if possible on broad lines, and I therefore venture today to follow Faust's aspiration, "Schau' alle Wirkenskraft und Samen," and present a certain aspect of the subject which I hope may at least be suggestive of a line along which some advance may be made in the correlation of these ancient rocks.

In his *Research in China* (Vol. II, chap. viii) Dr. Bailey Willis has put forward a theory to account for the origin of continental structure. In each of our present continents there are areas which during the evolution of the continent have always tended to rise—these he calls *positive* elements. There are certain other areas which have always shown a tendency to sink, relatively to the adjacent masses—these he calls *negative* elements. The movement of these elements is due to the greater relative density of the negative elements causing them to sink, while the relatively lighter positive elements tend to rise so as to bring about an isostatic adjustment. There have been horizontal movements as well as those in a vertical direction. These are of notable magnitude and their effects are seen in the schistose structure of these once deep seated rocks and the overthrust and folded structures of the more superficial strata. The tendency toward vertical displacement has actually resulted in movement only at long intervals and during relatively short periods. Hence we may recognize cycles of diastrophism each one of which comprises (a) a comparatively brief period of orogenic and epeirogenic activity which results in elevated lands and restricted mediterranea; and (b) a comparatively long period of continental stability, which results in extensive peneplanation. The critical times which bring out continental structure are the epochs of diastrophic activity. During periods of inactivity the distinction between the positive and negative elements becomes less obvious and may even become obscured by extended peneplanation and marine transgression.

In a subsequent paper,[1] the same writer outlines the positive and negative elements of the continent of North America. The Canadian Shield, which is also called *Laurentia*, is at once the largest and the most readily distinguished positive element of the continent. It has an area of approximately two million square miles and the true boundary may be traced along the St. Lawrence Valley into the deep of Baffin's Bay and then north of the Arctic Archipelago (which is scarcely to be separated from Greenland) across the Arctic Ocean

[1] Bailey Willis, "A Theory of Continental Structure Applied to North America," *Bull. Geol. Soc. of America*, Vol. XVIII, p. 392.

and back to the mouth of the Mackenzie. Beneath the Cretaceous of western Canada, the margin of this element lies hidden. It ranges past Lake Winnipeg toward the state of Wisconsin, and then follows the shore of the Paleozoic mediterranean east to the Adirondacks and St. Lawrence.

Now it would seem, if we select a single positive element such as Laurentia—remembering that the critical diastrophic periods will be short and the intervening periods of deposition and accumulation will be of long duration—that these epochs of diastrophism, with their development of schistose structure in the moving masses and the associated phenomena of igneous intrusion, might be employed as a basis for the subdivision of Proterozoic time, and if the element moved as a whole, might even serve as a basis of correlation over the whole vast area. Laurentia, however, has not as yet been studied geologically except in a general way. Its detailed study will supply problems for generations of geologists yet unborn. Its southern margin alone, and that only in a few comparatively small areas, has been mapped in detail, but nevertheless exploratory and reconnaissance work has been carried out over almost the whole of the great expanse of this ancient continent chiefly by the officers of the Geological Survey of Canada, so that we have a good general knowledge of the main outlines, at least, of its geological history. It is proposed here to present a general statement of the results obtained, as they bear upon the history of Laurentia in pre-Cambrian times and afford a basis for pre-Cambrian correlation, making use of this principle of critical diastrophic epochs and drawing evidence from the area as a whole, rather than from a few restricted areas on its southern border.

This task is rendered comparatively easy owing to the fact that a critical digest of the mass of information concerning the pre-Cambrian rocks of the great central and northern portions of Laurentia, which is found disseminated through the reports and papers by the various geologists who have worked in this great area, has recently been prepared by Dr. George A. Young, of the Geological Survey of Canada, who has himself traveled very extensively in this northern country. I am indebted to Dr. Young for permission to make use of this unpublished material, but the original papers have been consulted in the case of all the more important occurrences.

The great expanse of Laurentia is underlain predominantly by the rocks of the Laurentian system. These consist of gneisses in infinite variety which in the majority of cases have the mineralogical composition of granite, although some present foliated varieties of rocks ranging from syenite to diorite. The foliation is in some cases so faint that it can be detected only on large weathered surfaces, but generally it is quite distinct or even striking. In addition to the foliation the rock often displays a very distinct banding due to the alternation of varieties of diverse character or composition. This foliation is in many, and possibly in the majority of cases, a primary structure and the darker bands very frequently represent included masses of overlying rocks, softened and in some instances partially digested. This foliation and banding was at one time regarded as a partially obliterated bedding and considered to present indisputable evidence that the rocks were of sedimentary origin. These gneissic rocks are not all of the same age, for frequently one mass can be seen to cut another. In addition to these gneissic granites, syenites, and diorites, however, the Laurentian comprises other kinds of plutonic rocks of very diverse character. Thus, from Minnesota to the shores of Ungava Bay, intrusions of anorthosite are found. Several of these, for the most part distributed along the margin of the protaxis in the province of Quebec and in the Ungava peninsula, present areas of from a few miles to 10,000 square miles in extent, and represent some of the more recent pre-Cambrian plutonics, although they themselves have been cut by still later granites. In fact, it is becoming more and more evident with the progress of geological investigation that the Laurentian is a vast complex of plutonic rocks of widely varying types and differing greatly in age, although there is no evidence to show that any of them were intruded later than the close of the Proterozoic. Whether in this enormously extended complex, which we term the Laurentian in the northern protaxis, there still survive any primitive sediments or any portion of an original crust, through which these great bodies of intrusive rocks forced themselves, is unknown. None have as yet been distinguished with certainty, but if any do exist they are probably similar in composition to these earliest intrusive rocks and might easily escape notice.

It is certain, however, that the overlying Keewatin and Grenville series were deposited on some floor, although this floor has remained undiscovered up to the present time. Either the Laurentian gneiss, or some part of it, represents the original floor, subsequently melted and intruded into the overlying sediments, or the original floor remains unrecognized among the enormous bodies of intrusive rocks which resemble it in character.

Resting on this Laurentian complex, in the region of the Great Lakes, although penetrated by it, the lowest sedimentary series here recognized is the Keewatin series, a great body of rocks largely of pyroclastic origin, but in some districts containing great thicknesses of epiclastic material.

It is not necessary here to make further reference to this great series which has been so well described by so many writers. In this region it is the oldest sedimentary rock recognizable as such.

In the region of the St. Lawrence Valley this Keewatin is not seen, but there is a series of extraordinary thickness and enormous areal extent composed essentially of limestones, which rocks are practically absent in the Keewatin. Whether this series, known as the Grenville series, is the equivalent of the Keewatin is unknown as yet. If it be, the designation of the Keewatin by Van Hise as a series composed essentially of pyroclastic material to which stratigraphic methods cannot be applied and the assumption that such material characterized the earliest stratified deposits of the earth's history, must be abandoned, for the Grenville series is distinctly stratified and is one of the greatest limestones series in the earth's crust. However that may be, these two series constitute the oldest sediments in the earth's crust recognizable as such in their respective districts. Similar rocks apparently characterize extensive areas in the more northern and remote portions of Laurentia representing the oldest recognizable sediments in these districts.

At the close of this first period of long-continued sedimentation there came an epoch of diastrophism—a thrust exerted from a south-easterly direction against the ancient continent threw these series into a succession of great folds running approximately parallel to the present valley of the St. Lawrence. Enormous bodies of granitic magma rose in great bathyliths along the axes of the folds, disintegrating, fraying out, metamorphosing and partially absorbing the lower surfaces of the invaded sediments. Everywhere over thousands of square miles these ancient sedimentary rocks can be seen to have floated on the granite magma or to have been sunk into it and to have been cut to pieces by apophyses of it. That these movements were, in many cases at least, very slow, is shown by the fact that a study of the primary gneissic structure displayed by the bathyliths demonstrates that the upward movement of the latter began before crystallization had set in and continued while the magma was slowly filling with the products of crystallization and until it finally froze into a solid rock. This epoch of diastrophism, resulting in the elevation of great tracts of country, brings to a close the first clearly recognizable chapter in the history of Laurentia.

After prolonged and profound denudation the sea again transgressed upon the continent of Laurentia and in this sea were laid down the strata of the earlier Huronian time. The sea at this time passed over what is now the region of the Great Lakes and extended at least as far north as Lake Mistassini and as far west of the head of Lake Winnipeg. Locally it evidently extended as far inland as the latitude of the northern end of Hudson Bay. Within this earlier Huronian time there was, following the deposition of the Lower Huronian, a period of subordinate elevation and depression in the district of the Great Lakes marked by the deposition of the Middle Huronian. At the close of this period of deposition, there was again an epoch of widely extended diastrophism due to a thrust exerted upon the southern portion of the continent from the ocean bed to the southeast and resulting in the widespread folding of the sediments which had been deposited over the southern portion of the protaxis, into a series of mountain ranges running in a northeasterly to southwesterly direction, with accompanying metamorphism of the folded strata and deep-seated intrusion of vast amounts of igneous rock. It may be that the great body of sediments forming the Grenville series really belongs to this rather than to the earlier Keewatin period, but be that as it may, these great orogenic movements which took place at the close of the earlier (Lower and Middle) Huronian time, brought to a close the second great chapter in the pre-Cambrian history of Laurentia.

There then followed a period of deep and long-continued erosion, during which the Lower and Middle Huronian and the underlying sedimentaries were swept away over the greater part of the region, leaving only the lower portion of the folds—the roots of the mountains —in the form of long narrow belts, separated by the granitic rocks marking the axes of the intervening anticlinal uplifts. This period of profound erosion constitutes what Lawson has termed the Eparchean Interval. Up to this time the movements which affected the continent of Laurentia were due, as has been stated, to thrusts coming from the southeast and caused by the negative element underlying the Paleozoic plain in this direction, at that time constituting the ocean bed, by its subsidence crowding against the positive element which formed the continent of Laurentia. This is seen, as has been stated, in the distribution of the older rocks of the first two chapters of the pre-Cambrian in the form of long narrow belts running in a general northeasterly and southwesterly direction and representing the downward sagging portions of the ancient folds.

Succeeding this long period of intense and widespread erosion, which followed upon the conclusion of Middle Huronian or pre-Animikie time, there was again a very widespread transgression of the sea upon the surface of the continent of Laurentia. In this was laid down a series of sediments which while occurring at localities sometimes separated from one another by hundreds of miles, yet preserve the same general features. These younger rocks form chains of islands fringing the east coast of Hudson Bay over a distance of about three hundred miles and have been described under the title of the Nastapoka series. This assemblage of beds dips toward Hudson Bay, generally at low angles, and lies in long parallel ridges with steep eastern faces. The strata comprise a group of arkoses and sandstones overlain by sandstones, argillites, cherty limestones and dolomites and calcareous shales with great intrusive sheets of diabase. The series has been found in places to have a thickness of at least three thousand feet and is further characterized by the occurrence at certain horizons of beds of banded jaspilite and iron ores. In the interior of Labrador, where the series dips at low angles toward the Atlantic, there is throughout a zone at least three hundred miles long, a development of similar rocks and here again occur the jaspilite beds. On the Atlantic side, at the head of Hamilton inlet, and further up the river of the same name, occurs a similar series, while on the Atlantic shores, far north, is found a great group presenting many like features. West of James Bay and south of Hudson Bay, rocks lithologically like the Nastapoka series underlie a hilly district rising like an island above the surrounding flat-lying Paleozoic beds. In this great district of the pre-Cambrian west of Hudson Bay, large areas bordering the Arctic about the mouth of the Coppermine River, and extending to Great Bear Lake, are underlain by a development of rocks resembling in nearly all respects the Nastapoka series and similar rocks have been described from the region about Great Slave Lake.

In all these widely separated localities great developments of the same rocks occur and often are accompanied by beds of jaspilite and iron ore. Everywhere the members present the same general arrangement, the strata cut by many faults, dipping at comparatively low angles and forming ridges frequently capped by diabase, while in most cases the beds have been found overlying with a most striking unconformity older granitic and gneissic rocks. These points of similarity seem to indicate that the scattered groups are all of about the same age and belong to a pre-Cambrian series probably at one time nearly continuous over the northern regions from the shores of the north Atlantic to about the valley of the Mackenzie. In Labrador and in the districts west of Hudson Bay the evidence indicates that the Nastapoka series was deposited after an epoch of severe erosion. Lake Mistassini, in northern Quebec, lies in a basin-like depression occupied by nearly flat-lying beds of cherty dolomite representing a portion of the Nastapoka series, while south of the lake these rocks have been found almost in contact with a development of the Lower (or Middle) Huronian, differing in no essential features from this group of rocks as found in numerous localities further southwest toward Lake Superior. The Lower Huronian is in a highly disturbed condition and has been penetrated by large bodies of granite. Neither the disturbances nor the granitic intrusions have affected the near-lying Nastapoka series so that the latter seems to be undoubtedly of post-Lower (or Middle) Huronian age, to have been formed after the Lower Huronian had been folded and invaded by the granites and then deeply eroded. The relation of the two series resembles that existing between the Animikie and Lower Huronian at Port Arthur, and largely on these grounds the Animikie or Upper Huronian of the Lake Superior region and the Nastapoka series of Labrador and the territories south and west of Hudson Bay been have considered to be equivalent to one another.

The Nastapoka-Animikie series, forming the third major division of the pre-Cambrian in Laurentia, is of great importance, marking as it does one of the most widespread periods of submergence and depression in pre-Cambrian times, involving almost the whole continent of Laurentia. No division of the pre-Cambrian in Laurentia is exposed over such a great area of country. The positive movement which raised these rocks out of the sea was chiefly epeirogenic in character, for over the greater part of this area they still lie nearly flat. That the close of this time was, like those which preceded it, marked by an epoch of diastrophism, is shown by the widespread development of faults, accompanied in places by overthrusting. These are the superficial expression of the movements of deepseated intrusions, representing the last period of pre-Cambrian orogenic action. These post-Animikie granitic intrusions are to be seen on the east coast of Hudson Bay where, while the Nastapoka series in most places lies unconformably on the ancient Laurentian and the associated gneisses and schists, yet at some points it is cut by granitic intrusions.

This epoch of mild diastrophism brought to a close the third great period in the pre-Cambrian history of Laurentia.

The Nastapoka series seems to be the youngest division of the pre-Cambrian now found in the region east of Hudson Bay, but west of this inland sea, in a district bordering the southern shores of Lake Athabasca and stretching over an area of perhaps 24,000 square miles, is a great development of coarse sandstone in thick beds which along the shores of the lake aggregate at least four hundred feet in thickness. These, the Athabasca sandstones, lie in nearly horizontal positions, at times with a conglomerate layer at their base composed of fragments of the Laurentian granites and gneisses on which they rest with a strong unconformity. The Athabasca sandstones, or a very similar series, are exposed for a long distance up the valley which is continued seaward by Chesterfield Inlet, situated far north on the western shores of Hudson Bay. Between Lake Athabasca and the above locality, and in places associated with similar sandstones, are extensive areas underlain by basic and acid volcanics, porphyrites, and porphyries. These sandstones and volcanic rocks are, by the Canadian survey, classed provisionally as of pre-Cambrian age and it seems not improbable that they are later than the groups of rocks about Great Bear and Great Slave Lakes which have been correlated with the Nastapoka series. Thus it is possible that the Athabasca sandstones and associated volcanics are the northern representatives of the Keweenawan of Lake Superior, concerning whose pre-Cambrian age there is a similar doubt.

These sandstones are composed chiefly of quartz grains which it has been supposed have been largely derived from a series of quartzites known as the Marble Island quartzites and which on the western shores of Hudson Bay occur at intervals over a stretch of about one hundred and twenty miles. These are associated with masses of dark schists, etc., lying in a disturbed condition. The presence of siliceous material in the widespread Athabasca series, so like that composing the quartzites, would seem to indicate that these latter were at one time also widely developed. What their equivalents elsewhere are, if they have any, is not yet known. They apparently are older than both the Athabasca and the Nastapoka series and may belong to some division corresponding to the earlier Huronian.

The rocks of the Athabasca-Keweenawan series are unaltered and lie practically flat. They have not been affected by orogenic disturbances or deep-seated plutonic intrusions. The uplift which raised them from the waters of the ocean was epeirogenic in character. Since the close of the pre-Cambrian, the continent of Laurentia, while preserving its character as a positive element, has undergone many oscillations, but orogenic or mountain-making forces have never manifested themselves, and the successive epeirogenic uplifts have resulted in and to a certain extent been compensated by the deep and long-continued erosion to which the continent has been subjected throughout the greater part of post-Proterozoic time.

Using therefore the epochs of diastrophism, which mark the successive stages in the pre-Cambrian development of the continent, as a basis of correlation, provisionally grouping the Athabasca Sandstones with the Nastapoka series, it would appear that we have three major periods in the pre-Cambrian history of Laurentia separated by two critical epochs of diastrophism, with possibly a fourth period represented by the Laurentian rocks at the base of the series. That is to say we have three major periods in the pre-Cambrian succession separated by epochs of diastrophism, which diastrophism at each epoch exhausted itself for the time. These are as follows:

Neo-Proterozoic	Keweenawan-Athabasca
	Upper Huronian or Animikie-Nastapoka
Meso-Proterozoic	Middle Huronian
	Lower Huronian
Eo-Proterozoic	Keewatin (Intrusive contact) Laurentian (embracing the original crust, if any remains)

The lines drawn between the several subdivisions indicate unconformities, the heavier lines indicating the major breaks referred to in the text.

If we attempt to make a comparative study of the earlier continental evolution of North America and that of Asia, we note at the outset that the Siberian nucleus is a portion of that northern Polar region which comprises also Russia, Greenland, and Laurentia, against which stress has been continuously exerted by the denser masses of the more southern latitudes. As has been emphasized by Suess, the Siberian nucleus has been undisturbed since a pre-Cambrian date, and the same is essentially true of Laurentia also. We find that in Asia there were in geological time great mediterranea which, after they had been made the basins for the accumulation of great thicknesses of sediment, were successively closed by great thrusts from the south which folded up the sediments into mountain ranges and then converted these into dry land. In Europe the Alpine region was a marine strait in Cretaceous time, which was subsequently converted in this way into a mountain range.

In the North American continent, of which Laurentia forms a part, there seems to have been a somewhat similar sequence in continental development. Thus the Appalachian Mountains and the Cordilleran range of British Columbia represent ancient marine valleys or straits whose sediments are now folded into series of mountain ranges. The thrusts which closed up these mediterranea and developed mountain ranges from them, were exerted in a northeasterly direction against the southwestern part of the continent, and in a northwesterly direction against the southeastern border of the continent, so that the folds are parallel to the margin of the present continent of Laurentia. If we inquire whether similar long, narrow, belt-like mediterranea existed in Laurentia in pre-Cambrian times, the answer seems to be in the negative. The surface of the continent seems rather to have had upon it at intervals throughout geological time a succession of large, irregular-shaped bodies of water, somewhat resembling the present Hudson's Bay, in which, however, great thicknesses of sediment were accumulated.

The sediments deposited in these bodies of water in Keewatin, Grenville, and the Earlier Huronian times, were folded up into mountain ranges crossing the southern portion of the protaxis in a northeasterly and southwesterly direction, coinciding with the course of the Appalachian folding.

The intense diastrophism which brought to a close the Eo-Proterozoic and again the Meso-Proterozoic time was exerted apparently as far north as the middle of Labrador and the southern portion of Hudson's Bay.

In the later pre-Cambrian mediterranea the Nastapoka-Animikie series and the Athabasca-Keweenawan series were deposited. The almost entire absence of orogenic movement at the close of this time, combined with the great extent and comparatively unaltered character of the rocks, makes the break at the base of the Nastapoka-Animikie series probably the most pronounced in the whole pre-Cambrian succession in Laurentia. Thousands of square miles of practically flat-lying sediments overlie remnants of a highly folded and metamorphosed antecedent series.

We thus have two major breaks in the pre-Cambrian succession, each marked by an epoch of diastrophism which exhausted itself for the time.

An identical series of two major breaks in the Proterozoic succession, marked by epochs of pronounced diastrophism which in each case exhausted itself, is found in the Asiatic portion of the nucleus.

The succession here is as follows:[1]

Neo-Proterozoic...... (Hu-t'o system)......	Tung-yu limestone T'ou-t'sun slates	Slates, limestones and quartzite.
Meso-Proterozoic.....	Si-t'ai series	Chiefly chlorite schist; quartzite conglomerate at the base.
(Wu-t'ai system)......	Nan-t'ai series	Siliceous marble, jasper, quartzite, and schist.
	Shi-toui series	Mica schists, gneiss, magnetite quartize, and basal feldspathic quartzite.
Eo-Proterozoic.......	T'ai-shan complex	Basal complex of varied gneisses and younger intrusions.

The lowest of these series, the T'ai-shan, resembles the Keewatin penetrated by Laurentian intrusions, being

a metamorphic complex, the constituents of which are largely igneous, though perhaps in part sedimentary in origin.[2]

This was brought to a close by a period of intense diastrophism. Suceeding this:

We distinguish with great certainty a great thickness of very early Proterozoic sediments—the Wu-t'ai—which were intensely deformed and metamorphosed during a mid-Proterozoic epoch of orogeny, owing to pressure exerted by the outlying negative elements, and a later Proterozoic series—the Hu-t'o—which represents shore conditions and which was moderately deformed by pressure exerted by the same cause at the close of the Proterozoic.

Applying therefore this criterion of diastrophic epochs to the correlation of the Proterozoic succession of these widely separated portions of the great northern nucleus, we obtain an identical result in both cases—the diastrophic movements seem to have affected the nucleus as a whole.

It would seem that these diastrophic epochs designate certain of the unconformities in the succession both in the Siberian portion of the nucleus and in Laurentia, as major, dominant, and of special importance, and others as subordinate and of minor importance. We thus have indicated a division of the Proterozoic into Eo-, Meso- and Neo-Proterozoic. On this basis of correlation the T'ai-shan corresponds to the Keewatin-Laurentian complex; the Mu-t'ai to the Lower and Middle Huronian, and the Hu-t'o to the Animikie-Nastapoka series.

[1] *Research in China*, Vol. II, p. 4. [2] *Ibid.*, Vol. I, Part I, p. 19.

These major breaks would seem to be as well marked and as important as those which characterize the separation of the Eo-Paleozoic and the Neo-Paleozoic in eastern America, or perhaps as that which brings to a close the Paleozoic succession in Europe.

If, as our knowledge of the pre-Cambrian becomes more complete, the correlation of these rocks over great areas by a time relation to diastrophic epochs proves to be generally applicable, we have a basis of correlation of great value and importance. This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement.

All that we really know at present is that

> there are great sequences of pre-Cambrian sedimentary formations, separated by many gaps from each other, which give one picture, growing less distinct in outline the farther back one goes, of the remotest periods of geological history, or, in other words, of periods of the earth's pre-historic age which is, according to the author's opinion, probably of greater length than all subsequent geological time.[1]

It is believed, however, that through the recognition of these diastrophic epochs, the dominant outlines of these pictures may perhaps be more clearly brought out and the relative values of the different parts thrown into relief in the case of each individual positive element, and that these epochs which have marked the successive stages of advance in Paleozoic and Mesozoic times, may thus be employed with advantage in deciphering the history of the pre-Cambrian as well.

DISCUSSION

CHARLES R. VAN HISE

It is with pleasure that I discuss briefly Dr. Adams' paper, since, allowing for differences of terminology, I find him in nearly complete accord with the

[1] J. J. Sederholm, *Explanatory Notes to Accompany a Geological Sketch Map of Fenno-Scandinavia*, Helsingfors, 1908, p. 31.

United States geologists in reference to the succession and relation of the pre-Cambrian series of Canada. So far as there are differences they will appear below.

The elucidation of the pre-Cambrian succession for the Lake Superior region, which term as here used includes the great tract extending from the Lake of the Woods to north of Lake Huron and south to the Paleozoic rocks, has been the work of many men extending through many years. In 1892, when *Bulletin 86* of the United States Geological Survey, on the Archean and Algonkian, appeared, the Lake Superior succession, as now recognized, had been fully worked out,[1] with the exception that what was then called the Lower Huronian has since been found to comprise two series; also the series now called Keewatin was called Mareniscan, but was properly defined. Some years after the publication of this bulletin, Mr. A. E. Seaman discovered the unconformity mentioned in the lower Huronian of the Marquette district. As soon as this discovery was made it was appreciated that the two divisions of the Huronian in the original Huronian area worked out by Pumpelly, Leith, and myself correspond with the two divisions in the Marquette district. The classification of the pre-Cambrian as thus developed was fully accepted by the International Geological Committee in 1904, and the table giving the succession was published by Leith in 1904, and by the committee in 1905, as follows:[2]

CAMBRIAN
    Upper sandstones, etc., of Lake Superior
        Unconformity
PRE-CAMBRIAN
    Keweenawan (Nipigon)
        Unconformity
    Huronian {
        Upper (Animikie)
            Unconformity
        Middle
            Unconformity
        Lower
            Unconformity
    }
    Keewatin
        Eruptive contact
    Laurentian

This succession is repeated by Dr. Adams in his communication, except that the unconformities are omitted, and it is extended to the entire Canadian pre-Cambrian region.

It is indeed gratifying to have completely accepted for the great Canadian pre-Cambrian area the succession which has been worked out for the Lake Superior region, but Dr. Adams implies that his classification rests upon a sounder basis than the same classification offered by others since "drawing evidence from the area as a whole rather than from a few restricted areas on its southern border." But unhappily for the contention of Dr. Adams, it is still true that the Lake Superior region is the only very extensive area in which the detailed geology has

[1] C. R. Van Hise, "Archean and Algonkian," *Bull. 86*, U. S. G. S., p. 195.

[2] *Journal of Geology*, Vol. XIII, p. 104.

been worked out and the full succession given in the table has yet been found. Also when the succession was originally worked out all available information in reference to Canada as a whole was considered and it was suggested that within the regions about Hudson Bay and the Copper Mines Rivers, the equivalents of at least two divisions of the Huronian and of the Keweenawan appeared to be present.[1]

As to the question of a floor for the Keewatin, according to our view, the Keewatin is simply the most ancient series which has been discovered to the present time. Naturally being the oldest series discovered, we have not yet found the rocks upon which it was laid down, and we make no assumption in this matter. Dr. Adams speaks of the Keewatin as a sedimentary series. If he means by this that it is a series laid down at the surface, this characterization is correct. However, we have frequently pointed out that this series is essentially composed of igneous rocks, including both lavas and fragmentals, and is only very subordinately of ordinary sediments.

As to the position of the Grenville series, I hold my opinion in reserve. Miller and Knight have shown that in the Hastings district where the series which Adams places in the Grenville is most extensively developed, there is an unconformity in the sediments. It is their belief that the greater part of the Hastings sediments, including the great limestone of Adams, belongs above this unconformity, below which is the Keewatin. If they are correct in this view, the larger part of the Hastings series included in Adams' Grenville belongs not with the Keewatin but with the Lower or Middle Huronian.

Dr. Adams says in reference to correlation by diastrophism: "This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities, and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement."

In my address before the Geological Society of America a year ago, I introduced the table of pre-Cambrian series for China with their separated unconformities as given by Willis. I remarked that the Lake Superior Algonkian series in their number and their separating unconformities present a remarkable similarity to the Algonkian of China, but said it would "not be well to too strongly emphasize the close correlation suggested." Also I mentioned the "possibility that in the future we may be able to correlate the unconformable series of the Algonkian in provinces separated as far from one another as the Lake Superior region and Northern China."[2]

[1] Charles R. Van Hise, *Bull. 86*, U. S. G. S., pp. 496–502, 1892; *16th Annual Report*, U. S. G. S., Part I, pp. 807–9, 1896.

[2] "The Problem of the pre-Cambrian," *Bull. Geol. Soc. of Am.*, Vol. XIX, p. 29.

Dr. Adams in his paper repeats the quotation from Willis and makes an identical suggestion as to correlation, but implies that this is done upon the basis of diastrophism. Evidently he thinks that there is an "unwarranted satisfaction" in the first case and not in the second.

Each unconformity between any two series of the Canadian region or of China means that between their depositions there has been an epoch of diastrophism and one of erosion. I should be interested to know how the extents and the magnitudes of pre-Cambrian diastrophisms are to be determined except by studying the extents and magnitudes of the unconformities, that is, the extent and amount of the foldings, metamorphisms, erosions, etc., which intervened between the various series. In the paper which I have just read I pointed out that some unconformities are local, some regional, and some probably intercontinental. Adams points out that diastrophism may be regional or intercontinental. Is the distinction between the two greater than difference in language? One we may suggest talks English, the other Esperanto. Evidently if satisfaction is unwarranted in one case it is unwarranted in the other.

I am obliged to dissent altogether from the reasoning in Dr. Adams' paper which makes discriminations as to the magnitudes of the various breaks, upon the basis of Willis' hypothesis of positive and negative continental elements, and upon assumptions as to the sources of the thrusts. Even if these theories be assumed to be correct we do not know that they apply to the North American pre-Cambrian region, for we know nothing of the extent and distribution of the various pre-Cambrian series which are hidden under later rocks. In the western United States where extensive areas of pre-Cambrian protrude through the later rocks, and also in the Mississippi Valley, where are isolated areas of pre-Cambrian, several pre-Cambrian series occur, some of which are probably the equivalent of the series found in the Lake Superior region. Evidently the various pre-Cambrian diastrophic movements cannot be assumed to be limited to the surface areas of pre-Cambrian.

The question of the major groupings of the pre-Cambrian series I shall not attempt to go into in detail, since to do this would result in leaving less emphatic the reality of the accord as to the pre-Cambrian succession which has now come about and which I trust has come to stay between the Canadian and United States geologists, through the acceptance for Canada of the succession mainly worked out in a great area along the southern border of the pre-Cambrian region.

However, I may recall that I fully discussed the major classification of the pre-Cambrian in my presidential address before the Geological Society a year ago, and gave reasons for the primary divisions of the pre-Cambrian into the Archean and Algonkian. In that address I gave objections to a zoic classification, similar to but not identical with that which Dr. Adams adheres to. His proposed major classification is eo-proterozoic, meso-proterozoic, and neo-proterozoic. These terms imply that the pre-Cambrian had three distinctive life periods, an *eo*, a *meso*, and a *neo*. This may be the case, but until fossils are found in the pre-Cambrian in sufficient abundance to justify a zoic classification, there can be no sufficient warrant for proposing that the major divisions of the pre-Cambrian be made upon a zoic basis.

CLOSING DISCUSSION BY THE AUTHOR

The aim of the paper on "The Basis of Pre-Cambrian Correlation" was, as stated, to suggest a method by which it might be found possible to correlate the various subdivisions of the pre-Cambrian rocks over widely extended areas rather than to enter upon a discussion of the classification of the pre-Cambrian of North America.

With regard to this latter classification, however, it must be pointed out that the paper shows that in a general way the classification adopted by the International Committees (United States and Canada) on the "Correlation of the Pre-Cambrian Rocks of the Lake Superior Region" and on the "Pre-Cambrian Rocks of the Adirondack Mountains, the Original Laurentian Area of Canada and Eastern Ontario," probably forms a satisfactory basis upon which the classification of the whole expanse of the great pre-Cambrian development of the Laurentian protaxis can be founded. Professor Van Hise is mistaken in stating that in the paper under discussion the succession recognized by these committees was adopted but that the unconformities were omitted, for in the wall diagram used to illustrate the paper, and upon which the succession of the pre-Cambrian rocks in Laurentia and China was set forth, the unconformities were especially indicated, black lines being used to show those which were of minor importance while broad red lines appropriately emphasized the major breaks in the succession. The unconformities and their relative importance are also shown in the text of the paper. In fact, this is the crucial point of the paper so far as Laurentia is concerned.

Professor Van Hise has insisted, in a long series of papers, that in the pre-Cambrian succession of North America there is one break which in importance far transcends all others, namely, that at the close of the Keewatin. Professor Lawson, however, has insisted that in this succession the chief break lies at quite a different horizon, namely, at the base of the Animikie.

The International Committees, while recognizing the succession of the various elements of the pre-Cambrian, absolutely declined to commit themselves to any opinion as to the relative magnitude or importance of the several unconformities which they recognized.

A study of all the work—much of it recent—which has been done in the more northern portion of Canada indicates that Professor Lawson's break—the Eparchaean Interval as he terms it—is one of the greatest unconformities in the whole pre-Cambrian succession of Laurentia, and probably quite as important, if not more so, than the break at the close of the Keewatin, and that the pre-Cambrian rocks are represented, not by two great systems entirely distinct and separated from one another, but by three great systems.

In Professor Van Hise's presidential address he has referred to the succession of the pre-Cambrian rocks in Scotland, Finland, and China as determined by Geikie, Sederholm, and Bailey Willis, respectively, and notwithstanding the fact that in these successions from one to six unconformities exist, he has in each case selected one unconformity as of paramount importance, and correlating this with the break at the summit of the Keewatin in North America, has held that these various successions support a dual division of the pre-Cambrian rocks which he has maintained to be world-wide. He closes his address as follows: "I wish to express my firm belief that the dual division of the pre-Cambrian into two great groups of rocks [Archaean and Algonkian] seems now as firmly established as the division between any other two groups." I feel, as stated in the paper, that in this conclusion an "unwarranted satisfaction" is expressed.

To sum up, therefore, it seems that the division of the pre-Cambrian rocks of Laurentia into two great major divisions—Archaean and Algonkian—is not supported by the facts in our possession. The pre-Cambrian succession is apparently rather threefold, which three divisions may, for convenience, best be designated as Lower, Middle, and Upper (Eo- Meso- Neo-) Proterozoic, quite independent of any consideration of the presence or absence of life.

CHAPTER III

EVOLUTION OF EARLY PALEOZOIC FAUNAS IN RELATION TO THEIR ENVIRONMENT

CHARLES D. WALCOTT

CONTENTS

INTRODUCTION

The evolution of early Paleozoic faunas could be treated with far greater effectiveness if the studies now in progress on the Cambrian faunas were nearer completion. That of the brachiopods is well advanced[1] but the great collections of the U. S. National Museum, representing the crustacea and other invertebrates, have not been studied as to their mode of occurrence, geographic distribution, and biologic and environmental relations. Only a brief summary of the known evidence afforded by the Cambrian rocks and faunas of North America is considered in this paper.

Animals and plants, as now known, are profoundly influenced by their environment, hence we will first broadly outline the conditions under which the known marine organisms of Cambrian time lived.[2]

NORTH AMERICAN CONTINENT AT THE BEGINNING AND AT THE CLOSE OF CAMBRIAN TIME

The information obtained since the publication of my first map on this subject in 1891[3] has been assembled on the two accompanying maps by Mr. Bailey Willis. The first map outlines a central mass

[1] *Smithsonian Miscellaneous Collections,* Vol. LIII, No. 4, 1908, pp. 139–65.

[2] *Bull. Geol. Soc. Amer.,* Vol. X, 1899, pp. 199–244.

[3] *Bull. U. S. Geol. Survey,* No. 81, 1891, Pl. III.

of pre-Cambrian land, flanked on either side by large barrier islands that served to protect straits, sounds, or seas from the open ocean. Ocean currents flowed through the sounds with varying force and volume, not only from the cold arctic waters to the north, but from the warm tropical region to the south. The relative position of land and sea is based on the present interpretation of the observed characters and distribution of the pre-Cambrian and Lower Cambrian rocks. The distribution of Lower Cambrian faunas indicates the probable courses of the marine currents. A fundamental assumption is that the great ocean basins and continental masses occupied their present relative positions during at least the Algonkian portion of pre-Cambrian time.

The map of the continent at the close of Cambrian time shows that during this period upon the continental area marked changes in the positions of the land and sea took place. Broad shallow seas followed the transgressing shore-line of Middle Cambrian time, offering most favorable conditions for the long-continued development and distribution of marine life.[1] There were undoubtedly deep and shallow seas and bays, cold and warm waters, strong and weak ocean currents of unlike temperatures, protected bays with sandy and muddy bottoms, shore lines gently sloping to deep water, and many conditions promoting the evolution of the faunas through favorable or unfavorable changes in environment, temperature, and food-supply.

The sediments of Cambrian time are mainly those deposited near the shore-line and in adjacent relatively shallow waters. There is little if anything to indicate deposits of the abyssal sea. If the littoral fauna of the Cambrian sea had begun to work its way down the continental slopes beyond the continental margin into the depths, we can find no evidence of it, either in the Cambrian rocks, or in the character of the present deep-sea fauna.

The life of Lower Cambrian time included Crustaceans (trilobites, ostracods), Mollusca (gasteropods), Molluscoidea (brachiopods), Vermes (annelids), Echinodermata (cystoids), Coelenterata (sponges, corals, jelly-fishes), and the simplest animals, the Protozoa (rhizopods). Immense quantities of microscopic, unicellular plants were undoubt-

[1] See theoretic section at the close of Cambrian time: *Bull. U. S. Geol. Survey,* No. 81, 1891, Pl. II.

edly present, and, together with the minute Protozoa, must have formed the primary food-supply.[1]

The rôle assigned by Dr. W. K. Brooks to microscopic forms was an important factor in Cambrian time, for the organisms found in the rocks of that period were mainly carnivorous, and were adapted either to straining minute organisms from the water, or to gathering them up from the bottom.

Uniform marine physical conditions over the submerged portions of the continental platform in Lower Cambrian time are indicated by the uniformity of the fauna on opposite sides of the present continent. Whether this fauna was distributed between the east and the west to the north of the central land-area, or south of it, is not definitely determined, yet the absence of Lower Cambrian rocks and fossils from the collections made in the Arctic region, and the presence of closely allied species in the Lower Cambrian rocks of Alabama and California, point to the southern coast-line as the probable highway for the distribution of the littoral fauna. Nothing that suggests the Lower Cambrian fauna is known from South America; in this case, deep water may have been the barrier.

With the advent of Middle Cambrian time land-areas came into existence on the northeast, forming barriers which so affected marine conditions in relation to life that the Paradoxides fauna developed in the Atlantic basin and the Olenoides fauna in the Appalachian region south of the Champlain Valley. To the south and on all sides of the central land-area the advancing seas forced the faunas to shift their habitat and either to adjust themselves to the new conditions or to perish. Local isolation for long periods led to the development of new forms, and these, when the barriers were removed, contested and competed for their position and life with other faunas until, by a process of elimination of those least fit to survive, there was hastened the development of a large and varied fauna. With the close of Middle Cambrian time more stable conditions returned, and the era of rapid evolution was checked until the impulse of new conditions of environ-

[1] W. K. Brooks, *Studies from the Biological Laboratory, Johns Hopkins University*, Vol. V, 1893, pp. 136–38. On p. 137 Dr. Brooks says: "The simplicity and abundance of the microscopic forms and their importance in the economy of nature show that the organic world has gradually shaped itself around and has been controlled by them."

ment and an accumulated tendency to change resulted in the great evolution of life in the lower Ordovician.

LIFE AT THE BEGINNING OF KNOWN CAMBRIAN TIME

The traces of pre-Cambrian life, though very meager, are sufficient to indicate that the development of life was well advanced long before Cambrian time began. The characteristic fossil of the known pre-Cambrian fauna is *Beltina danai*,[1] a crustacean probably more highly organized than the trilobite. The associated annelid trails indicate that this phase of the fauna was also strongly developed. Stratigraphically, this fragment of what must have been a large fauna occurs over 9,000 feet beneath an unconformity at the base of the upper portion of the Lower Cambrian in northern Montana.[2] This fact indicates that it is practically hopeless to search for the first forms of life—those that could leave a trace of their existence—in strata now referred to the Cambrian or early Paleozoic. With this thought in mind we shall consider what is known of the life of early Lower Cambrian (Georgian) time.

The oldest known Cambrian fossils are found deep down in the Lower Cambrian strata of southwestern Nevada and the adjoining Inyo County area of eastern California. In sections 120 miles apart the Lower Cambrian has a thickness of over 5,000 feet, with a great limestone forming the upper 700 to 2,000 feet. Below this limestone calcareous strata occur, but the predominating rocks are sandstones, and arenaceous, siliceous, and calcareous shales. In the lower 400 feet of the Waucoba Springs section and the Barrel Spring section south of Silver Peak in western Nevada[3] the fauna includes:

Annelid trails
Protopharetra, sp. undt.
Archaeocyathus, sp. undt.
Ethmophyllum cf. *whitneyi* Meek[4]
Mickwitzia occidens Walcott[5]
Trematobolus excelsis Walcott[6]
Obolella, sp. undt.
Orthotheca, sp. undt.
Holmia rowei, new species
Nevadia weeksi, new species

[1] *Bull. Geol. Soc. Amer.*, Vol. X, 1899, pp. 238, 239.

[2] C. D. Walcott, *Observations of 1908.*

[3] Walcott, *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 5, 1908, pp. 185–89.

[4] See *Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84.

[5] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[6] *Ibid.*, p. 146.

Although this fauna, according to our present knowledge, is the oldest known Cambrian fauna, it includes representatives of the several classes of invertebrates which I will enumerate.

Actinozoa.—The corals are represented by a very primitive form of *Protopharetra*, a small form of cup-shaped *Archaeocyathus*, and a small *Ethmophyllum* closely allied if not identical with *Ethmophyllum whitneyi* (Meek),[1] which occurs higher in the section. The latter is not a notably simple or primitive form of the Archaeocyathinae; on the contrary, it is nearly as far advanced as any species known in the Cambrian.

Vermes.—The annelid borings and trails that occur in and on the sandstones and shales are much like those of the Middle and Upper Cambrian.

Molluscoidea.—The two species of brachiopods represent widely separated genera. *Mickwitzia occidens* Walcott[2] is one of the primitive forms of the Paterinidae, while *Trematobolus excelsis* Walcott[3] is a typical form of the Siphonotretidae. The interval represented by the relative development of *Mickwitzia* and *Trematobolus* is sufficient to convince us that we must look far back in Cambrian, or it may be pre-Cambrian, time for the progenitors of the inarticulate brachiopods.

Pteropoda.—The forms representing *Orthotheca* are abundant, large, strong, and evidently as well developed as those of the Middle Cambrian.

Crustaceans.—The trilobites thus far found at this horizon are confined to one species of the genus *Holmia*. *Nevadia weeksi*, new species (referred at first to *Holmia*), has many segments, and is more primitive than such forms as *Olenellus thompsoni* Hall[4] and *Holmia bröggeri* (Walcott)[5] of the upper portions of the Lower Cambrian section. The other species, *Holmia rowei*, new species, is of the same general type as *Holmia bröggeri*. The absence of all other trilobite genera is the most marked feature of this early Cambrian fauna.

[1] *E. gracile* is considered to be a synonym of *E. whitneyi* (*Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84).

[2] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[3] *Ibid.*, p. 146.

[4] See *Bull. U. S. Geol. Survey*, No. 30, 1886, p. 167.

[5] See *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 638.

In the section 100 miles to the south, at Resting Springs, Inyo County, California, a brachiopod closely related to *Billingsella highlandensis* Walcott[1] occurs 2,800 feet below the upper limestone, in association with the trilobite *Holmia rowei.*

Comparing the species in the early Lower Cambrian fauna with the Olenellus fauna, in strata 5,000 feet higher in the section, we find a marked advance in the variety of the later fauna, but we do not know how much of this may be due to the absence, from our collections, of genera and species that may have existed during the deposition of the earlier sediments. In the earlier fauna of the Waucoba section the class characters of the Arthropoda, Mollusca, Molluscoidea, Vermes, and Coelenterata were developed, and while the study of the genera and species adds a little more to our knowledge of the rate of convergence backward in geologic time of the lines representing the evolution of animal life, it, at the same time, proves that a very long time-interval elapsed between the beginnings of life and the epoch represented by the Olenellus fauna.[2]

DISTRIBUTION OF THE LOWER CAMBRIAN (OLENELLUS) FAUNA OVER THE NORTH AMERICAN CONTINENTAL PLATFORM OF CAMBRIAN TIME

The Olenellus fauna lived on the eastern and western sides of a continent that rudely outlined, in its general configuration, the North American continent of today. Strictly speaking the fauna did not live upon the outer shore facing the ocean, but on the shores of interior seas, sounds, straits, or lagoons that occupied the intervals between the several land-masses that rose from the partly submerged continental platform east and west of the central continental area. On the eastern side, the first land east of the central portion of the continent extended from Alabama northeast along the line of the present Appalachian range to and including the Green Mountains of Vermont. Whether or not the fauna existed in the Connecticut River region to the east of the Green Mountains is unknown. That it occurred further east is shown by its presence in eastern Massachusetts and northwestern Newfoundland. Its presence in a still more easterly

[1] *Proc. U. S. National Museum,* Vol. XXVIII, 1905, p. 237.

[2] *Tenth Annual Report, U. S. Geol. Survey,* 1891, p. 595.

basin is proved by its occurrence on the peninsula of Avalon, to the east of the area of Archean rocks crossing central Newfoundland.

It is not my intention to discuss the evidence upon which the assertion of the presence of these various outlying seas, sounds, etc., is based. The evidence of the existence of such bodies of water has been well presented by Dana.[1] What I wish to call attention to now is that the Olenellus fauna lived upon the eastern and western sides of the main North American continental area of late Algonkian and early Cambrian time. This view is sustained by the following observations: (1) The strata containing the Olenellus fauna are known only in the eastern and western portions of the continent; (2) as far as known the Lower Cambrian strata are absent in the interior of the continent; (3) the Upper Cambrian strata are unconformably superjacent to the Algonkian and Archean rocks over the areas where the Middle and Lower Cambrian formations are absent; (4) the strata of the Middle and Lower Cambrian are comformably beneath the Upper Cambrian on the eastern and western sides of the present continent in all sections where the three divisions are present.[2]

The oldest known portion of the Olenellus fauna is limited to that section of the Cordilleran area mentioned on p. 197. This fauna was undoubtedly present on the continental shelves to the north and south, and may have been distributed around the southern extremity of the central land-area to the Hudson and Champlain valley region. Future investigation may thus prove that the *Holmia asaphoides* fauna[3] of eastern New York is the oldest part of the Olenellus fauna upon the eastern side of the continent, and that it may be compared with the *Holmia rowei* fauna of the Cordilleran area. The presence in both localities of genera belonging to the Archaeocyathinae indicates that warm currents were passing through the straits or sounds to the east and west of the central continental areas, and that condi-

[1] "Areas of Continental Progress in North America, and the Influence of the Conditions of These Areas on the Work Carried Forward within Them." *Bull. Geol. Soc. Amer.*, Vol. I, 1889, pp. 36–48. "Archean Axes of Eastern North America," *Am. Jour. Sci.*, 3d ser., Vol. XXXIX, 1890, pp. 378–83.

[2] The matter contained in the two preceding paragraphs appeared under the heading "Habitat of the Olenellus Fauna" in the *Tenth Annual Report, U. S. Geol. Survey*, 1891, pp. 556, 557.

[3] *Tenth Annual Report, U. S. Geol. Survey*. 1891, p. 570.

tions were favorable for a varied fauna. The arenaceous beds (with ripple-marks and trails) of the western Nevada-California area and the interformational conglomerates of eastern New York prove the presence in both areas of relatively shallow water.

The *Olenellus thompsoni* fauna,[1] of late Lower Cambrian time, is widely distributed about the margins of the continental area. Beginning at the Straits of Belle Isle on the northeast, it has been found in eastern Massachusetts, western Vermont, eastern New York, eastern Pennsylvania, and along the Appalachian area as far south as central Alabama. In the Cordilleran area it is known to extend from Inyo County, California, to the Wasatch Mountains of Utah, and northward to the line of the Canadian Pacific Railway in British Columbia.

With the exception of vertebrates, echinoderms, and cephalopods, the class-characters of the early Lower Cambrian fauna of Nevada were well advanced toward the varied and rich fauna of the lower Ordovician.

CONDITIONS DURING MIDDLE AND UPPER CAMBRIAN TIME

The physical conditions of the late Lower Cambrian time continued into early Middle Cambrian time, followed during Middle Cambrian time by a gradual submergence through erosion and probable warping of the surface of most of the continental area south of the Great Lake region.[2] As the marine waters slowly encroached upon this great area and upon the shores adjoining the Appalachian and Cordilleran seas the marine life of the times met with conditions favorable to a large development. This is illustrated by the abundant and varied Paradoxides fauna on the Atlantic side and the equally varied Pacific basin Olenoides[3] fauna found in nearly all localities where the Middle Cambrian sediments were deposited.

[1] *Ibid.*, p. 569.

[2] *Am. Jour. Sci.*, Vol. XLIV, 1892, pp. 56, 57.

[3] The Olenoides fauna is found on both the eastern and western sides of the northern Pacific Ocean, and the Paradoxides fauna on both sides of the northern Atlantic Ocean. This fauna includes a group of trilobites that are represented more or less fully in the Middle Cambrian rocks of North America, east of the Atlantic basin Paradoxides faunas, and in eastern Asia. The fauna includes: *Olenoides* Meek, *Dorypyge* Dames, *Neolenus* Matthew, *Dorypygella* Walcott, *Damesella* Walcott, *Blackwelderia* Walcott, *Zacanthoides* Walcott, and *Kootenia* Walcott.

EVOLUTION OF FAUNAS

That the environment of the faunas of Middle Cambrian time was more favorable for their rapid evolution than that of Lower and Upper Cambrian time is strikingly shown by the stratigraphic distribution of the brachiopods. In the restricted waters of Lower Cambrian time the known brachiopods (of the entire world) were represented by 20 genera and 75 species. In the expanding seas of Middle Cambrian time 31 genera and 243 species are known to have existed. With the more uniform conditions of Upper Cambrian time, and the dying-out of the impulse to variation created by both favorable and unfavorable environments in Middle Cambrian time, the brachiopods decreased in variety and numbers, and are represented by only 23 genera and 137 species.

About the same relative numerical ratios are exhibited by the trilobites but the exact statistics are not yet available. The favorable environment of the Middle Cambrian fauna is well illustrated by the development of *Ogygopsis*, *Asaphiscus*, and *Bathyuriscus* of Cordilleran Middle Cambrian time,[1] genera which are so far in advance of contemporary trilobitic genera that they have sometimes been referred, upon biological grounds, to the Upper Cambrian.[2]

The closing of Cambrian time was accompanied and followed by changes in the relations of the sea and land upon the continental platform that were favorable, like those of Middle Cambrian time, to the evolution of new genera and species, and to the existence of multitudes of individuals of the prolific species.

This is not the place for a detailed discussion of the faunas and sediments of the lower Paleozoic. Only the broadest generalizations can be touched upon. I think, however, that sufficient has been said to fix in your minds the following conclusions: (1) That more or less uniform and favorable, even warm, climatic conditions must be appealed to in explanation of the widespread occurrence of almost identical coral-like organisms in the Lower Cambrian, and of the vast number of individuals of various species of trilobites, etc., which existed in Middle Cambrian time; (2) that the rapid and accentuated devel-

[1] See *Bull. U. S. Geol. Survey*, No. 30, 1886, Pls. XXX, XXXI, and *Canadian Alpine Journal*, Vol. I, No. 2, 1908, Pl. 3.

[2] G. F. Matthew, *Trans. Roy. Soc., Canada*, 2d ser., Vol. V, 1899, p. 64.

opment of the Middle Cambrian faunas was due in great measure to enlarged opportunity caused by the extension of the Cambrian seas and the consequent shifting of shore-lines and changes in habitat, etc.; (3) that the diversification of the Middle Cambrian fauna, as a whole, may have been due, in a large degree, to the rapid development of narrowly provincial or isolated faunas that were subsequently merged into the more widely distributed fauna by the breaking-down of the restrictive barriers; and (4) that a free and more or less complete interchange of currents in the Cambrian seas was strongly instrumental in producing those cosmopolitan faunas so characteristic of the early Paleozoic. In other words it is evident that the evolution of the early Paleozoic faunas was profoundly influenced by their environment.

NOTE.—Since this paper was written in November, 1908, I have made a detailed examination of the genera and species referred to the *Mesonacidae* (*Smithsonian Miscellaneous Collections*, Vol. LIII, No. 6, 1910) and referred *Holmia meeksi* of the original paper to the genus *Nevadia* and limited its range to the basal Lower Cambrian fossiliferous strata in Nevada. The *Holmia rowei* fauna (p. 31) is now closely limited in stratigraphic range and is below the *Archaeocyathinae*-bearing strata.

MAY, 1910

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

1 AND 2. EARLY CAMBRIAN AND LATE CAMBRIAN[2]

BAILEY WILLIS
U. S. Geological Survey

At the Baltimore Meeting of the American Association for the Advancement of Science a number of paleogeographic maps of North America, representing the continent at intervals from Cambrian to Quaternary, were exhibited. They had been prepared in collaboration with some of the geologists who presented papers in the symposium on correlation, and to a certain extent they serve to illustrate the changing geologic conditions which form a factor in the problems of correlation. I have been requested to publish them in connection with the correlation papers in the *Journal of Geology*, and am glad to do so, although it is not practicable to present a discussion of the particular facts which have been considered in the construction of each individual map.

In general the lines of evidence have been considered somewhat in the following manner.

A certain period having been selected as that which should be mapped, the epicontinental strata pertaining to that time interval have been delineated. The phenomena of sedimentation and erosion have then been correlated, with a view to determining the sources of sediment and topographic conditions of land areas, and from these data the probable positions of lands have been more or less definitely inferred. Thus, certain areas within the continental margin are distinguished as land or sea, and these areas may be defined as separate bodies or connected according to inferences based upon isolated occurrences or upon later effects of erosion.

It is assumed that the great oceanic basins and such deeps as the Gulf of Mexico and the Caribbean have been permanent features of the earth's surface at least since some time in the pre-Cambrian. These deeps can thus be placed upon the map and their connection with the epicontinental seas may be tentatively established.

[1] Published by permission of the Director of the U. S. Geological Survey.

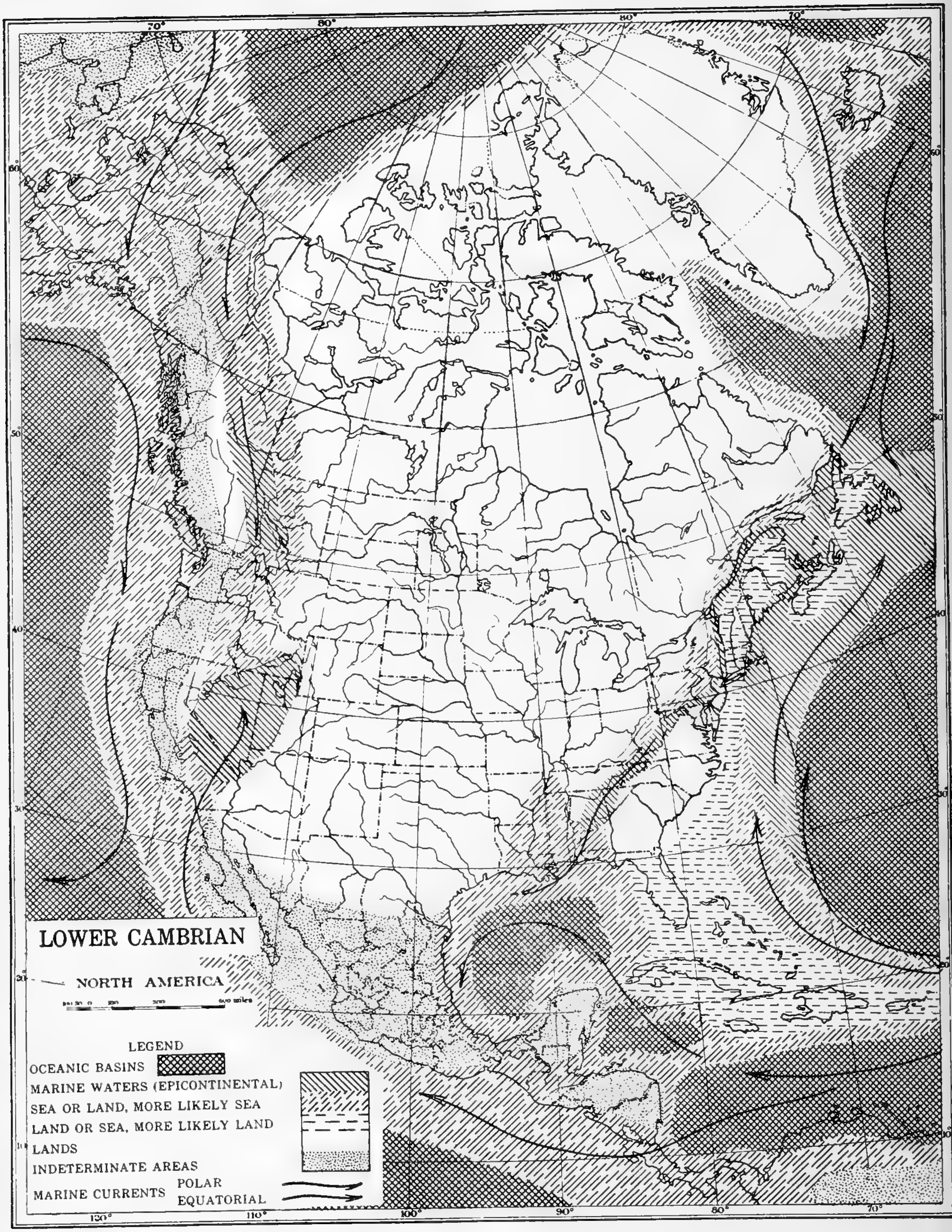
[2] Based largely on data furnished by C. D. Walcott.

When the distribution of lands and waters is thus inferentially completed, we may infer further that the dominant features of oceanic circulation have obeyed the conditions of atmospheric circulation and of rotation of the sphere which now govern the great oceanic eddies. We may introduce in the Atlantic and Pacific the dominant drifts from east to west in equatorial regions with the resulting circulation northward along the east coast and southward along the west coast of the continent. A circulation of the oceanic waters in the epicontinental seas must result from the great oceanic drifts, and the direction of flow will be determined by the configuration of the lands and the depths of the seas.

From the geographic conditions thus developed inferences regarding the climate and the life habitats of the time may be drawn. If now we turn to the records of paleontology and compare the distribution of faunas and floras with the conditions of distribution which should result from the inferred physical phenomena, we may check the whole line of reasoning and by a readjustment draw a step nearer to the truth. This is the method which has been pursued in making the maps of North America that are published with the papers in this number and that will appear in connection with further papers of the series.

In a first essay of this kind (and I am not aware of any earlier attempt to combine the various lines of evidence in a similar manner) it is probable that important facts have been overlooked. The very broad scope of the discussion makes this probability almost a certainty, and it is not to be expected that the maps here presented should give a final or satisfactory solution of the problems. They are to be regarded as tentative and suggestive only.

On one point they have been particularly criticized, it being said that each individual map covers so long a period of time and such diverse conditions that they do not truly represent any special geographic phase of the continent. This criticism is valid, and one of the steps in the advancement of knowledge will be that of selecting narrower time limits and more precise correlations than have been attempted in these cases. We may undoubtedly make progress in this direction at the present time so that the fifteen maps which will accompany this series may be replaced by two or three times as


LOWER CAMBRIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
120°
110°
100°
90°
80°
70°

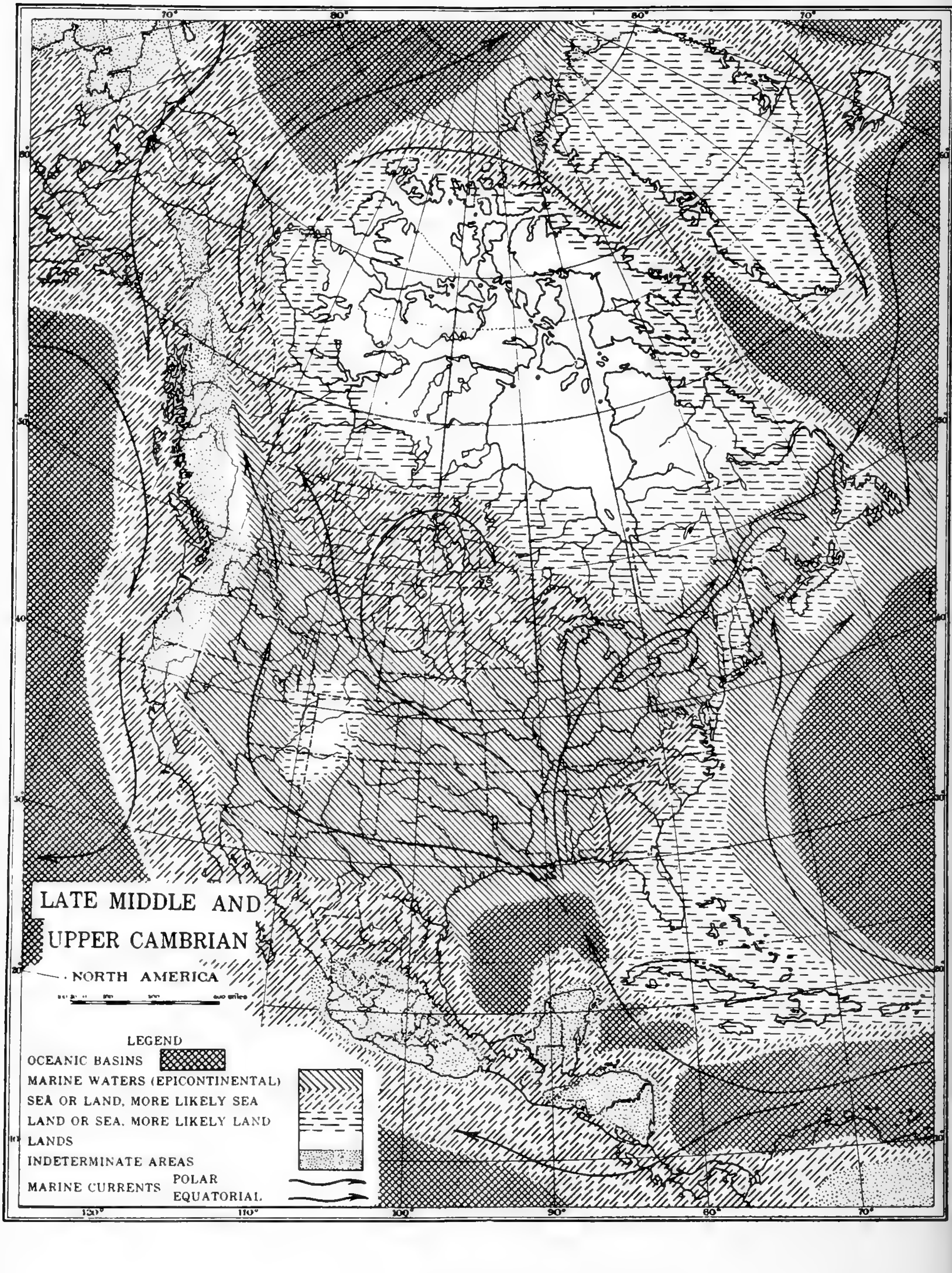
many; but there is danger in carrying the refinements too far on the basis of paleontologic correlation alone, since it is still difficult to distinguish between synchronous and homotaxial faunas or floras. It may be hoped that these paleogeographic studies will themselves assist us to a better understanding of the evolution of life conditions and thus lead to a solution of some of the problems of correlation with the aid of biologic evidence.

1. LOWER CAMBRIAN NORTH AMERICA

The map of lower Cambrian North America presented herewith conforms to the outline developed by Mr. Walcott in the course of his studies. East and west of the central land mass are relatively narrow sounds limited on the oceanic side by islands or land masses of indeterminate extent. The old land area of Appalachia is believed to have covered the region of the West Indian Islands, it being well established that a somewhat extensive land extended to the southeast of the Appalachian trough, and it being plausible that that land lay between the Atlantic deep on the northeast and the deeps of the Caribbean and Gulf of Mexico. In the adaptation of marine currents to oceanic and continental features, it is inferred that the return waters from the Arctic occupied the sounds along the inner continental margins. The distribution of these currents suggests that the habitat of the lower Cambrian fauna of the Appalachian trough on the east and the British Columbia-Nevada trough on the west was determined by the cool waters flowing southward. This view of dispersion of the faunas from the north is not shared by Mr. Walcott, who presents the alternative hypothesis of a connection of the faunas around the southern margin of the continent. The fauna of the Nevada basin appears to belong to warmer waters than that of British Columbia, inasmuch as it contains corals. The land areas of lower Cambrian time throughout the northern hemisphere appear to have been large. There is evidence in the character of the sediments and in glacial deposits in China that there were marked contrasts of climate.

2. LATE MIDDLE AND UPPER CAMBRIAN NORTH AMERICA

The map of late middle and upper Cambrian North America represents an expansion of the area of the epicontinental sea which


LATE MIDDLE AND UPPER CAMBRIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
120°
110°
100°
90°
80°
70°

probably was not at any time actually reached. The middle Cambrian sea extended further in certain areas than the upper Cambrian and retreated while the upper Cambrian sea spread over other regions. These details are not well worked out, though in part recognized. The map truly presents, however, the general fact that North America was to a great extent submerged and the land areas very markedly reduced. The prevailingly fine and calcareous sediments of the wide seas and the siliceous coastal plain sediments of the littoral deposits indicate that the relief of the land was low.

The conditions of marine circulation had apparently been modified by the expansion of the interior sea, and the climate conditions incident to widespread seas and low lands had become so ameliorated that similar habitats prevailed throughout a very wide range of latitude.

CHAPTER IV

PHYSICAL AND FAUNAL EVOLUTION OF NORTH AMERICA DURING ORDOVICIC, SILURIC, AND EARLY DEVONIC TIME

AMADEUS W. GRABAU
Columbia University

The following classification of the Ordovicic[1] and Siluric has recently been published by the author and will be made the basis of the present discussion of these systems:[2]

F. Upper Siluric or *Monroan.*
E. Middle Siluric or *Salinan.*
D. Lower Siluric or *Niagaran.*
C. Upper Ordovicic or *Trentonian.*
B. Middle Ordovicic or *Chazyan.*
A. Lower Ordovicic or *Beekmantownian.*

A. THE LOWER ORDOVICIC OR BEEKMANTOWNIAN

At the beginning of Ordovicic time, as now generally recognized, the great marine transgression or positive diastrophic movement, which obtained throughout Upper Cambric time, was in progress, so that the early Beekmantown strata overlapped the Upper Cambric (Saratogan) and came to rest directly upon the crystalline basement. The basal portion of the sedimentary series is generally quartz sandstone of greater or less purity, or sometimes a conglomerate with crystalline pebbles of local origin. This basal sandstone is commonly referred to the "Potsdam," that term being used synonymously with Upper Cambric. Aside from the question as to whether or not the Potsdam sandstone of the type locality is really of Upper Cambric age, it must of course be apparent that in a normally overlapping series of strata deposited by a transgressing sea, the basal sand member would naturally rise in the series in the direction of transgression and overlap, and that hence a basal sand is not everywhere of the same age. In northwestern New York, in Ontario, and in northern Michigan, these basal sands are probably in all cases

[1] The editor does not approve the terms "Ordovicic," "Siluric," etc.

[2] *Science*, N. S., Vol. XXIX, pp. 351–56, February, 1909.

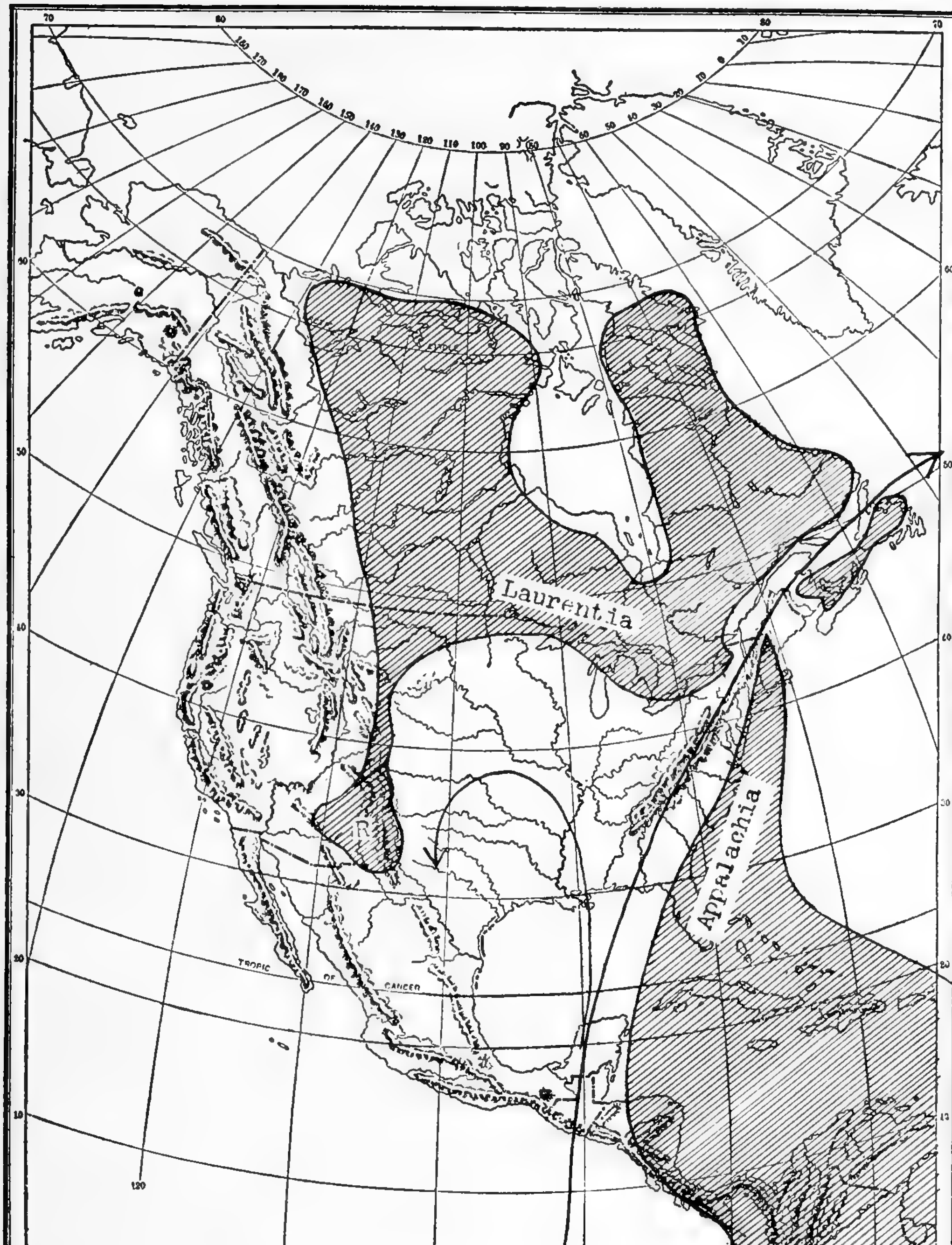


Fig. 1.—Paleogeographic map of North America at end of Upper Cambric time, and probable currents. R. Peninsula of Rockymontana.

post-Saratogan, belonging to the basal portion of the Beekmantown series as generally defined. This is clearly true of the conglomeritic layer at the base of the Little Falls dolomite in the Mohawk Valley, and is probably also true of the so-called Potsdam of the Black River region and the westward continuation of the outcrop in Canada. There is good reason for believing that the sea at the end of Saratogan time did not cover the present site of Lake Ontario, and that the basal sandstones of the Ontario region belong to the base of the overlapping early Beekmantown. In some cases the basal sands (St. Mary's sands) are even younger than this (Lowville, N. Y., Encampment d'Ours, Isle Lacloche, etc.), for the immediately overlying strata carry late Chazy (Lowville) or even Black River fossils, and, so far as now known, there is no break in sedimentation between these basal sands and the beds immediately succeeding, which thus determine their age. In all such cases, until positive evidence of a pronounced physical break or disconformity is determined between the two series, or until the basal bed is shown by unquestionable fossil evidence (exclusive of Scolithus, burrows, trails, and other problematic markings which may characterize various Paleozoic sandstones) to be of Cambric age, logical reasoning compels us to regard the age of the basal sandstone in each case as essentially that of the fossiliferous beds immediately succeeding, unless these are the very lowest post-Cambric beds.

One other point should be clearly emphasized. It is by no means established that the basal sandstones are everywhere of marine origin. In fact, the general absence of fossils, the frequent cross-bedding and other characters point rather to a continental origin of a part, at least, of this basal series, the agents of deposition being rivers or the wind. There is scarcely a geologist today who is satisfied with the complacent explanation, current only a short time ago, that the absence of fossils in a sandstone is due to "unfavorable conditions at the time of deposition," or to subsequent destruction of the fossils, in some mysterious way or other. That fossils abound in marine sandstones of all kinds, and even in conglomerates, is a well-known fact, and that the sands along our modern sea-shores are rich in shells and other hard parts of organisms, is equally a matter of common knowledge. The argument that the absence of fossils in a rock which elsewhere carries them, indicates some peculiarity of the sea-shore at that point, capable of barring the life of the sea, is a laborious explanation to fit a preconceived notion of the origin of the formation in question. Nor must we forget that the North American continent was above the sea during long periods of pre-Cambric and Cambric time, and that on those vast land areas subaërial deposition as well as erosion must have been in progress. It is therefore to be expected that in many, if not in most, regions the Paleozoic series begins with a formation of continental origin, the upper portion of which was reworked by the transgressing sea, and became incorporated as a basal member of the marine series succeeding. In this manner the contact between the continental and marine series often became an apparently conformable and perfectly gradational one, the hiatus between them being masked. It will of course be impossible in such a case to determine whether a basal bed of continental origin is of pre-Cambric, of Cambric, or of post-Cambric age; all that can be determined is the period at which its upper portion was reworked by the transgressing sea. If the basal bed is of slight thickness it is in such a case best referred to the age of the immediately succeeding marine formation.

The question naturally arises, should the lower portion of the Beekmantown be referred to the Cambric with which it forms a continuous transgressive series, or should it be retained in the Ordovicic with the remainder of the Beekmantown? While in New York the fauna is, so far as known, an Ordovicic one, in other localities beds considered of the same age carry a mixed Cambric and Ordovicic fauna. In this respect these beds and the typical Saratogan, as well as the St. Croix series of Minnesota and Wisconsin, probably correspond to the Tremadocien of Europe, which is classed as Upper Cambric by British geologists, but by German and other continental geologists as basal Ordovicic (Unter Silur). Matthew correlates these beds with the *Asaphellus homfrayi* beds of the St. John section, and so places them above the *Dictyonema flabelliforme* beds, which at present are also included in the base of the Ordovicic by some continental geologists. That such transitional formations are to be expected in any complete depositional series is, of course, obvious, and their precise reference is a matter of secondary importance.

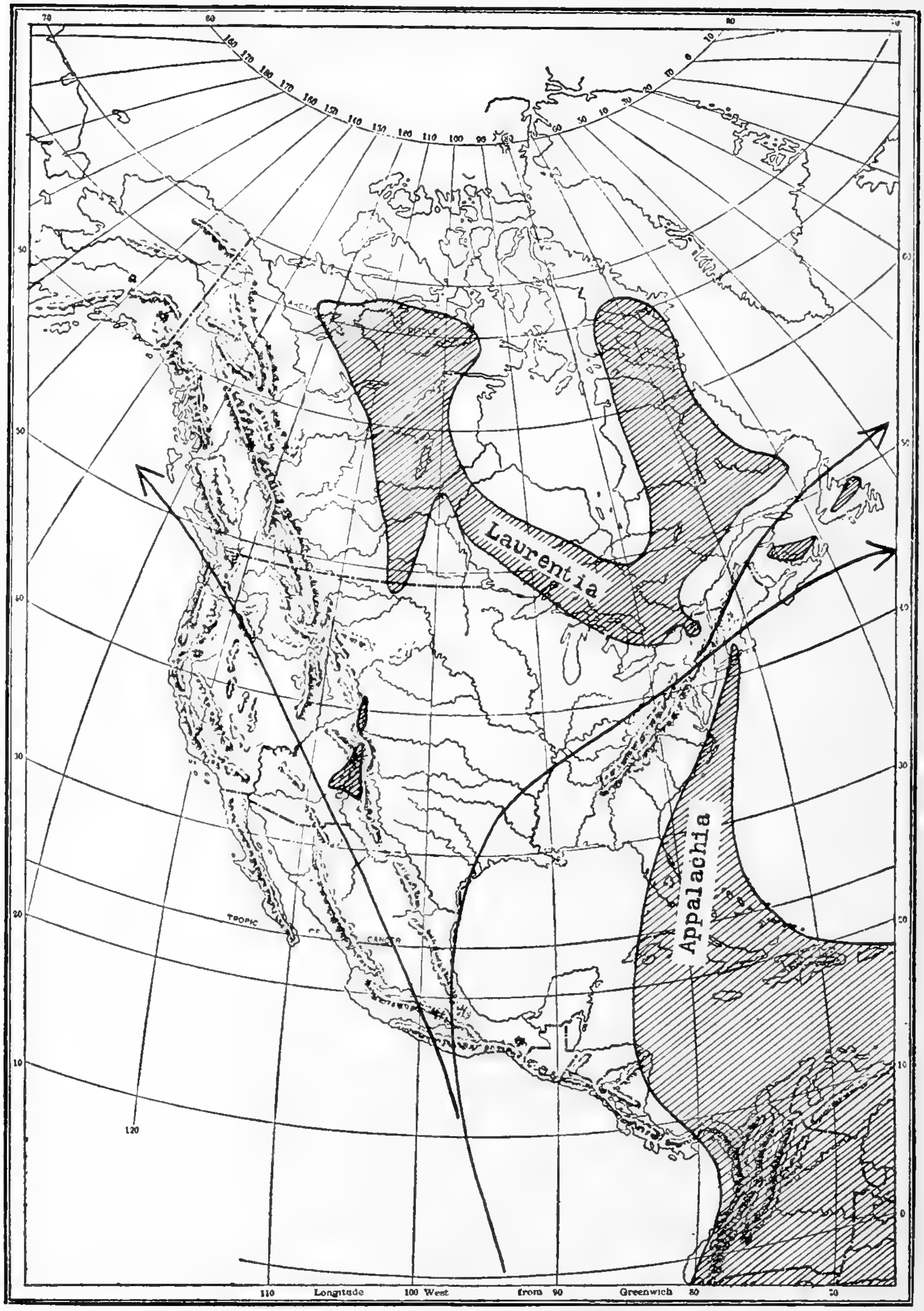


Fig. 2.—Paleogeographic map of North America in early Beekmantownian time, showing extent of maximum transgression and probable currents.

To make a distinct system of them, as has been proposed by some, will not solve the difficulty, because the transitional beds are likely to be of very variable quantitative and chronologic values in different localities. The accepted base of the Ordovicic—the summit of the Saratoga formation in New York, of the Franconia sandstone in the Mississippi Valley, and of the *Asaphellus homfrayi* beds on the Atlantic coast—is a perfectly satisfactory one, as long as the synchroneity of these formations is granted. (Compare Figs. 1 and 2.)

REGRESSIONAL PHASE OF THE BEEKMANTOWN

As has been fully demonstrated by the author elsewhere[1] and by Berkey,[2] the chief event of Beekmantown time in North America was the widespread regressive movement of the sea and the re-emergence of the continent. The extent of the movement is shown by the extensive disconformity between the Beekmantown and the succeeding Chazy formations. From this it appears that only a narrow trough remained in the Appalachian region as the sole representative of the interior or Mississippian sea, while most of the Pacific coast region, west of the Rocky Mountains axis, was probably uncovered (see map, Fig. 3). In the interior of North America the emergence was accompanied by widespread continental deposition recorded in the St. Peter sandstone. The detailed characteristics of this formation; the all but complete absence of fossils; the cross-bedding shown in many exposures; the rounded character of the sand grains, their grooved and pitted surfaces; the absence of the finer impurities; the uniformity of the size of grain in the same region—all point to long-continued shifting about of these sands by winds, and testify against their marine origin. The inclusions in the quartz grains show them to be derived from the crystalline oldland, the chief source being probably the Canadian shield. In some cases the contact with the underlying formations is abrupt and disconformable, showing that erosion of the uncovered limestones preceded the deposition of the sands. Not infrequently the contact

[1] A. W. Grabau, "Physical Characters and History of Some New York Formations," *Science*, N. S., Vol. XXII., pp. 528 ff., October, 1905; also, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 616 ff.

[2] C. P. Berkey, "Paleogeography of St. Peter Time," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 229–50.

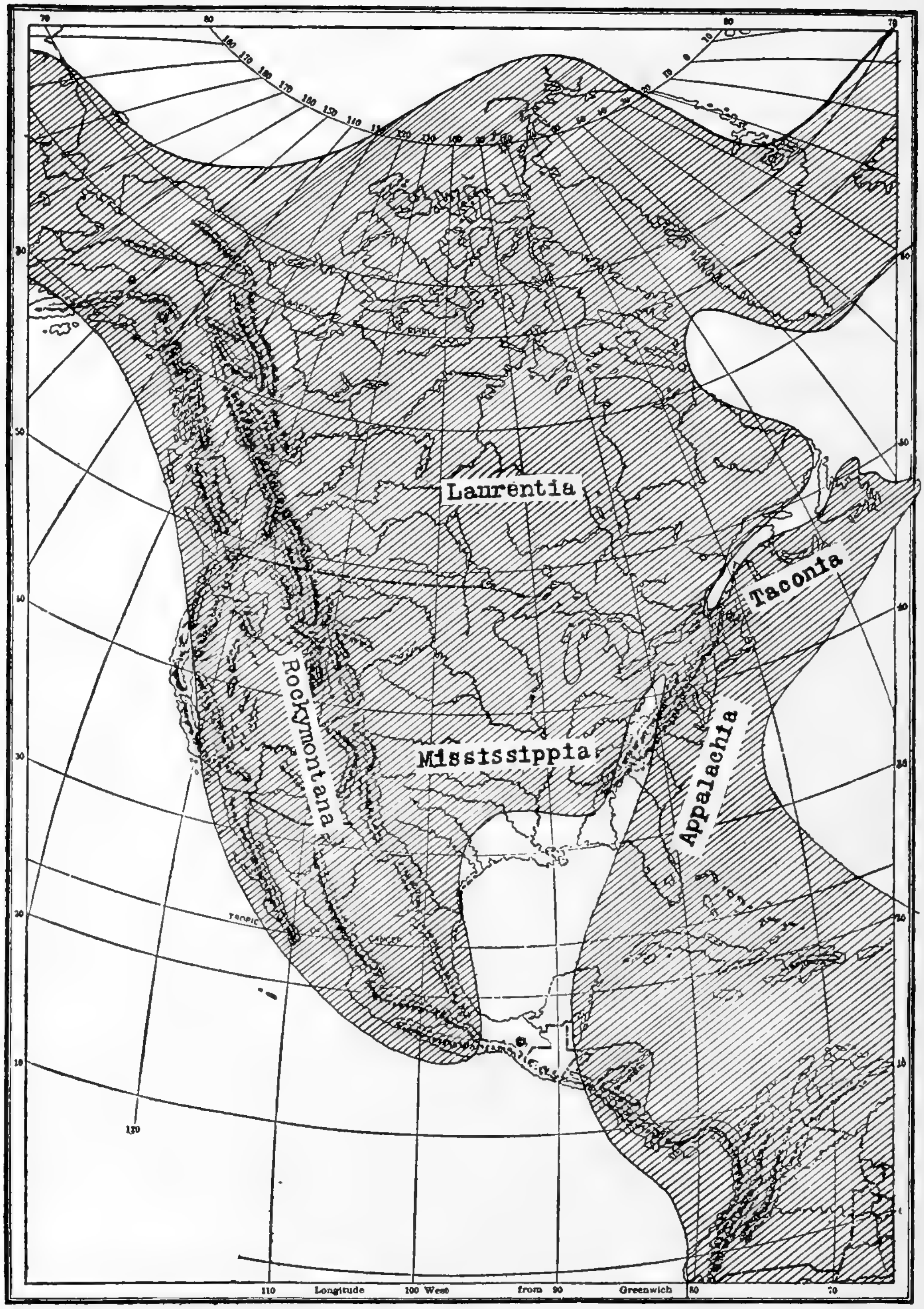


Fig. 3.—Paleogeographic map of North America at the end of Beekmantownian time, showing maximum retreat of the sea.

is as sharply marked as that of aeolian quartz sands found upon the clear-swept limestone floors of some modern deserts.[1] In some cases, however, there appears to be absolute conformity between the St. Peter sandstone and the underlying dolomites, pointing to continuous deposition. Both in Wisconsin and in Minnesota, the lower Magnesian beds are often slightly folded, and the lower St. Peter sandstone is likewise involved in these folds[2] (Fig. 4). The upper St. Peter, however, and the overlying Stones River, which are perfectly conformable, are not involved in these folds. In Minnesota, the Oneota, New Richmond, and Shakopee formations have a combined thickness of 105 to 260 feet. If the Jordan and St. Lawrence beds are regarded as Ordovicic, though they still contain Dicellocephalus, the thickness is increased to 190 feet minimum or 673 feet maximum. The faunas of all the beds of the Lower Magnesian series indicate lowest Ordovicic and close relationship to the Upper Cambric. In the Black River region, Cushing records 20 to 60 feet of lowest Beekmantown (Theresa), succeeded disconformably by Upper Chazy (Pamelia and Lowville limestones). The base is probably not exposed in this section, the basal sandstone, called Potsdam by Cushing, being most likely of later age. In the Mohawk Valley, 350 feet of Beekmantown (Little Falls dolomite) is followed disconformably by Upper Chazy (Lowville); but here, too, the base of the Beekmantown is not shown, and hence the true thickness is unknown. In the Lake Champlain region the Beekmantown is 1,800 feet thick; in southern Pennsylvania 2,250 to 2,300 feet; in central Pennsylvania nearly 2,500 feet; and in the Arbuckle Mountains of Oklahoma 1,250 feet. In all these localities, except central Pennsylvania, the upper limit of the Beekmantown is marked by a dis-

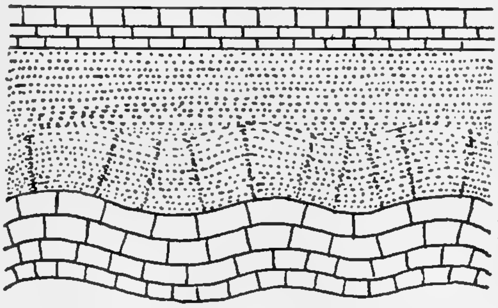


Fig. 4.—Showing the relationship of the Upper Stones River (S. R.) and lower Beekmantown (B.) Beds of Minnesota and the included St. Peter (St. P.) (Redrawn from Hall and Sardeson.)

[1] Compare Zittel, *Beiträge zur Geologie und Palaeontologie der lybischen Wüste.*

[2] Hall and Sardeson, *Bull. Geol. Soc. Amer.*, Vol. III., pp. 354, 355.

conformity, and the highest beds are thus wanting. In Center County, Pennsylvania, the upper beds appear to be completely represented. They are succeeded by 2,335 feet of dolomitic limestones, classed by Collie with the Beekmantown, but for reasons given elsewhere[1] referred by the author to the Chazy; and by 235 feet of limestones of Upper Stones River (Upper Chazy) age. The succession seems to be uninterrupted, placing this section in the region of non-emergence, while the others cited belong in that of emergence during late Beekmantown time. The section in central Pennsylvania does not, however, show the base of the Beekmantown, which is thus thicker than 2,500 feet (see Fig. 5). There seems no reason for doubting that the higher

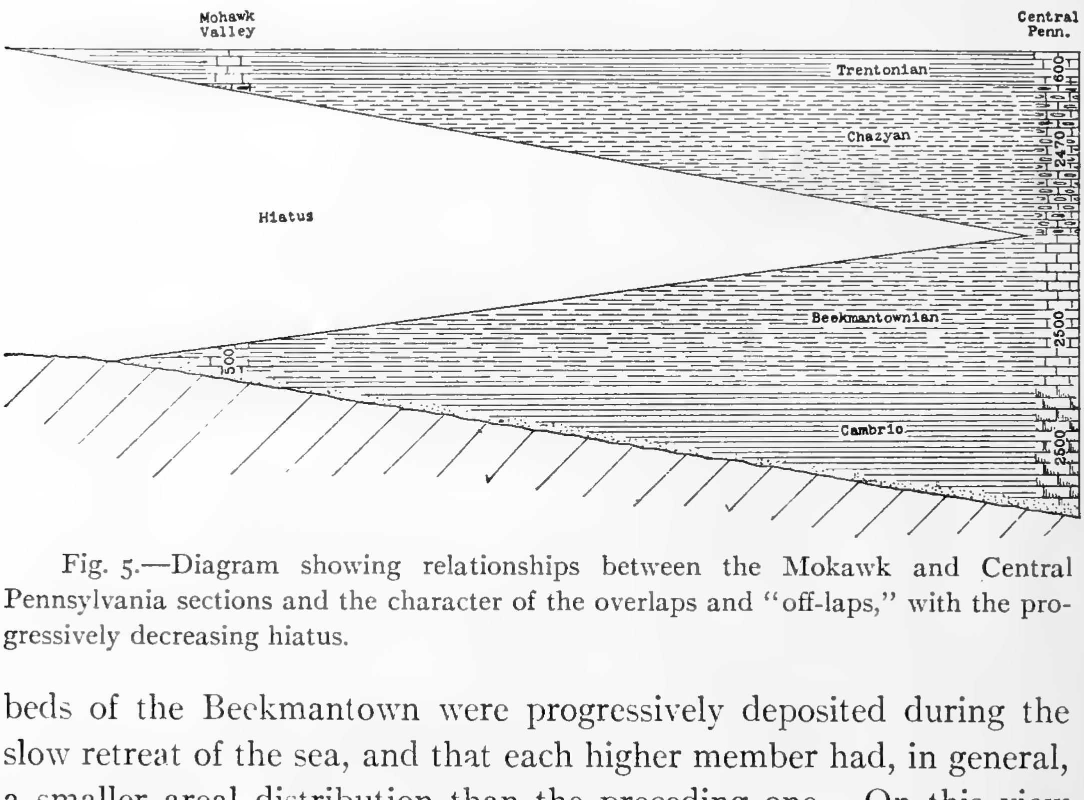


Fig. 5.—Diagram showing relationships between the Mokawk and Central Pennsylvania sections and the character of the overlaps and "off-laps," with the progressively decreasing hiatus.

beds of the Beekmantown were progressively deposited during the slow retreat of the sea, and that each higher member had, in general, a smaller areal distribution than the preceding one. On this view the successive members have the "off-lapping" arrangement of shingles, except that the earlier and lower formations are continuous beneath the higher ones. This is regressive overlap or "off-lap," and seems to supply the only rational explanation answering to the facts. To assume that the whole of the Beekmantown was deposited before retreat began, not only makes the negative diastrophic movement a cataclysmic one, where the positive movement was a very slow

[1] *Types of Sedimentary Overlap*, p. 619.

and regular one, but also necessitates the further assumption of an enormous erosion during the succeeding transgressive movements, which not only removed the greater part of several thousand feet of strata over the northern United States area, but also the whole of the extensive Canadian deposits of Beekmantown which must have reached far toward the Arctic regions, if the entire Beekmantown was deposited as a transgressional series. Aside from the fact that erosion would scarcely be very active during a positive diastrophic movement or transgression of the sea, it can hardly be assumed that such extensive erosion preceded the deposition of the St. Peter sandstone and the Chazy formation. Moreover, the intimate relation between the Lower St. Peter and the underlying Lower Beekmantown demands a close succession in deposition, the lower sand beds being probably deposited by the shoaling sea itself. If that is indeed the case, no higher dolomites of Beekmantown age than are now found ever existed in the Minnesota area.

West of the Rocky Mountains, the basal Uinta quartzite is chiefly if not wholly a continental deposit of pre-marine Cambric time, 12,000 feet or more in thickness. Upon this enormous basement series the eastward-transgressing Cambric sea laid down its progressively overlapping strata, the upper beds of the series being reworked during the progress. The transgressing sea apparently did not reach the region of the eastern Uintas, where the basal quartzite is succeeded by the Lodore shales. From these shales Powell reported Carboniferous (Mississippic?) fossils,[1] and he gives evidence of the existence of a disconformity between these shales and the basal sandstone. Weeks[2] identifies the Lodore with the Iron Creek shales of Berkey, which lie between the Uinta and the so-called Ogden[3] quartzites, and which Berkey correctly correlates with the Cambro-Ordovicic Ute limestone of the Wasatch. Weeks fails to recognize that, as Berkey has shown, the "Ogden" quartzite has united with the Uinta in the eastern section, the intervening shales having wedged out. The Lodore of the eastern Uintas thus lies above the "Ogden" horizon, and corresponds to a part of the overlapping Mississippic series (see Fig. 6).

The Lower Ordovicic retreat is shown in the western section by the

[1] *Geol. of the Uinta Mountains.* [2] *Bull. Geol. Soc. Amer.*, Vol. XVIII, pp. 435, 436.

[3] Blackwelder has recently shown that the "Ogden" of the Uintas is not the true Ogden.

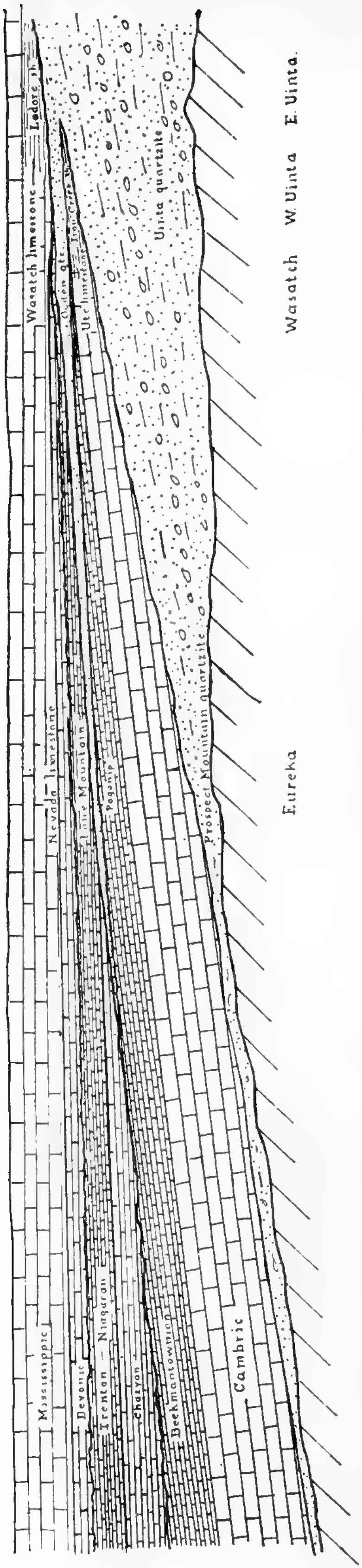


Fig. 6.—Diagram showing the relationships and overlaps of the Paleozoic strata west of the Rocky Mountains.

appearance of the so-called Ogden quartzite and conglomerate, which bears internal evidence of continental, chiefly river, origin; and to all appearance represents the sand and gravel wash which followed the retreating sea westward, and which was probably in large part derived from the basal Uinta quartzites, with which the "Ogden" seems to become confluent in the eastern Uintas.[1] This quartzite rests on higher beds in the western sections than in the eastern, thus showing the same relationship to the underlying series that is exhibited by the St. Peter sandstone. In the western Uintas it is underlain by 1,200 feet of shales, regarded as Cambric, though the highest beds may represent the Lower Ordovicic. In the Wasatch Mountains the Ute limestone, 2,000 feet thick, and of Cambro-Ordovicic age, lies between the "Ogden" and Uinta quartzites. In the Eureka section of central Nevada, the Pogonip limestone, 2,700 feet thick, underlies the Eureka quartzite, the westward continuation of the Ogden. The Pogonip represents, in its basal portion, the transition beds from the Upper Cambric, but corresponds mostly to the Beekmantown of eastern North America. Beneath it are 6,200 feet of fossiliferous shales and limestones of Cambric age. Here, as in the eastern region, succes-

[1] Berkey, *Bull. Geol. Soc. Amer.*, Vol. XVI, pp. 517–30.

sively higher beds appear beneath the quartzite in the direction of the retreat, indicating continuous deposition during the slow regressive movement of the sea, this being checked as the localities successively emerged.

A widespread negative diastrophic movement is thus shown to have taken place over the whole of the North American continent, accompanied and followed by the spread of subaërial clastics over most of the area. At least 2,500 feet of calcareous strata were deposited in the non-emerging areas, and most of this constitutes the depositional equivalent of the retreatal movement (see map, Fig. 3).

The Beekmantown faunas.—The Beekmantown faunas are, so far, best known from the Lake Champlain region, the Mingen Islands, and the Newfoundland section. The Lake Champlain region, including the Phillipsburg section of the Canadian extension, has furnished a considerable number of species. Its distinctive character will be seen on consulting published lists.

The Pogonip limestone of Nevada contains mostly species unknown outside of this formation in the West, though a number of them have been referred by Walcott to eastern species, largely Trenton and Chazy types. In almost all such cases, however, the identification is provisional, and regarded by Walcott himself as doubtful. There is nothing in the character of the fauna which positively demands its reference to either the Chazy or Trenton, as has been done.

GRAPTOLITE FACIES OF THE BEEKMANTOWNIAN

In the Hudson and St. Lawrence valleys the Beekmantown is represented by the lower portion of the Hudson River shales, above the beds with *Dictyonema flabelliformis.* Some 340 feet of strata appears to be referable to this series, of which the lower 300 feet constitutes the first and second Deepkill zones, synchronous with the Upper Point Levis zone of Canada and the St. Anne zone of Newfoundland. Here the genera Chlonograptus, Goniograptus, Tetragraptus, and Phyllograptus (*P. anna*), with *Didymograptus bifidus*, characterize a succession of zones recognizable in various parts of the world. The upper forty feet of this series (third Deepkill zone) is characterized by *Diplograptus dentatus* and *Cryptograptus antennarius.* This zone has been correlated by Ruedemann with the Chazy limestones of the Champlain region, but it probably is also referable to the Beekmantown, since most of its characteristic types occur in the Upper Arenig of Great Britain. The world-wide distribution of these graptolite faunas suggests that they were dispersed by strong currents sweeping through an open channel along the inner or western side of an Appalachian continent and its New England extension (Taconia). The fauna was most likely spread from Australia by strong currents passing up the west coast of South America and entering the Appalachian synclinal trough, along which it flowed northeastward to Newfoundland. Northwestward of this zone of mud-deposition we find the limestone of the Beekmantown grading down, by the addition of quartz grains, into the basal quartz sand, without intervening mud deposits (see map, Fig. 2).

With the progress of Beekmantown retreat the channel was closed, a land bridge connecting Taconia with Laurentia. Thus the mud deposition was checked and only a moderate thickness of Beekmantown strata of this type was formed. This represents, therefore, largely the lower part of the Beekmantown. As has been stated, it is probable that the Chazy is unrepresented by deposits of mud, the channel remaining closed until the end of that period, when it reopened through the progress of Chazy transgression, and the Normanskill beds, with a late Chazy (Lowville) and Black River graptolite fauna, were formed. In spite of some similarities, the *Diplograptus dentatus* and the *Coenograptus gracilis* zones are quite distinct, the important genera, Odontocaulus, Thamnograptus, Corynoides, Azygograptus, Leptograptus, Nemagraptus (Coenograptus), Dicellograptus, and Dicranograptus, appearing suddenly. In like manner, the characteristic Beekmantown genera, Dendrograptus, Goniograptus, Loganograptus, Dichograptus, Tetragraptus, Phyllograptus, and Didymograptus, continue through the third Deepkill zone, only the last of them extending into the Normanskill zone. Certain long-lived genera, Desmograptus, Diplograptus, Clonograptus, Climacograptus, and Cryptograptus, begin in the third Deepkill zone and extend through all or most of the remaining Ordovicic. Of the genera in common between the third Deepkill and the Normanskill, Didymograptus is represented by three species,[1] all common in the Normanskill, and all distinct from those of the lower horizons, where eighteen species are recorded. Of the genera beginning in the third Deepkill, or Point Levis zone, Climacograptus has only one species in the lower zone, which is not known above that zone, while there are thirteen species, most of them abundant, in the Normanskill; Cryptograptus has one species in the lower and two others in the higher zone, common in each case; Desmograptus has two species in the lower and one in the higher, the latter rare; Diplograptus has four species in the lower and thirteen in the higher horizon, all distinct; while Clonograptus has two rare species in the lower and nine in the upper, mostly common. It is thus seen that there are no species in common between the two zones, and the most characteristic genera of each are unknown or rare in the other. On the other hand, six out of the twenty-four species listed by Ruedemann for the third Deepkill zone, or 25 per cent., occur also in one or both of the lower zones. Its relationship to that and distinctness from the Normanskill zone thus becomes evident. The forty feet of the third Deepkill zone probably represents the last deposits in an already shoaling and contracting channel before interruption took place, this break continuing to the end of Chazy time, when a new graptolite fauna came into existence.[2]

On the whole, the Beekmantown represents one of the large stratigraphic divisions of the Ordovicic of North America. Its fauna is essentially a unit, and although the succeeding Chazy fauna is in part, at least, derived from the Beekmantown, its distinctness is nevertheless marked. The Beekmantown corresponds to a great negative diastrophic movement, with the exception of the lower portion, and its thickness (2,500 feet where fully developed) shows that it represents fully one-third of the entire Ordovicic series, and presumably represents one-third of Ordovicic time. From this it follows that the Beekmantown alone represents the Lower Ordovicic in North America, the Middle Ordovicic beginning with Chazy deposition. The term *Beekmantownian* has therefore been proposed as the North American equivalent of Lower Ordovicic, while the

[1] Varieties are here classed as species.

[2] See Ruedemann, *Graptolites of New York*, Vols. I and II.

term Canadian becomes obsolete. The *Beekmantownian* corresponds essentially to the *Arenigian* of England and its continental equivalent.

B. THE MIDDLE ORDOVICIC OR CHAZYAN

In its maximum development, the Chazy shows nearly 2,500 feet of limestones, many portions of which are highly fossiliferous. An apparently complete development of this series, resting with conformity upon the Beekmantown, is described by Collie from Center County, Pennsylvania. Here 2,335 feet of dolomitic limestones, with fossils poorly preserved, succeeds the Upper Beekmantownian; and above this is 235 feet of fossiliferous limestones of Upper Stones River (Upper Chazy) age, succeeded in turn by the Black River. Sedimentation seems to have been continuous throughout, and this section may therefore be regarded as typical of the Mid-Ordovicic in its entirety. In southern Pennsylvania, Stose reports a disconformity and hiatus between the Beekmantown and Chazy (Stones River) limestones. The latter are from 800 to 1,000 feet thick, and are succeeded by the Chambersburg limestone (100 to 600 feet thick), which carries an Upper Chazy and Black River fauna. Continuous deposition seems to have obtained between the two series. In the Lake Champlain region, a hiatus also exists between the Beekmantown and Chazy, with the result that only about 900 feet of Chazy occurs in this region below the Black River beds. In western Newfoundland at least 2,000 feet of strata is referable to this series, the succession being conformable. Here, however, the upper limit of the Chazy is not known, the highest bed (P) being succeeded by continental sediments of much later age.

In the Arbuckle Mountains the hiatus between Beekmantown and Chazy is marked by a sandstone, and only the upper 2,000 feet of the Chazy (Simpson) is shown, followed by Black River. The Chazy is absent in the Mohawk Valley, except for a few feet of Lowville which lies disconformably upon the eroded surface of the Lower Beekmantown (Little Falls dolomite), and is conformably succeeded by the Black River. In the Black River Valley, at Watertown and northward, the sedimentation from Lowville to Black River is continuous and gradual. Cushing[1] finds in the Theresa quadrangle

[1] *Bull. Geol. Soc. Amer.*, Vol. XIX, pp. 155–76.

from 115 to 215 feet of strata beneath the Black River, and resting disconformably upon the Lower Beekmantown (Theresa formation), which, with its basal sandstone (called Potsdam by Cushing), has a maximum thickness of 140 feet. Cushing restricts the term Lowville to the upper 75 to 85 feet of pre-Black River strata, separating the lower part, on paleontologic grounds, as the Pamelia limestone. At Lowville and elsewhere this series overlaps the Beekmantown, resting with a basal sandstone upon the crystallines. The Pamelia fauna is an Upper Stones River fauna, according to Ulrich, while the fauna of the Lowville is compared with that of the Upper Chazy.[1]

In the Canadian region, only Upper Chazy (Lowville and possibly the Pamelia equivalent) is present. In a number of localities it rests directly upon the pre-Cambrics, generally with a basal sandstone (St. Mary's sandstone). In some cases, however, lower beds (Beekmantown, with basal sands) have been reported. In Minnesota and Wisconsin the Upper Chazy is called Stones River, though it represents only the upper part of the Stones River formation of Safford's Tennessee section where the thickness is 360 feet. The Minnesota beds are 32 feet thick and are probably the exact equivalent of the Lowville of New York, though the fauna is stated to be more like that of the Pamelia. The relation of these beds to the underlying St. Peter sandstone is significant, since the contact is perfectly conformable and gradational. Moreover, Stones River fossils (*Hormotoma gracilis*, *Lophospira perangulata*, etc.) are found in some of the upper beds of the St. Peter, showing that with the advent of the Chazy sea, the sand dunes of the St. Peter desert were incorporated as basal sands in the overlying formation. This meant, of course, a slight reworking of the sands by the encroaching sea. That this reworking did not reach to the bottom of the St. Peter, at least not in all cases, is shown by the persistence of the folds and faults in the lower beds, whereas they are absent in the upper (see Fig. 4). A comparison of sections shows that in general lower beds of Chazy age appear progressively above the St. Peter as we proceed southward and eastward. The relationship of these beds to the St. Peter has not been discussed in detail, but it is certain that in some localities, at least, the gradation observed in Minnesota obtains. The relation-

[1] See Cushing, *loc. cit.*

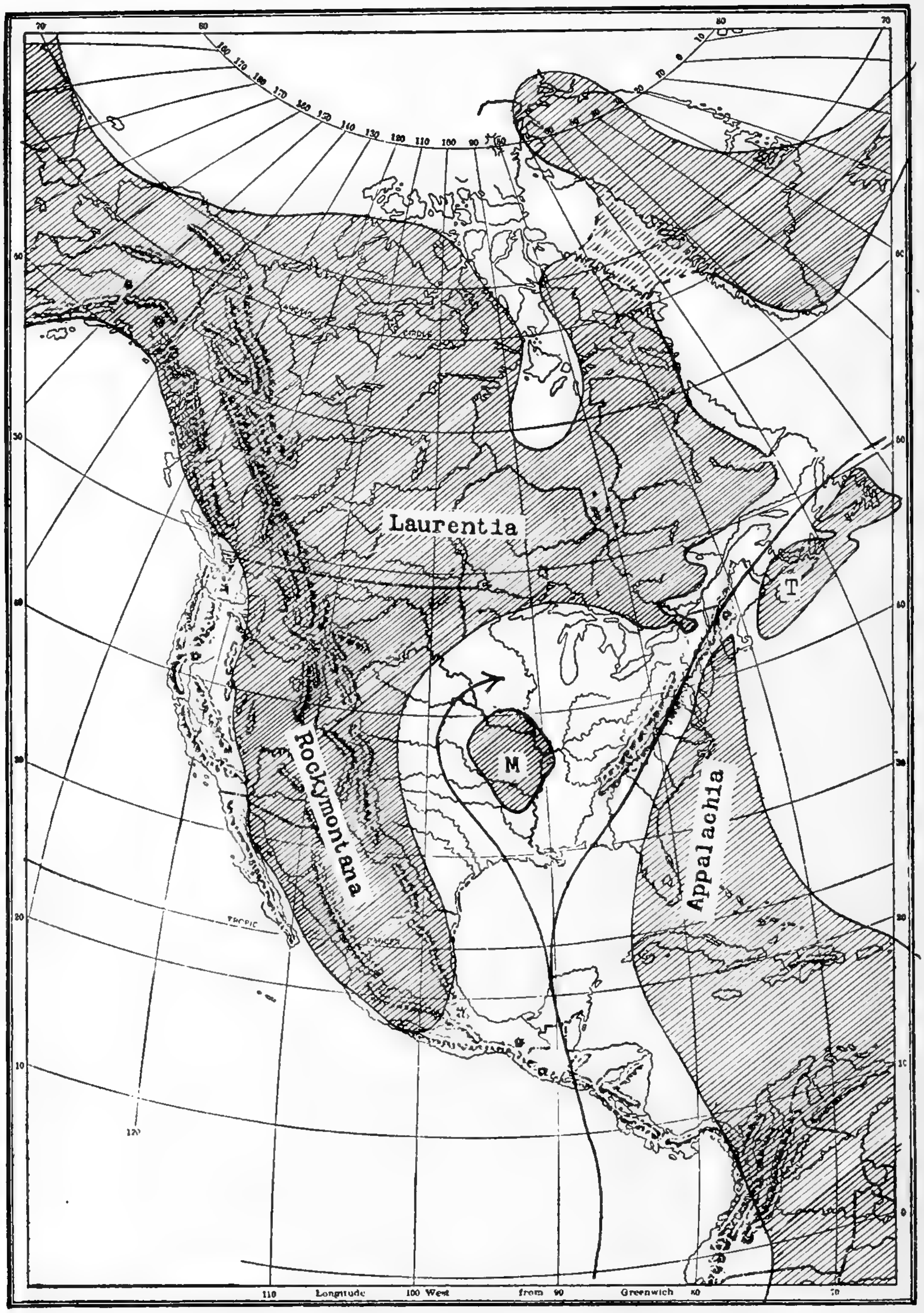


Fig. 7.—Paleogeographic map at the end of Chazy time and the probable currents. M, Ozark Island, the remains of Mississippia; T., Taconic Island.

ship is, accordingly, that of a progressively overlapping transgressional series to its basal bed, and this is the interpretation favored by all the sections. The Chazy was, in fact, characterized by a transgressive or positive diastrophic movement throughout (barring possible minor oscillations), and therefore only the higher beds are found in the region of late submergence. The thickness of the formation beneath the Black River, forms in general a reliable guide to the division of the Chazy represented, though of course there may be discovered some minor disconformities which would vitiate detailed correlations made on this basis in a given region.

No unquestionable Chazy beds have been reported from the Pacific region, where the Trentonian seems to rest directly upon the Eureka quartzite in Nevada, and either Siluric or Devonic succeeds the Ogden quartzite of the Wasatch, with Mississippic beds succeeding the same in the Uintas. The west coast transgression was, therefore, less pronounced, the Nevada region remaining still uncovered at the end of Chazy time (see map, Fig. 7). If Chazy beds occur in the West, they must be sought for in western Nevada and California. It is, of course, impossible to say how much has been removed by late Ordovicic erosion. It is not improbable that the Chazy extended east of Eureka, Nev., but was removed again in Upper Ordovicic time.

The Chazy fauna.—At the beginning of Chazy time, the Champlain gulf was entirely distinct from the Appalachian gulf, there being a land connection between the Laurentio-Mississippian continent and the united Appalachia and Taconia, or Ancient New England continent (see map, Fig. 3). The faunas were thus to a large extent distinct, representing, in fact, the Atlantic and the southern type. The southern type was, in general, the Stones River type of fauna; the character of which may be seen by consulting published lists. The Atlantic type is seen in the fauna of the Champlain basin, which admits of a threefold division, a lower (Div. A) with *Orthis costalis*; a middle (Div. B) with *Maclurea magna*; and an upper (Div. C) with *Camarotoechia plena.*

That these two types of faunas were not wholly distinct in middle and later Chazy time is shown by the occurrence of true Champlain species of Mid-Chazy age, including *Maclurea magna* in the middle portion of the "Stones River beds" of southern Pennsylvania; and of Upper Chazy species, including *Camarotoechia plena,* in the Chambersburg limestone of the same region. Whether this implies an Appalachian extension of the Champlain gulf or a connection with the Atlantic in the southern part of North America must be determined by further detailed study. It is probably true, however, that the open passage along the west border of Appalachia and Taconia, through which the mud-bearing currents swept in early Beekmantown time, and which formed the route of dispersal for the graptolite fauna of that age, was not re-established until late Chazy or Black River time. This accounts for the slight development of the graptolite-bearing shales referable to the Chazy in the Hudson and Levis series. The disconformity which represents this interruption would probably be difficult to trace in strata of such similar lithic characters.

THE BLACK RIVER FORMATION

This formation is widespread, having been traced by its fauna from the Champlain Valley to the upper Mississippi and southward to Oklahoma and the Appalachians. Over this area it forms an excellent datum plane from which correlation of overlying and underlying formations becomes possible. Its thickness is never very great; it is only 7 feet in the type region, at Watertown, N. Y., 50–60 feet in Minnesota, less than 100 feet in Oklahoma, 90 feet in southern Pennsylvania, and 70 feet in the Champlain Valley. Faunally, it represents a transition between the Chazy and Trenton, as will be seen by consulting published lists. Its classification with either the Chazy or the Trenton is therefore permissible. Since the formation represents the unchecked continuance of the transgressive movement initiated at the opening of Chazy time, its classification with that series of strata as Mid-Ordovicic is perhaps most desirable.

THE NORMANSKILL BEDS AND FAUNA

The Normanskill shales are generally regarded as representing the shale facies of the Lower or Middle Trenton. Ruedemann, in his recently published monograph parallels them with the *Lowville, Black River,* and *Lower Trenton.*[1] In Rysedorf Hill, the shale includes a conglomerate, the pebbles of which, regarded as nearly syn-

[1] *Graptolites of New York,* Part II.

chronous with the shale, carry a Lowville–Black River–Lower Trenton fauna, with some elements (*Christiania trentonensis*, *Ampyx hastatus*, Remopleurides, Sphaerocoryphe, Cybele, etc.) suggesting a geographic connection with the European sea of that time. The typical graptolite fauna of the Normanskill includes more than 60 species in all, though the widely distributed forms are much fewer. The more constant and characteristic species comprise: (1) *Coenograptus* (*Nemagraptus*) *gracilis;* (2) *Dicellograptus sextans;* (3) *D. divaricatus;* (4) *Dicranograptus furcatus;* (5) *D. ramosus;* (6) *Diplograptus foliaceous;* (7) *D. angustifolius;* (8) *Climacograptus parvus;* and (9) *C. bicornis.* Of this list, Nos. 1, 2, 4, and 8 are the most characteristic index fossils of this zone. *Didymograptus sagitticaulis,* Gurley, and *Climacograptus scharenbergii,* Lapw, may also be mentioned as characteristic though less widely distributed forms.

Besides the numerous localities along the Hudson and St. Lawrence valleys, this fauna is known from Maine and New Brunswick. In the Appalachian region it is definitely known only from New Jersey and from Bebb County, Alabama; it is also doubtfully identified from western Virginia and eastern Tennessee. It has been found in Arkansas and the Ouachita Mountains of Oklahoma; in southern Nevada (Belmont and Letson peak); and in the Kicking Horse Pass of the Rocky Mountains of British Columbia. It is also known from New South Wales and Victoria in Australia; and from southern Scotland, Scania, and France.

The distribution of this fauna is such as to suggest an eastern and a western land mass (Appalachia and Rockymontana) of low relief, with currents of the Gulf Stream type sweeping along their inner borders and distributing the graptolites, which became entombed in the muds that accumulated in these channels of moderate depth. The division of what was probably a single great current, sweeping north along the South American coast, and carrying the graptolites from Australia, was probably due to the existence of an Ozarkian island or Archipelago, along the borders of which, as in Arkansas and Oklahoma, were deposited some of these black muds. One arm of the divided current swept along the east coast of Rockymontana to the Arctic Sea of Alaska; the other along the west coast of Appalachia, past a Newfoundland island, and across the North Atlantic

Fig. 8.—Paleogeographic map at the end of Trenton time, showing second maximum transgression in the Ordovicic. The currents are indicated for Black River time. ⊕ indicates distribution of Normanskill graptolites.

to northern Europe (see Fig. 8). Within the protected interior sea, limestones (Upper Stones River and Black River) accumulated. Limestones accumulated also along the shores of Laurentia (Canadian shield) in the St. Lawrence channel, the two types of sediment and faunas thus occurring side by side. There is no need for postulating a dividing ridge in this channel, for the faunas and sedimentation would remain different as long as the different physical conditions persisted.

In Great Britain and elsewhere in Europe the zone of *Coenograptus gracilis* forms the summit of the Middle Ordovicic. The next succeeding zone (Hartfell shales of the Moffat district) is of Upper Ordovicic or Caradocian age. This begins with the zone of *Dicranograptus clingani*, which in North America is represented by the Magog shales or *Diplograptus amplexicaulis* zone, which succeeds the Normanskill beds.

The diastrophic movement, which in North America resulted in the emergence of most of the continent at the end of Lower Ordovicic time, was likewise marked, though to a less extent, in Europe. Lamansky has recently shown[1] that between Baltic Port and the banks of the river Volkov, the Lower Ordovicic beds (Etage B) show the progressive off-lapping structure characteristic of a retreatal or beveled-off series of sediments. At Baltic Port only the *Megalaspis planilimbata* zone (BIIα) occurs. Farther east, at Reval, the higher *Asaphus bröggeri* zone (BIIβ) and a part of the *Asaphus lepidurus* zone (BIIγ) have appeared. In the extreme east of the gouvernement of St. Petersburg, on the Volkov, the whole of BIIγ, and the *Asaphus expansus* zone (BIIIα) have come in above the others. The line of disconformity and erosion is marked by slight irregularities, by glauconite, iron oxide, and phosphate concretions, rarely by siliceous sediments. Above the erosion plane, the beds of BIIIβ and BIIIγ (zones with *Asaphus raniceps* and *Asaphus eichwaldi*) show progressive overlapping, the latter being represented only by clastic material at Baltic Port. Above these lies the Echinosphaerites limestone C, which shows continued westward overlapping.

[1] W. Lamansky, "Die ältesten silurischen Schichten Russlands," *Mém. du Comité Geol.*, N. S., Livr. XX, 1905.

The regressional movement here indicated appears to coincide with that of North America, but the transgressive movement seems to have begun somewhat earlier, unless the Lower Ordovicic is regarded as ending with the *Asaphus expansus* zone.

C. THE UPPER ORDOVICIC OR TRENTONIAN

Most current classifications of the Ordovicic formations of North America unite the Black River and Trenton limestones under Clarke and Schuchert's term Mohawkian, which is made synonymous with Middle Ordovicic. As we have seen, the Middle Ordovicic is represented by the Chazyan, which in its maximum development includes some 2,500 feet of limestone strata, and is therefore comparable in

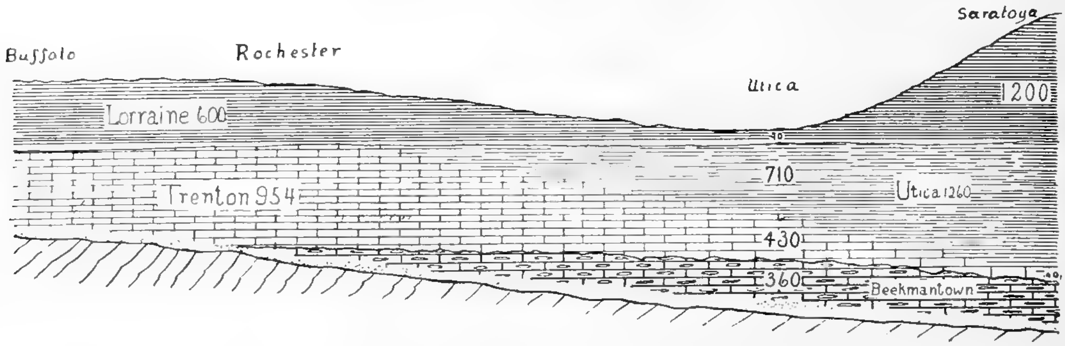


Fig. 9.—Diagram showing the relationships of the Ordovicic strata of New York between Saratoga and Buffalo.

magnitude and, inferentially, in time value, to the Beekmantownian or Lower Ordovicic. The fauna of the Chazyan is, moreover, distinct from both preceding and succeeding faunas, and the natural dividing-line between the Middle and the Upper Ordovicic is shown, by paleontologic, stratigraphic, and diastrophic reasons, to be within or above the Black River horizon; a division coinciding with that made in the European series. The Trenton limestone of America is not a stratigraphic unit, but, as has been repeatedly demonstrated by Ruedemann and noted by many observers, it is the limestone phase of a series which elsewhere is in part or mostly represented by Utica shale. In the Mohawk Valley the dividing-line between Utica and Trenton is a line constantly rising to the west, the transition being in some cases abrupt, though probably in most cases it is gradual. Ruedemann has pointed out the progressive increase in thickness westward of the limestone, and corresponding decrease in the shale; the former increasing from 40 feet at Saratoga to 430 feet at Utica, and to 954 feet at Rochester, while the latter decreases from 1,260 feet to 710 feet to probably zero over the same localities (Fig. 9). In the South Mountain region of southern Pennsylvania, the Chambersburg limestone of Stones River, Black River, and Lower Trenton age is succeeded by 1,000 feet of gray fossiliferous and dark bituminous shales, with intercalated limestone members in the basal portion which carry a Lower Trenton fauna. The shales contain *Leptobolus insignis*, *Triarthrus becki*, and Utica graptolites, and are succeeded by a sandstone with the fauna of the Eden beds of the Cincinnati region, formerly identified as Utica, but now regarded as younger than that formation. In central Pennsylvania, some 600 feet of Trenton succeeds to Black River, and is followed by 650 feet of Utica shale. In this zone also we have some typical Trenton species, such as *Dalmanella testudinaria*, *Isoteles platycephalus*, etc., associated with *Triarthrus becki* and other Utica species. The various sections clearly show that along the western border of the Appalachians, dark graptolite shales continued to form in Upper Ordovicic time, while westward from this the Trenton limestone represents the calcareous phase of the Utica-Trenton series (see map, Fig. 8).

THE TRENTON-UTICA GRAPTOLITE FAUNAS

The Normanskill fauna is succeeded by that of the Magog shales or zone of *Diplograptus amplexicaulis*—the upper Dicellograptus zone of Gurley. This represents, according to Lapworth, highest Llandeilo or lowest Caradoc, and forms a transition to the true Utica fauna. Many of its species are characteristic of the Hartfell shales (Caradocian) of southern Scotland, though others are equally characteristic of the Normanskill and Glenkiln shales. Ruedemann regards this fauna as a relict of the preceding one.

> The Didymograptidae have vanished entirely, and the Dicranograptidae almost; only the long range forms, *Dicranograptus ramosus* and *nicholsoni*, are still observed, and the Diplograptidae . . . . hold now almost entirely the field, with the genera Diplograptus, Climacograptus, and Cryptograptus.[1]

The fauna is best developed near Quebec and at the north end of Lake Memphremagog, only fragmentary representation occurring

[1] *Op. cit.*, II, 30.

in New York. The fauna is rapidly changing, the true Upper Ordovicic faunas begin to appear, and soon the typical Utica fauna, with *Glossograptus quadrimucronatus*, *Climacograptus typicalis*, *Corynoides curtus*, and, less frequently, *Leptograptus flaccidus*, *Dicranograptus nicholsoni*, and *Climacograptus putillus* is established. The association of typical Utica graptolites with characteristic Trenton limestone fossils, as *Trocholites ammonius*, *Cameroceras proteiforme*, and *Schizocrania filosa*, bears on the previously discussed question of the synchroneity of the Utica and Trenton.

Climacograptus typicalis, the typical Utica species, is reported by Winchell and Ulrich from the Fusispira and Nematopora beds of the middle Galena of Minnesota. Since the Galena of that section follows directly upon the Black River, this occurrence is only a short distance above the base of the Trenton, which is thus indicated to be the western limestone equivalent of the Utica shale of the east. As already noted Ruedemann has cited abundant evidence of the gradual westward extension of the successively higher zones of the Utica, and the replacement of the limestone phase (Trenton) by them. The Galena-Trenton limestone of the Lake Winnepeg region contains *Dictyonema canadense* (Whiteaves), *Thamnograptus affinis* (Whiteaves), and the typical Utica species, *Climacograptus typicalis* (Hall). Whiteaves concludes that the Galena-Trenton of Lake Winnepeg "most probably represents the whole of the Utica and Trenton formations, inclusive of the Galena."[1]

THE CINCINNATI GROUP

This is the upper calcareous phase of the latest Upper Ordovicic, and comprises, in ascending order, the Eden, Maysville, and Richmond. The Eden was formerly correlated with the Utica, but the underlying Trenton mainly represents that formation. The Eden is in part equivalent to the Frankfort shales, though the occurrence of *Climacograptus typicalis* in the Eden strata would favor its former correlation with the Utica. The Maysville represents later Lorraine as developed in New York, though the fauna, being that of a calcareous facies, is markedly different.

Ulrich has reported a disconformity at the base of the Eden, in the Cincinnati section, but this, if it exists, does not appear to be

[1] Quoted by Ruedemann, *op. cit.*, II, 28.

of great importance. It certainly does not represent Utica shale. There is, however, a marked and widespread disconformity between the Lower and Upper Trentonian, the late Richmond resting on Trenton or even earlier beds. This is observed throughout the Rocky Mountain area, the upper Mississippi region, and to a less extent in other sections. It signifies a retreat of the sea, probably at the end of Trenton time, and a return during late Richmond time.

THE TRENTON-CINCINNATI FAUNAS

While on the whole the faunas of the Trenton limestone and of each one of the three divisions of the Cincinnati group are sufficiently distinct, so that it is not difficult to recognize the exact horizon of each by a careful analysis of the fauna, there is, nevertheless, a unity in these faunas, which shows their unmistakable relationship to one another and their distinctness from the preceding faunas. It is this broad similarity of faunas, together with the distinctness from the preceding faunas, the intimate relation of the limestone to the Utica shale which it replaces, and the moderate thickness of the formation in its best development, as compared with that of the Chazy and Beekmantown, that has led me to place the Trenton limestone in the Upper Ordovicic. In England, the Upper Ordovicic or Caradocian (Bala) is characterized by the same faunal elements which here appear for the first time. The more common species characterizing the Upper Ordovicic from the Trenton up, and occurring in most if not all of its beds, include *Rafinesquina alternata*, *Plectambonites sericea*, *Dinorthis subquadrata*, *Plectorthis plicatella*, *Dalmanella testudinaria*, *Platystrophia biforata; Protowarthia cancellata*, *Liospira micula*, *Clathrospira subconica*, *Trochonema umbilicatum*, *Cameroceras proteiforme*, *Calymmene callicephala*, *Isoteles gigas*, *I. maximus*, and *Ceraurus pleurexanthemus*.

Some of these species begin in the Black River or even in the Upper Stones River, but they are most characteristic of the higher horizons.

THE CONTINENTAL PHASE OF UPPER ORDOVICIC TIME

The later epochs of Upper Ordovicic time were characterized by continental or non-marine sedimentation in the Appalachian region. The earliest of these is the conglomeratic and quartz-sand series found directly overlying the fossiliferous marine Ordovicic of southern Pennsylvania, and generally classed by Pennsylvania geologists as "Oneida." This is a gray to white, rarely red, conglomerate and quartz sandstone with rounded quartz pebbles and characterized by extensive cross-bedding. Its maximum thickness today is in Bald Eagle Mountain, near Tyrone City, Blair County, Pennsylvania, after which locality I originally named it.[1] This name, however, was preoccupied, and the formation under consideration is therefore called the Bald Eagle conglomerate, this ridge being due to the resistant character of this and the succeeding formation. At Tyrone the thickness is 1,319 feet, while thirty miles to the northeast, at the Bellefonte Gap, through the same ridge, the thickness is only 550 feet, and the formation is divisible into a lower hard gray sandstone without pebbles, 170 feet thick, and an upper greenish-gray somewhat ochery and micaceous sandstone with intercalated greenish shales. One hundred and sixty miles northwest from Tyrone, at Buffalo, this formation (Oswego sandstone) is 75 feet thick. It is here a white quartzite lying below the red Queenston shales, and represents only the upper layers of the gradually spreading fan of clastic sediments. In central New York the Oswego is 185 feet thick at the falls of the Salmon River. It there succeeds the Lorraine beds with perfect conformity, some Lorraine fossils extending into the lower Oswego.

There can be little doubt that these beds represent the northern and western attenuated upper beds of the Bald Eagle conglomerate of Pennsylvania, unless indeed they belong to one or more distinct fans with a source in the north.

The character of the rock, its cross-bedding, and absence of fossils indicate continental origin, and this is also shown by the nature of the overlap, which is that characteristic of river deposits. The intimate relationship between the Lorraine and the highest bed (Oswego sandstone) of this formation, indicates that the age of this formation is Lorraine. The Bald Eagle conglomerate is everywhere succeeded by the red shales and sandstones of the Juniata formation. In southern Pennsylvania this overlaps the preceding formation and rests directly upon the Eden sandstone. The forma-

[1] *Science*, N. S., Vol XXIX, p. 355.

tion here contains remnants of the Lorraine fauna with *Byssomichia radiata* and other types. These beds are clearly the lower Juniata, for the base of the series is seen in contact with the Bald Eagle conglomerate not far away. The maximum thickness of the Juniata in central Pennsylvania is from 1,000 to 1,200 feet. On the Niagara, the corresponding Queenston shale is 1,100 feet thick, and it thins away almost wholly before reaching Michigan, where only a few red beds mark the summit of the Ordovicic.

The Juniata has all the characters of deposits in arid regions. The total absence of fossils, except where, at the beginning, a lagoon extended north into Pennsylvania, is a striking feature. That fossils could be preserved in the formation is proved by the occurrence

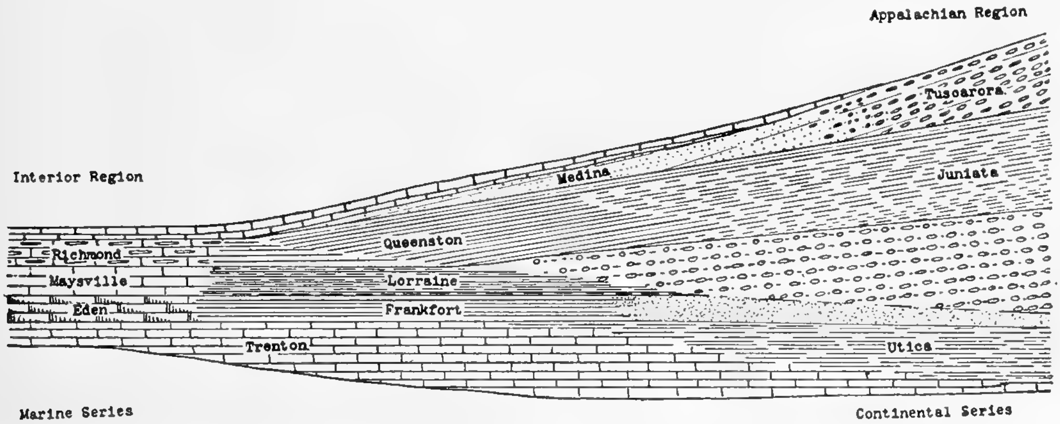


Fig. 10.—Diagram showing relationships of marine and continental upper Ordovicic and lower Siluric strata. The conglomerate beneath the Juniata is the Bald Eagle, and beneath it is the Eden sandstone.

of Lorraine species in the basal beds. Their absence from the others must then be taken as indicating that none were inclosed in the strata. This absence of fossils, together with the character of the beds, their red color, frequent mudcracks, and numerous clay slugs or "Thongallen" in the sands, and the aeolian cross-bedding, all point to a continental origin, under conditions of semiaridity and tropical climate. That the Juniata and Queenston beds are equivalent, and were formed under the same physical conditions, cannot be doubted. Their correspondence in thickness indicates an almost complete equivalency. They may, however, have distinct sources, one in the southeast and the other in the north. In western New York the Queenston shales are succeeded by the true Medina sandstones and green shales, which are partly fossiliferous, carrying a true

Niagaran fauna. This fixes the age of the Queenston and Juniata as Richmond, so far as their major portion is concerned; though, as already noted, the lower part must be considered as Lorraine (see Fig. 10).

In eastern Tennessee a second deposit of red sands of this period forms the Bays sandstone. This is from 1,100 to 1,300 feet thick in its maximum development near Loudon, but thins away by overlap in all directions. In some localities, as at Walker Mountain, it is fossiliferous, carrying the late Lorraine fauna with *Byssonychia radiata*, *Modiolopsis modiolaris*, etc. Wherever the contact with the underlying Sevier shale is exposed, it is seen to be a gradational one, the fossils extending part way up into the red beds. The basal white bed, comparable to the Bald Eagle conglomerate, if it ever existed here, was overlapped by the Bays, the portion east of the overlapping edge having been removed by erosion. The Bays may be regarded as an independent fan, or group of fans, of red sedimentation with a distinct center of supply.

The correlation of this series of continental sediments with the contraction of the sea known to have occurred in Upper Ordovicic time has not yet been attempted. It is not improbable that the initial uplift of the land which caused the retreat of the sea, also initiated the strong river-activities which resulted in the formation of the Bald Eagle conglomerate and sandstone. This probably corresponded to the period of folding of the Ordovicic and earlier strata in New England and northward. If that is the case, the emergence was probably post-Trenton, falling in early Lorraine (Frankfort or Eden) time and extending toward the end of Lorraine time. The period of red sedimentation in the east may have coincided with the period of erosion in the upper Mississippi and Rocky Mountain areas, and deposition of the Richmond in the narrow interior basins. The late Richmond expansion may coincide with the climatic change indicated by renewed river deposits of white quartzose material.

D. THE LOWER SILURIC OR NIAGARAN

The following divisions of the New York Niagaran are in common use as the North American standard: Guelph, Lockport, Rochester, Clinton.

The Clinton of the best known section, that of western New York, begins with the true or Upper Medina, which, along the Niagara River, admits of a number of subdivisions, which are, however, of only local significance.[1] The total thickness is nearly 125 feet, with 25 feet of white quartzose sandstone (Whirlpool sandstone) at the base, and about 8 feet of a similar sandstone at the top. The middle series consists of red sandstones and green and gray sandstones and shales. The red sandstones generally show aeolian cross-bedding and appear to have accumulated above water. The green sandstones and shales are fossiliferous. The white Whirlpool sandstone exhibits beach features,[2] and probably marks the advance of the sea, though it is likely that the sand was originally dune sand, as suggested by A. W. G. Wilson.

The fossils are generally most abundant in the shales and thin-bedded sandstones. The heavy-bedded sands are either free from fossils or have only scattered shells of Lingulae. At Lockport and elsewhere some layers are crowded with gastropod shells. The characteristic fossil, *Arthrophycus harlani* is everywhere in New York restricted to the upper beds just below the upper white sandstone.

The fossils so far obtained from the Medina are: *Arthrophycus harlani* Conr.; *A.* sp.; *Daedalus* several species; *Scolithes verticalis* Hall; *Dictyolithes beckii* (Conr.); "*Fucoides*" *auriformis* and "*F.*" *heterophyllus; Holopea fragilis* Hall; *Lingula cuneta* Conr.; *Whitfieldella oblata; Camarotoechia* sp.; *Uncinulus stricklandi* (Sowerby); *Plectorthis medinaensis* sp. nov.; *Rhipidomella* sp.; *Pentamerus* sp.; *Modiolopsis orthonota; M. primigenius; Pterinea cf. emacerata; Pleurotomaria pervetusta* Conr.; *P. littorea* Hall; *Holopea* (?) *conridea; Bucanopsis trilobatus* (Conr.); *Oncoceras gibbosum; Orthoceras* sp.; *O. multiseptum* Hall; *Ascidaspis* sp.; *Dalmanites* sp.; *Isochilina cylindrica* Hall.

This is a Lower Siluric fauna, and favors more especially the Clinton and Rochester faunas. It is so far known only from western New York, with the exception of *Arthrophycus harlani*, which is widely distributed. In western New York this species occurs at the top of a heavy-bedded unfossiliferous sandstone with an aeolian type

[1] See *Bull. 45, New York State Museum*, pp. 88–95.

[2] H. L. Fairchild, *Amer. Geol.*, Vol. XXVIII, 1909.

of cross-bedding; and just below the upper white quartzite. In east-central New York it is found at the base of the Oneida conglomerate, which is the approximate equivalent of the upper white sandstone of Niagara. In the Appalachians, it is found mostly in the upper part of the Tuscarora and Clinch sandstones, the stratigraphic equivalent of the Medina. Sarle[1] has recently interpreted this structure as due to worm borings. So far as I have observed in the field, the raised ridges of this fossil always occur on the under side of the sandstone layers, representing, therefore, the relief molds of grooves generally formed in the clays beneath. These grooves had a median ridge and a regular succession of transverse ridges separated by broad concave grooves. A similar structure, known as Climatichnites trails, but of a much broader type, occurs in the Potsdam sandstone of New York. Woodworth[2] has suggested that it represents the trail of an animal comparable to some extent to modern Chiton.

There are no known remains of organisms in the Medina or Clinton capable of making such an impression, and the organism which made it either had no parts capable of preservation or else it was a terrestrial type frequenting the shores and sandy wastes, where it left its trail in the mud, but not its remains, just as the Triassic Dinosaurs left their footprints but seldom their skeletons.

The Tuscarora has a thickness of 820 feet in Logan's Gap, Jack's Mountain, Mifflin County, Pennsylvania, but thins perceptibly westward and southward, being 400 to 500 feet thick in Bald Eagle Mountain and 287 feet in Wells Mountain and the Pennsylvania-Maryland line. This thinning appears to be due to failure of the lower beds, showing a true case of non-marine progressive overlap. In New York, the upper part is represented by the true Medina, which has a thickness of 125 feet, and begins and ends with a pure white quartz sandstone. More strictly speaking, the upper white sandstone alone represents the true Tuscarora, but the lower beds, still partly red, and the shales, probably are the equivalent of the lower reddish sandstones and greenish shales underlying the true white Tuscarora, and sometimes referred to the Upper Juniata. The Oneida conglomerate of central New York, 40 feet thick, is likewise

[1] *Rochester Acad. of Sci. Proc.*, 1906, No. 4, p. 203.

[2] New York State Pal. Rep., 1907, *Bull. New York State Museum, No. 69,* p. 959.

the representative of the upper part of Tuscarora, though it may have had a more local origin.

All of these beds, including the basal white Bald Eagle formation, belong to the much-washed and reworked type of continental sediments, in which concentration of the indestructible quartz had been brought about by long exposure, resulting in the decomposition of all the other minerals, and the removal of the resultant clay and dust by wind and running water.

The Clinton shales succeed the Oneida conglomerate in Oneida and Herkimer counties, New York, and the Upper Medina quartzite in western New York. In the southern Appalachians, the series is largely composed of sandstones (Rockwood), highly impregnated with iron, and often containing beds of workable iron. It is generally succeeded by late Siluric (Monroan) or by Helderbergian or later beds, there being a pronounced disconformity at the summit of the Rockwood throughout. That part of the series in Virginia is of continental origin is indicated by the general character of the rocks, but marine intercalations are not uncommon. In some cases in eastern Tennessee the iron ore itself is fossiliferous, having replaced a marine limestone. In such cases the bulk of the formation is shale. In no case is the original thickness preserved since the formation is everywhere bounded above by an erosion plane. In northern Virginia today the thickness is 750 feet (Piedmont folio), and not over 400 feet in southern Virginia. In southern Tennessee and northern Georgia it is from 1,100 to 1,600 feet thick, decreasing westward and northward. With our present knowledge of the formations, it is safe to say that the eastern sandy phase represents near-shore deposits, if not actually continental conditions, formed probably at the embouchures of several Appalachian rivers; and that westward these deltas merged gradually into true marine deposits, mainly sands and clays, with some limestones intercalated. That the Rockwood represents more than the Clinton of New York cannot be questioned. Where the series is developed in its totality, it probably represents the entire Niagaran, if not a part of the Salinan as well. Along the Alleghany front, fossiliferous shales and iron ores represent this series, with a thickness of not less than 1,000 feet, on the western branch of the Susquehanna. The lower series, 700 feet thick, consists mainly of fissile shales, including an iron sandstone, and with Buthotrephis in the upper part. This is succeeded by 110 feet of calcareous fossiliferous shales; and this by 230 feet of fossiliferous shales and limestones with a Niagaran fauna. Above this follows 350 feet of red shales, probably representing the Upper Salina, and separated by a hiatus from the fossiliferous Niagaran shales.

In eastern New York, at Swift's Creek, the type locality for the Clinton, this formation is 226 feet thick and is followed by 5 feet of Niagaran and then by the red shales of the Upper Salina. On the Niagara River the Clinton shale with the two succeeding limestones has a total thickness of 32 feet, followed by 68 feet of Rochester shale. The total of the Niagaran, including the Guelph, is from 270 to 325 feet, as shown by borings. This is followed by Lower Salinan. In the Rochester region the Clinton has a thickness of 80 feet, including the Irondiquoit or upper limestone (17 feet), which Chadwick refers to the Rochester. The eastward thinning of the Upper Niagaran beds indicates either that these beds were eroded before the deposition of the red shales, probably during the Shawangunk epoch (see beyond); or that the Rochester-Lockport of the West is in part represented by Upper Clinton in the East. The Guelph element may never have extended to the Clinton type region, which may have been above water and so subject to erosion.

The most typical section of the North American Lower Siluric or Niagaran is found in Wisconsin, where the series exceeds 700 feet in thickness and is wholly calcareous. At the base of the series, however, in a few localities, as at Iron Ridge, occurs a remarkable iron ore, composed of flat lentils of varying size and heaped together in a mass strongly suggestive of dune history. This idea is borne out by the position of these pellets, which are not laid flat, as would be the case if they were deposited by water, but are placed in all positions. Cross-bedding and irregular wedging-out of layers and a rapid thinning away of the entire mass, further suggest an eolian origin. There are no fossils in the ore, and it rests upon an uneven surface of the Upper Ordovicic, with a layer of highly polished clay pebbles marking its base. The interpretation of this formation that I am at present able to advance is that of dunes of calcareous pellets of concretionary or phytogenetic origin, similar to the oölite dunes of Great Salt

Lake and other regions; and that these dunes were subsequently altered, by replacement, to iron ore.

The series of limestones overlying this basal bed, or resting directly upon the Ordovicic, is for the most part richly fossiliferous. Some of the beds, as the Racine and the Coral Beds, are characterized by reefs of Stromatoporoids and other corals, widely distributed and connected by more or less barren lime sands (calcarenytes) which resulted from the erosion of the reefs. Some beds are of shallow-water origin and bear the marks of periods of exposure, resulting in the formation of mud cracks, etc. The fauna is more or less uniform throughout, and the series represents continuous deposition, recording only minor oscillatory movements. Southward we find these beds extending through northern Illinois, Indiana, and Ohio, with a more or less uniform fauna, while further south, in the Cincinnati and western Tennessee regions, part of the limestones is replaced by shales and new faunal elements appear.

The typical Niagaran fauna.—This is to be found in the strata of the Wisconsin section and in their continuations in northern Illinois, Indiana, Michigan, and Ohio. It is an exceedingly rich fauna, and, as Weller has ably demonstrated, has many elements in common with the Mid-European Siluric. The Stromatoporoids abounded on the reefs of the Coral Beds and the Racine. They have not been much differentiated in Wisconsin, but from other sections, especially Canada and Ohio, a considerable number of genera and species have been recognized. Corals abound, especially Halysites and Favosites, while Bryozoa are most common in the shales of New York and the southern area, Fistulypora making extensive reefs in western New York. The brachiopods, except the large Pentamerus, are likewise more characteristic of the shales. Crinoids, Cystoids, and Trilobites appear to be most common in the limestones of the interior.

The Guelph fauna.—This fauna demands a special notice, because it is so distinct in its eastern manifestations. The peculiar aspect of the fauna is produced by the great Trimerelloid brachiopods (*Trimerella grandis*, *T. ohioensis*, *Monomorella prisca*, etc.); the peculiar corals Pycnostylus; the large pelecypod *Megalomus canadensis;* the gastropods *Pycnomphalus solarioides;* and the genera

Euomphalopterus, Hormotoma, and Coelidium, together with various species of Eotomaria and other Pleurotomarioids, and the remarkable *Trematonotus alpheus*. This represents a new invasion of the interior sea, probably from the rich fauna of northern Europe. In North America the physical conditions accompanying this spread of the fauna appear to have been shoaling of the water and inclosure and restriction of the interior sea. The fauna appears as early as the lower Coral Bed in Wisconsin, while the Guelph element of the Racine fauna is very marked. *Trimerella grandis*, *Megalomus canadensis*, *Pycnomphalus solarioides*, *Coelidium macrospira*, and *Sphaeradoceras desplainense* are among the species which occur in association with the rich Racine fauna. Many of the typical corals, brachiopods, and other types continue into the Guelph in Wisconsin, the fauna not differing markedly from the Racine. In New York Clarke and Ruedemann have found the Guelph fauna intercalated between the normal manifestations of the Niagaran coral fauna (Lockport), and it appears that in the Canadian type region alone does it occur in its purity.

THE ATLANTIC AND SOUTHERN NIAGARAN

The Atlantic Niagaran has generally been recognized as belonging to a distinct province separated by a land barrier from the interior sea. This is made evident not only by the distinctness of the faunas, as exhibited in the Anticosti group and the development in Maine and New Brunswick, but also by the fact that the entire interior Appalachian region contains only shallow-water or continental deposits, indicating a continuous land mass in the East. That the Anticosti fauna nevertheless communicated with the interior is shown by its occurrence in Georgia and elsewhere in southeastern United States. This occurrence represents either a distinct embayment from the Atlantic, or the fauna migrated into the interior, going around the southern end of Appalachia, which may then have been separated from South America. An invasion of the interior from the south is indicated by the fauna of the Cape Girardeau or Alexandrian[1] formation of Illinois and Missouri, and perhaps also by the fauna of the

[1] See T. E. Savage, *Amer. Jour. Sci.*, Vol. XXV (1908), pp. 431–44; Schuchert, *Jour. Geol.*, Vol. XIV (1906), pp. 728, 729.

St. Clair[1] limestone of Arkansas. The Alexandrian series of Savage contains many types unknown from the true Niagaran, some Ordovicic genera also being present (Rafinesquina, Platystrophia, Rhynchotreta, Zygospira). Few typical Niagaran species occur, but the presence of the genera Favosites, Atrypa, Whitfieldella, Homoeospira, Schuchertella, Chlorinda, and Lichas (Metopolichas) indicates the Siluric age of this fauna. It probably represents an invasion from the south before the Niagaran transgression from the north had reached the southern Illinois region. Northward, in central and northern Illinois, this fauna seems to be wanting, the true Niagaran fauna here succeeding the Cincinnatian.

The Alexandrian is succeeded disconformably by 30 to 75 feet of limestones with a Lower Niagaran fauna. A transgression is indicated by the fact that "where the formation is thinnest, it is the lower, and not the upper layers that are absent."[2] The Niagaran fauna includes: *Favosites favosus*, *Halysites catenulatus*, *Atrypa rugosa*, *Orthis flabellites*, *O. cf. davidsoni*, *Plectambonites transversalis*, *Stricklandinia triplesiana*, and *Triplesia ortoni;* which grouping, as stated by Savage, corresponds to that of the Clinton of the Dayton, Ohio, region.

The invasion of the interior by a southern fauna, in later Niagaran time, seems to be indicated by the later Siluric formations of Tennessee and possibly in part by the Louisville limestone of Indiana and Kentucky. The higher beds of western Tennessee, called by Foerste[3] the Brownsport beds, and subdivided into the Beech River, Bob, and Lobelville formations by Pate and Bassler[4] contain faunas apparently not found in the typical or northern Niagaran formations, and which are well developed in the underlying series, named, in ascending order, Clinton, Oswego, Laurel, Waldron, Lego, and Dixon.

[1] Gilbert Van Ingen, "The Siluric Fauna near Batesville, Ark., Part I," *School of Mines Quarterly*, Vol. XXII (April, 1901), pp. 318–29.

[2] Savage, *op. cit.*, p. 435.

[3] A. F. Foerste, "Silurian and Devonian Limestones of Western Tennessee," *Jour. Geol.*, Vol. XI, pp. 554–715.

[4] W. F. Pate and R. S. Bassler, "The Late Niagaran Strata of West Tennessee," *Proc. U. S. Nat. Mus.*, Vol. XXXIV, pp. 407–32. See also Roemer, *Die silurische Fauna des westlichen Tennessee*, in which the fauna of these higher beds is described.

E. THE MIDDLE SILURIC OR SALINAN

This is typically known only from New York, Michigan, western Ontario, northern Illinois, and Ohio, and is everywhere a series of more or less calcareous shales and gypsiferous beds, with salt beds up to 100 feet in thickness. The maximum development is in central New York and southern Michigan, where it exceeds 1,000 feet in thickness. In western New York it is only 350 feet thick. The only fossils known from the beds are from the lower (Pitsford) shales, where they represent the last survivors of the Guelph. They are chiefly Eurypterids (Hughmilleria, Eurypterus, etc.) and occur in muds alternating with dolomites carrying a Niagaran fauna. The Eurypterid fauna also occurs in the mud layers in the Shawangunk conglomerate, which hardly admits of any other interpretation than deposition by torrential rivers. This would make the Eurypterid fauna a fresh-water fauna, an interpretation which best corresponds with the distribution of these fossils geologically as well as geographically. The Salina series is best understood as a desert deposit. The absence of organic remains (with the exceptions noted), known to be abundant in all modern salt deposits of sea-margin origin; the thickness of the salt beds; their limitation to circumscribed basins,[1] the red color of the lower shales, their mud cracks, "Thongallen," etc., all point to a continental origin. The absence of true marine strata of Salina age[2] and erosion of the surrounding Niagaran beds further indicate that North America was above water. The salt was derived from the marine limestones of Niagaran and earlier age.

THE GREEN POND SHAWANGUNK CONGLOMERATES AND SUCCEEDING RED SHALES

The general retreat of the sea at the end of Niagaran time was marked in the east by an uplift followed by continental sedimentation. The series began with a conglomerate (Green Pond) 1,500 feet thick in northern New Jersey, but thinning northward to 500 feet at Ellenville (Shawangunk conglomerate), to 200 feet at Rosendale, and to nothing at Rondout. Southward and westward it thins

[1] See Walther, *Gesetz der Wüstenbildung*. Lack of space forbids the full discussion of this interesting problem. It will be treated at length in another paper.

[2] The so-called marine Salina of Maryland is of Monroan age.

to 700 feet at the Delaware water gap, to 400 feet at the Lehigh, and to less southward. The thinning is by failure of the lower beds, showing this to be a true non-marine overlap, and therefore stamping the series as of river origin. The Eurypterid layers in the upper beds are probably contemporaneous with the basal Eurypterid beds of the Salina of New York. The succeeding series of Longwood shales resembles the Juniata-Queenston, and, like it, has all the earmarks of a continental series formed under semiarid conditions. They thin from 2,385 feet in New Jersey to 120 feet at Cornwall, 75 feet at High Falls (High Falls shale); and 25 feet at Rosendale, and disappear farther north. Southward they thin likewise, while westward only the upper 400 feet of the series is shown in the red Lower Salina shales of Ithaca and Syracuse, New York, where they are succeeded by salt deposition, and less than 200 feet at Buffalo. Like the conglomerate, the shales thin by failure of the lower beds, i. e., by non-marine overlap away from the source of supply.

F. THE UPPER SILURIC OR MONROAN

This is typically developed in southern Michigan, Ohio, and western Ontario, where it is divisible into Lower Monroe or Bass Islands series, 500 feet thick, or more; middle Monroan or Sylvania sandstone 30 to 150 feet thick; and Upper Monroan or Detroit River series, 300 to 400 feet thick.[1] The entire series is involved in gentle folding of early Devonic age, the Dundee resting upon the eroded surfaces of various members of the series.

The Lower Monroan represents an invasion from the Atlantic across Maryland, Pennsylvania, and southern Ohio, to Michigan and probably Wisconsin. Western Ontario was involved, but apparently not western New York. The fauna is Upper Siluric, genetically related to the Manlius limestone fauna, and, like it, representing an Atlantic type. The Upper Monroan fauna, on the other hand, is of a distinct type, especially in the lower members (Flat Rock, Amherstburg, and Anderdon beds). Besides being related to the later Niagaran fauna, it has a new coral and brachiopod element suggestive

[1] See Sherzer and Grabau, *Bull. Geol. Soc. Amer.*, Vol. XIX. The full discussion of these formations and their fauna will appear in the report of the Michigan Survey.

of Devonic affinities. This is further shown by the occurrence of Panenka and Hercynella in these beds. The highest division (Lucas) is characterized by gastropods, most nearly related to late Siluric types of northern Europe.

The Amherstburg beds of the Upper Monroan appear to be the chronologic equivalent of the Cobleskill of eastern New York, several characteristic species being common to both. It represents the junction of an eastern and a western sea, and a commingling of the faunas of both. The typical Upper Monroan coral and brachiopod fauna seems to have invaded Michigan from the northwest, a somewhat similar fauna appearing near the headwaters of the Saskatchewan. In Pennsylvania the Lewistown limestone appears to represent this horizon.

The Sylvania sandstone has all the characteristics of a wind-drifted sand. Its cross-bedding is of the aeolian type, its grains well rounded, pitted, grooved, and of uniform size; there is a total absence of impurities, and all the characteristics compare favorably with those of the sands of the Lybian desert of today. It indicates a period of land condition between the retreat of the Atlantic embayment (Lower Monroan) and the Pacific invasion of Upper Monroan time.

G. THE LOWER DEVONIC

The Lower Devonic comprises the Helderbergian and the Oriskanian of Clarke and Schuchert. The Helderbergian includes the Coeymans, New Scotland, Becraft, and Port Ewen. The latter is transitional to the Oriskany, and Chadwick proposes to unite it with that formation.[1] The Coeymans is the direct depositional successor of the Manlius, there being frequently a transitional zone between them, with a commingling of the fossils. The former extent of the Coeymans can be estimated from its occurrence at Syracuse and the uniform character which it maintains in that region. This indicates that the western shore of the Helderberg sea was west of Syracuse and perhaps in the region of Buffalo. The eastern and northern limit of the formation is indicated by its mergence into shore deposits in New Jersey, and the southward overlap of the later formations,

[1] *Science*, N. S,, Vol. XXVIII, p. 347.

the Virginia, western Tennessee, and Oklahoma occurrence of this series beginning with beds carrying a New Scotland fauna.[1]

The emergence of the North American continent at the end of Siluric time was accompanied by the first pronounced doming of the Cincinnati region and basining of the Michigan area. Local oscillations seem to have preceded this, but the first great movement apparently did not occur until the end of the Siluric. Between the Michigan basin and the Cincinnati dome were formed the Wabash anticline and the minor folds of Michigan, Ohio, and Canada. When these regions were again wholly submerged in Mid-Devonic time, the deposits of this later epoch came to rest on the beveled surfaces of various Siluric members (see Fig. 11). A subsequent movement

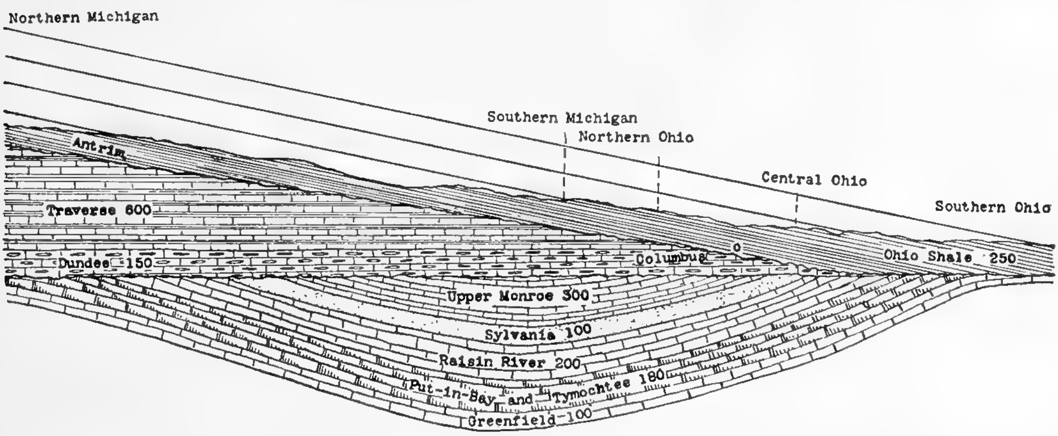


Fig. 11.—Section from northern Michigan to southern Ohio, showing the relationship of the Middle Devonic to the Siluric and of the Upper to the Middle Devonic. O = Olantangy shale.

in the same direction, at the end of Paleozoic time, threw the later beds into similar folds, while emphasizing those of the earlier series.

A marked hiatus occurs between the Helderbergian and Oriskanian. The former series is beveled, so that the Oriskany comes to rest, as it extends westward, upon lower and lower members of the Helderbergian, and finally upon the Manlius, and still farther west upon the Akron dolomite (Cobleskill). This beveling is in part due to retreatal "off-lap" but also to extensive erosion which indicates a time-period of some magnitude for the Oriskany. The depositional equivalent of this hiatus is found in the Gaspe region of Canada, where 550 feet of Oriskanian (Grand Greve limestone) follows

[1] See Grabau, *Bull. 92, New York State Museum.*

1,200 feet of Helderbergian (St. Albans and Bon Ami limestones), the succession being a conformable one.[1]

The Oriskany of the United States is mostly a sandstone, often of pure quartz grains, at other times calcareous. The source of the sandstone is to be sought in the sandstones of the eastern extension of the Siluric and Ordovicic formations, and perhaps in the exposures of the St. Peters and the Sylvania. It seems most likely that the distribution of the sand over eastern North America was largely effected by wind, during the long period of erosion preceding the submergence of the continent. On the westward extension of the Oriskany sea these accumulated sands were reworked and were transformed into the fossiliferous marine sands which they are found to be today. In the east, after a short period of sedimentation, an extensive accumulation of black muds occurred, forming the Esopus-Schoharie shale series. This has its greatest thickness at Port Jervis, whence it thins away in all directions, apparently by overlap. Since the source of the material was clearly in the east, and the overlap is toward the west, north, and south, the formation must be a subaerial fan. This is further indicated by the general absence of fossils, except for occasional intercalations, such as would be expected in a fan of this kind, probably rising but slightly above the level of the shallow Oriskany sea. The continuance of the Oriskany invasion is found in the spread of the limestone with the Schoharie fauna and the succeeding Onondaga submergence. During Onondaga and Hamilton time, continuous deposition and spreading of the seas went on, but at the close of the Middle Devonic, renewed emergence affected most of southern and southeastern United States, accompanied by erosion. This again was followed by the slow resubmergence, which commenced from the north and slowly advanced southward and eastward. The basal member of this transgressing series is the black shale, which, in northern Michigan, is of Lower Devonic (Genesee?) age, but becomes of later and later age southward, at the same time resting always on lower strata. Thus late Upper Devonic (Portage) black shale rests on Lower Hamilton in southern Michigan and northern Ohio; still later beds (Chemung) on the Onondaga (Columbus)

[1] See J. M. Clarke, "Early Devonic History of New York and Eastern North America," *New York State Museum Memoir 9*, 1908.

in central Ohio; while the highest beds rest on Monroan or even Niagaran, in southern Ohio. Continuing southeastward, the black shale rises in the series, until in eastern Tennessee it is of Lower Mississippic age, and rests on Lower Siluric or on Ordovicic strata.[1] (Fig. 11).

DISCUSSION

PROFESSOR CALVIN

I have studied the St. Peter sandstone in Iowa, Wisconsin, Minnesota, and Illinois, and nowhere have I seen any marked indications of cross-bedding such as would be consistent with an aeolian origin of the formation. In Iowa and Minnesota there are few structural bedding planes seen in fresh sections, but those that do exist are always horizontal and parallel. Bedding planes are more numerous in this sandstone west of Ottawa, Ill., but they are all precisely of the character one sees everywhere in aqueous sediments. When the St. Peter is exposed on sloping hillsides, by a process akin to exfoliation, it breaks off in thick flakes parallel to the exposed surface and so often presents a false appearance of cross-bedding; but this feature has no relation to the original structure. One hardly needs to go to the Libyan desert to ascertain the characteristics of aeolian sands. The region around the south end of Lake Michigan affords ample opportunity, nearer home, to study the structural features and topographic forms of wind-blown deposits. I have seen nothing in the St. Peter suggesting similar origin. Furthermore, the St. Peter occasionally contains marine fossils, as shown by Winchell and Sardeson.

REJOINDER

PROFESSOR GRABAU

Most writers on the St. Peter have described it as showing marked cross-bedding. It is not always readily recognized and is often overlooked in sandstones of this type. But even if there were no cross-bedding in the known exposures, this would be no argument against the eolian origin of the formation, since modern eolian deposits often lack such a structure—and, indeed, sometimes lack all bedding. The comparison with the sands of the Libyan desert is made because they represent precisely what is believed to be the origin of the St. Peter and Sylvania. These sands are derived from an older sandstone—not from glacial sands as are those of Lake Michigan. They show a similar purity, rounding, and uniform size as found in the St. Peter and Sylvania. Finally they have been transported a great distance and rest with a sharp contact on eroded limestones, often including the weathered-out fossils of this limestone in their base. The fossils obtained from the St. Peter were, as noted in the text, obtained from the lower and upper parts, the latter of the Stones River type, included in the rewashed upper sands on the advance of the Stones River sea over the old dune area. The fossils included in the basal part are either weathered-out Beekmantown or included in the sands during the retreatal phase. Such inclusions are to be expected in deposits of this type.

[1] See Grabau, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 593–613.

CORRELATION TABLE I

		Champlain Valley	Black River and Mohawk Valleys	Western New York	Appalachian: Southern Penn. Maryland	Appalachian: Tenn.	Interior: Cincinnati Region	Interior: Upper Mississippi Valley, Ill.
ORDOVICIC	Upper or Trentonian	Utica / Trenton	Basal Oswego; Lorraine; Frankfort / Frankfort; Utica; Trenton	Queenston Shale; Basal "Oswego" s.s.; Lorraine; Trenton	Juniata; Bald Mt.; Eden; Utica / Trenton	Bays; Sevier; Chickamauga, etc.	Richmond-Maquoketa; Maysville; Eden ?; Point Pleasant-Galena	Richmond-Maquoketa; Hiatus and Disconf.; Point Pleasant-Galena
	Middle or Chazyan	? Black River ?; C, B, A } Chazy; Hiatus and Disconformity	Black River; Lowville; Pamelia / Bl. Riv. Low; Hiatus and Disconformity; Hiatus and Disconformity	Hiatus and Disconformity	Chambersburg; Stones River; Group	Chickamauga, etc.; Hiatus	Black River; Upper Stones River; Upper St. Peter; Hiatus and Disconformity (often masked)	Black River; Upper Stones River; Upper St. Peter; Hiatus and Disconformity (often masked)
	Lower or Beekmantownian	Hiatus and Disconformity; E, D, C, B, A } Beekmantown	Hiatus and Disconformity; Hiatus and Disconformity; Theresa "Potsdam" / Little Falls Dolomite; Hiatus and Unconformity	Hiatus and Disconformity; Lower Beekmantown; Hiatus and Unconformity	Beekmantown; Shenandoah	Disc.; Knox	Hiatus and Disconformity (often masked); Lower St. Peter; Lower Magnesian	Hiatus and Disconformity (often masked); Lower St. Peter; Lower Magnesian
Sub-jacent		Upper Cambric	Pre-Cambric	Pre-Cambric	Upper Cambric	Upper Cambric	Upper Cambric	Upper Cambric

A "disconformity," as defined by Grabau, is an erosional unconformity, without discordance of dip

CORRELATION TABLE II

System	Series	Michigan, Ohio, and Canada	West and Central New York	East—Central New York	Helderbergs and Penn.
SILURIC	Upper or Monroan	Hiatus and Disconformity Detroit River Series { Lucas Dolomite, Amherstburg Lime, Anderdon Limestone, Flat Rock Dolomite Hiatus and Disconformity Sylvania Sandstone Hiatus and Disconformity Bass Island Series { Raisin River Series, Put-in-Bay Series, Tymochtee Shale, Greenfield Dolomite Hiatus—Disconformity	Hiatus and Disconformity Akron Dolomite Bertie Waterlime Hiatus and Disconformity	Manlius Limestone Rondout Waterlime Cobleskill Limestone Braymans Shale Binnewater Sandstone Hiatus—Disconformity	Manlius, Rondout, Cobleskill, Rosendale } Lewistown Limest. Hiatus—Disconformity
	Middle or Salinan	Salina—Salt, Gypsum and Lutites	Salina { Camillus, Syracuse, Vernon, Pittsford Hiatus & Disc.	Salina Hiatus, Disconformity	Longwood Shales (High Falls Shales) Green Pond Conglomerate (Shawangunk)
	Lower or Niagaran	Hiatus—Disconformity Niagara, Clinton | Wisconsin | Guelph, Racine, Waukesha, Mayville Hiatus and Disconformity	Guelph Lockport Rochester Clinton.. { Clinton Shales and Limestone, Medina sandstone (sens-strict.)	Niagara Clinton (of type-section) Oneida Conglomerate Hiatus and Disconformity	Hiatus and generally an Unconformity
ORDOVICIC		Richmond	Queenston Shales	Frankfort Shales	Hudson Shales

PALEOGEOGRAPHIC MAPS[1]
MIDDLE ORDOVICIAN AND SILURIAN

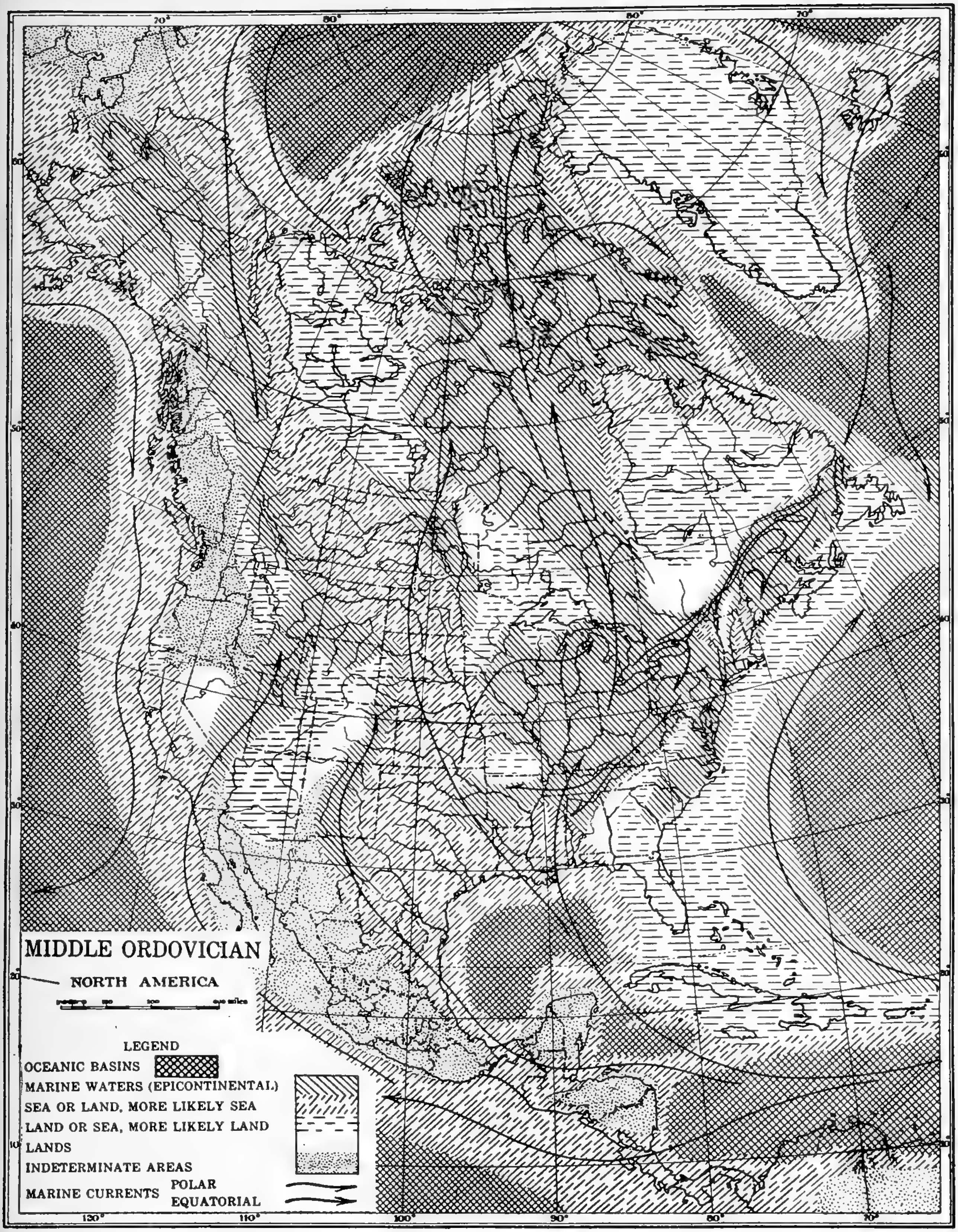
BAILEY WILLIS
U. S. Geological Survey

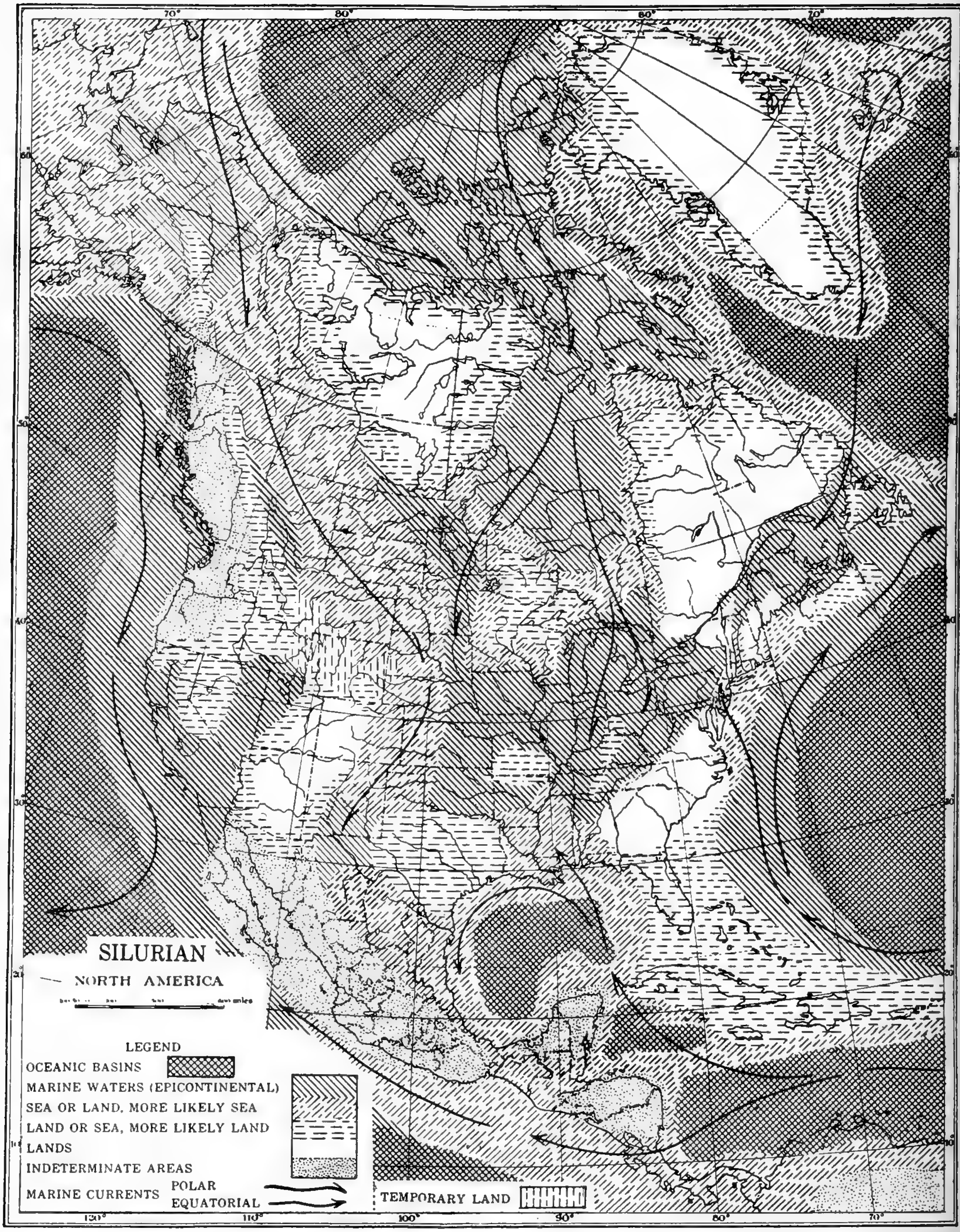
3 AND 4. MIDDLE ORDOVICIAN[1] AND SILURIAN[2]

The passage from the upper Cambrian to the Ordovician appears to be marked in many localities by inconspicuous but notable evidences of non-deposition or erosion which may be attributed to submarine scour or the actual subaërial denudation of low-lying lands. The phenomena differ from those which commonly accompany marked continental deformation. They are believed to have resulted from the deepening of ocean basins which gave rise to a widespread ebb of the epicontinental seas. Effects of continental warping of a subordinate character may naturally have accompanied the sub-oceanic movements. The conditions of oceanic circulation which result from a consideration of the probable distribution of seas and lands are those of general northward currents flowing from the Gulf of Mexico through to the Arctic. They carried with them the characteristic middle Ordovician fauna, which, however, developed local diversities in the eddies of the North American archipelago. In contrast to the central marine currents and their fauna we have the polar southward-trending return currents which may have been congenial to the graptolites. Their distribution would seem to explain the similarity of graptolite faunas in the eastern and western troughs. A peculiar circumstance is suggested in the occurrence of the graptolites in Arkansas. This is recognized on the map by the crossing of the arrows indicating marine currents. It is a well-established fact of oceanography that marine currents pass over or under one another, and this fact affords a possible explanation of the relations which appear to have existed in Tennessee and Arkansas. As a supplemental hypothesis the student should consider Professor

[1] Based largely on data furnished by C. D. Walcott.

[2] Based on data furnished by Dr. E. M. Kindle.


MIDDLE ORDOVICIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
130°
110°
100°
90°
80°
70°


SILURIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
TEMPORARY LAND
70°
80°
60°
70°
120°
110°
100°
90°
80°
70°

Chamberlin's suggestion of an inversion of oceanic circulation which is based upon the possibility that saline equatorial waters may have been denser than, and have sunk beneath, relatively fresh and lighter polar waters. The conditions of circulation today are determined by temperature and not by salinity, but the differences of temperature which developed during the glacial period and which still persist are exceedingly great, and it may well be doubted whether temperature had a like effect in Ordovician time, when, as is established by the distribution of faunas, climatic conditions were relatively very equable.

The period covered by this composite map is essentially that of the Niagara. North America was still an archipelago. The continental plateau was widely submerged on the north and was still covered by an interior sea. On the east, however, lands appear to have been elevated in consequence of the Taconic orogenic movements which proceeded from the Atlantic basin, and shallow seas or lands appear to have extended across the region which is now that of the Gulf states. It has been suggested that the sea was generally absent from the western portion of the continent, but recent investigations in Alaska and Utah indicate the presence of a Silurian fauna and we are at least justified in an alternative assumption that marine conditions existed quite extensively, but presented a habitat unfavorable to the rich fauna that occupied the interior Niagaran sea. The conditions of marine circulation appear to have restricted the equatorial currents to the Atlantic on the east and to the Gulf on the south, while the polar currents coming along the coast of Siberia and along Greenland penetrated into the interior sea where the slowly circulating waters became warm enough to afford a very genial habitat. As in the middle Ordovician, the climatic conditions were equable throughout wide ranges of latitude and marked differences of temperature probably did not exist.

CHAPTER V

CORRELATION OF THE MIDDLE AND UPPER DEVONIAN AND THE MISSISSIPPIAN FAUNAS OF NORTH AMERICA

STUART WELLER

INTRODUCTION

In its essential features a problem in geologic correlation is an investigation in the parallel histories of two or more regions, basins, or provinces, involving the points of contact between these areas. Since it is the fossil faunas which most satisfactorily indicate these points of contact, correlation problems, as applied to the stratified rocks of an age younger than the pre-Cambrian, are largely questions in paleontologic interpretation.

All questions in correlation become progressively more complex as the territory occupied by the faunas under consideration is extended.

So long as one's observations are restricted to a limited area contained entirely within a single life province, the problems are usually simple, and some beds with similar lithologic characters and similar faunules usually may be traced from section to section without abrupt changes. However, when one's observations extend beyond the limits of a single province or subprovince, the factors in correlation multiply, and frequently the problem becomes one of extreme complexity. In solving these problems the history of the faunas under consideration must be diligently studied in order to determine the elements in their composition, the source of these elements, and their relations one to another, both biologically, geographically, and geologically. The solution also involves the investigation of the paleogeography of the region being studied.

One of the first considerations in connection with any correlation problem is the determination of the several faunal provinces involved and their geographic limits.

NORTH AMERICAN DEVONIAN PROVINCES

Upon the North American continent four well-defined faunal provinces may be recognized in the Devonian strata. These have been designated by Williams:[1] (1) Eastern Border Province, (2) Eastern Continental Province, (3) Interior Continental Province, and (4) Western Continental Province. Although the boundary between the Eastern Continental and Interior Continental provinces is now known to be somewhat different from that assigned by Williams, the names themselves express better than any others which have been proposed the geographic relations of the provinces, and will be used here.

The Eastern Border Province is confined to the easternmost extremity of the continent, within the maritime provinces of Canada and the State of Maine. The outcropping strata of the Eastern Continental Province extend from eastern New York westward across New York and Ontario into Michigan, southwestward along the Appalachians across New Jersey, Pennsylvania, Maryland, West Virginia, and Virginia, also down the Ohio Valley through Ohio, Indiana, and Kentucky to southern Illinois, and southward into Tennessee, northeastern Mississippi, Alabama, and Georgia. Outliers are found in

[1] *Am. Jour. Sci.* (3), XXXV, 51–59.

two regions which are at present wholly isolated from the main body of the province, (1) at Lake Memphremagog near the international boundary between Vermont and Quebec, and (2) southwest of James Bay in Canada. In both of these regions the faunas recognized are so like those of the Eastern Continental Province that there must have been direct communication to them during the life of the faunas.[1]

The Interior Continental Province is typically developed in Iowa, where the Devonian strata are exposed from Muscatine County on the Mississippi River, northwestwardly across the state into the southern border of Minnesota, and it includes also the Devonian strata of Rock Island and Calhoun counties, Illinois, and those of Central Missouri. Beyond this the Devonian beds of Manitoba and the Mackenzie Valley are to be included in this same province, which seems to be connected in a northwesterly direction with the Eurasian Devonian Province. The Western Continental Province is confined to the Great Basin region, and its faunas are best known from the studies of Walcott[2] upon the Devonian faunas of the Eureka District in Nevada.

Since the faunas of the Eastern Continental Province have a more complete and continuous history than those of either of the other provinces, and because they are much better known, their succession is taken as the standard with which the other Devonian faunas of the continent are compared.

THE EASTERN BORDER PROVINCE

For substantial additions to our knowledge of the Devonian faunas of the Eastern Border Province we are recently indebted to Clarke,[3] although contributions of great importance were made many years ago by the Canadian geologists, Logan and Billings. In this region the Helderbergian and Oriskany faunas of Lower Devonian age have a great development, and the faunas of the Gaspé basin give evidence that this region was a center of dispersion of these two faunas. During Middle Devonian time, in this same region, many of the Lower Devo-

[1] For composition of the Lake Memphremagog fauna see Ami, *Ann. Rep. Geol. Surv. Canada*, VII, N. S., 157J; also, Schuchert, *Am. Geol.*, XXXII, 155. For James Bay fauna see Parks, *Ont. Bureau Mines, Report for 1904*, Pt. I, pp. 180–91.

[2] *Monograph*, U. S. G. S., Vol. VIII.

[3] "Early Devonic History of New York and Eastern North America," *Mem. N. Y. State Mus. Nat. Hist.*, Vol. IX.

nian types of life persisted to such an extent that the Gaspé sandstone has sometimes been correlated with the Oriskany of the Eastern Continental Province. It has been shown by Clarke, however, that associated with these Lower Devonian types there is a much more important element which allies the fauna with the Hamilton of the interior, the evidence being sufficient fully to justify the correlation of the Gaspé sandstone with the Middle Devonian. The Onondaga fauna is not differentiated in the Gaspé region.

The origin of the Hamilton fauna in the Gaspé basin is assumed by Clarke to have been by migration from the interior by way of the Connecticut and St. Lawrence troughs, and the presence of a similar fauna, showing a mingling of Oriskany and Hamilton types, on the island of St. Helen's near Montreal, gives some strength to such an assumption. However, the possibility of a southern origin, by way of the Atlantic border, should not be lost sight of.

THE EASTERN CONTINENTAL PROVINCE

Middle Devonian of the Eastern Continental Province.—In the Eastern Continental Province two major divisions of the Middle Devonian, the Onondaga and the Hamilton, are clearly recognized. These two faunas, with only minor, subprovincial differences, are persistent throughout the province, in New York, Ontario, Michigan, the Ohio Valley both east and west of the Cincinnati arch, in southern Illinois, and even in northeastern Mississippi and northern Alabama. The Onondaga fauna is in part an evolution product from the subjacent Oriskany, but, in addition, there are included in it at least three conspicuous elements which are entirely new, the corals, the cephalopods, and the fishes. This fauna has a greater distribution to the north than the superjacent Hamilton, it alone being represented in the outlying areas at Lake Memphremagog and James Bay. East of the Cincinnati arch, which was evidently a peninsula at this time, the Onondaga fauna does not extend far beyond the Ohio River, but west of this arch it is clearly recognized as far south as northeastern Mississippi. Throughout this entire area the composition of the fauna is wonderfully uniform.

The origin of the new elements in the Onondaga fauna is not entirely clear. It has been suggested by the writer[1] that these elements

[1] *Jour. Geol.*, X, 429.

have immigrated from the north by way of the tract now occupied by the fauna about James Bay, but there are few facts to support this hypothesis in the known distribution of the Devonian faunas of the Arctic region except the presence of several genera of fishes which occur in the fauna in America and in Devonian strata in Spitzbergen. The mingling of the Onondaga and Oriskany faunas in western Ontario, however, suggests that this was the first point of contact between the immigrant fauna and the pre-existing Oriskany, and would therefore indicate a northern origin for the fauna as a possibility. Ulrich and Schuchert[1] have postulated a southwestern origin, and later Schuchert[2] has suggested a northeastern origin for the fauna through the St. Lawrence Gulf and the Connecticut trough, but there seems to be as little basis for either of these hypotheses as for its northern origin.

East of the Cincinnati arch the Hamilton epoch is initiated by the fauna of the Marcellus shale which is evidently of Atlantic origin in so far as it is not evolved from the Onondaga, but this eastern incursion was of brief duration and did not penetrate to the subprovince lying west of the Cincinnati arch. The Hamilton proper is introduced throughout the province, both east and west of the Cincinnati arch, by the appearance in the faunas of certain peculiar brachiopods which are apparently of southern hemisphere origin, the most conspicuous of which are *Tropidoleptus carinatus* and *Chonetes coronatus*. Aside from this southern element the Hamilton fauna is in large part a derivative from the subjacent Onondaga, a considerable number of species being common to the Hamilton and the Onondaga, while many Hamilton species are closely allied, apparently genetically, to forms in the Onondaga fauna.

In its geographic distribution the Hamilton fauna does not extend as far north as the Onondaga, but it has a greater distribution southward along the Appalachians. West of the Cincinnati arch it is clearly defined in southern Illinois; it is probably present with the Onondaga in northeastern Mississippi, although data are not at hand to make a definite statement to that effect, and it has been clearly recognized in northern Alabama.[3]

[1] *Rep. N. Y. State Pal.*, 1901, p. 652.

[2] *Am. Geol.*, XXXII, 156.

[3] Schuchert, *Am. Geol.*, XXXII, 152.

During the Hamilton period the sea retreated from the northern embayments in the James Bay region and the Connecticut trough, and at the same time it transgressed toward the south and occupied territory which had been dry land during Onondaga time, and connection was apparently established between the eastern and western subprovinces to the south of the Cincinnati arch, which at this time became an island.

Upper Devonian of the Eastern Continental Province.—During Upper Devonian time the faunas of the Eastern Continental Province were far more local in their development than they had been at any time during the Middle Devonian. At no time during the period was there so uniform a fauna as either the Onondaga or the Hamilton had been, distributed throughout the entire province. In the early Upper Devonian time the sea retreated northward from its greatest southward extension of Hamilton time, and later again transgressed toward the south and southwest until it extended much farther than it had in the earlier period, this retreat and readvance being recorded in the unconformity at the base of the Upper Devonian black shale which is commonly exhibited south of the Ohio River and to some extent north of that stream.[1]

The earliest Upper Devonian fauna in the province is the Cuboides fauna of the Tully limestone in New York, characterized by a totally new immigrant element in the Devonian faunas of the province, of which the brachiopod species *Hypothyris cuboides* is the most conspicuous representative. This fauna has been shown by Williams[2] to be closely allied to the Cuboides fauna of the European Devonian which initiates the Upper Devonian of that continent. The Cuboides fauna in America must have had a common origin with the same fauna in Europe, and the path of its immigration into the Eastern Continental Province of North America is commonly considered to have been by way of the Interior Continental Province.

Following the Tully limestone in the northeastern portion of the province is the Genesee black shale with a meager fauna of which the Lingulas are the most conspicuous members. In the southern portion

[1] Data concerning this unconformity have been assembled by Foerste, *Ky. Geol. Surv., Bull. No.* 7, p. 129.

[2] *Bull. G. S. A.*, I, 481–500.

of the province the entire Upper Devonian epoch is represented by a black shale which has been variously called the Ohio shale, the New Albany shale, or the Chattanooga shale, which is widely distributed in southern Ohio, Indiana, and Illinois, in Kentucky, Tennessee, and northern Mississippi, Alabama, and Georgia, and extends westward into northern Arkansas. Throughout the southern portion of the province this black shale rests unconformably upon the subjacent strata, and in some parts of Kentucky, at least, is unconformable upon Middle Devonian limestones. In the Ohio Valley the fauna in the basal portion of the black shale indicates its Genesee age,[1] but as the shale was a transgressing formation toward the south and southwest, its age in these directions becomes younger and younger, and at the extreme limits of its extension it may even be younger than any true Devonian, and be contemporaneous with the basal member of the Mississippian.

While these monotonous black shale conditions obtained in the south, a series of waves of faunal immigration were penetrating the northeastern portion of the province. In the Portage of western New York occurs the Intumescens fauna[2] characterized by its numerous goniatites of the type of *Manticoceras intumescens*. This fauna, like the Cuboides fauna of the Tully limestone, is of European origin. The path of its migration into New York is believed by Clarke to have been the same as that of the earlier fauna, by way of the Interior Continental Province, but Ulrich and Schuchert[3] express the opinion that it came in from the Atlantic basin by an eastern route. Following the Intumescens fauna, in the same general region, is a fauna in the High Point sandstone, at the extreme summit of the Portage group, characterized by *Pugnax* of the type of *P. pugnus*, which is another European immigrant, and which has many species in common with the Lime Creek shales of the Interior Continental Province in Iowa. Succeeding the High Point fauna is the typical Chemung fauna with *Spirifer disjunctus* and its associates, which again are European immigrants, but are associated with other forms which are of Hamilton derivation.

[1] For a summation of the opinions which have been held in regard to the age of the black shale, see Girty, *Am. Jour. Sci.* (3), VI, 385, 386.

[2] Clarke, "The Naples Fauna in Western New York," *Sixteenth Ann. Rep. New York State Geol.*, 1896, pp. 31–161; also *Mem. N. Y. State Mus.*, No. 6.

[3] *Loc. cit.*

In central New York the history is somewhat different in that the Intumescens fauna does not penetrate there in its typical expression, and the Ithaca beds, which are equivalent to the Portage, carry a fauna which is in large part a Hamilton derivative, this being followed by the Chemung fauna. Still farther east, in the same state, the Portage epoch is represented by the non-marine Oneonta sandstone which is followed by marine beds with a recurrent fauna, which pass upward into the Chemung. In the extreme eastern portion of New York the non-marine Catskill conditions were doubtless constant from the beginning of the Upper Devonian until its close.

THE INTERIOR CONTINENTAL PROVINCE

Middle and Upper Devonian of the Interior Continental Province. In passing from the Eastern Continental to the Interior Continental provinces, both the stratigraphic and faunal conditions are found to be totally different in almost every detail. In New York, where the Middle and Upper Devonian beds of the Eastern Continental Province have their most typical development, a maximum thickness of more than 3,000 feet of strata is recognized, and in the Appalachians in Pennsylvania the thickness is much greater, but in Iowa the total thickness of the Devonian beds of the Interior Continental Province is less than 300 feet. The entire series of Devonian beds in Iowa are commonly referred to the Middle and Upper Devonian, the Upper beds being unconformable upon the Middle,[1] but the limits of these divisions do not correspond at all with the limits of the Middle and Upper divisions of the Devonian in the Eastern Continental Province.

In the Middle Devonian of the Iowa geologists two major divisions are recognized, the Wapsipinicon and the Cedar Valley. Both the Wapsipinicon and the Cedar Valley are made up of minor formational units of more or less local development, and of these the Independence shales occupy a position near the base of the Wapsipinicon. The fauna of the Independence shales is the oldest of the Devonian faunas of Iowa,[2] and it shows much in common with the fauna of the Lime Creek shale of the Upper Devonian of the same state.

In the Upper Devonian three formations are included in Iowa, the Lime Creek shales, the State Quarry beds, and the Sweetland Creek

[1] Calvin, *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] Calvin, *Bull. U. S. Geol. Surv. Terr.*, IV, 725.

shale. As regards the relations of these three formations Calvin says:[1] "The three units referred to the Upper Devonian—the Sweetland Creek shales, Lime Creek shales, and State Quarry limestone—do not lie one above the other, but each is locally developed and lies unconformably on the Cedar Valley limestones."

The lower beds of the Wapsipinicon stage, other than the Independence shale, do not furnish any considerable fauna, *Martinia subumbona* being the most conspicuous species, but the higher beds, as well as the succeeding Cedar Valley beds, are abundantly fossiliferous, and faunally the dividing-line between the Wapsipinicon and Cedar Valley stages presents no more conspicuous break than that between the successive beds included within the Cedar Valley.

In correlating these faunas of the Iowan Devonian with those of the Eastern Continental Province, difficulty is met with because of the few points of contact between the two faunas. The faunas in the two provinces are so distinctly different that we are forced to the conclusion that there could have been no free communication between the two regions, but that they must have been entirely separated during the whole or the greater part of Middle Devonian time by some barrier, probably a land mass. During Upper Devonian time there was much more in common between the Iowan and New York faunas, showing that communication had been established ere that time. In the correlation of the faunas in the two provinces the important point to determine is the time of the establishment of this communication. Williams[2] has shown that the Cuboides fauna of the Tully limestone in New York is a distinct immigrant fauna from the Eurasian province, probably by way of the Mackenzie Valley and Iowa. The characteristic species of this fauna is *Hypothyris cuboides*, a species which is represented in the Iowan faunas by *Rhynchonella intermedia* Barris, the Iowan form apparently being specifically identical with the New York species. In Iowa this species is limited in its range to the upper portion of the Wapsipinicon stage, where it is highly characteristic of one of the divisions of the Fayette breccia,[3] and where it is associated with *Gypidula comis*. Because of the limited range of this species in

[1] *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] *Bull. G. S. A.*, I, 481–500.

[3] Norton, *Iowa Geol. Rep.*, IV, 160.

these Iowan beds, it seems safe to conclude that these higher Wapsipinicon beds are essentially equivalent in time with the Tully limestone of New York. Furthermore, almost the only fossil species in the lower Wapsipinicon beds is *Martinia subumbona*, which also is a common Tully limestone species.

Another point of contact between the faunas of the Iowan and the New York provinces is found in the faunas of the Lime Creek shales of Iowa and the High Point sandstone near Naples, N. Y. The High Point bed lies at the extreme top of the Portage in the New York section, and in a total fauna of 26 species, 14 are also present in the Lime Creek beds of Iowa.[1] This large proportion of identical species may be considered as a sufficient basis for the essential correlation of the beds.

If these two correlations are correct, a basis is established for the correlation of the entire Devonian series of Iowa, the Wapsipinicon being, in the main, the time equivalent of the later Hamilton of the New York section, its termination being essentially contemporaneous with the Tully limestone, the Cedar Valley being contemporaneous with the Portage group of New York, and the Lime Creek being contemporaneous with the closing stages of the Portage and the opening of the Chemung. There is no evidence whatever of the presence of any beds of Onondaga age in Iowa.

The invertebrate faunas of the so-called Upper Devonian formations of Iowa are less prolific than those of the Cedar Valley beds. The Lime Creek fauna includes a number of forms which are recurrent from the Independence shales near the base of the Wapsipinicon, a distribution which suggests the unity of the entire Devonian fauna of Iowa, and, further, that the Lime Creek is not far removed from the subjacent beds although there is apparently an unconformity between them. The State Quarry beds contain a number of distinctly Devonian brachiopods, among which may be mentioned *Pugnax alta* which also occurs in the Lime Creek shales, but the most conspicuous feature consists of the fish remains, *Ptyctodus calceolus* being the most abundant form. In the Sweetland Creek shales invertebrates are few in number, a species of *Spathiocaris* being perhaps the most common, a species which also occurs in the New Albany black shale of southern

[1] Clarke, *Bull. U. S. G. S.*, No. 16, p. 75.

Illinois and Indiana, as well as in a basal Kinderhook shale in Missouri. At the base of the formation a thin band occurs which is frequently crowded with the teeth of *Ptyctodus calceolus*, the same species which is present in the State Quarry beds and one which also has a wide distribution at the very base of the Kinderhook formations.

Following the Devonian of the Interior Continental Province to the northwest, it is next well exposed in Manitoba, and has been well described by Tyrrell.[1] Approximately 510 feet of strata are recognized, the lower 100 feet not having afforded any fauna. The beds referred to the Middle Devonian (Winnipegosan) are characterized by the presence of *Gypidula comis* throughout, and by *Stringocephalus burtoni* in the upper portion. The last of these species does not occur in Iowa, but *Gypidula comis* is an abundant and characteristic member of the fauna of the upper beds of the Wapsipinicon stage, where it is associated with *Rhynchonella intermedia* Barris (*Hypothyris cuboides*). In western Europe *Stringocephalus burtoni* is the index fossil of the Stringocephalus limestone at the summit of the Middle Devonian, and occurs immediately beneath the Cuboides zone. The Devonian beds superjacent to the Stringocephalus beds in Manitoba have been referred to the Upper Devonian by the Canadian geologists, a correlation which is doubtless correct, since the faunal succession is similar to that in Europe, where *Stringocephalus burtoni* marks a distinct horizon at the summit of the Middle Devonian.

The Devonian fauna of the Mackenzie basin has been described by Whiteaves[2] and has been correlated with the Cuboides zone of Europe and New York, a correlation which seems to be based on substantial evidence. Seventy-six forms are specifically identified, twenty-nine of which are either present or are represented by close relatives in the European faunas of similar age, while twenty-two are identified with American Hamilton species, ten with Iowan and seven with Chemung forms. In the Mackenzie basin the Stringocephalus zone has not been so clearly recognized as in Manitoba, although it is indicated in at least one locality. The entire Devonian section in the Mackenzie Basin consists of 2,800 feet of strata, but a considerable part of the lower portion may be of greater age, and the entire fauna is

[1] *Geol. Surv. Canada, Ann. Rep.* V (N. S.), Pt. I, pp. 204–9 E.

[2] *Cont. Can. Pal.*, I, 197–253, pls. 27–32.

known from 200 feet of beds between 300 and 500 feet below the summit of the entire series.

JUNCTION OF THE EASTERN CONTINENTAL AND INTERIOR CONTINENTAL PROVINCES

As has been indicated in the previous discussion of the faunas of the Eastern Continental and Interior Continental Provinces, the time of the establishment of a path of communication between the two was at the very opening of the Upper Devonian, when the Cuboides fauna found its way into the East, but the relations of the Iowan faunas with those of the East is not such as to suggest an entirely unobstructed intermingling of faunas even after this communication was finally established. Schuchert has suggested in his paleogeographic maps[1] that this communication was by way of a narrow and somewhat tortuous strait, the "Traverse Strait," which passed from southeastern Iowa in a general northeasterly direction, across Illinois through the Lake Michigan basin to northern Michigan. Within the limits of this strait occur the Devonian beds near Milwaukee, Wis., and those of the Grand Traverse region of Michigan, where there is a greater commingling of eastern and western forms than elsewhere, as might be expected under the circumstances. The waters of this strait were separated from those of the Eastern Continental basin by the comparatively narrow Kankakee peninsula.

THE WESTERN CONTINENTAL PROVINCE

The Devonian strata of the Western Continental Province occur at various localities in the Great Basin region, and their faunas have been described by Walcott in his *Paleontology of the Eureka District.*[2] One hundred and eighty specifically identified forms are recorded, of which 61 are new and 119 are identified with already known forms. The composition of the previously known portion of the fauna is as follows: 83 species are identical with forms from the Eastern Continental Province, including New York, Michigan, and the Ohio Valley, the other 36 being known from Iowa and other parts of the Interior Continental Province. Of the eastern species 29 are found only in the Onondaga fauna, 21 only in the Hamilton, and 13 only in Devonian

[1] *Am. Geol.*, XXXII, Pl. 21; also, *Ia. Geol. Surv.*, XVIII, pl. 16.

[2] *Monograph,* U. S. G. S., Vol. VIII.

beds younger than the Hamilton; the remaining species are common to the Onondaga and the Hamilton, with one exception, which occurs in the Hamilton and the Chemung. From these figures it is evident that this Great Basin fauna contains a strong Onondaga element, 48 species in all. Of the Hamilton species neither *Tropidoleptus carinatus*,[1] *Chonetes coronatus*, nor any of the strictly foreign species in the fauna are recognized, the entire Hamilton element being of that association which seems to have originated from the Onondaga. Of the three highly characteristic elements of the Onondaga fauna of the East, corals, cephalopods, and fishes, we find 11 species of corals and 11 species of cephalopods, but none of the latter are identical with those of the East, although they are congeneric. Of icthyc remains but a single tooth was collected by Walcott, but in the Kanab Cañon of northern Arizona a strongly marked Devonian fish horizon is recorded,[2] although the composition of the fauna has not been made known.

In its entirety the Devonian fauna of the Western Continental Province may be said to be composed of a combination of two distinct elements: (1) the Middle Devonian fauna of the Eastern Continental Province, exclusive of the southern hemisphere element in the Hamilton, and (2) the fauna of the Interior Continental Province. These two elements are not fully differentiated in the faunas, since species from the Iowan or Mackenzie Basin faunas occur indiscriminately in either the lower, middle or upper divisions of the Great Basin Devonian. The Onondaga element also occurs through all of the divisions, although it is most conspicuous in the lower beds. Within this province there is no faunal evidence indicating the presence of Devonian rocks of greater age than the Onondaga, but sediments were doubtless deposited in the area contemporaneously with the Onondaga, Hamilton, and Upper Devonian of the Eastern Continental Province, but no beds can be correlated definitely with either of the eastern formations. The older of the beds are doubtless of greater age than the oldest Devonian beds of Iowa, although they may not be older than some of those of the Mackenzie Valley.

[1] *Tropidoleptus carinatus* has been recorded from the Pinon Range, Nevada, but the species has not been figured, and the identification has not been confirmed, *Monograph*, U. S. G. S., VIII, 276.

[2] Walcott, *Monograph*, U. S. G. S., VIII, 7; also *Am. Jour. Sci.* (3), XX, 225.

The path of communication between the Eastern Continental Province, in Onondaga time, and the Western Continental Province must have been indirect, although there was certainly some community of origin of the faunas in the two regions. If the northern origin of the Onondaga fauna, as has been suggested by the writer,[1] has sufficient foundation, which is perhaps doubtful, the fauna may have migrated southward into two epicontinental embayments, one into the Eastern Continental Province, by way of Hudson Bay and James Bay, and another farther west into the Western Continental Province. The mingling of the Onondaga and the Iowan faunas might be accounted for on this basis, since it is quite definitely recognized that the latter fauna has a northwestern origin, at least in so far as North America is concerned. One objection to this view is the fact that the Onondaga fauna is not represented among the known faunas from the Mackenzie Basin, although there is sufficient room for its occurrence in some of the older Devonian beds of that region which have not yet afforded any fauna. A southern pathway of communication between the two provinces is a possibility, although on such an hypothesis the absence of the southern hemisphere element of the later Middle Devonian faunas of the East is not easy to account for.

THE NORTH AMERICAN MISSISSIPPIAN PROVINCES

The early stages of the Mississippian period were marked by a continuation of the transgression of the sea in the south and southwestern part of the Eastern Continental Province, which had been initiated during Upper Devonian time, but it was extended also to the northwest. Before the close of the Kinderhook epoch, the sea had crossed the Kankakee peninsula and had surrounded the Ozark land which became an island or was perhaps entirely submerged, and had stretched away toward the Rocky Mountain land, so that the earlier Eastern Continental and Interior Continental provinces were merged into one great interior province with three subordinate basins or subprovinces, (1) the Appalachain Basin lying between Appalachia and the Cincinnati arch and extending from Michigan to Alabama, (2) the Mississippi Valley basin extending westward from the Cincinnati arch and merging with the Appalachian Basin to the south, (3)

[1] *Jour. Geol.*, X, 429.

the Rocky Mountain Basin. The Western Continental Province remained much as in Devonian time, faunally isolated to a great extent from the interior province. The Eastern Border Province was even more isolated, its faunal history, so far as known, having no points of contact with the interior.

The more complete and differentiated faunal history of the Mississippian is that of the Mississippi Valley Basin which will be used as a standard of comparison for the other provinces or subprovinces considered.

THE MISSISSIPPI VALLEY BASIN

The Southern Kinderhook fauna.—When the Upper Devonian or New Albany black shale is well developed in southern Indiana and Illinois, the initial Kinderhook bed, the Rockford limestone, follows it with no stratigraphic break. In following the Kinderhook beds to the north, however, they are found to succeed, unconformably, formations of much greater age. The same condition also probably holds in passing from Burlington, Ia., to the south, although the transition beds from the Devonian to the Kinderhook are not exposed in the Burlington section. An actual land barrier, the Kankakee axis of Schuchert, separated these northern and southern basins at the beginning of Kinderhook time, when each basin was occupied by its own distinctive and characteristic fauna. Before the close of the Kinderhook this barrier was submerged and a common fauna occupied the entire Mississippi Valley Basin.

The fauna of the Rockford limestone contains new elements which were unknown in the preceding Devonian faunas, associated with certain other forms which are clearly Devonian derivatives. The typical expression of this more southern type of the Kinderhook fauna, however, is found in the Chouteau limestone of central and southern Missouri and Illinois, although there are several modifications of the fauna in the various more or less local formational units of the Kinderhook of this region. Among other things the fauna contains numerous goniatites, some of which are notable forms and have no relationships with any of our known Devonian goniatites. *Aganides rotatorius*, from the Rockford goniatite bed of Indiana, is identical with a form in the basal Mississippian beds of Belgium and Ireland. Associated with this form at Rockford is *Prodromites gorbyi* which occurs also in the Chouteau limestone of central Missouri. This latter goniatite is the most advanced one of the Mississippian faunas, having, as it does, a secondarily lobed suture such as, at no very distant period in the past, was considered to be characteristically Mesozoic in type. Another peculiar cephalopod in the fauna is *Tribloceras digonum* which occurs in the fauna at various localities. A peculiar type of pelecypod is found in the genus *Promacrus*, which occurs also in the early Mississippian beds of Belgium. These and many other forms in the fauna characterize it as something distinctly younger than any Devonian fauna, with numerous bonds of affinity uniting it with the higher and more typical Mississippian faunas. However, there occur associated with these characteristic portions of the fauna certain species, especially among the pelecypods, which are clearly Devonian derivatives, and, strange to say, their relationships are usually with members of the Hamilton fauna, rather than with the higher Devonian faunas of the Eastern Continental Province. The Hamilton relationships of the fauna are perhaps best seen in the fauna of the Glen Park limestone,[1] where the pelecypods and gastropods are all close allies of Hamilton forms, and where one form even seems to be specifically identical, but associated with these is a member of the highly characteristic Mississipian genus *Syringothyris*.[2]

The origin of this southern Kinderhook or Chouteau fauna is believed to have been in the Atlantic Basin, where Middle Devonian faunas of Hamilton type had probably retreated as the Upper Devonian immigrants became established in the Eastern Continental Province, or where they had persisted during Upper Devonian time, having never been encroached upon by the immigrants. During the long lapse of time most of the species had been modified, and there had been absorbed into the fauna a new element from some unknown region. The return of this fauna into the Mississippi Valley Basin marks the opening of the Kinderhook epoch and the Mississippian period.

[1] Weller, *Trans. St. Louis Acad. Sci.*, XVI, 435–71.

[2] The species described in the *Fauna of the Glen Park Limestone* (*loc. cit*). as *Spirifer jeffersonensis*, has since been definitely identified as a member of the genus *Syringothyris*.

The Northern Kinderhook fauna.—North and west of the Kankakee peninsula, in the eastern portion of the Devonian Interior Continental Province, the earliest Mississippian faunas were as distinctly different from those of the southern portion of the Eastern Continental Province, as had been the preceding Devonian faunas. The oldest of these northern Kinderhook faunas is that of the Chonopectus sandstone[1] at Burlington, Ia., and elsewhere in Iowa and Illinois. This fauna contains a large Devonian derivative element, especially among the pelecypods, but its relationships are with the Chemung faunas of the Upper Devonian, and are totally different from the Devonian derivatives of the southern fauna. Another modification of the northern Kinderhook fauna is found in the Louisiana limestone, which is believed to be in part contemporaneous with, and in part younger than, the Chonopectus fauna. One of the most characteristic members of this northern Kinderhook fauna is the striated rhynchonelloid genus *Paraphorhynchus* which occurs also in the early Mississippian faunas of northwestern Pennsylvania.

In the Burlington, Ia., section the Chonopectus fauna occurs at the summit of a series of shales, becoming arenaceous above where the fauna occurs, which have a total depth of 160 feet. The lower 100 feet of the formation lies beneath the level of the Mississippi River, so that the contact with the underlying formation and the age of the subjacent bed is not known. This lower bed, however, is probably Devonian, and is not unlikely the Cedar Valley limestone, since that formation lies unconformably beneath the Kinderhook beds farther south in Calhoun County, Ill. If this is the case then these lower shales of the Kinderhook correspond in position with the Sweetland Creek shales of the Upper Devonian in Muscatine County, Ia. There is, however, perhaps insufficient faunal evidence upon which to base a definite correlation of these two shale formations. The most conspicuous faunal character of the Sweetland Creek beds is the presence of numerous *Ptyctodus* teeth in the basal bed, occupying a few inches above the unconformity. A similar *Ptyctodus* bed occurs not infrequently at the base of the Kinderhook in both the northern and southern provinces. Such is the case at the base of the Louisiana limestone at Louisiana, Mo., where *Ptyctodus* occurs abundantly in a thin shale

[1] Weller, *Trans. St. Louis Acad. Sci.*, X, 57–129; also *Jour. Geol.*, XIII, 617–34

bed beneath the limestone. In southeastern Missouri a one-foot bed of sandstone occurs at the base of the Kinderhook with numerous phosphatic nodules and some worn *Ptyctodus* teeth. In southwestern Missouri a thin formation at the base of the Kinderhook has been described by Shepard[1] as the Phelps sandstone, in which *Ptyctodus* teeth are abundant, and the same conditions obtain at Providence,[2] in central Missouri. In all of these localities the same species, *Ptyctodus calceolus* N. and W., seems to be the usual form. Occupying, as these *Ptyctodus* beds do, a position immediately superjacent to a more or less profound unconformity, it is not likely that it is strictly contemporaneous in all of these localities, but that they are all associated with one general geologic movement, and are contemporaneous within comparatively narrow limits, is quite certain. The presence of the remains of this fish fauna, in both the southern and northern Kinderhook provinces, while the invertebrate faunas are so distinct, is doubtless due to the fact of the greater mobility of the fishes, and their greater powers of adaptation to certain changing conditions. Besides these fish remains, the most common fossil in the Sweetland Creek beds is a crustacean belonging to the genus *Spathiocaris*, which also occurs in the Upper Devonian black shale in southern Indiana and Illinois, and in a basal Kinderhook shale in southwestern Missouri. This crustacean, like some of the Lingulas, seems to be associated rather with a peculiar type of sediment than with a definite time period of narrow limits. Neither the *Ptyctodus* nor the *Spathiocaris* have been found in the basal Kinderhook shales at Burlington, but the fauna of the basal portion of the formation is of course not known.

During the progress of Kinderhook time the sea was encroaching from both the north and the south, until before the close of the epoch free communication was established between the earlier separated provinces and the fauna of the southern province became the dominant type throughout the entire Mississippi Valley Basin. This northern incursion of the southern fauna is well exhibited in the uppermost 15 feet of the Kinderhook section at Burlington and elsewhere.

From the outline of the faunal history here given, it is evident that the arrangement of the Kinderhook formations into three successive

[1] *Mo. Geol. Surv.*, XII, 77.

[2] "Bed No. 4, Stewart," *Kansas Univ. Quart.*, IV, 161.

divisions, the Louisiana, Hannibal, and Chouteau, as has usually been done, does not express the proper relationships of the faunas. The Chouteau fauna, in some of its expressions, is without doubt as old as the Louisiana fauna, and it is as impracticable to make one continuous section to contain all of the Kinderhook formations, as it would be to make a standard Devonian section to include the formations of New York and Iowa.

Early Mississippian faunas of the Appalachian Basin.—In the waters between the Cincinnati arch and the old Appalachian land in early Mississippian time, the faunal conditions were more like those of the southern Kinderhook province than the northern. In the Bedford shale of that basin a fauna occurs which is largely of Devonian derived species, and like the southern Kinderhook faunas these species have their relationships with Hamilton rather than with Upper Devonian forms. The succeeding formations in Ohio constitute the several members of the Waverly group with faunas showing more or less close relations with those of the southern Kinderhook. In the northern part of the basin, as in the Waverly beds of northwestern Pennsylvania, the presence of such forms as *Paraphorhynchus*[1] suggest relationships with the northern Kinderhook faunas of the Mississippi Valley, a relationship which might have been established by faunal migration from the West to the East by way of the Traverse Strait and Michigan.

Post-Kinderhook faunas of the Mississippi Valley Basin.—With the submergence of the Kankakee Peninsula and the partial or complete submergence of the Ozark land, the source of the clastic sediments in the immediate Mississippi Valley region was removed, and a great period of limestone formation was initiated which is best exemplified in the Burlington and Keokuk formations. The fauna of this clear sea was in large part an outgrowth of the later Kinderhook faunas, and is best characterized by the wonderfully rich crinoidal element.

The fauna of the formations which together constitute the Osage division of the Mississippian is in some respects unique. The great crinoidal element is in large part or wholly indigenous to this province,

[1] *Rhynchonella medialis* and *R. striata* Simpson (*Trans. Am. Phil. Soc.*, XV, 144), rom Warren County, Pa., are members of this genus.

although it had its beginnings in the preceding Kinderhook. No locality in the world, so far as known, has furnished so large a number of crinoids of similar age, either in genera, species, or individuals, as this Mississippian province. The fauna, in its entirety, exhibits much in common with the mountain limestone of England, Ireland, and elsewhere in Europe. Many species of brachiopods in the formations either are identical or are so closely allied as to be difficult of separation, and the correlation of the Osage with the Mountain Limestone of England, or at least of some part of it, is based upon substantial evidence. Evidence sustaining the indigenous character of the crinoidal element in the fauna is found in a comparison of these forms from the Osage of the Mississippi Basin and from the Mountain Limestone of Europe. Every genus in the Mountain Limestone occurs also in the American faunas, while there are many genera which do not occur outside of the Mississippi Basin; furthermore, all of those genera which occur in both this Mississippian province and in Europe are represented by a larger number of species in America. These facts seem to indicate that the Mississippi Valley Basin was the metropolis for this great crinoidal fauna.

During this period the Cincinnati arch was above sea level, and from this island clastic sediments were being deposited off its western and southwestern shore, which constitute, in part at least, the Knobstone formations of Indiana and Kentucky, although the basal portion of the Knobstone is undoubtedly of Kinderhook age. The faunas associated with these clastic sediments are usually more meager than in the calcareous sediments of the clear seas farther west, and are somewhat different in character; however, they possess much in common as is evidenced by the wonderfully prolific crinoid fauna of the Crawfordsville beds in Indiana.

The later phases of the Osage sedimentation became more clastic, especially toward the north, doubtless because of the elevation of the land to the north, and in the Keokuk formation numerous shaly layers occur, intercalated between limestone beds. The shales become more and more dominant until, in the Warsaw formation, shales constitute the major portion of the sedimentation. In the southern portion of the Mississippian Basin this change in sedimentation was less or even not at all effective, since the Warsaw, as a distinct shale horizon, is scarcely or not at all recognizable beyond a short distance south of St. Louis. The fauna of these shaly Warsaw beds is more or less closely allied to that of the subjacent formations, but it contains numerous species which are quite distinct and some which are either identical with, or related to, members of the superjacent faunas.

Subsequent to the Warsaw sedimentation the land to the north of the Mississippi Valley Basin was elevated. The Salem limestone which lies immediately above the Warsaw has a thickness of only 8 or 10 feet at Warsaw, Ill.,[1] where the formation consists of an impure, arenaceous limestone. To the south it increases in thickness to a maximum of about 100 feet, and is for the most part a very pure limestone, although magnesian layers are not unusual. The formation extends eastward beneath the younger formations, and is again exposed in western Indiana, off the western shore of the old Cincinnati island. A notable feature of the formation is the presence in it, throughout its entire geographical extent, of more or less extensive oölitic beds.

The fauna of the Salem limestone, commonly known as the Spergen Hill fauna, contains many diminutive forms, one of the most common species being *Cliothyris hirsuta*, which was present in a Kinderhook oölite at Burlington, Ia. Several small forms of *Conocardium* are also common in the fauna, one of the species, *C. meekana*, being somewhat closely allied to *C. pulchellum* from the same Kinderhook oölite. A comparison of the fauna with the Mississippian faunas of other parts of North America indicates a close relationship with certain faunas far to the northwest in Montana and Idaho. Meek[2] has recorded a fauna from a limestone in Idaho in which nearly one-half of the forms are identical with Spergen Hill species, and in the Yakinikak limestone[3] in northwestern Montana a similar fauna also occurs. These limestones in Montana and Idaho are doubtless to be associated with the Madison limestone of the Yellowstone National Park, in which occurs a fauna having relationships with the Kinderhook of the Mississippi Valley, and especially with that of the Kinderhook oölite bed at Burlington, Ia., a relationship which may account for the partial recurrence in

[1] *Ill. State Geol. Surv., Bull. No.* 8, p. 90.

[2] *Am. Jour. Sci.* (3), V, 383.

[3] *Bull. Geol. Soc. Am.*, XIII, 324.

the Salem limestone of a fauna which has some features in common with this earlier fauna of a similar earlier oölitic bed.

Superjacent to the Salem is the St. Louis limestone which attains a maximum thickness of 250 feet, but in the northern portion of the Mississippian province it is reduced in thickness and lies unconformably upon the Salem, this unconformity being well shown near Warsaw, Ill. This unconformity indicates that the Mississippian sea retreated to the south during late Salem time, and readvanced in early St. Louis time. The retreat did not reach as far as Alton, Ill., however, as near that city the succession is perfectly conformable. The lowermost bed of the St. Louis in the north is a conspicuous limestone breccia which may be a northward continuation of a brecciated horizon near the middle of the formation in the region about St. Louis and Alton, but in following the formation to the south this brecciated horizon becomes less conspicuous and disappears. The fauna of the St. Louis is on the whole a meager one, and is quite different from that of the Salem. In some respects it suggests a recurrence of the Osage fauna, although the species are essentially all different, and some forms, of which the coral *Lithostrotion canadense* is perhaps the most notable, are distinctly new elements in the fauna.

The St. Louis is followed conformably by the Ste. Genevieve limestone. This formation differs from the St. Louis and resembles the Salem in the presence of oölitic beds, and with the recurrence of these conditions favorable for the formation of oölitic limestone, there is also a recurrence of the Salem fauna. Many species of the Ste. Genevieve are identical with those in the Salem, although the fauna contains species also which are characteristic to it. Among the latter a conspicuous one near Alton and in Monroe County, Ill., is *Pugnax ottumwa*, this species being present to the exclusion of all others in some localities. The abundance of the same species in the Pella beds of Iowa, the highest division of the so-called St. Louis of that state, suggests the correlation of these beds with the Ste. Genevieve rather than with any part of the St. Louis proper. This occurrence in Iowa is in accord with conditions elsewhere which indicate that the Ste. Genevieve was a time of great expansion of the Mississippian sea in all directions. It was at this time only, during the entire Mississippian period, that limestone conditions obtained in the northern part of the more or less inclosed Appalachian Basin east of the Cincinnati island, where the Maxville limestone represents the Ste. Genevieve formation of the Mississippi Valley. To the southwest, in northern Arkansas, the Spring Creek limestone, a formation which, with the Batesville sandstone, is essentially contemporaneous with the Ste. Genevieve, and probably uncomformable upon the subjacent Osage beds, carries a most remarkable fauna with peculiar immigrant forms from the far southwest,[1] a faunal character which indicates that the Mississippian sea reached so far in that direction as to communicate with the Western Continental Province, where these peculiar forms had existed, some of them having persisted from Devonian time.

Subsequent to the great extension of the sea during Ste. Genevieve time the northern portion of the Mississippi Valley Basin became dry land, and so remained until it was reoccupied by the sea in Pennsylvanian time, with only a partial readvance in early Chester time. In the extreme southern portion of Illinois and in Kentucky, Ulrich[2] has recognized three members in the Ste. Genevieve formation, the Fredonia, the Rosiclare, and the Ohara, but in all the region north of Chester, Ill., the upper portion is wanting and the superjacent Cypress sandstone rests unconformably upon the lower beds of the Ste. Genevieve. The higher beds of the Ste. Genevieve in the extreme southern Illinois, especially the Ohara beds of Ulrich, bear a fauna which has much in common with the faunas of the Chester above the Cypress sandstone, but even here there is possibly an unconformity between these beds and the Cypress.

The Cypress sandstone initiates the Chester, the closing epoch of the Mississippian in the typical portion of the Mississippi Valley Basin, during which period the conditions of sedimentation were continually shifting, there being interbedded limestone, shale, and sandstone formations, the limestone and shale predominating below, above the initial Cypress sandstone, and the sandstones being more conspicuous above. No remnant of these beds is preserved, so far as known, north of a point some miles south of St. Louis, although it is possible that the Chester sea extended further north than this. It is quite certain, however, that this sea never had the great extent to the

[1] Williams, *Am. Jour. Sci.* (3), XLIX, 94–101.

[2] *Professional Paper*, U. S. G. S., No. 36, p. 38.

north which had obtained during some of the earlier Mississippian periods.

The faunas of the Chester beds have a certain individuality of their own, although the successive limestone beds, in which the fossils mostly occur, have not yet been faunally differentiated with any great success. A conspicuous feature of the fauna is the presence of numerous blastoids of the genus *Pentremites*, and bryozoans, especially of the genus *Archimedes*. Among the brachiopods, especially, there is some recurrence of species identical with, or closely allied to, forms in the Salem and Ste. Genevieve limestones, but this characteristic is not limited alone to the brachiopods.

In the typical portion of the Mississippi Valley Basin the Mississippian period closes with the withdrawal of the Chester sea. Farther to the southwest, in Arkansas, however, toward the more open sea, it has been suggested by Ulrich[1] that similar faunas persisted into beds which are really of Pennsylvanian age, under which interpretation the line between the Mississippian and the Pennsylvanian, in that region, would be somewhat arbitrarily drawn. It is not improbable that the Arkansas beds are younger than any in the Mississippi Valley, yet that fact should not necessarily be considered as sufficient basis for referring them to the Pennsylvanian. The time boundary between the two periods should be marked by the time of maximum withdrawal of the sea or the subsequent readvance during which new sets of conditions were introduced.

MISSISSIPPIAN FAUNAS OF THE APPALACHIAN BASIN[2]

During Mississippian time the Cincinnati arch constituted a barrier between the central Mississippian sea and the Appalachian basin, a gulf which lay between this island and Appalachia. Into this basin clastic sediments were being carried from the east, north, and west, so that the pure limestones of the Mississippi Valley are absent, and the faunas are neither so prolific nor so well differentiated. In this basin the Mississippian formations are included within the Pocono and Mauch Chunk formations of Leslie. The most definite point of faunal contact between this basin and the Mississippi Valley Basin is found in

[1] *Professional Paper*, U. S. G. S., No. 24, p. 109.

[2] For a detailed description of the stratigraphy and correlation of the Mississippian of the Appalachian Basin, see Stevenson, *Bull. Geol. Soc. Am.* XIV, 15–96.

the Maxville limestone, whose fauna is to be correlated essentially with the Ste. Genevieve of southern Illinois and Missouri. It has been shown by Stevenson[1] that only the upper portion of the Pocono is of Mississippian age, and that this part is stratigraphicaly continuous with the Waverly group of Ohio. The basal member of the Waverly group, in the more general application of that term, is the Bedford shale in which occurs a fauna with Hamilton affinities.[2] As has already been pointed out, this fauna is believed to be associated with the incursion of the Hamilton-like forms which constitute one element in the southern Kinderhook faunas. The composition of the succeeding Waverly faunas has been more carefully studied by Herrick[3] than by anyone else, and they exhibit throughout more or less affinity with the Kinderhook faunas of the Mississippi Valley Basin. Numerous members of the fauna suggest a Devonian derivation sometimes from Hamilton and sometimes from Chemung progenitors, as if they were to some extent a mingling of the two Kinderhook faunas of the Mississippi Valley. These Waverly faunas are, however, in no wise to be considered as contemporaneous with the Kinderhook alone of the Mississippi Valley, but they must also represent the Osage. In the Appalachian Basin, with its continuity of clastic sedimentation, environmental conditions similar to those of the Kinderhook persisted through Osage time, consequently there is no sharp differentiation of the faunas as there was in the Mississippi Valley where the period of clastic sedimentation was displaced by the clear seas in which nothing but calcareous sediments were deposited. For this reason the typical Burlington and Keokuk faunas do not occur in the Appalachian Basin, but an occasional member of these faunas found its way into the basin and such forms left records which are of value in the correlation of the faunas.

Outside of Ohio little or no detailed faunal study of these beds has been made, but Stevenson[4] has pointed out the stratigraphic correlation of the beds throughout the Appalachian Basin from Pennsylvania to Alabama.

[1] *Loc. cit.*

[2] Herrick, *Geol. Surv. Ohio,* VII, 507.

[3] A summary of Herrick's work is to be found in *Geol Surv. Ohio,* VII, 495–515.

[4] *Loc. cit.*

In the Mauch Chunk series of earlier authors, Stevenson[1] recognizes three members, a lower the Tuscumbia, a middle the Maxville, and an upper the Shenango. Toward the close of Pocono time there was a marked contraction of the sea in the Appalachian Basin, just as was the case at a corresponding time in the Mississippi Valley Basin. This contraction was of such proportions that the Tuscumbia beds were not deposited in Ohio in the area occupied by the earlier Waverly, except at the Kentucky border, but, as in the west, there was a readvance of the sea until it had reached its maximum extent in the deposition of the Maxville limestone which is to be correlated essentially with the Ste. Genevieve limestone of the Mississippi Valley. Such a correlation would make the Tuscumbia essentially contemporaneous with the St. Louis limestone of the Mississippi Valley, a correlation which is sustained by the paleontologic evidence. The Shenango is said to contain fossils characteristic of the Chester of the Mississippi Valley,[2] and may be correlated with that formation.

MISSISSIPPIAN FAUNAS OF THE ROCKY MOUNTAIN BASIN

In Montana and elsewhere in the northern Rocky Mountain region, limestones of Mississippian age are widely distributed, although but little data in regard to the faunas have been published. The most notable contribution to our knowledge of these faunas is that of Girty on the Carboniferous fossils of the Yellowstone National Park.[3] The faunas here described are distributed through more than 1,600 feet of strata of the Madison limestone, but they do not show any such differentiation as is recognized in the Mississippi Valley. One general fauna persists with but minor changes throughout the entire series and this fauna shows many affinities with the southern Kinderhook faunas of the Mississippi Valley, as well as with the fauna of the Salem limestone. Faunas allied to that of the Salem have also been detected elsewhere in the region, as the Idaho fauna noted by Meek and the fauna of the Yakinikak limestone already mentioned. These relations suggest that in this northwestern region a long-lived fauna, having more or less close relationships with the Salem fauna, was contemporaneous with the larger part of the entire Mississippian series of the

[1] *Op. cit.*, p. 85.

[2] Stevenson, *op. cit.*, p. 85.

[3] *Monograph*, U. S. G. S., XXXII, Pt. 2, pp. 479–599.

Mississippi Valley. At intervals this fauna made incursions into the Mississippi Valley Basin, as is evidenced by its representatives in the Kinderhook oölite at Burlington, Ia., in the Salem limestone, again in the Ste. Genevieve, and to some extent also in the Chester. That this is not a complete interpretation, however, is shown in the occurrence of a group of crinoids described by Miller and Gurley from near Bozeman, Mont.,[1] which strongly suggests the crinoid fauna of the lower Osage horizons of the Mississippi Valley. It is not improbable that when our knowledge of these faunas in the northwest is expanded, we may be able to recognize elements related to most or all of the faunal divisions of the Mississippi Valley. The evidence at present available suggests that this region occupied a distant part of the same sea which was present farther to the southeast, and that there was more or less unobstructed means of faunal communication between the two regions.

From the Lake Valley region in New Mexico, there has been described an early Mississippian fauna[2] which is a close ally of the fauna of the Fern Glen formation at the summit of the Kinderhook in the Mississippi River section south of St. Louis. This occurrence idicates that the Mississippian sea had transgressed at least as far to the southwest as New Mexico by the close of Kinderhook time, and that means for faunal communication was unobstructed in that direction.

The Mississippian faunas from Colorado have been described by Girty[3] who has reported on materials collected in nine separate regions from the Ouray, Leadville, and Millsap limestones. All of these faunas are separated into two groups by that author, both of which are considered to be of essentially the same age, early Mississippian, probably Kinderhook or early Osage. The composition of the fauna is strikingly like that of the Madison limestone of the Yellowstone National Park, its relationships being especially with the Chouteau of the Mississippi Valley Basin, but the presence of such forms as *Eumetria marcyi ?*, *Straparollus cf. spergenensis*, *Fenestella serratula ?*,

[1] *Bulletin*, Ill. St. Mus. Nat. Hist., No. 10. "*Poteriocrinus bozemanensis P. douglassi*, and *Platycrinus douglassi*;" *ibid.*, No. 12. "*Batocrinus douglassi, Rhodocrinus douglassi, R. bozemanensis, R. bridgerensis, Platycrinus bozemanensis, P. bridgerensis, Dichocrinus bozemanensis.*"

[2] Miller, *Jour. Cin. Soc. Nat. Hist.*, IV, 306–15; also Springer, *Am. Jour. Sci.* (3), XXVII, 97–103.

[3] *Professional Paper*, U. S. G. S., No. 16.

etc., suggest also a relationship with the Salem limestone fauna of the Mississippi Valley. The conditions are therefore similar to those in the Madison limestone of the North, and the interpretation of the faunal relations in that region can doubtless be extended to the more southern area.

MISSISSIPPIAN FAUNAS OF THE WESTERN CONTINENTAL PROVINCE

For a knowledge of the Mississippian faunas of the Great Basin region we are especially indebted to Walcott, who has described them from the Eureka district of Nevada.[1] The faunas occur at various horizons through a series of "Lower Carboniferous" limestones 3,800 feet in thickness, and are most remarkable from the fact that there is a general mingling of forms which, if found in the Mississippi Valley, would be considered as characteristic either of the Devonian, the Mississippian, or the Pennsylvanian. There is, however, a notable absence of the more conspicuous elements of the Mississippian faunas of the Mississippi Valley, such as the crinoids of the Osage faunas, the large Spirifers of the *S. striatus* type, the *Archimedes* and *Pentremites* of the Chester faunas, etc. None of the specialized Mississippi Valley faunas can be recognized. This basin must have been isolated, during Mississippian time, both from the Mississippi Valley and from the Rocky Mountain basins. The one point of faunal contact between the Great Basin and the Mississippi Valley is found in the presence of several of the peculiar Great Basin forms in the fauna of the Spring Creek limestone of northern Arkansas, among which *Rhynchonella eurekensis* and *Leiorhynchus quadricostatus* are perhaps the most notable. The age of the Spring Creek limestone is believed to be very close to that of the Ste. Genevieve limestone, at which time, perhaps, the Mississippian Sea had its greatest extension in the East. With this expansion of the sea there would seem to have been established a brief communication with the Great Basin region, of such a nature as to allow a group of these peculiar forms to migrate at least as far east as northern Arkansas. It is apparently impossible to correlate this incursion in the Great Basin, however, perhaps because of our imperfect knowledge, because the most notable of the immigrant species, *R. eurekensis*, has a long range in the Great Basin beds.

[1] *Paleontology of the Eureka District*, Monog., U. S. G. S., Vol. VIII.

DISCUSSION

PROFESSOR CALVIN

The paper presents very fairly and fully the taxonomic relations of the Devonian and the Mississippian so far as Iowa is concerned. I should be disposed to question the propriety of correlating the Sweetland Creek shales of Muscatine County with any part of the Kinderhook. It is true that in Missouri beds which have been referred to the Kinderhook furnish *Ptyctodus* and some other Devonian types; but at Burlington the Kinderhook shales carry a fauna that, in practically all its aspects, is Carboniferous. On the other hand, the fauna of the Sweetland Creek shales is characteristically Devonian. Leaving out *Ptyctodus*, which may belong to either of the two formations, all the other life forms will be found to be distinctively Devonian. The Sweetland Creek beds furnish two species of *Synthetodus*, a form very common in the State Quarry limestone. Now the State Quarry limestone is in large part made up of imperfectly comminuted shells of that most intensely non-Carboniferous of all the Devonian types, *Atrypa reticularis*, with occasional shells of another almost equally intensely Devonian form, *Gypidula comis*. Fossils are rather rare in the Sweetland Creek beds, but all that have been noted are such as to exclude this formation from any close relation to the Kinderhook.

PALEOGEOGRAPHIC MAPS

DEVONIAN AND MISSISSIPPIAN

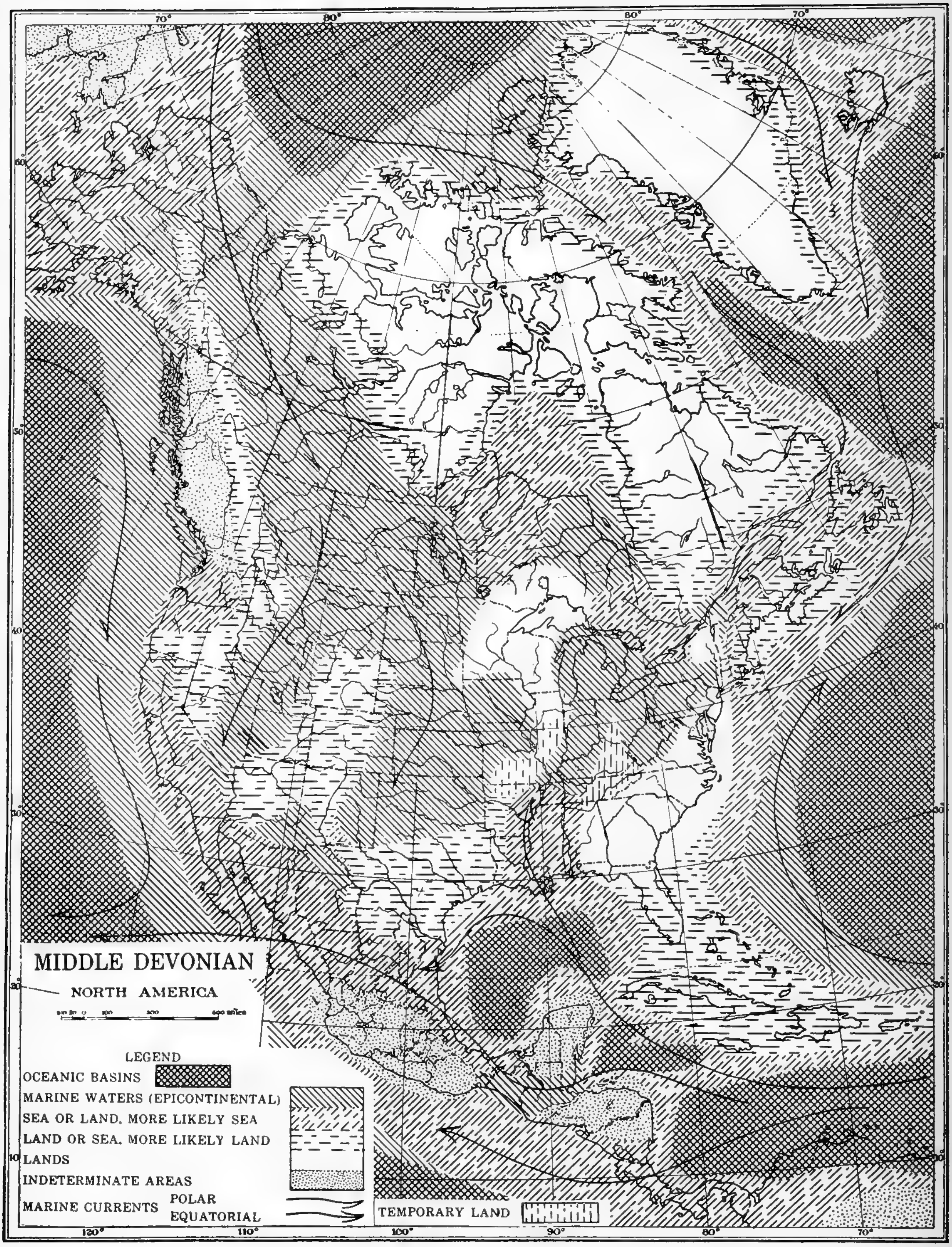
BAILEY WILLIS
U. S. Geological Survey

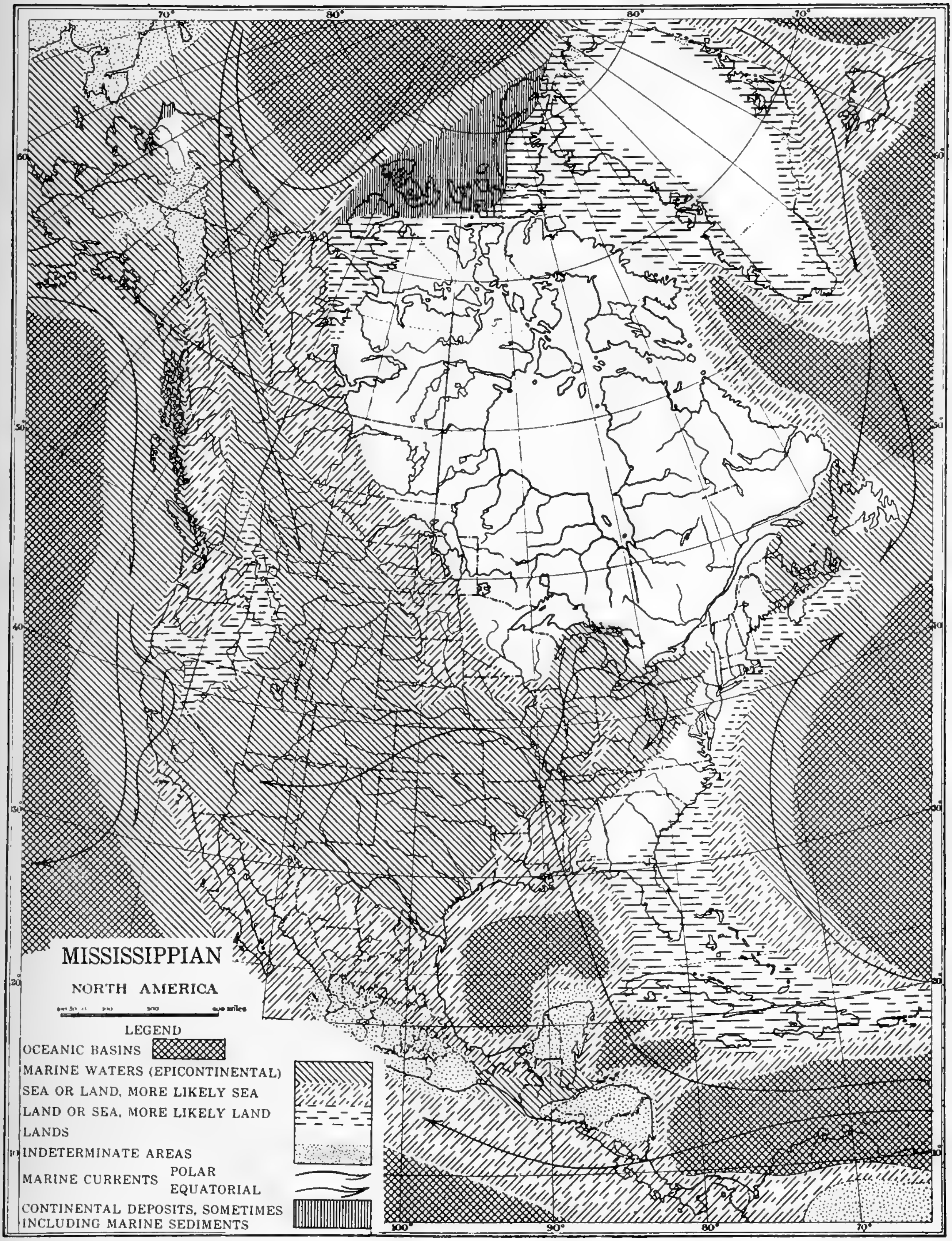
5 AND 6. MIDDLE DEVONIAN AND MISSISSIPPIAN[1]

The archipelagic condition of North America which began in the Ordovician persisted through the two succeeding periods with many changes of land and sea. Any refined study of these changes involves somewhat precise correlations which have already been carried far. The map here presented is of one passing phase only. The time represented is that before and after the invasion of the Hamilton fauna into the New York embayment, as is indicated by the temporary land barrier shown in Illinois and Missouri. The great thickness of sediments in the eastern Appalachian trough indicates marked orogenic movement during the middle and upper Devonian in the land lying toward the Atlantic. The southeastern expansion of the sea over Appalachia began apparently in middle Devonian and extended into upper Devonian time.

The distribution and character of the Mississippian sediments leads to the inference that the time was one of an extended epicontinental sea with low and relatively limited lands. The archipelago of the immediately preceding period gave way to a general submergence of all the southwestern portion of the continent. In the far north conditions were favorable to the deposition of coal and other continental deposits associated with marine beds. The Atlantic and eastern portion of the interior sea and the wide sea covering all the western states present differences of habitat which are emphasized by Dr. Weller in his discussion. Toward the close of the Mississippian or early in Pennsylvanian time, an extensive land area emerged in the Colorado-New Mexico region, as indicated by erosion of the Mississippian sediments.

[1] Prepared in collaboration with Dr. G. H. Girty.


MIDDLE DEVONIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND
120°
110°
100°
90°
80°
70°


MISSISSIPPIAN
NORTH AMERICA
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MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS

CHAPTER VI

UPPER CARBONIFEROUS OR PENNSYLVANIAN[1]

GEORGE H. GIRTY

The Upper Carboniferous, rather in contrast with the Lower, was a period of emergence of shores and of shallowed waters, and it presents the variety that appertains to such conditions. In considering the stratigraphic relations of the Pennsylvanian and Permian one cannot fail to be struck by the local character of the phenomena, and the vast amount of detail, from which it is difficult to disengage facts of broader significance. One of the facts of larger moment is the general unconformity which occurs at the base of the Pennsylvanian rocks. The extent of the phenomenon may be gauged by this: that an unconformity probably occurs at this horizon all the way from Pennsylvania to the Mexican boundary, except possibly in the deeper troughs. The underlying strata range in age from pre-Cambrian to Upper Mississippian. This is evidently, therefore, an unconformity by overlap, but the overlap is sometimes not appreciable unless extensive areas be kept in view. Very rarely, I believe, is any angular unconformity to be observed, but there are basal conglomerates and in many places unmistakable evidence of erosion in the subjacent strata. Some of the most noteworthy instances of erosion are to be found in Missouri where shales of Pennsylvania age were deposited in sink holes and subterranean channels in the Lower Mississippian limestones. On the other hand, evidences of erosion are often wanting and sometimes any physical suggestion of an interruption in sedimentation. A striking instance of this sort occurs in southern Arizona. In the Bisbee area limestones of Pennsylvanian age rest upon limestones of Lower Mississippian age, the two series being extremely similar in physical characters, though carrying different faunas. The same condition probably exists in the Redwall limestone of the Grand Canyon region, whose lower part is of lower

[1] Published by permission of the Director of the U. S. Geological Survey.

Mississippian age and whose upper has furnished, according to Meek, a long list of Pennsylvanian species. The presence of this unconformity is to be detected therefore not always by local evidences of erosion or changes in sedimentation, but sometimes only by paleontologic evidence in the abrupt and great change in the faunas and floras, and by stratigraphic evidence in the overlap, sometimes appreciable only by considering rather wide areas.

Inasmuch as we find this extensive area in which a hiatus exists at the base of the Pennsylvanian, and inasmuch as over part of the area unmistakable evidence of erosion is found, the inference is probably a safe one that everywhere within this region the hiatus is partially at least due to post-Mississippian erosion.

The presence of this erosion period implies the existence of a land surface over the eroded area, for the alternative hypothesis of submarine erosion may probably be disregarded.

The boundaries of the land cannot be exactly defined. On the east I would judge that it must have followed a presumably irregular line southwestward from northern Pennsylvania to southwestern Texas. At least, there is a well marked unconformity west of such a line, while in some sections east of it, sedimentation appears to have been continuous from the Mississippian into the Pennsylvanian. An estimate of where the boundary lay on the western side is conditioned somewhat by our correlations of the western Mississippian faunas with the eastern and with one another, especially as to areas over which the Upper Mississippian is wanting.

It is pretty well established by many observations that faunas with a Kaskaskian facies are not known west of the Mississippi Valley.[1] There are, however, some faunas peculiar to the West which may be of Kaskaskian age. The best known and most notable of these occurs in the Baird shale of California, and has not been found elsewhere on the continent. It is characterized among other things by the European *Productus giganteus*, and can be correlated more easily with the Mountain limestone of Europe than with our own Mississippian.

[1] Since this statement was written there has come to hand from the Wasatch range in northern Utah, a fauna having much in common with the upper Mississippian of the East. Among other species it contains *Productus Cestriensis* in abundance.

Although the *Productus giganteus* fauna strictly speaking is, so far as we know, restricted to California, there is another western fauna having a different facies which I am inclined to correlate with it. It comprises little besides corals, chiefly large Cyathophylloids. I have noted it in Utah, Montana, and Idaho. We have some reason to believe that it represents the Upper Mississippian to the East and the Baird fauna to the West. If this is so, the evidence upon which we chiefly relied for recognizing post-Mississippian erosion—the absence of the Upper Mississippian—is lacking over this area and the hypothetical land mass would appear to have extended westward on its northern margin no farther than western Montana and central Utah.

As to what were probably the northern and southern boundaries, evidence is wanting, Carboniferous strata being absent in Canada across its trend and absent or concealed by Cretaceous overlap in Mexico except just over the Texas border in the state of Chihuahua.

The unconformity of which I have just been speaking occurs at the base of the Upper Carboniferous. There is, however, a second important unconformity which occurs in the middle of the Upper Carboniferous and is less widespread as to the area in which it has been recognized. Like the other, it is marked rather by overlap than by discordance. The overlap is most conspicuous in western Texas and New Mexico, but equivalent strata, distinguished from the preceding ones by a distinct faunal change, and in some cases by basal conglomerates, probably extend into Arizona and Nevada, or even farther.

Lithologically the beds of the Upper Carboniferous and Permian present the greatest variety, and about the only truth of broad applicability has long been known. I mean that in eastern North America the sediments of the Upper Carboniferous are chiefly shales, sandstones and conglomerates with some thin limestones, while in the West the limestones have a much larger development, and coals, which toward the East play so important a part, if not in thickness at least economically and significantly in the Carboniferous sediments, are there practically absent. From this it has been justly inferred that the character of the eastern Carboniferous indicates shore and estuarine conditions of deposition, while that of the western indicates marine conditions of deposition. There are, however, vast amounts of sandstone and shale in the Upper Carboniferous of the West.

It seems to be true that the greatest deposits of limestone in this series are found rather to the Southwest than to the West and the most notable thicknesses of sandstone and conglomerate rather to the Northeast than to the East.

There is one other phenomenon of more than local interest which should not be omitted in a commentary on the lithologic features of the Upper Carboniferous. I refer to the red beds of the West and Southwest. The age, the stratigraphic relations, the sources, and the cause of the peculiar coloration of this great series of sandstones and conglomerates form a problem of no mean difficulty and importance. Although it is difficult to trace these beds stratigraphically, and though fossils are rarely found in them, we know now that sediments of this character were formed rather early in the Pennsylvania and successive manifestations recurred at various periods on into the post-Cretaceous. That there were continuous red beds conditions during all this period seems out of the question, and also that red beds conditions repeatedly recurred. Some of the occurrences can probably be best explained as a reworking of older materials under conditions unlike those which determined their original character.

In considering the faunas of the later Paleozoic—those of the Pennsylvanian and Permian—several facts of a general nature can be stated. The Upper Carboniferous faunas of western North America have a facies markedly different from those of the eastern part and are closely comparable to the corresponding faunas of Asia and eastern Europe. A second fact of general import seems to be that, quite in contrast to the unstable physical conditions in which they lived, these eastern faunas, which range, let us say, westward to the Rocky Mountains, are remarkably uniform both in their geographic distribution and in their range. I would be far from saying that the Upper Carboniferous faunas of the continental basin do not show differentiation during this long interval, for the Pottsville group has a distinct fauna and appreciable changes occur in the later Pennsylvanian. But the changes are by no means so marked as one would be led to expect from the thickness of the strata involved, the extent of the territory they cover, and the varying conditions of the time and the place. The truth of this statement will be appreciated upon a consideration of the Mississippian series of the Upper Mississippi Valley and the subdivisions which have been established in it.

When we speak of the variety of conditions under which the sediments in question were laid down, and remember that they include the great coal deposits of this era, we are led to inquire whether the faunas are marine or fresh water, or perhaps both, with the important difference in facies which such difference in habitat would doubtless entail. Fresh-water faunas, or at least fresh-water genera and species, have been recognized elsewhere in the Carboniferous, notably in the Coal Measures of England and the Permian of Russia. In North America, although we have a facies which appears to be non-marine, there are no Carboniferous faunas which in my belief can be called fresh water. The facies in question recurs frequently, particularly in the Appalachian region, and manifests little change in its general aspect, although appearing at widely different horizons in the Pennsylvanian. It is very restricted in variety though often abounding in individuals. A mollusk probably identifiable as *Naiadites elongatus* Dawson is a characteristic feature. Ostracods are also abundant, and the large bivalve Crustaceans, *Estheria* and *Leaia*, sometimes occur. *Spirorbis* is another type frequently met with, while fish scales, fragments of *Limuloid* Crustaceans, and wings of insects are rare. Usually this peculiar assemblage of forms is associated with abundant coal plants.

The genus *Naiadites* was described by Dawson from the Nova Scotia Coal Measures, in which it occurs with a fauna similar to that sketched above. Dawson regarded the sediments and faunas as representing fresh-water conditions, and considered *Naiadites* to be related to the Naiads of our fresh-water lakes and rivers.

The fresh-water mollusks of the English Carboniferous were included by Dr. Wheelton Hind under the three genera, *Anthracoptera*, *Anthracomya*, and *Anthrocosia* in a valuable monograph published a few years ago. Later, after studying specimens of *Naiadites* from Nova Scotia, he reached the conclusion that *Anthracoptera* and *Naiadites* were the same genus.

Thus far the balance of evidence and opinion seems to be in favor of the fresh-water habitat of the fauna. On the other hand, externally and internally, *Naiadites* is extremely like the marine genus *Myalina*, and Dr. Hind has referred many of our marine *Myalinas* to *Naiadites*. In fact, he has even placed the names of some of our American *Myalinas* which always occur associated with marine faunas in the synonymy of English species of *Naiadites* which are supposed to be strictly fresh water. Furthermore, the fauna under consideration is in some instances associated with specimens of *Lingula* and *Aviculipecten*. The living *Lingulas* sometimes inhabit brackish waters near the mouths of rivers, but never the fresh waters of lakes and streams, while the living *Pectinoids* are strictly marine. The fossil Pectinoids in question are small and depauperate examples and belong to a rather peculiar group, that of *Aviculipecten whitei*.

This assemblage can hardly be explained as due to the accidental commingling of types having different habitats. If it consisted of fresh-water animals washed out to sea we would expect to find the fresh-water types few and the marine ones numerous, varied, and characteristic. Such is not, however, the case. One would not a priori much expect to find marine animals washed into a fresh-water fauna, and in such an event we would probably look for an entire marine fauna, or, at least, granting that only a few specimens were washed in, that some such invaders would be of the usual marine types. Instead, the alien forms are always limited to one or two peculiar varieties. That abundant and differentiated marine life was always at hand waiting for an opportunity to migrate wherever the conditions became possible seems to be evidenced by the occurrence now and again of marine faunas in close association with beds of coal. On the whole, it seems most reasonable to regard this fauna as a natural assemblage of species selected and modified by a habitat, if not in strictly marine, at least not in strictly fresh waters.

There is another reputed occurrence of fresh-water forms in the Carboniferous, reported by Mr. Walcott from the Eureka district, of Nevada. I have examined the fossils in question only casually, and it has been many years since I have seen them at all, but I doubt whether in this instance, any more than the other, the evidence warrants saying more than that they are possibly non-marine.

The Upper Carboniferous faunas of the West appear to be better differentiated than those east of the Rocky Mountains. At least three well-marked facies can be recognized. The oldest of these is found in the limestones whose occurrence has already been mentioned, resting directly upon Lower Mississippian limestones of similar character in Arizona and probably in Utah. This fauna is succeeded by one which is best considered from its development in the Transpecos region of Texas, because it is there more highly developed, more favorably studied, and more determinable in its stratigraphic relations with higher beds. It occurs in the Hueco formation which is 5,000 feet thick, and is practically calcareous throughout. As has already been noted, the Hueco formation by overlap rests upon the pre-Carboniferous in this region. The Mississippian faunas, together with the earlier Pennsylvanian ones, appear to be absent. The Hueconian fauna is widely distributed over the West, ranging indeed into Alaska, while it is even recognizable in Asia and eastern Europe. Most of the occurrences of Carboniferous in the West can be referred to this series, although some or them present more or less distinctive facies. The more important of the facies provisionally referred to the Hueconian are these: that of the Aubrey group of Arizona, rather widely distributed; that of the phosphate beds of the Preuss formation, local in Utah, Idaho, and Wyoming; the *Spiriferina pulchra* fauna with a considerable distribution in Idaho, Wyoming, Utah, and Arizona; the fauna of the McCloud limestone of California probably extending into Nevada; and that of the Nosoni formation of California (in part the "McCloud shale"), apparently recognizable to the eastward and to the North and West, even into Alaska.

In the Transpecos the beds of the Hueco formation are succeeded by those of the Guadalupe Mountains. The contact between the Hueco formation and the Guadalupian series is obscured by faulting and by desert deposits, but it is assumed that the interval between the highest known beds of the one and lowest known beds of the other is not a long one and that no unconformity exists between them. The Guadalupian includes two formations, the Delaware Mountain formation and the Capitan limestone. The Delaware Mountain formation consists of sandstones and limestones, largely arenaceous to the North and largely calcareous to the South. The Capitan consists of whitish limestones and dolomites. Thus constituted the Guadalupian series is about 4,000 feet thick. The faunas of the two divisions of the Guadalupian are closely related to one another. They are very rich and varied, having already furnished over 325 species. The Guadalupian fauna is peculiar. But few of its species are common to the other American faunas and some of its genera, such as *Richthofenia*, *Leptodus*, *Geyerella* and *Aulosteges*, have not been noted elsewhere in the western hemisphere. Even the more common genera are in many cases represented by uncommon types. As an instance may be mentioned the genus *Composita* (*Seminula*), which, by the way, seems to be rather characteristic of our American faunas where it is ever present and ever abundant. In the Guadalupian this genus develops a bi-lobed species with a sinus on the dorsal as well as on the ventral valve and a deeply emarginated anterior border.

It is possible that the Guadalupian fauna may have an equivalent in California in the Robinson formation, in which I have noted a species of *Leptodus*, and a suggestion is contained in some forms from Nevada, but aside from this the Guadalupian facies is known only in a limited area in New Mexico and Texas.

It remains to speak of still another western fauna having a pronounced facies, a wide distribution, and a range through a considerable thickness of rocks. I mean the fauna of the so-called Permo-Carboniferous of the Wasatch Mountains, and the Permian of Mr. Walcott's Grand Canyon section. This fauna, which ranges also into Wyoming and Idaho, comprises little else than pelecypods, of which *Myalina* and *Aviculipecten* are the most common types, the Pectinoids being especially abundant and varied. It may tentatively be correlated with the Guadalupian (Delaware Mountain division), athough it presents but little resemblance to the Guadalupian fauna as at present known. At least, it appears to occupy a corresponding position in the section, resting upon strata which in the light of our present knowledge are correlated with the Hueco formation.

These western faunas are more easily correlated with those of Europe, especially Russia, than with those much nearer geographically, in eastern North America. Indeed, the correspondence of our western faunas with those of Russia is truly remarkable. The Russian series consists, in ascending order, of the Mountain limestone, or *Productus giganteus* zone; the Moscovian, or "Lower Carboniferous;"

the Gschelian or "Upper Carboniferous;" the Artinskian or "Permo-Carboniferous" and the Permian. One school of Russian geologists includes the Artinskian or Permo-Carboniferous beds in the Permian, and some Americans have followed them, but this seems to be of doubtful propriety. Murchison, DeVerneuil, and Keyserling mistook the Artinsk sandstone for the Millstone grit and distinctly excluded it from the Permian. If the faunal relations demand this extension of the term Permian to the Artinsk it would be justifiable, but such is not the case. At least, this appears to be the judgment of Tschernyschew, the chief of the Russian Survey, and other distinguished paleontologists. At all events in this recital the term Permian is used in exclusion of the Artinsk beds.

The *Productus giganteus* zone seems to be represented on this continent by the Baird shale of California whose fauna likewise contains *P. giganteus*.

The Moscovian, which has a facies very like our common Pennsylvanian faunas, may be compared with the earliest Pennsylvanian of Arizona and Utah, the term "Lower Carboniferous," as used by the Russians, having no relation to our own Lower Carboniferous or Mississippian. The Gschelian is clearly related to our Hueco formation, but with this zone the closeness of the analogy ceases. One is tempted to place in alignment the Artinsk and Permian which succeed the Gschelian in the Russian section, with the Delaware Mountain formation and Capitan limestone which succeed the Hueco formation in the American section, but such a correlation is neither sharply contradicted nor substantially supported by the faunal evidence. In fact, as exhibited in the literature, the faunas of the Artinsk and Permian are much less varied and individualized than those of the Guadalupian. The following suggestions are made with the diffidence of second-hand and imperfect knowledge, but it would appear that after the Gschelian stage there was in the Russian area a gradual progression from marine to at least near-shore conditions. This seems to be indicated by the great reduction in the marine facies, especially in the brachiopod representation, so that in the Permian there remains scarcely a tithe of the greatly diversified brachiopod fauna of the Gschelian, and by the introduction of fresh-water types of which not less than 60 species have been recognized. Apparently the typical Permian deposits of Russia represent local and not normally marine conditions of deposition.

I am tentatively assuming, on the grounds noted above, that the Guadalupian is equivalent to the Permian or to the Permian and Artinskian, the one representing a normal marine and the other an abnormal facies. It may prove, however, that all or part of the Guadalupian is younger than the Permian. A recent monograph by Tschernyschew gives a complete account of the brachiopods of the Gschelian, but the other types remain undescribed or else the descriptions are badly scattered. The literature on the Artinskian and Permian is also somewhat scattered, but one receives the impression that the brachiopods of the latter do not present many positive differences from those of the Gschelian though much less varied, and reduced to a few types of long range and wide distribution. Whether the same is true of the rest of the fauna it is difficult to say, although it seems rather doubtful. In view of the striking difference between the faunas of the Guadalupian and the Hueco formation, in which the brachiopods are most in point, of a lack of a corresponding difference between the Gschelian and Permian, of the marked resemblance of the brachiopods of the Hueco and Gschelian, and of the lack of agreement between the Permian and Guadalupian, there is a possibility, if not a certain probability, that the Artinsk and Permian may be correlated with the Hueco formation.

Having compared the western faunas with those of Russia, let us consider what their relations may be with those of eastern North America.

We find in such a comparison really fewer resemblances than with the faunas of Russia. Of the three or four western faunas which I have noted, by far the greatest resemblance is to be found in the oldest of all; perhaps because it is least varied and most generalized. The Hueconian presents much more numerous and extensive differences and the Guadalupian the strongest of all. In fact, of the 325 species recognized in the latter scarcely a single variety can be definitely identified in the eastern faunas. The species are in most cases not only not the same but they are not even similar. It seems possible to me that the Hueconian fauna may be equivalent, in spite of its differences, to the faunas of the East, but hardly that of the Guadalupian. This opinion is based upon the striking differences existing between the Guadalupian and any eastern fauna, upon the much closer resemblance of the eastern faunas with the Hueconian fauna, and upon the important differences between the latter and the Guadalupian. However, as so little is known of the character and potency of the environmental conditions under which these faunas existed, there is a possibility which I do not wish to deny that the relations noted may have to be ascribed to the environment element, rather than to the time element.

Provisionally I am regarding the Guadalupian as younger than any known faunas of the eastern region, thus interpreting the faunal differences of the Hueconian when compared with the Pennsylvanian and Permian of the East, as due to environment rather than to time. There is some evidence, however, that the Hueco formation should be considered younger than the so-called Permian of the Kansas section instead of equivalent to it. Mr. Beede has recently described several occurrences of a fauna which I should perhaps have mentioned as representing one of the interesting and important differentiations found among the faunas of the Upper Carboniferous of the East. They were obtained from the red beds of Oklahoma and the horizon is known to be considerably above the highest occurrences of invertebrate fossils in Kansas. This fauna appears to me to present more important differences from the Kansas Permian than exist between the latter and the underlying beds referred to the Pennsylvanian. Accordingly, if any of the faunas of the eastern section are to be classed as Permian it would appear to me more appropriate that the dividing line should pass above rather than below the Kansas Permian. When compared with the western faunas, that described by Mr. Beede is far from being identical either with the Guadalupian or with any facies of the Hueconian, but of the two its affinities appear to be decidedly with the latter. If this evidence is to be relied on, even Mr. Beede's fauna is older than the Guadalupian and if the latter is equivalent to the Permian, older than the Permian.

Another fact which might be brought forward to support the contention that even the Hueconian is younger than the Kansas Permian is the important unconformity which preceded Hueco sedimentation and was accompanied by a corresponding change in the subsequent fauna. According to this interpretation, the oldest of the western faunas, which, as already noted, presents a closer resemblance to the characteristic Pennsylvanian fauna than any other, would correlate with all of the eastern section to the top of the Kansas Permian. Its failure in the strata which it occupies to measure up to the thickness of the Mississippi Valley section, and the absence from it of some of the modifications found there, would be ascribed to pre-Hueconian erosion. After this episode there was, it might be claimed, a faunal change represented in the Hueconian fauna of the West and in Mr. Beede's red beds fauna of Oklahoma, this in turn being succeeded by the Guadalupian fauna.

Though keeping this interpretation of the facts well in mind, I am at present adopting the more conservative hypothesis—that the top of the Kansas Permian may be as high as the base of the Guadalupian; but that no part of the latter correlates with any part of the invertebrate-bearing beds of Kansas.[1] From this it would follow that if the Guadalupian is equivalent to the Russian Permian then the Kansas Permian is distinctly older, possibly Artinskian, possibly Gschelian. If, on the other hand, the Kansas Permian is really equivalent to that of Russia, the Guadalupian would appear to be a distinct and faunally well characterized series younger than the Permian.

It is well in considering the use of the word Permian for North American strata to discriminate Permian time, Permian conditions, and Permian faunas. Permian conditions, or conditions such as were prevalent in Russia during Permian time, might recur more than once. Indeed, it is safe to say that most conditions are repeated in one area or another many times during geologic history. Permian conditions would give character to the sediments and to the faunas of Permian time. But, while the same peculiarities of sedimentation would presumably be manifested at every recurrence of Permian conditions, the character of the fauna would be partially determined by another factor, the biologic factor. It is conceivable, or even probable, that similar conditions acting upon two unlike faunas might produce rather similar results. The resulting faunas might be less diverse than the original ones. This is perhaps particularly true of conditions such as appear to have prevailed in the typical Permian, conditions

[1] By this expression I mean to include the Marion and subjacent formations.

hostile to marine life, hostile especially to the continuance of specialized types of life, at least of brachiopods.

In the Kansas section we appear to have a single faunal sequence gradually passing to extinction but undergoing some minor modifications in the process. The upper portion of the sequence is the Kansas Permian. We are told by those who are familiar with both, that Permian conditions are manifested in the so-called Permian sediments of the Mississippi Valley. I believe that there is no strictly Permian fauna in that area. The question at issue is: Do the higher invertebrate-bearing beds of the Kansas section represent Permian time? On the assumption that such is the case, a comparison of the evolution of the faunas of the two continents is interesting. Let any one acquainted with our eastern faunas look over Trautschold's monograph on the Moscovian fauna and he would exclaim at once, "This is our Pennsylvanian facies." Let him next examine Tschernyschew's monograph on the Gschelian brachiopods, and he would find that nothing at all comparable is known among the faunas of eastern North America. He would even find that the few Pennsylvanian species which Tschernyschew has recognized among the Gschelian brachiopods are wrongly identified. If he furthermore studies the scattered accounts of the Artinskian and Permian faunas I think, too, that he will find less resemblance between them and the Kansas Permian than has often been supposed.

Apparently there was a basal generalized type of Upper Carboniferous fauna distributed over both continents without any wide difference of facies—the Moscovian of Russia, the pre-Hueconian of western North America, and the early Pennsylvanian of eastern. Then changes occurred which brought about striking and similar modification in the faunas of western America and Russia, the Gschelian of Russia and the Hueconian of western North America. Then again other changes occurred which brought about a third modification, this time restricted to western America, or, at all events, not developed similarly there and in Russia. Meanwhile the fauna of eastern North America must have remained essentially static until similar conditions, setting in in Perm and in Kansas, eventually extinguished those already moribund faunas, while the intervening faunas, those of western America, remained vigorous and rich. The considerable differences found between the Russian Permian and the Kansas Permian faunas would, according to this hypothesis, be explained as due to the play of like conditions upon unlike organic bases, the pre-Permian faunas in the one region having changed, and those in the other having remained unchanged. But this appears to me improbable. One would hardly expect that the Pennsylvanian fauna would remain static during so long a period in which such important faunal changes were taking place in adjacent areas. Nor would one expect that Permian conditions would be inaugurated simultaneously in two areas so far apart, whose biologic histories are so different, and which were separated by an area having a more or less independent set of faunal phenomena. Finally, if the Kansas Permian is Permian, what is the fauna from the Oklahoma red beds, obtained at a considerably higher horizon, and showing a considerably different facies? It does not seem probable to me therefore that the Kansas Permian and the Russian Permian were contemporaneous.

An extreme interpretation of the resemblances and differences noted in comparing the successive faunas of Russia and eastern North America would result in correlating the Kansas Permian not with the Russian Permian, as in the last hypothesis, but with the Moscovian. In this case the quasi-Permian facies of the upper beds of Kansas would be accounted for as showing the yield of an unlike and older fauna to Permian conditions which arrived on this continent at a much earlier period than in Russia, just as in the previous case the *differences* of the same fauna from the typical Permian would be explained as the opposite or complementary phenomenon, the resistance of an unlike fauna to Permian conditions. Probably the ultimate fact lies somewhere between these two extreme interpretations of the evidence.

I do not wish to appear as having a rooted aversion to admitting the Permian age of the higher faunas of the Kansas section. My position is merely that of a skeptic and the only point upon which I feel justified in assuming the positive attitude of dogmatism is that the evidence at present is so inconclusive that dogmatism itself would be ill-advised. At present, it is true, the weight of evidence, as presented by invertebrate paleontology, appears to me to be in favor of its pre-Permian age. This view has much of precedent against it, although it has considerable authority in its support. It will be remembered that some half century ago there was a conscious and competitive attempt between a number of invertebrate paleontologists to discover the presence of Permian rocks in our then western states. From this the correlation of the Kansas beds with the Russian Permian took its rise. I am inclined to believe that were the investigation of this subject taken up on its merits from the richer accumulations now available, and not compromised by this early rivalry, few if any would think of separating the upper formations of the series from the lower, or, if a separation were thought of, the divisions would be held rather to rank with the subdivisions recognized in the Mississippian than to be co-ordinate with the larger groups such as Mississippian and Pennsylvanian.

At all events, it appears to me from such evidence as I have seen, that the Russian Permian represents peculiar, one may perhaps say abnormal, conditions which were probably local or regional in extent. That Permian time is represented by our sediments seems undoubted; that Permian conditions prevailed here is attested by good witnesses; that Permian conditions occurred here in Permian time seems to me open to question, and that any of our known faunas present the authentic Permian facies, I do not believe. Consequently the propriety of employing the term Permian in the geology of North America seems to me decidedly doubtful, at least in so far as the evidence of invertebrate fossils is concerned. It would be better, I believe, to use the term Permian wherever the Permian fauna can be traced and no farther; to use the term Pennsylvanian wherever the Pennsylvanian fauna can be traced and no farther; to use the term Guadalupian wherever the Guadalupian fauna can be traced and no farther; but, if, for instance, it could be shown that for all their faunal differences the Gschelian and Pennsylvanian were contemporaneous, to use for both the same name, whether Pennsylvanian or Gschelian, would be to obscure and gloss over facts of biology, climatology, and possibly geography, fully as important as that of chronology.

CHAPTER VII

THE UPPER PALEOZOIC FLORAS, THEIR SUCCESSION AND RANGE[1]

DAVID WHITE

CONTENTS

STRATIGRAPHIC VALUE OF LAND PLANTS

Diastrophism and floral changes.—The terrestrial plant is inseparably dependent on the conditions, not only of the soil and the water, but also of the air from which it derives an important part of its substance. Any change, therefore, in the climatic, terrestrial, or water conditions of its environment directly affects the plant and causes morphologic changes to a greater or less degree, the greater plant variations corresponding usually to the greater environmental changes. The great floral revolutions of geologic history are connected with the great diastrophic movements.

Sensitiveness of land plants to complicated environment.—The land plant, being essentially without the power of locomotion except by accidental dispersion of its progeny, is most vitally susceptible to changes in composition, temperature, etc., of its environmental elements. Accordingly it constitutes a most sensitive indicator of changes in these elements. The more highly organized the type the

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greater, in general, is its value as evidence either for identity of environment or for altered conditions. It must be admitted, however, that in the interpretation of the environmental criteria afforded by fossil plants, relatively little serious study has been given to anything other than climate. The ecology of the fossil floras is a new and almost unexplored department of paleobotany, though splendid work along certain lines was begun by Grand'Eury. The results of differences in soils or in altitude have received little attention. In general the conditions of fossilization naturally presuppose the origin of the vegetal forms at an elevation not far from that of the water-level beneath which they have, in most cases, been preserved, though here and there certain types have been regarded as drifted from higher altitudes.

THE DEVONIAN FLORAS

Probable origin of land flora in Devonian.—From the paleobotanical standpoint no period within the existence of land floras is of such imminent interest and yet is so little known as the Devonian. This fact is no doubt due mainly to the relative rareness of indubitably botanical material, its usually fragmentary condition, or its partial obliteration through metamorphism. Yet the Devonian period probably covers the early development, if not the actual beginning, of terrestrial plant life on the earth. It witnessed the origin of ferns, scouring rushes, Lycopods, and Gymnosperms, including the earliest relatives of the conifers. It is supposed to have given birth to the Pteridosperms, a group of seed-bearing ferns (Cycadofices), standing in the gap between the ferns and the Cycads.

Features of early land plants.—The development in early Devonian time of flat land surfaces and low coasts whose bays were bordered by broad marshes intermittently covered by brackish or fresh waters was most favorable for the nearly simultaneous development of a terrestrial habit in some of the highly varied types which then populated the seas. On some accounts it seems permissible to suppose that the ancestors of the land plants were amphibious, perhaps growing where exposed only at the recession of the tide. It is, I believe, probable that these early plants were but sparsely foliate, their leaves being either spinoid or very small, slender, and delicately thin. The latter were probably dorsally rolled at first during the intervals of exposure to the air. The stomatiferous surfaces may have been very small for a time, and the stomata of periodic function only while the greater part of the carbonic-acid gas to serve as plant food was still drawn in the old way from the richly charged waters. The expansion of a proper leaf and the production of an aërial system of transpiration were presumably gradually evolved as the plant became weaned from its subaqueous habitat and accustomed to gain its food from an atmosphere which, it may be, was then better adapted to the nourishment of the emergent amphibian. However this may be it is fairly clear that the early representatives of the dominant Devonian types were of limited foliar expanse. Cuticular transmission of gases is still observed in the living ferns and Lycopods, the latter being far less susceptible to carbon-dioxide poisoning than are the higher plants.

It also appears that to support their weight in air a reinforced cuticle, later developed as a very thick and complicated cortex, was made to serve until a woody axis and, eventually, secondary wood should be fully produced by their descendants. From the characters of some of the fossils it seems probable that, unable to stand alone, they sprawled or clambered about on the ground or on other plants.

The mode of occurrence of their fossil remains usually in fresh or brackish water lagoonal or estuarine deposits, which are frequently ripple-marked, or even sun-cracked, may be regarded, though not without caution, as pointing out the conditions of their earliest habitats.

MIDDLE DEVONIAN

Characters.—The first Paleozoic land flora sufficiently known to make it eligible to the series of correlation discussions is that of the Middle Devonian.

This flora, whose apparent meagerness is perhaps due mostly to meagerness of information, is of strange and forbidding aspect. Its most characteristic types are Psilophyton, Arthrostigma, and Rhachiopteris of Dawson. It is also marked by the presence of Protolepidodendron, a primitive forerunner of the great lycopod group and, before reaching the Portage we find added Archaeopteris, together with the curious Pseudosporochnus, which may supply the missing fronds to the defoliated Caulopteris-like stems from Ohio and New York.

Place of origin.—Though eastern America has contributed most to our knowledge of this flora, it is probable that either the estuaries of northwestern Europe or the Arctic regions offered the conditions most favorable for its development. It extended both east and west in a high degree of unity. For example, the flora which occurs in the "Chapman" sandstone in Maine, and which is present in the gulf region of Canada, is largely the same as that of Scotland, at Burnot in Belgium, or in the Lenne shales of the Rhine Provinces. The flora from Barrande's *H-h*, stage at Hostim in Bohemia is nearly counterfeited in the upper Middle Devonian of New York. The route of migration between Europe and America was presumably by Arctic lands beyond the North Atlantic. Nothing that can be called a land flora is yet known from the Middle Devonian of the Southern Hemisphere.

UPPER DEVONIAN

Floral characters.—Evolution of forms and the advent of new types mark the Upper Devonian flora, which bears no evidence of any great climatic separation from the preceding. Pseudobornia, perhaps first of the Protocalamariales, Dimeripteris, Leptophleum, Barrandeina, and Barinophyton are characteristic. It is pre-eminently the stage of Archaeopteris. The Protolepidodendreae are developing along divergent lines to Cyclostigma and to the Carboniferous Lepidodendron, while Archaeosigillaria makes its rare appearance.

Place of origin and migration.—I am strongly inclined to believe that this flora received its greatest contribution from eastern America, or, perhaps, from the Arctic regions; in either event its migration was probably over boreal land; for it extends with remarkable identity from Pennsylvania to southern Europe and is partially present even in Australia. *Archaeopteris obtusa* and *A. sphenophyllifolia* of Pennsylvania and New York are *A. archetypus* and *A. fissilis* of Ellsmere Land, Spitzbergen, and the Don; while Barinophyton, a unique type from New York, Maine, and Canada, extends to the British Isles, Belgium, Queensland, and Victoria, where also is found *Leptophloeum rhombicum*, another American plant.

The Devonian woods present no annual rings to bear evidence of seasonal changes in temperature or intervals of prolonged drought.

THE CARBONIFEROUS FLORAS

MISSISSIPPIAN ("LOWER CARBONIFEROUS")

Characters.—The step from the Upper Devonian flora to that of the Mississippian (" Lower Carboniferous ") is marked by a floral contrast which, in some regions, is unexpectedly sharp though the warping of the Devonian floor to form the new Carboniferous synclines and the contraction of the seas naturally premise distinct climatic as well as other environmental changes. The new flora which lived in the restricted basins of the early Mississippian consists of Triphyllopteris, the broad, large-pinnuled Aneimites, the linear (*flaccida*) type of Sphenopteris, Cyclostigma, Eskdalia, and the acuminate Lepidodendra chiefly of the *corrugatum* group.

Lowest stage—Pocono.—The early Mississippian was a time of sea expansion; and in a number of distant areas, such as the northern part of the Appalachian trough, northern Alaska, the eastern Arctic, Scotland, and southern Siberia, the conditions at this moment were favorable for the formation of considerable coals.

Source.—Since the vegetation was presumably most luxuriant in these regions of coal formation, and since greatest evolution of forms attends most rapid and luxuriant expansion of a flora, we are perhaps safe in supposing that these are probably the regions of evolution of the flora as a whole.

Regional differences.—In this connection it may be noted that, either on account of land or marine barriers, or because the climatic conditions throughout the northern hemisphere may at the outset have been less uniform than in the preceding epoch, the different areas exhibit more or less distinct local floral differences. Thus in the Pecono of West Virginia and Eastern Pennsylvania where Triphyllopteris and the *corrugatum* type of Lepidodendron are almost without competition, the former achieved a remarkable differentiation far surpassing that known in any other area. In Nova Scotia, on the other, hand, the Horton series, which I regard as practically contemporaneous with the Pocono, contains the same Lepidodendra, accompanied, however, by Aneimites instead of Triphyllopteris. In both these regions the formations are in close relations with the Upper Devonian—in fact, probably in continuous sequence at one point or another. But the Pocono flora is apparently nearer to the Arctic

Alaskan where the same linear-lobed Sphenopteris forms are also present; the Nova Scotian affiliates more closely with the eastern. All the genera mingle in Arctic Europe and in Siberia, where Cyclostigma, probably of Arctic birth, has a good development. The Pocono flora may have connected by a more northern route with Europe, where Triphyllopteris sparingly mingles with the Horton Aneimites, which presumably migrated by the Northeast Arctic land bridge. It is possible, however, that some of the regional differences, especially differences in species, are due to lack of exact synchronism in the plant beds of these remote regions.

Middle Mississippian flora.—The basal Carboniferous floras are largely replaced in the middle Mississippian by a plant association which is more varied and of very different aspect. Where conditions were favorable for plant growth and preservation we find a flora essentially consisting of Rhacopteris (of Schimper, including Rhodea of authors), Cardiopteris, Asterocalamites (=Bornia), with *Lepidodendron volkmannianum*, and *L. veltheimianum*, accompanied by a gradually increasing group of Sphenopterids.

Source and distribution.—The middle Mississippian flora probably had its greatest development among the islands and estuaries of western Europe; at least it is best known in that region. From there it seems to have extended almost homogeneously to the eastward into Siberia and to the southeast, either through the Balkans, Persia, and the Himalayas (linking together its discovered occurrences), or possibly by a more southern route, to South Africa and Australia where the flora was largely identical with that in Siberia. The flora at Cacheuta, in Argentina, which though small is mainly composed of European species, presumably traversed the same route as that later followed by the Gangamopteris flora—that is the "Gondwana land." The middle Mississippian flora of the Appalachian trough is but little known, and for the most part is unpublished. Though less closely bound to that of Europe than are the corresponding Pennsylvanian floras its genera and a number of its species are present in the basins of Europe. I may add that the Megalopteris-bearing beds along the Mississippi River in Illinois, long ago credited to the Chester, are of upper Pottsville age.

Moderate uniformity of climate.—The members of this flora do not attain the gigantic proportions nor the specific differentiation of their Carboniferous successors; yet the relative homogeneity and the great radial distribution of this flora argue for the absence of distinct climatic zones in the recent sense while the apparent lack of annual rings, so far as the woods have been specially examined, is opposed to the idea of seasonal changes.

Upper Mississippian. Probable greater severity of climate.—Our knowledge of the flora of the uppermost part of the Mississippian is too insufficient, both as to its composition and its geographical distribution, to permit any very definite conclusions as to its province and climatic environment. Some at least of the plants exhibit a limited foliar expansion and semi-coriaceous character suggestive of conditions far less favorable for growth than in the Pennsylvanian ("Upper Carboniferous"), or even in the early Mississippian. They seem to forewarn us of the great floral change which was, perhaps, already in progress. From this highest stage may have come *Dadoxylon pennsylvanicum*, the only wood from the American Carboniferous which appears on authoritative testimony to show annual rings, but whose geologic age is unfortunately recorded merely as "Carboniferous." Also it is possible that the *Araucarites tchihatcheffianus*, from western Siberia, said to have been found in the Carboniferous limestone series, may belong to the same horizon. The occurrence of severer climatic conditions with seasonal changes within upper Mississippian time is provisionally admissible; but it is probable that a radical climatic change attended the post-Mississippian elevation, the maximum variation being presumably marked by the climax of the uplift. The paleobotanical revival which set in at the beginning of the Pennsylvanian is known to all. Even in regions of supposed continuous Mississippian-Pennsylvanian deposition the contrast between the older and the younger floras (which do not really come in contact) is very strongly marked.

PENNSYLVANIAN ("UPPER CARBONIFEROUS")

The Westphalian

Environmental changes.—Following the retirement of the sea from great areas at the close of the Mississippian ("Lower Carboniferous"), the new land surfaces were warped into new forms, with the production of additional as well as more complicated synclines. In these at first greatly restricted basins the sea began a great readvance, attended by the subsidence and deformation of the new basins under loading. These changes were most active during the Pottsville, the lowest of the American Pennsylvanian series. The new climatic and terrestrial conditions were most favorable to the extraordinary growth and differentiation of the plant life which spread across broad base-level plains and over the marshes and lagoons that flanked its long inland-reaching estuaries.

Appalachian deposition.—In the Appalachian trough the basin in earliest Pottsville time was confined to a very narrow estuary extending from the anthracite region of northeast Pennsylvania southward to Alabama where it became confluent with a small lobe of the sea extending northward toward southern Illinois and Indiana. Subsidence under loading was most rapid, with successive periods of sea advance to the north and west during all Pottsville time, at the close of which the water-level may have proximated its greatest Pennsylvanian extent; at least it exceeded the present limits of the coalfields.[1] The enormously expanded water-level of the Allegheny formation attended a westward migration of the axis of deposition, probably with the development of minor subordinate basins. Slight warping occurred during the period, especially to the southward, so that the connection with the Eastern Interior basin presumably migrated northward into the Kentucky region, foreshadowing the probable exclusion of the sea from the southern area of the present Appalachian coalfield during later Conemaugh and Monongahela time.

Rapid Evolution. Floral characters definite, with many short-lived genera in early Pennsylvanian.—The most rapid evolution of the Pennsylvanian flora occurred during Pottsville time, though the generation of new forms continued at a slower rate into the Allegheny, which, together with the Pottsville, approximately represents the Westphalian or Muscovian in North America.

The Westphalian is the period of Cheilanthites, Mariopteris, Diplothmema, Crossotheca, Eremopteris, Palmatopteris, Lonchopteris, Megalopteris, Lesleya, Neriopteris, Bothrodendron, Ulodendron, Lepidophloios, and Whittleseya, besides a number of genera repre-

[1] *Bull. Geol. Soc. Amer.*, Vol. XV (1904), p. 267.

senting filicoid types of fructification. One-half of these genera scarcely, if at all, survive the Pottsville. Three or four only outlive the Allegheny. The Westphalian witnessed the maximum development in Sphenopteris, Neuropteris, and Alethopteris, and of the great Lycopod group. It is pre-eminently the stage of the Cycadifilices.

Remarkable distribution of identical species.—The intercontinental distribution of the Westphalian plants is probably less remarkably uniform than is generally stated. The examination of the floras shows minor differences between the floras of different basins, as, for example, freshwater or marine basins in the same country, though many of these differences disappear as additional material is collected. Also different areas in the same basin, and, similarly, different horizons in the same basin may show predominances of Lycopods, or ferns, etc., or the apparent absence of certain genera. But as between the larger provinces, and taking the flora as a whole, from continent to continent, the number of genera not common, for example, to Europe and America, is so small as to excite special interest. The proportion of identical species is so large as to necessitate an extraordinary lack of barriers to the freest migration. The flora of the basin of Heraclea in Asia Minor[1] lends itself to ready correlation, stage by stage, with three corresponding formations of the Pottsville in the Appalachian trough; also, of the 33 species reported by Zeiller in a collection from the Westphalian of the Djebel-Bechar region of Persia, 25 are present in the Pottsville of the Appalachian trough.

The uniformity of distribution of the Westphalian flora complicates the geographical question of its origin. Taking therefore as most reliable the evidence of first appearances, we may note that Cheilanthites (including portions of Pseudopecopteris and Sphenopteris), Mariopteris, Eremopteris, Neuropteris, Alethopteris, and perhaps Pecopteris, were more highly differentiated in America, though Sphenopteris experienced a perhaps greater development in Austria and Bohemia. In Europe the Lycopods appear to have had greater advancement. Also, Cingularia, unknown outside of the freshwater basins of Germany, and Lonchopteris, largely confined thereto, have not yet been found in North America; while the unique genus Neriopteris is still unknown in Europe. On the other hand, the rare

[1] *Jour. Geol.*, Vol. IX (1901), p. 192.

genera, Lesleya, Megalopteris, and Whittleseya, apparently originated in America whence they spread northeastward. The same is true of the lower Pottsville Phyllotheca, which appeared a little later in Heraclea, and finally, in a new group of forms, became somewhat characteristic of the Gangamopteris flora of "Gondwana land." On the whole, therefore, it is probable that the Westphalian flora is the joint contribution of the lagoonal—i. e., coal-forming—regions of western Europe and eastern America. Free inter-communication was almost certainly by an Arctic land bridge, possibly by way of a Greenland-Scandinavian shore connection. The general regional distribution of the Pennsylvanian floras is shown in Fig. 1.

The Stephanian

Conditions of deposition and probable equivalents.—The Stephanian or Ouralian (including the Gschellian) of Europe dates from the Hercynian uplift. Prior to this movement the sea had reached its maximum extension in the coalfields of the northern hemisphere. The Hercynian thrust caused its practical expulsion from the old synclines of western Europe and the creation, especially to the southward, of new basins, mostly of fresh or brackish water, to which were transferred the scenes of coal-formation. In America the line between the Westphalian and Stephanian is not yet accurately drawn, the fossil floras being not studied in sufficient detail. In view, however, of the paleobotanical evidence indicative of a point near the Allegheny-Conemaugh boundary, I, personally, am inclined to regard the formation of the Mahoning sandstone (conglomeratic), the changed sedimentation of the Conemaugh formation, the probable upwarp of the southern Appalachian region which later resulted in the exclusion of the sea from the northern area also, and the consequent climatic changes, as due to the same great orogenic influence. Accordingly I would provisionally place the greater part, if not all, of the Conemaugh together with the Monongahela in the Stephanian.

The final exclusion of the sea from the Appalachian trough appears to have occurred soon after the deposition of the Ames limestone, near the middle of the Conemaugh, since, according to reports, only fresh, or possibly brackish water mollusca occur in the higher terranes.[1]

[1] I. C. White, *Report IIA*, Geol. Surv. W. Va., p. 622.

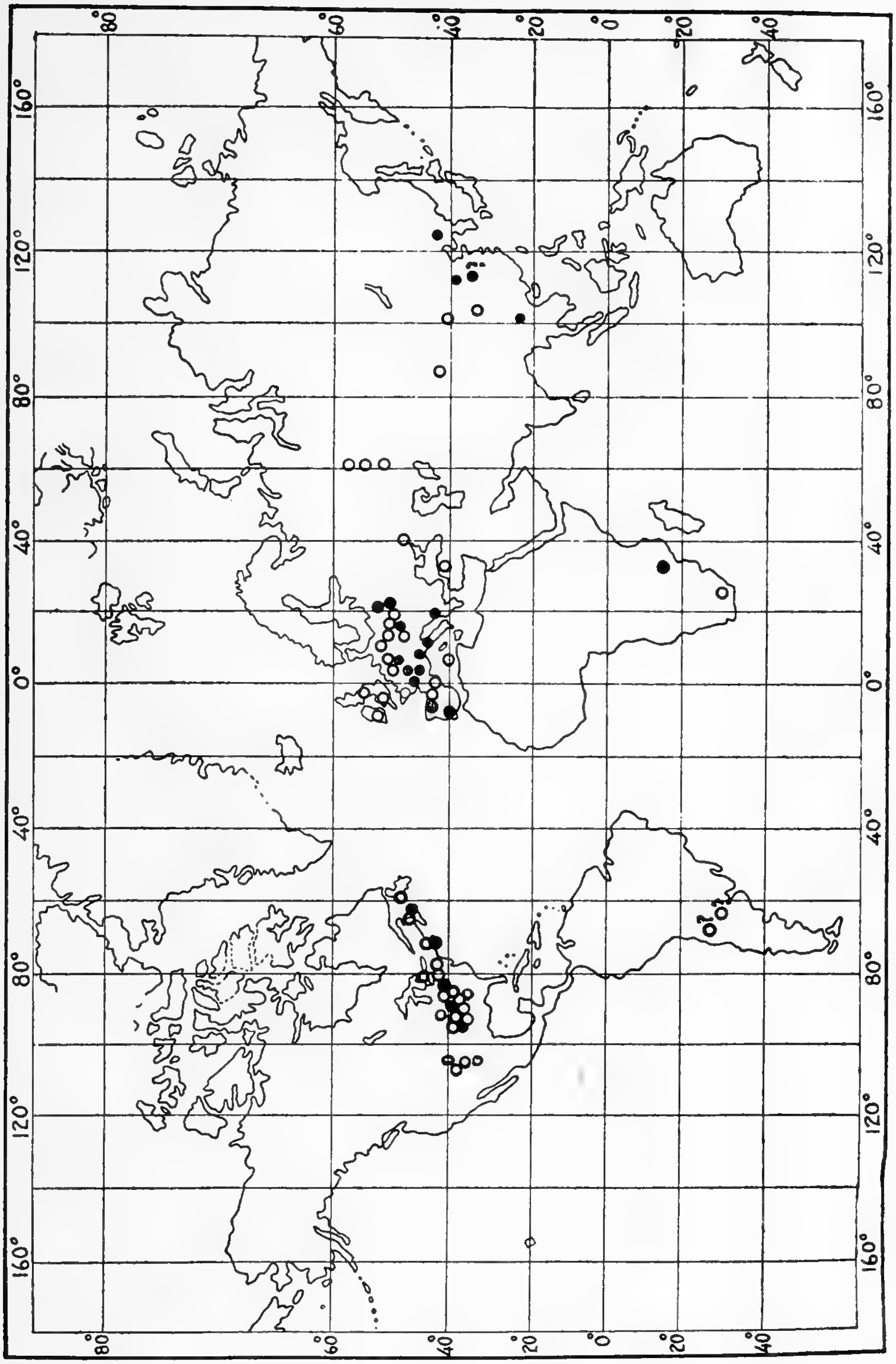


Fig. 1.—Regional distribution of Pennsylvanian ("Upper Carboniferous") floras. White rings = Westphalian plants; black rings = Stephanian plants.

It is probable that the Monongahela was never deposited in the southern Appalachian region, from portions of which the Conemaugh may also have been absent, the red oxidized sediments of the latter being in part derived, I believe, from the eroded unconsolidated older Pennsylvanian to the southeastward.

Floral characters.—The Stephanian is marked by the great development of Pecopteris, Callipteridium, and Odontopteris of the true type. It witnessed the nearly complete disappearance of Alethopteris, Sigillaria, and Lepidodendron. Neuropteris of the large-pinnuled forms enters its period of decadence. Before its close appear the first representatives of Callipteris, Walchia, Taeniopteris of the simple type, Pterophyllum, Zamites, and Plagiozamites, all characteristic of the Permian or later periods.

In eastern America, where the relations of land and water were but gradually altered and the sedimentation was continuous, the passage to the Stephanian flora has no line of sharp paleobotanical demarkation. The change appears to be gentle and the older forms drop out more slowly. In Europe, on the other hand, the contrast is a little sharper; the old types disappear more abruptly and many new ones take their places. A number of these new types have not yet been found in the Permian of this country. Among these are the four Permian coniferal and cycadalean genera above mentioned.

Source and distribution of the flora.—It is clear that the new elements of our Stephanian flora are chiefly, at least, of European origin, the plant life there having been directly influenced by the important physical changes to which it was immediately subjected. The various exotic types migrated to North America, probably, along or near the general route traversed by their Westphalian predecessors. Also, since the Stephanian flora of the American basins seems to afford no evidence of a rapid or strongly pronounced climatic alteration, it becomes fairly probable that the more abrupt plant changes described in western Europe were induced chiefly by the sweeping orogenic effects of the Hercynian movement, rather than by a great climatic change of world-wide extent. This does not, however, preclude a moderate but far-reaching modification of climate, in which changes in the atmospheric composition may have played a subtle if not important part. It seems hardly possible that the tremendous amounts of carbon then being stored away in the coalfields as the result of plant extraction from the air could have failed to produce some effect on the atmospheric content of CO_2.

Though the Stephanian flora has less unity in its distribution than had the Westphalian, it is nevertheless remarkable for its geographical range. The flora reported by Zalessky[1] from the Yen-tai mines near Mukden in Manchuria embraces eight species, seven of which are found in western Europe, while six are present in the Appalachian trough. Or, looking southward, at Tete on the Zambesi in southern Africa, we find that all of eleven species reported by Zeiller are present in Europe and nine or ten, about 80 per cent., in America also. In harmony with these facts we find but slight traces of annual rings in the woods of the Stephanian, either in Europe or in America. This is the more noteworthy because the date of the Gondwana-land glaciation has been referred by various geologists to the Stephanian.

THE PERMIAN FLORAS

Floral characters.—The coming of the Permian is characterized not only by orogenic movements in the eastern hemisphere, but also by indications of increasing climatic differences. The first paleobotanical effect of these is the extinction of nearly all characteristic Carboniferous types, except in Pecopteris, Cordaites, and Neuropteris, the latter, however, disappearing nearly completely by the close of the Autunian or lower stage. They are replaced by varied forms of Callipteris, the lingulate Odontopteris and the ribbon-like Taeniopteris, together with expanding gymnospermous types, such as Walchia, Dicranophyllum, Doleropteris, Psygmophyllum, and Ginkgophyllum. Later, in the Saxonian, or Middle Permian, Voltzia, with the thick-leaved Equisetites, appears while more of the older types go out; and in the Thuringian, or Zechstein (Upper Permian) Rhipidopsis, Araucarites, Gomphostrobus, Voltzia, and Ullmannia, become the characteristic genera, while Pecopteris, dominant in the Stephanian, has nearly vanished. Though lacking the abundant Cycad and Cladophlebis-Asterocarpus elements, the Upper Permian is in many respects transitional to the older Mesozoic flora.

The Gangamopteris or lower Gondwana flora.—Meanwhile in the South a new flora, the Gangamopteris flora, or so-called Glossopteris

[1] *Verh. Russ. K. Min. Gesell.* (2), Vol. XLII (1905), p. 485.

flora, has arisen in the wake of retreating ice, though it is not really a glacial flora. It probably originated in a great region, the "Gondwana land" of Suess, from which the Stephanian flora had been more or less completely expelled by the rigorous climate, and to which it had not yet been able to return, presumably on account of either temperature or isolation.

The dominant characteristic types are Gangamopteris, Glossopteris, and its rhizome Vertebraria, Neuropteridium, Noeggerathiopsis, Phyllotheca, Schizoneura, Ottokaria, and Derbyopsis. The distribution and the relations of this flora to the Northern or Cosmopolitan flora have already been discussed in this journal.[1] The geographical extension of this flora in Paleozoic time, as also the distribution of the northern or cosmopolitan Permian flora, are shown on the Permian map, Fig. 2.

Distribution.—The uniformity of the Gangamopteris flora is so nearly complete as emphatically to indicate freedom of migration between all the areas in which it dominated; but whether Australia communicated with South Africa by way of India and Arabia, or by connection through an Antarctic land mass is a matter of opinion. The former is perhaps more probable. South America was almost certainly made accessible either to Africa or Australia by route over Antarctic land.

Gondwana climate.—The Gondwana climate following the glaciation was not too severe for the early return at distant points of a few of the presumably hardiest representatives of Psaronius, Sigillaria, Lepidophloios, and Lepidodendron, and at a higher stage, Voltzia Psygomophyllum, and Pterophyllum, both in Africa and South America. The early return of a climate not so widely different from that of the western Permian is further shown by the fact that though the early Gondwana woods found in beds more or less closely associated with the bowlder beds in Australia and South Africa show annual rings indicative of sharp seasonal changes, the woods from the higher portion of the series in South America show nearly continuous growth with but slight trace of seasonal differences.

Ability of types to mingle in later Permian and early Mesozoic environments.—This amelioration of temperature harmonizes, firstly,

[1] *Jour. Geol.*, Vol. XV (1907), p. 615.

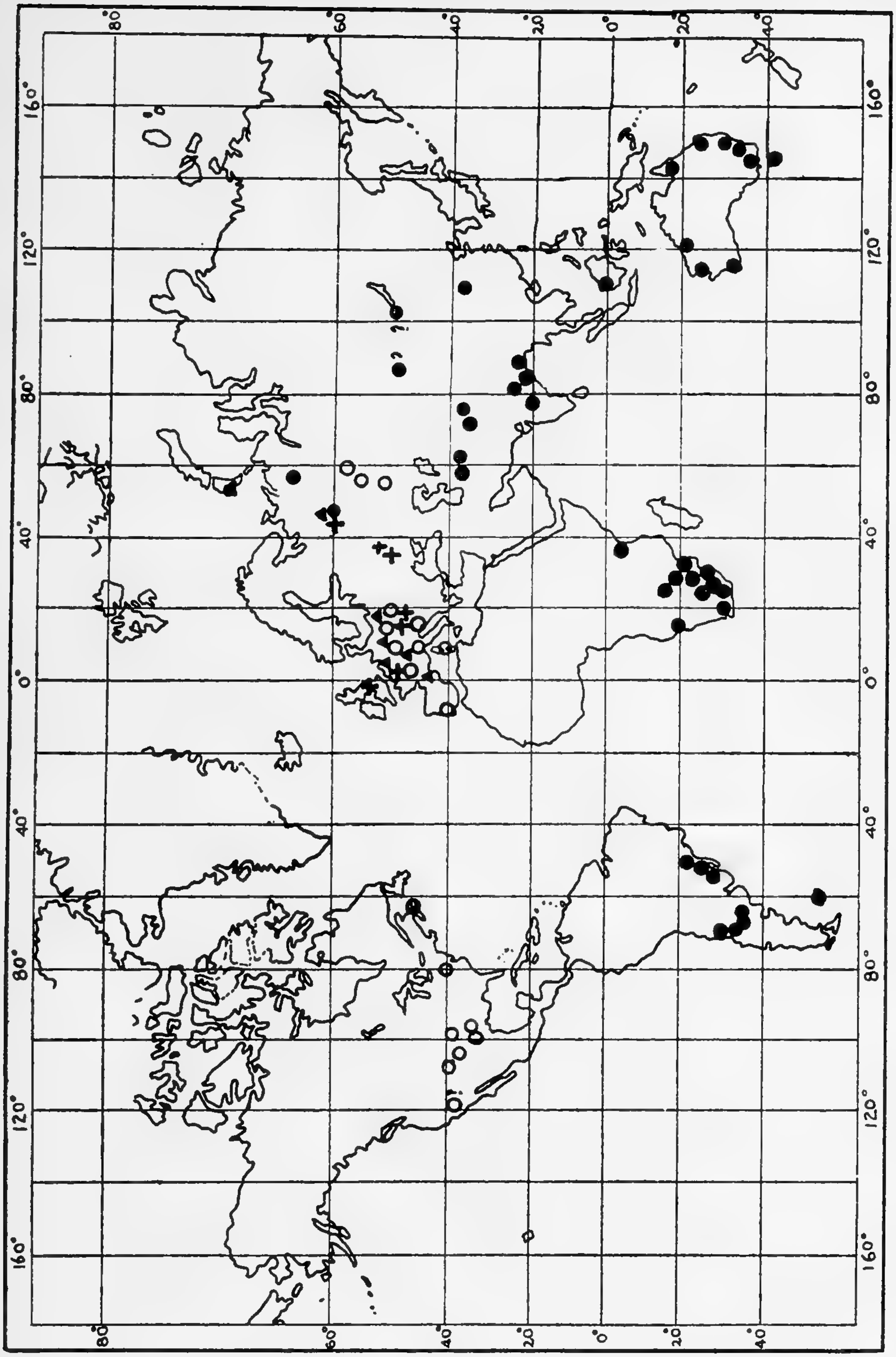


Fig. 2.—Regional distribution of Permian floras. White rings = Lower Permian; triangles = Middle Permian; crosses = Upper Permian; solid rings = Gondwana flora.

with the return of some of the northern types to portions of Gondwana land, and, secondly, with the fitness of some of the Gondwana types, especially Glossopteris, Phyllotheca, and Noeggerathiopsis, not only to join with Walchia and Callipteris in the Zechstein flora of northern Russia, but later to meet with Podozamites, Ctenophyllum, Cladophlebis, Clathropteris, and Dictyophyllum, under the mild climatic conditions of the early Mesozoic. Glossopteris, perhaps most adaptable of the older Gondwana types, was able to reach as far as the supposed Rhetic of Tonquin where it is last seen.

Glaciation.—It appears, therefore, that the interval, or better the *intervals*, of glaciation in Gondwana land were of relatively short duration as compared to all Permian time, though the thickness and distribution of the glacial deposits indicate a magnitude far exceeding that of Pleistocene glaciation. At the same time it seems improbable that refrigeration could have occurred in so many regions of the southern and eastern hemispheres, even approaching the equator, without some corresponding, though unequal, changes of world-wide extent. Concerning this very important point, the evidence is quite inconclusive and the opinions varied.

American Permian types derived from Europe.—If we compare the plants of eastern America with those of western Europe we find the greater changes in Europe where the extensive orogenic movements and attendant shifting of basins of deposition doubtless stimulated the evolution of the Permian flora. On the other hand, in the Appalachian trough, where environment was but little affected by orogeny, and where sedimentation was uninterrupted, there is only gradual change, many of the Stephanian types persisting far up in the Dunkard formation. The relatively few species characteristic of the European Permian which occur in the Dunkard, and which were not able to conquer the older flora under the conditions then existing, are clearly migrants from western Europe. It must be noted, though, that both West Virginia and Kansas exhibit new generic types, the products of local conditions, that have not been found outside of these regions. On the other hand, Walchia, which is present in Kansas and New Mexico has not yet been discovered in the Appalachian trough though it is present in the Nova Scotian basin, which seems to have been in closer touch with Europe at this time. The floral changes in the western American areas, which are more pronounced than in the Appalachian trough, may be due either to changed physical conditions consequent to nearer and greater orogenic movements, or possibly to position nearer to the region of Gondwana glaciation. In our trans-Mississippi region the contrast between the Permian and Stephanian floras does not seem so sharp as that between the Ural flora and those, for example, of the fresh-water basins of France or England.

Greater contrasts in eastern Europe.—In France and in the Appalachian trough the early Permian floras are to a large extent identical, thus indicating continued freedom of intercourse. Also the woods present obscure rings or none at all. But in Kansas and Texas annual rings while still but slight are increasing in distinctness though many of the associated plants have a European distribution.

The plant fragments from the Permian of Nova Zembla are quite too insufficient to support the hypothesis of a far-northern route of intercontinental migration, or even to show that the climate of western Europe extended so far north.

Ural Mountains on western edge of a great climatic zone.—Indeed, on the contrary, the great scarcity of true Neuropterid and Pecopterid elements, the great development of Psygmophyllum, and the remarkable phases of Callipteris observed even in the Artinsk of the Ural region indicate, in my judgment, either temporary isolation or an appreciable difference in climatic conditions. At the same time the somewhat unique forms of Odontopteris are not without representation both on the central plateau of France and in the Wichita of Texas. This testimony of migration is supported by the supposed land relations, which, if Lapparent is correct, should have been particularly favorable for such a migration during portions of Permian time.

Extension of Gondwana flora into northern Asia.—Eastward of the Ural Mountains the floras of the Altai and headwaters of the Yenesei and in northern Mongolia, though provisionally referred to the Permian on account of the presence of Rhipidopsis, mingled with other types, including some of Gondwana facies, are possibly wholly lacking in specific types characteristic of the Cosmopolitan Western Permian. Though the stage of these plant beds is not yet fixed on account of the strange character of the flora, I am inclined to regard the peculiar floral association as due to the extension of the early Gondwana climatic influence into north-central Asia and the subsequent isolation of the flora from western influences. This theory is supported by the presence of the older Gondwana flora in the coalfield of Shensi in China. On the other hand the floral differences between the Ural and eastern localities may be due to geographic position of the latter in the interior of the great Asiatic continent while the Ural flora which has more elements in common with the western world is located on the west coast of this continent.

The contrast is certainly not due to mere latitude, nor can it be credited wholly to aridity; for the eastern plants are associated in great series with coals in each region. A few stray wood fragments of uncertain location and age appear to offer slight evidence of seasonal changes, but the criteria deserve careful re-examination both as to this point and as to the geological horizon of the material described.

It would be most interesting to know to what extent the plant life of Permian time on the west coast of North America was influenced by the Gondwana glacial climate and as to how far it was allied to the older Gondwana floras.

The sharp contrast between the Chinese Gondwana plants and the floras of the very latest Stephanian in the same region involves a pronounced break either in climate or in time in that quarter of the globe. Probably both are concerned. The most satisfactory illumination of the stratigraphical and paleontological history of this period will probably be found in China or southern Siberia.

"PERMO-CARBONIFEROUS CLIMATES"

Climate of the Carboniferous.—The climate of the Pennsylvanian ("Upper Carboniferous") as viewed in perspective was mild and relatively humid, and, above all, equable over the greater part of the earth. It was moderate in temperature, not tropical, possibly not even subtropical, but, during the Westphalian at least, always and everywhere equable. It was truly temperate. The criteria which may be interpreted in support of this generally accepted proposition include:

1. The tremendous size and great height of the types, and their rank foliar development, indicating favorable conditions of environment and vigorous nutrition.

2. The succulent nature of many of the forms, the large size of the vessels and cells and the relatively great proportion of soft tissue, all indicating rapidity of growth in a moist, mild climate.

3. Spongy leaves suggestive of a moist atmosphere, and abundant and large intercellular spaces, as in the Lycopods, pointing to rapid moisture loss; also water pores for disposal of excess of moisture.

4. Stomata placed in grooves, as in the Lycopods, as if to prevent obstruction by falling rain.

5. Absence of annual rings in the woods; hence absence of marked seasonal changes.

6. The analogies of the present day show that aërial roots, so prominent in many of the Carboniferous types are characteristic of moist and tropical climates; that the nutrition—i. e., the decom position of CO_2—is most rapid and the consequent growth also greatest and most rapid where the light is not too strong; that the ferns and Lycopods, so abundant in the Paleozoic, usually avoid bright glare. The same types are able to withstand larger amounts of CO_2 with benefit to themselves.

7. The nearest living relatives of the Paleozoic vascular Cryptogams reach their greatest size in humid and mild or warm climates. The successors of the marratiaceous, and gymnospermous types are now mostly confined to tropical or subtropical regions. The cycadalean stock, now characteristic of the same zones, was actually present in the upper coal-measures.

8. The formation of great amounts of coal indicates a rank growth, but in a temperature not so warm as to promote decay beyond the limit of rainfall protection.

9. Living nearest representatives of Paleozoic fishes now inhabit the estuaries of warm countries; while the nearest relatives of the Carboniferous insects are now found in mild and moist habitats.

10. The most forcible argument, after all, for an equable and uniform climate lies in the extraordinary geographical distribution of the floras in relative unity over the face of the earth. Humidity must naturally have attended such equability, extending, without

distinct terrestrial climatic zones, possibly completely into the polar regions.

Some of the criteria above mentioned are susceptible of different interpretations; but taken collectively they appear to admit of but one conclusion. Whether or not we admit that climatic changes may be caused by reasonable or practicable changes in the amount of carbonic-acid gas in the air it is certain that in geological times the vegetation of the earth must have been more or less influenced by the constitution of the atmosphere from which the plant derives so important a part of its real food.

Gradual loss of uniformity of climate, with brief glacial interruption in Permian.—As has already been indicated the Westphalian probably witnessed the greatest extension of uniformity and equability of climate over the earth. In the Stephanian the flora is hardly so homogeneous, though the world-climate appears still to have been so equable as to allow free migration of the larger part of the flora from a moderate latitude on one side of the equator to the opposite without encountering seriously obstructive seasonal changes. In the Permian the regional distinctions between the floras are much clearer; and presently climatic zones, and consequently botanical provinces, are recognized. Yet, about the North Atlantic the climate of the Lower Permian was still relatively uniform so that moderately free migration of the floras without the development, so far as we know, of pronounced annual rings, took place in the Autunian of France, the Permian of Prince Edward Island, the Dunkard of southwestern Pennsylvania, the Chase of Kansas, and the Wichita of Texas.

Red beds and climate.—It will be remembered that the period now considered is characterized in western Europe, England, Eastern Canada, the Appalachian trough, and the Western Interior basin, by the deposition of red beds which in some areas carry deposits of gypsum, etc., and which are generally regarded as laid down under an arid climate. Viewing the matter from the paleobotanical standpoint, we may ask whether equability and uniformity of climate, such as is shown by the fossil floras, is compatible with aridity in latitudes so high as northern England and the Gulf of St. Lawrence. If all the regions of Permian red-bed deposition were arid it would seem that humidity could not have been essential to equability of climate.

Coal-formation in Permian.—The lower Permian of Germany, France, Russia, and Pennsylvania, is commercially coal-bearing, while the Permian red beds of Kansas and Texas carry thin coals. Professor C. A. Davis informs me that in the United States today the formation of peat, the first stage of coal, is practically confined to the zone having twenty inches, or more, of rainfall.

Flora in red beds not perceptibly different from that in other sediments.—The plants in the Monongahela and Conemaugh do not seem to differ in kind whether the series are gray and limestone-bearing in Pennsylvania, or red and nearly devoid of limestones seventy-five miles to the south in West Virginia; except that although sometimes fairly abundant, they are very difficult to find in the red shales because the carbon of the plants is almost or entirely gone, as the result of destructive decomposition, only impressions of the leaves being left. Is it not possible that, in some instances, the causes of red-bed deposition lie to a large extent in relatively slow subsidence of the basin, and in differential warping to permit exposure, with some redeposition and dehydration? It is probable that there was aridity in certain regions and during certain intervals of the Permian; but there was evidently enough moisture to produce most extensive glaciation, and, later, to promote the formation of coals over broad areas in the great fresh-water Gondwana series laid down on the continents of South America, Africa, and Asia. The beds with the Gangamopteris flora are in most regions coal-bearing, usually commercially.

Date of glacial episode.—If one looks for climatic fissures, or dislocations into which to fit the relatively brief episode of Gondwana glaciation it is difficult either in western Europe, or in America, to find an opening between the base of the Westphalian and the top of the Lower Permian in which it may be fixed. It is true that, in most sections, we have intervals in which no plants are found; and, further, the lesson of Pleistocene deposition shows what sweeping climatic changes may occur and recur within a relatively insignificant thickness of strata. Yet, while the gap is often large enough in stratigraphical view, the plant-sequence so tightly closes it as to preclude a possible very distant exile of the flora for a time. We may therefore conclude that the glacial episodes probably occurred at the time of one of the orogenic movements; and, if so, preferably at one marked by the most striking floral changes, since the effects of so important a climatic event must have been widespread.

If, therefore, the glacial interruption did not occur at the close of the Mississippian, as Bodenbender seems to see it, we may, I think, continue provisionally to regard it as occurring at the close of the Stephanian, or possibly (as would better suit many of the facts) as late as the middle Permian. The totally unaffected aspect of the topmost Stephanian flora near Mukden in Manchuria and in Italy, as well as of the somewhat earlier Stephanian flora in South Africa, would, if evidence of other kinds to the contrary were absent, tend somewhat strongly to prejudice in favor of the later date. The moderate temperature of the fairly equable "Permo-Carboniferous" climate in general may explain why the shock of the climatic episode was not more severely and for a longer time felt by the cosmopolitan Permian flora of western Europe and America.

PALEOGEOGRAPHIC MAPS

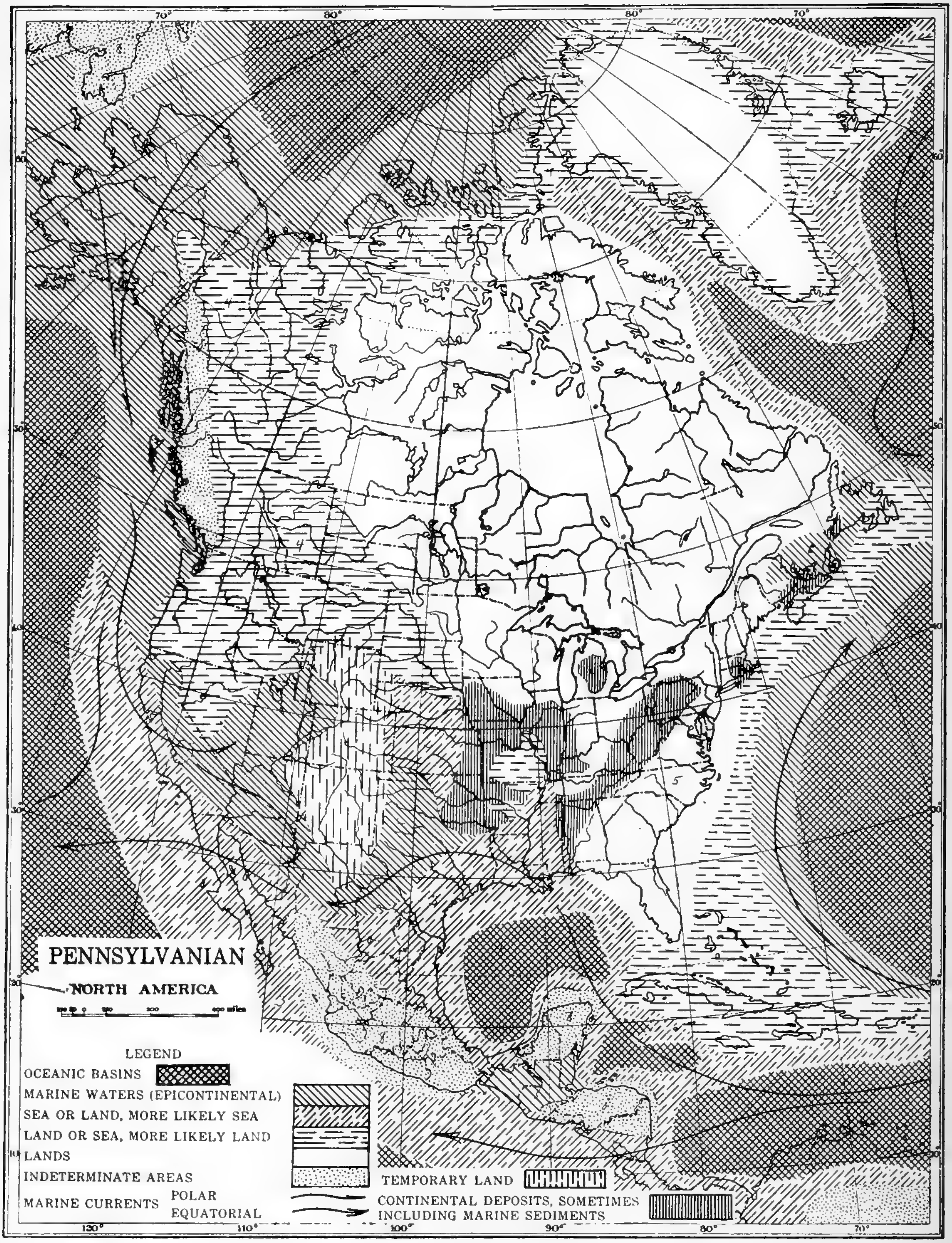
BAILEY WILLIS
U. S. Geological Survey

7. PENNSYLVANIAN[1]

The passage from Mississippian to Pennsylvanian was characterized by that emergence of lands, which is indicated on the map by the districts assigned to continental deposits and temporary lands. In the eastern United States the tendency toward emergence was progressive though interrupted. In the central west the emergence was but temporary and the transient land area was submerged under the Pennsylvanian sea. In contrast with the Mississippian, the Pennsylvanian continent probably extended far to the west—north of the fortieth parallel. As is shown by White there was land connection with England and Europe, probably around the North Atlantic.

The southeastern portion of the continent appears to have been embraced by branches of the equatorial Atlantic current. The northwestern part was washed by currents from the Arctic and north Pacific. The period was one during which climatic differences developed, and the situation of North America favored that development. The accumulation of coal in the southeastern portion in contrast to red sediments in the southwestern part may thus be explained as an effect of climate, in the one district favorable, in the other unfavorable to vegetation. Red beds are to some extent interbedded with coal measures, as glacial deposits of the Pleistocene are with interglacial, and it is probable that the relations may be interpreted as evidence of climatic fluctuations.

[1] Prepared in conference with Dr. G. H. Girty.


PENNSYLVANIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
130°
110°
100°
90°
80°
70°

CHAPTER VIII

THE FAUNAL RELATIONS OF THE EARLY VERTEBRATES

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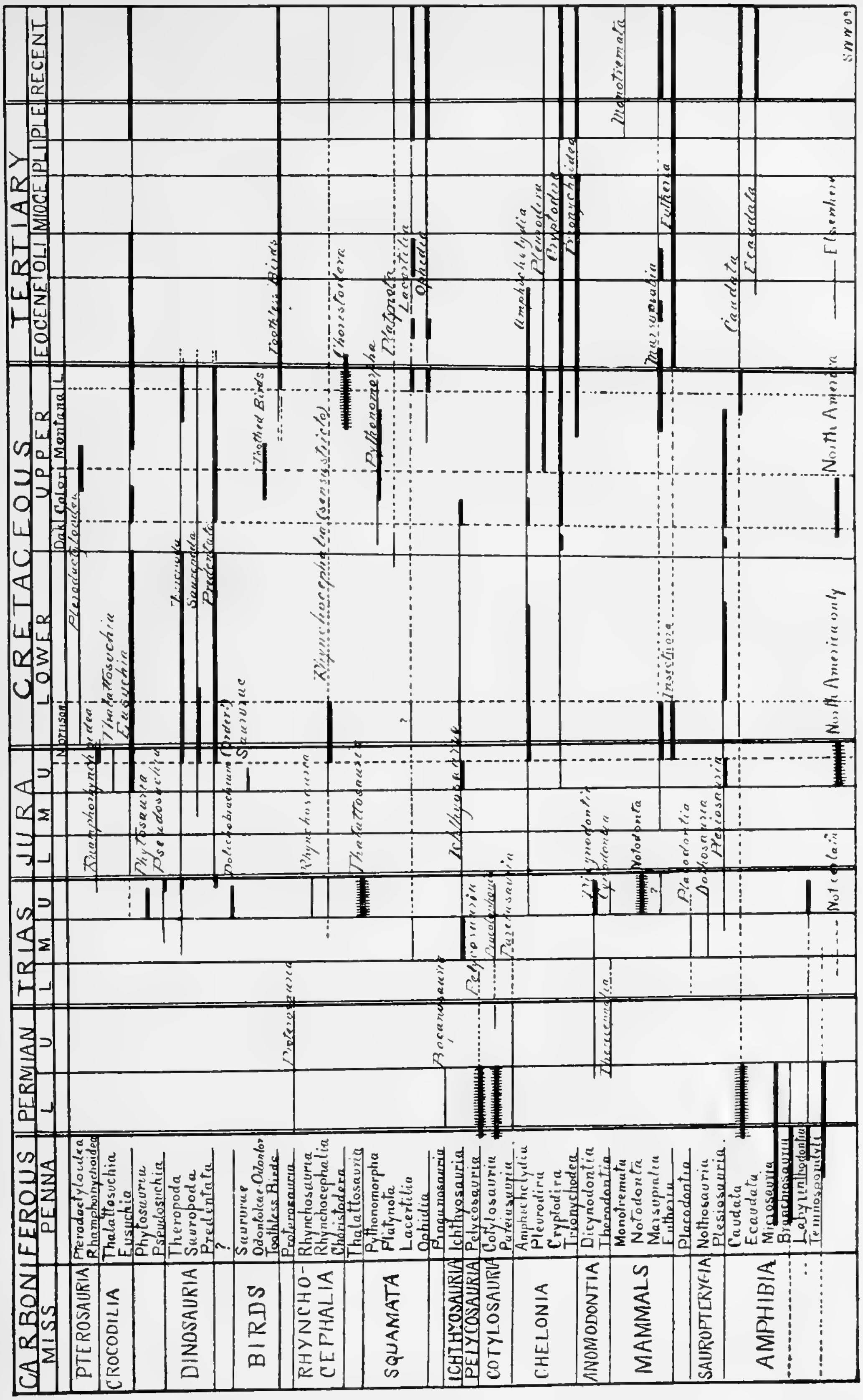
The environmental conditions affecting the evolution of the early air-breathing vertebrates offer at the present time many peculiarly difficult problems, problems which must depend in large measure upon the geologist for solution. They are very different from those which confront the student of the neozoic vertebrates, since we have better data for comparisons and conclusions in the living faunas as well as in our existing climatic and geographic conditions. And especially are the problems more involved and complicated when we attempt to deal with the marine or aquatic air-breathers of those early times. Here we can practically predicate little as to the conditions of the oceans and climates in which they lived. But these early vertebrates do offer, it seems to me, much that is suggestive regarding the migrations and evolution of faunas, involving theories as to paleogeographic conditions and changes, and, within certain limits, the climatic conditions which surrounded and controlled the migrations. And it is of this phase of the subject that I would choose to speak now.

As has been said, the evidence offered by the vertebrates, when available, is often, if not usually, more decisive than that of any other class of organisms in the determination of the relationships and correlations of faunas. A single species of the higher vertebrates found to occupy two remote provinces would furnish more positive evidence of contemporaneity and the possibilities of faunal migrations than would scores of others of lower types. But of species in vertebrate paleontology we can say little; the term with us is usually a far more vague and indefinite one than it is among students of living faunas, partly because much of the evidence which the neozoölogist has, the paleozoölogist has not, partly because the taxonomy of living creatures is still based too much upon superficial resemblances. And really, for most purposes, genera express in vertebrate paleontology about what species suggest among invertebrates and plants, that is for correlative and evolutional purposes, at least.

The evolution of vertebrate life, air-breathing vertebrate life, for I shall not presume to speak of the fishes, during Carboniferous times was quite as great as at any subsequent period. Indeed, I think I am quite safe in saying that, so far as the chief problems in vertebrate evolution are concerned, the life of the Carboniferous is the most important of all. From forms scarcely differing from fishes which must have existed at the beginning, of which, alas, we yet have no knowledge, we find evolved at the close forms foreshadowing the chief groups of life of modern times. The predominant types of the Pennsylvanian were what we usually call the branchiosaurs and microsaurs, for the most part small or very small creatures, at least as small as their nearest relatives of the present time, the salamanders. We are quite justified in the belief that their habits in general were not greatly unlike these descendants, rather sluggish creatures living about or in the water, for the branchiosaurs at least passed through larval stages. They were more or less protected by an external bodily armor against their enemies, whether of their own or other kinds, in all probability terminating their existence as distinctive types long before the close of the Paleozoic. But among them there were some classed with the heterogeneous group which we call microsaurs, which had made a very distinct advance, both toward a higher existence and away from the water. It has been assumed on entirely insufficient evidence that they too were all amphibians, having an early larval existence in the water, but of this we have, for many of them, little or no proof, and there is very little to differentiate the most advanced of them in structure from the reptiles. Some lost the dermal armor completely and became fleet of movement, as is evidenced by the structure of their limbs, limbs mimicking in form and in structure so closely those of modern quick-running lizards as to be practically indistinguishable. We may be assured that some of them before the close of the Pennsylvanian were inhabitants of high-and-dry land regions where fleetness of movement, rather than obscurity, preserved them from their enemies, crawling reptiles in everything save some insignificant technical details of their palates. Specializa-


CARBONIFEROUS
MISS
PENNA
PERMIAN
L
U
TRIAS
L
M
U
JURA
L
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U
CRETACEOUS
LOWER
UPPER
TERTIARY
EOCENE
OLI
MIOCE
PLI
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RECENT
PTEROSAURIA
Pterodactyloidea
Rhamphorhynchoidea
CROCODILIA
Thalattosuchia
Eusuchia
Phytosauria
Pseudosuchia
DINOSAURIA
Theropoda
Sauropoda
Predentata
BIRDS
Saururae
Toothless Birds
RHYNCHOCEPHALIA
Protorosauria
Rhynchosauria
Rhynchocephalia
Choristodera
Thalattosauria
SQUAMATA
Pythonomorpha
Platynota
Lacertilia
Ophidia
Proganosauria
ICHTHYOSAURIA
Ichthyosauria
PELYCOSAURIA
Pelycosauria
COTYLOSAURIA
Cotylosauria
Pareiasauria
CHELONIA
Amphichelydia
Pleurodira
Cryptodira
Trionychoidea
ANOMODONTIA
Dicynodontia
Theriodontia
MAMMALS
Monotremata
Marsupialia
Eutheria
SAUROPTERYGIA
Placodontia
Nothosauria
Plesiosauria
AMPHIBIA
Caudata
Ecaudata
Microsauria
Labyrinthodontia
Temnospondyli
Morrison
Dakota
Colorado
Montana
Laramie
Toothless Birds
Toothed Birds
Rhynchocephala (sensu stricto)
North America only
North America
Elsewhere

tion of the microsaurs had reached the extraordinary extent of snake-like limbless forms.

In addition to these two types of land animals we have two others which either persisted from unknown ancestors or made their advent: the temnospondylous type of amphibians from which the mammals eventually arose, and the stereospondylous type which terminated in the gigantic labyrinthodonts of the Upper Trias, the only group of the Pennsylvanian air-breathing vertebrates which we may say with certainty has left no modern descendants behind them. However, till near the close of the Pennsylvanian we have no knowledge of anything distinctive in the American land-vertebrate fauna. There was nothing strikingly peculiar to either eastern or western continent, so far as our knowledge yet extends, and some of the forms, indeed, are almost if not quite identical generically. And the only possible explanation of this homogeneity of types is freedom of communication and migration, the persistence and wide extent of like climatic and freshwater conditions that would permit, for instance, the migration of snake-like forms of small size from Ohio to Ireland and Bohemia without material modification in structure.

However, either the divisional lines between the Pennsylvanian and the Permian have been placed too high, or else, it seems to me, evolution among the vertebrates was more rapid in America than elsewhere near the close of the period. As a continent I believe that the land of North America was absolutely and continuously isolated, so far as the intermigrations of land forms was concerned, from some time before the close of the Pennsylvanian till well into Triassic times, as they reckon them in Europe. Of the Permian vertebrates by far the richest and most varied fauna known is that of America, and especially that of Texas and Oklahoma. Professor Case has recently presented what evidence he could for the Permian age of this fauna and has admittedly failed in proving anything save its utter isolation, and from the evidence we yet have no one can do better than he has done. The fauna was literally *sui generis* and I may almost say *sui ordinis*. But two or three genera of two types out of the scores of genera known from these regions can be correlated as showing resemblances—family resemblances I mean—with foreign forms. And both of these types had made their appearance, admittedly now here in America, before the close of the Pennsylvanian, one the derivative of Upper Carboniferous, possibly sub-Carboniferous stock, the other a later development, and both continuing for a brief period in Europe during Permian times. Of all the remainder of the air-breathers not one can be compared with forms known elsewhere in the world, save in the general characters, ordinal characters at best.

These facts can mean but one thing, the faunal isolation of land and freshwater vertebrates during all of the so-called Permian times in America. The faunistic evolution here was great, however. At least three very distinct phyla of reptiles and as many of amphibia are known with certainty: the Pelycosaurs (Naosaurus, Dimetrodon, etc.), derivatives of a prior type which had branched off before the close of the Pennsylvanian; the true Cotylosaurs (Diadectes, etc.) with, in some cases, singular developments of dermal carapace, strongly suggestive of the turtles, unknown elsewhere; and a third type (Labidosaurus, Pariotichus, etc.), for the present nameless, small crawling reptiles with large head, short tail, short limbs, whose nearest, but remote relatives are found among the pareiasaurs of South Africa, doubtless derived from the same common stock as the pareiasaurs, but modified by long isolation. Of the amphibia the most numerous and best developed are those with temnospondylous vertebrae, that is those which have the vertebrae divided into separate elements, the type from which the mammals doubtless eventually arose, as well as the cotylosaurs, and pareiasaurs. This group is also abundantly represented in the Lower Permian of Europe, but reached the highest expression in the Texas Permian (Eryops) A second type, represented by a few forms, in America, known from the latter part of the Pennsylvanian throughout the Permian (Diplocaulus, Crossotelos, etc.) represents sparsely the continuation of the microsaurs perhaps, but with marked modifications in structure peculiar to the American forms which separate them widely from their Permian relatives of Europe. The third, representing the earliest known type of the modern amphibians (Lysorophus), is, so far, entirely peculiar to our Permian, another evidence of isolated evolution. There are no known representatives of the stereospondylous types of Stegocephalia, that is the true labyrinthodonts, which, however, as we shall see, suddenly reappear in the Upper Trias, and doubtless were represented in the later Pennsylvanian of this country by known forms from Kansas, and by Marsh's Eosaurus from Nova Scotia, etc. Upon the whole, then, our Permian fauna is sharply and almost completely distinguished from any supposed contemporaneous or indeed any fauna known elsewhere, and may have been evolved wholly in America from known Pennsylvanian forebears. The Texas and Oklahoma Permian deposits were undoubtedly for the most part or entirely those derived from extensive flats of slight elevation, deposits composed for the most part of the finest, almost impalpable mud, with little extraneous material, traversed here and there by current channels, and streams which have left for evidence interrupted ribbons of fine or coarse sandstone, and some beds of gravel, with intercalations everywhere of lenticular masses of very fine sandstone of aeolian or quiet water origin. In other words, as has often been said, the deposits are typical shallow freshwater deposits, gradually merging on the north, as Beede has recently shown, into the shallow marine deposits of the Lower Kansas Permian. Few if any real marine vertebrates are known from all these extensive and varied deposits, since the shark and dipnoan remains not infrequently found may have been, and doubtless were, of fishes already habituated to fresh or brackish water. That there may have been in America contemporaneous forms living on the higher lands of which we have yet no knowledge is doubtless true, but not very probable; the higher grounds of the Wichita Mountains on the north have sent abundant gravel and sand material southward into these deposits, and they surely would also have sent some fragments of distinctive high-land creatures with them had there been any. There is, I believe, in all these deposits, not a single hint of the ancestry of modern reptiles save possibly of the turtles. Nor do I believe that there is any evidence of the great phyla of archosaurian and synaptosaurian reptiles here, for I, for one, am pretty thoroughly convinced that the Pelycosaurs have no genetic relationship with either of these groups. The origin of the branch leading to the mammals, so far as our knowledge yet goes, was in Africa; there is nothing to prove that it was in North America. What then became of the Permian land fauna of North America? Not a trace of it is found later in the Mesozoic land fauna of America. Until we know more of the land fauna of South

America, during these and later times, it is impossible to say just what became of it, but certainly, with the close of the Permian time, so far as our knowledge yet goes, it was completely blotted out of our records.

How much longer this Permian isolation continued it is of course impossible yet to say, since the gap in our records to the Upper Triassic is complete and absolute, at least so far as distinctively land forms are concerned. Dr. Merriam has brought to light within recent years from the Pacific regions a comparatively rich and varied marine vertebrate fauna of the Middle and Upper Trias, but it does not throw much light on continental faunal conditions. The remarkable demonstration of evolutional characters presented by the numerous ichthyosaurs which he has discovered indicates, it seems to me, a dispersal center of these animals, a group which must have been derived from the most primitive of reptiles, such indeed as the Permian fauna of America presents; and they may have been the direct descendants of that fauna. With them, moreover, is associated a remarkable new group of reptiles, the thalattosaurs, of almost subterrestrial type, unknown elsewhere in the world, a form which may have arisen from Lower Triassic land reptiles of true rhynchocephalian affinities, the first indication of this type, I believe, in America. Where their ancestors came from we cannot say, but I believe that they were immigrants, since we know of nothing that could have been their progenitors from the Permian of America.

With the land fauna of the Upper Trias of America we have again the most astonishing proofs of an intermingling of European and American faunas, an opening-up of some broad land connection which had been interrupted during Permian times. In the phytosaurs and the nearly contemporaneous thalattosaurs of the Pacific Triassic we have the first definite indication of the great archosaurian group of reptiles, already represented since early Permian times in Europe. Both they and the associated labyrinthodonts, which had been wholly absent since Carboniferous times, show the most intimate affinities with the European types, proving beyond doubt the equivalency of the deposits yielding them with the Keuper of Europe. And, also associated with them, are true dicynodonts—of this I have no doubt—forms intimately allied to those of similar age in the Trias of South Africa, the first representatives in America of another great group of reptiles, the Synaptosauria. Between the horizons yielding Permian fossils, whether vertebrate or invertebrate, and that affording these Keuper Triassic animals, there are, in both Kansas and the Lander region of Wyoming, at least a thousand feet of continuous, conformable, uninterrupted, and homogeneous deposits of red sandstones, deposits utterly barren of all animal or plant remains. I have asked geologists in vain what such deposits mean. One thing they do mean, for the Rocky Mountain region at least—continuous and uniform physical conditions. What became of the Permian vertebrates during this interval we cannot say, for, as I have said, there is, I believe, not the slightest trace of them or their descendants in the land fauna. And from the east, as also from the west, we get before the close abundant evidence of dinosaurs and aetosaurs; and a peculiar type of possible mammals, from Carolina.

Again comes a most lamentable gap in our knowledge of land vertebrates in America, that of the Lower and Middle Jurassic. With the Upper Jurassic marine beds, come in the most specialized of the ichthyosaurs and highly specialized plesiosaurs and a single fragmentary specimen of a crocodile, the first from the American continent. Both the ichthyosaurs and the plesiosaurs show such high evolution that we must admit their recent migration from Europe, where indeed a closely related ichthyosaur had anticipated our form and the plesiosaurs had long been known.

With the close of the Jura a rich land fauna appears in the Morrison beds, rich but not varied, composed almost exclusively of dinosaurs, dinosaurs big, dinosaurs small, carnivorous, herbivorous, walking, running, almost flying dinosaurs, of high and low degree, but among them all not a single type that is distinctively American, not one that is not, prior to this time or as a contemporary with it, known from the eastern continent. Morosaurus mimics Cetiosaurus, Camptosaurus Iguanodon, Stegosaurus Omosaurus, Allosaurus Megalosaurus, etc. We are confident then that during Morrison times there was freedom of migration between the eastern and western continents, so free that nothing distinctive of our fauna had been developed through isolation. Here now we find for the first time meager representatives of the first turtles, of a single type, which had been known on the eastern continent since Middle Triassic times, almost the first crocodiles, well known also there since Triassic times, but represented here by a single form with relatively few individuals, of a distinctively European genus. Nothing else save a single fragmentary bone of what may have been a pterodactyl, and a recently discovered (Gilmore) terrestrial rhynchocephalian, known over there from the Permian, Trias, and Jurassic; not a nothosaur, so characteristic of the European Triassic land fauna, not a lizard, known from the Triassic of Africa, not a bird, known from the Upper Jura of Solenhofen, practically nothing but dinosaurs, and mammals very closely allied to the Kimeridge or Wealden mammals of Europe—the first known multituberculates here, but known from the oölite there. Can one conceive of more favorable conditions for the preservation of the remains of all these creatures and of the small salamanders known contemporaneously in Europe, than those which existed through the thousands of miles of extent of low-lying, marshy lands of Morrison times? It will not suffice to say that we may yet find them in America. Under far less favorable conditions, apparently, bird remains are found in the Upper Cretaceous of New Jersey, Kansas, and Wyoming.

The conditions and faunas of the Morrison times are continuous throughout the Lower Cretaceous, so far as we know them; nothing new, nothing different save the reappearance of the plesiosaurs, nothing strange, nothing distinctive, and scarcely a type missing.

With the Upper Cretaceous the meager fauna of the Dakota gives only the footprints of a bird and a more distinctively terrestrial turtle. In the Benton, aside from the marine plesiosaurs, which here reach their culmination perhaps, and the ichthyosaurs, which now are dying out here after their disappearance in Europe, we find the last of the broad-nosed crocodiles (Coelosuchus) of ancient type, another lingerer, which had apparently disappeared in Europe, and the first of the slender-nosed crocodiles of olden type, their first appearance here after their last records from the eastern continent. And with them appears for the first time a new type of dinosaurs, the armored polacanthids (Stegopelta) which had appeared in Europe in the Wealden, but which is unknown from the earlier deposits of America among all the vast numbers of dinosaurs. With the close of the Benton and the beginning of the Niobrara, we find the first appearance of distinctive American types of air-breathing vertebrates since the decay of the Permian fauna, save the thalattosaurs of the Pacific Trias, in the large marine turtles (Protostega) and the duck-billed dinosaurs (Claosaurus). And what is very interesting is the first appearance of the scaled reptiles, the mosasaurs, in America. But the mosasaurs had already reached a high degree of importance in the east and perhaps in the south. They appear here suddenly without any such premonitions as are found in southern Europe, long after their appearance there. Although marine animals, they live near the shores and doubtfully ever braved the oceans; they must have followed the land. The birds, too, now are numerous and of considerable diversity of form; and the pterodactyls swarmed the seas, pterodactyls which had gradually been evolving in Europe till they had reached almost or quite the American specialization in the Cambridge Greensand. What was the cause of their delay in reaching this continent? Certainly not our lack of knowledge of the faunas, for I believe that we can say with tolerable certainty that no pterodactyls were in existence here till the time of the Colorado Cretaceous, certainly none of the Cretaceous type which began in the Wealden of Europe. The plesiosaurs, on the other hand, have taken on specializations which, notwithstanding their supposed freedom of migration, indicate comparative isolation from the European forms, for not a single genus is identical, and, save possibly Platecarpus, there is not a single genus of mosasaur quite identical with those of the European fauna. Unfortunately we know little of the land animals of this epoch, but altogether I think we are justified in saying that the freedom of communication between European and American land vertebrates was somewhat restricted.

During the times of the Fort Pierre and Laramie, inclusive of the New Jersey and Judith River faunas, we get some notable, though very dilatory appearances of European forms, the first land scaled reptiles, the first salamanders, and, with them, the first of the modern type of crocodiles, allied to the Borneo gavials. And with them also, the very much belated long-headed crocodiles of ancient type gave up the ghost, while the duck-billed and horned dinosaurs and the marine turtles, all distinctively American forms, the most distinctive of American Mesozoic vertebrates save thalattosaurs that we have, waxed and grew mighty. A new type for America of terrestrial turtles appeared. The polacanthid dinosaurs, long since unknown in Europe, continued to the very close (Paleoscincus). The mosasaurs present a European genus (Mosasaurus), but one that was most certainly developed here in America, and emigrated. Finally at the close a new type of reptiles (Choristodera), with marked rhynchocephalian affinities, appears, continuing on into the Tertiary, both here and in Europe, in forms almost generically identical; and the same may be said of the American crocodiles (Thoracosaurus) which reappear in Europe in the early Tertiary, with scarcely any differences.

And all these facts indicate conclusively a continued intermigration between the eastern and western continents of land animals, with possibly some less freedom during late Cretaceous times.

To summarize: The Pennsylvanian fauna has nothing distinctive, at least till near the close; there must have been a continuous and free interchange of land animals with the eastern continent till near the close. Before its close, it had already diverged and certain true reptiles had appeared. Before the beginning of Permian times an interruption of migration occurred, producing a complete and continuous isolation of the Permian American fauna. With the close of these times a long interval elapsed, during which physical conditions were almost uniform over a large part of the Rocky Mountain area at least; during which interval we have no records of land or freshwater life, but which is represented in part by marine forms of remarkable character, possibly in part derived from American ancestors. With the reappearance of land forms in the Upper Trias we find certain evidence of free migrations again, with the closest relationships between eastern and western forms, none of which could have been derived, immediately at least, from the known American Permian types. The marine vertebrates of the Upper Jurassic, the next American air-breathers of which we have any knowledge, indicate an advance in specialization over the contemporary forms from the eastern continent, but they also indicate a continued migration of the aquatic forms at least. With the land forms again appearing at the close of the Jurassic and in the Lower Cretaceous, we find strong evidence of a community of faunas, but with a striking absence, hitherto, of some of the smaller forms known from earlier times in the eastern continent. The Upper Cretaceous again shows a belated arrival on the western continent of eastern types, after their advent or even disappearance there. With the exception of certain Triassic marine types, we have no distinctively American Mesozoic groups of air-breathing vertebrates, until we reach the Benton, Niobrara, and Pierre Cretaceous, all indicating a continued, but possibly restricted intermigration between the eastern and western continents during the whole of Mesozoic times. In which way did these migrations occur? That the communication between the two continents in Pennsylvanian time may have been by way of the north Atlantic region is not at all improbable. Indeed, taking into consideration the close relationships known to exist between the European and American type of this period, closer perhaps than existed at any subsequent time during the Mesozoic, this more direct way of communication would seem very probable.

On the other hand, the very close relationships existing between the species of the Proganosauria, hitherto found only in South America and Africa, one genus of which is exclusively American while the other genus, Mesosaurus, according to McGregor's recent observations, is represented in both continents by closely allied species, would suggest a close land communication between the two continents during early Permian times at least. That Mesosaurus may have reached the two continents, Africa and South America, by the long, roundabout way of the north Atlantic, is hardly possible, for the same freedom of communication would have opened up North America to the ingress and egress of European and American forms. It would seem altogether probable, then, that there not only was a free communication between Africa and South America in Permian times, but that also the communication between North and South America was closed during the same interval, though of this we cannot be at all sure till we know more of the South American Permian fauna, which, so far, lacks every distinctive form peculiar to North America.

Whether or not the communication between North America and the eastern continents was by way of the north Atlantic, it is quite probable that there was more or less free communication during part or all of the Mesozoic time between North and South America, proof of which is seen in the dinosaurs, mosasaurs, and crocodiles, some of them, according to competent observers, identical generically even with North American forms. We have yet much to learn about the Mesozoic fauna of South America, but, so far as our knowledge yet goes, there is a close relationship between them. This similarity, of course, may have been the result of a westward migration from Africa to South America by the way of a southern land communication, and a concurrent intermigration of the same types from Africa northward to Europe and thence by the north Atlantic to North America. But a simpler explanation would be that of a land communication between North and South America, and a single trans-Atlantic bridge, which, in my opinion, was the southern one.

It is very true that such hypotheses as I have offered are largely based upon negative evidence. Future discoveries may bring to light, both in Europe and America, types which now appear to have a more restricted geographical distribution; especially may future discoveries in South America and Africa show more distinctive types, or, on the other hand, more common forms. I do believe, however, that the long-continued exploitation of the Mesozoic rocks of North America is gradually converting negative into positive evidence; that we may say with tolerable certainty that certain types of land vertebrates, such as the Proterosauria, Proganosauria, Pareiosauria, Therodontia, etc., have never existed in North America.

In the accompanying table I have given, as fully and as accurately as the present state of our knowledge will permit, the geological range and distribution of the larger groups of air-breathing vertebrates, with especial reference to North America. In not a few instances precise stratigraphical data are wanting, so that groups must be recorded throughout a division of the chart, which later may be found to have a more restricted range. An attempt has been made to indicate by association the phylogenetic relationships of the groups, but it must be remembered that opinions differ not a little concerning the phylogeny of the reptiles, and those expressed in this chart are merely the ones which seem most reasonable to myself. I am indebted to Dr. v. Huene for a number of suggestions and facts of distribution which have been incorporated in the table; and to Dr. W. D. Matthew I am also obliged for the data for the mammals. It is to be hoped that Dr. Matthew will confer a favor upon us all by publishing soon a complete table of the distribution and range of the mammals; no one is more competent.

PALEOGEOGRAPHIC MAPS

BAILEY WILLIS
U. S. Geological Survey

8, 9, AND 10. LATEST PALEOZOIC,[1] TRIASSIC, AND LATE JURASSIC[2]

North America during the latest Paleozoic, the period which corresponded in a general way with the Permian in Europe, was an expanding land. On the east the Appalachian peninsula had been eroded during Pennsylvanian time and erosion continued vigorously during the later Paleozoic. The elevation which gave the process of erosion this opportunity was probably due to pressure from the Atlantic, that raised all the eastern margin and exposed any then existing coastal plain, out to the edge of the continental shelf. The pressure ultimately occasioned the displacements apparent in the folded and overthrust zone of the Appalachian and St. Lawrence valleys, and it is probable that the continental margin on the Atlantic side was then moved westward to near its present position, the oceanic basin expanding westward to an equal amount.

In the eastern central United States the area of continental deposits shrank within narrower limits. The condition of the Mississippi embayment is unknown.

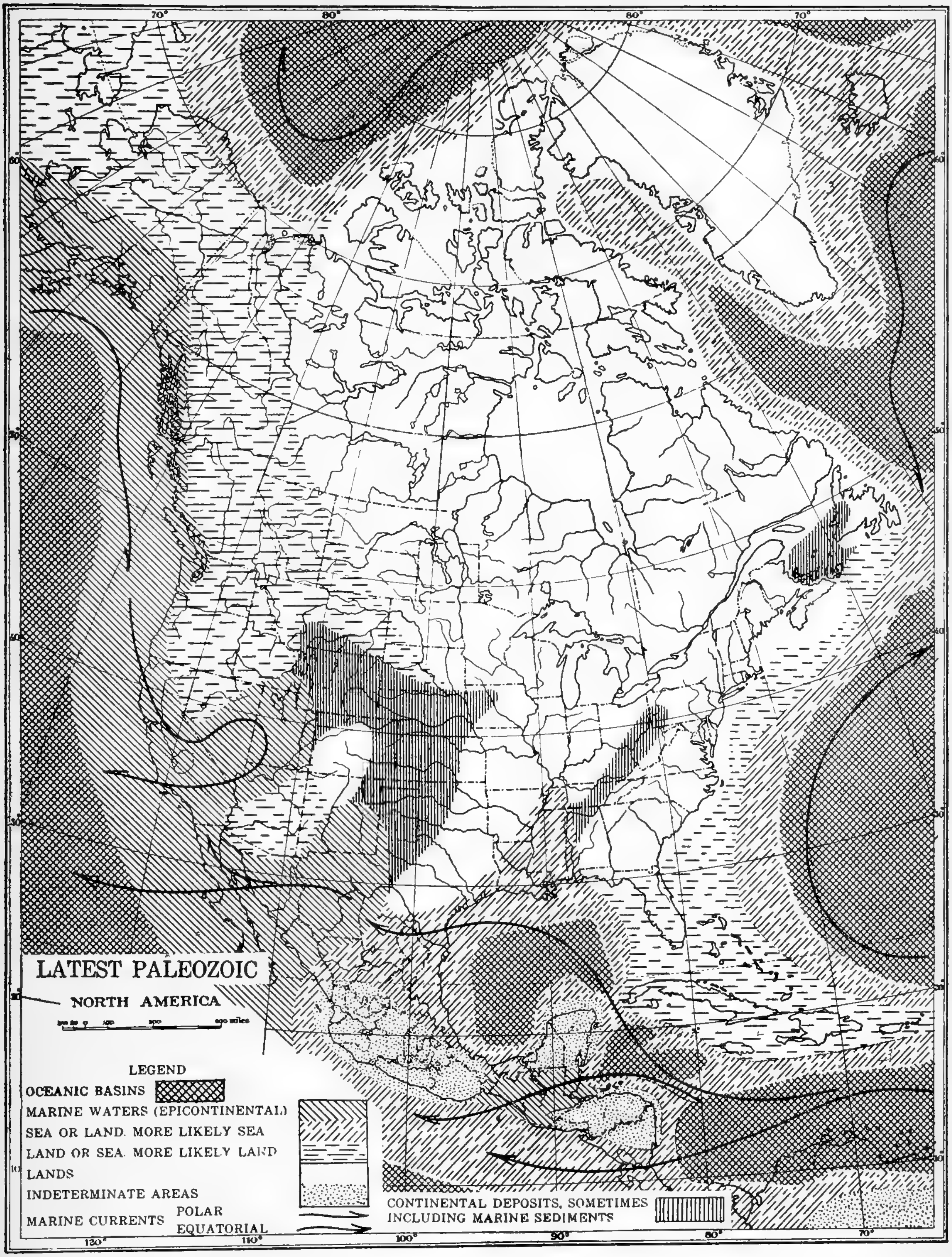
In the northwest the land extended, apparently, nearly if not quite to the Pacific; but in southern Alaska the sea prevailed.

The island which stretched from Colorado to southern Arizona obstructed to some degree the general distribution of the red sediments, chiefly of continental character, which were derived from the wide lands to the northwest, north, and northeast. The island also separated the northern embayment of waters which were probably cool from the southern sea, through which flowed a warm current; and thus it divided two faunal districts.

The geographic conditions and the independent evidence of climatic diversity indicate that the north was cool, if not cold, and the

[1] Map prepared in collaboration with Dr. G. H. Girty.

[2] Map prepared by Dr. T. W. Stanton; modified, as regards marine connection between the Pacific and the Arctic in the Mackenzie Valley, by Bailey Willis.


LATEST PALEOZOIC
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND. MORE LIKELY SEA
LAND OR SEA. MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS
70°
80°
80°
70°
120°
110°
100°
90°
80°
70°

south warm. The vertebrates known from Nova Scotia to Texas appear to have lived in the more genial regions and to have had no communication (unless closely following the Pennsylvanian) with Europe or South America, although the latter was connected with Africa by some southern route. The barriers to intermigration in the north may have been marine waters (North Atlantic) and cold climate (Alaska-Siberia).[1]

In Triassic time North America attained a larger connected land area than at any known epoch of its earlier history. The eastern region was apparently subject to erosion till the close of the period, when the continental or estuarine deposits of the Newark group gathered in basins near the probable margin.

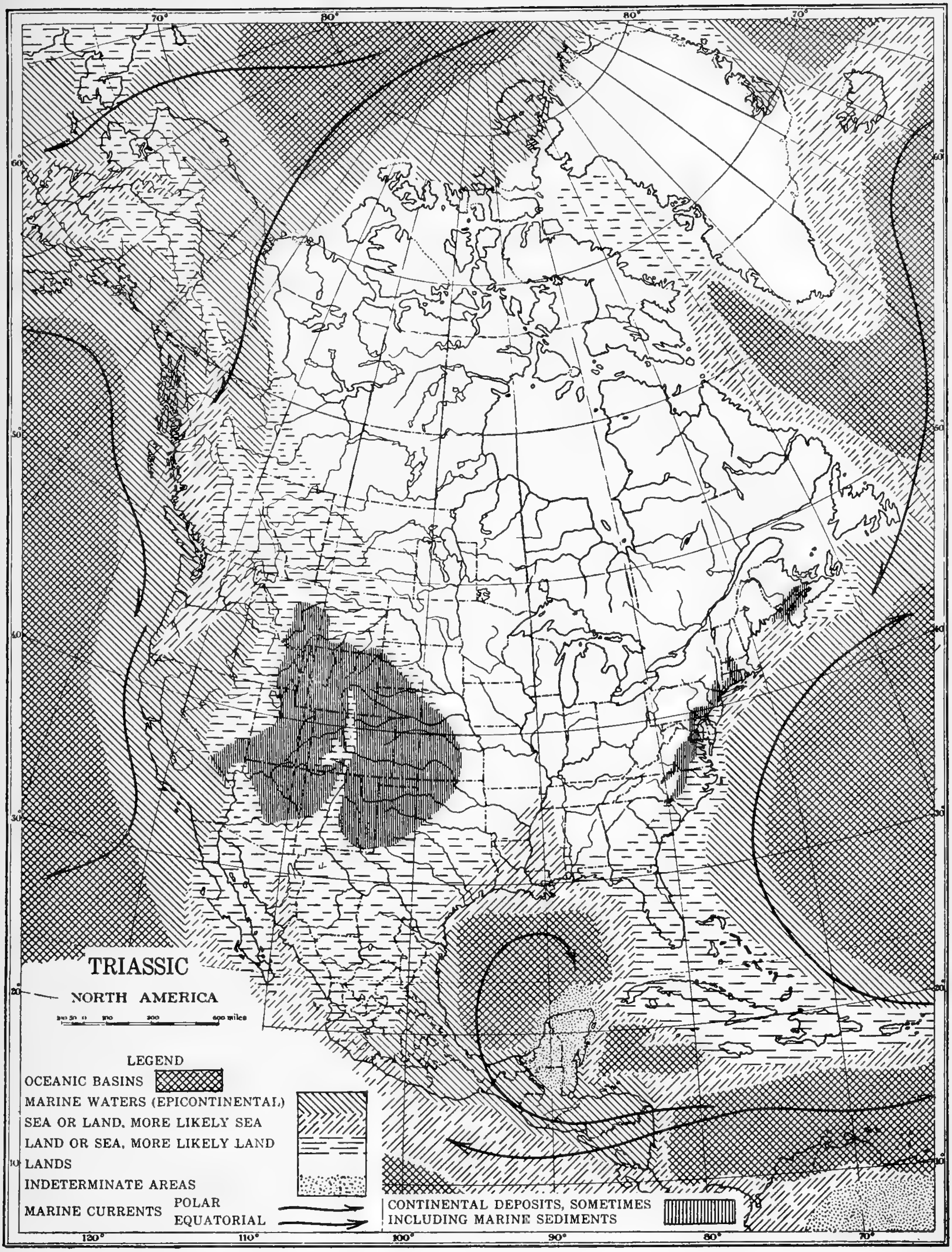
Lower Triassic marine strata occur in southwestern Idaho in an area mapped as occupied chiefly by continental deposits. The principal epicontinental seas, however, appear to have formed embayments in British Columbia and west of longitude 115° in the United States. They were probably not connected. Southern Alaska was submerged and Behring Strait also.

With the close of the Triassic the embayments upon the continental plateau appear to have become land and the continent attained in the early Jurassic a still greater expansion. Both eastward and westward it exceeded its present coasts in middle latitudes and no part of the intervening continent was submerged.

The Triassic continental deposits indicate an arid climate in the central west; whereas on the southeastern Atlantic border there was a humid climate in which marsh conditions prevailed.

The very extensive land area which North America presented during a part of the Jurassic period was reduced in the late Jurassic by marine invasion from the Pacific. The sea transgressed to western Nevada. It apparently occupied much of British Columbia, but the subsequent intrusion of the great batholith of the Coast Range destroyed the record near the coast. Further inland volcanic effusive rocks are associated with marine sediments, which on meager paleontological evidence are classed by Stanton as probably Jurassic and by Whiteaves as "Lower" Cretaceous.

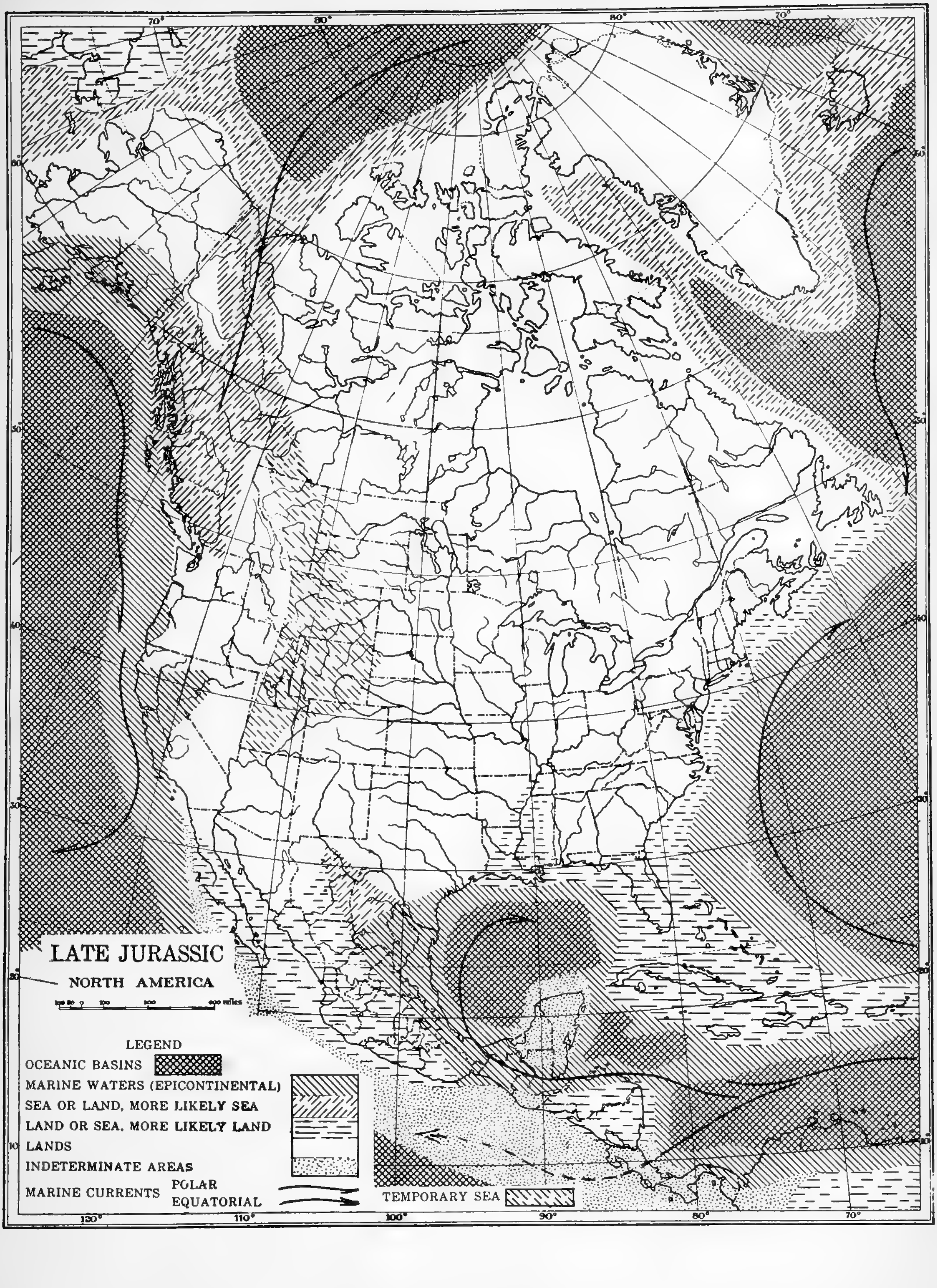
[1] My thanks are due to Dr. S. W. Williston for discussion of the evidence regarding vertebrates.—B. W.


TRIASSIC
NORTH AMERICA
600 miles
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
120°
110°
100°
90°
80°
70°

Communication of Pacific waters through the Arctic with the seas of eastern Europe and Asia is indicated by similar boreal species in both regions, but the connection is not known. It may have been by Behring Sea, as Stanton thinks probable, or by the Mackenzie, as Willis infers.

Marine waters (the Sundance sea) extended temporarily to Dakota, Wyoming, and southern Utah.

On the east the continent was low. The lower part of the Potomac formation, long considered to be late Jurassic, is according to the latest work under W. B. Clark probably "Lower" Cretaceous (Comanche). The limit of the coastal plain is therefore unknown. It was beyond the present coast.


LATE JURASSIC
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
TEMPORARY SEA
130°
110°
100°
90°
80°
70°

CHAPTER IX

SUCCESSION AND DISTRIBUTION OF LATER MESOZOIC INVERTEBRATE FAUNAS IN NORTH AMERICA[1]

T. W. STANTON

EARLIER MESOZOIC FAUNAS

In early Mesozoic time the marine invertebrate faunas of North America were closely confined to the borders of the present continent, and particularly to the western border. The land-area, or at least the area above sea-level, was nearly as large as it is now. The early Triassic sea with a rich ammonite fauna extended as far as eastern Idaho but its area was apparently restricted and its most probable connection with the ocean was through Utah, Nevada, and southern California. Later Triassic marine faunas are not known east of western Nevada and eastern Oregon in the United States. They occur also at many localities in British Columbia and Alaska, and in a very limited area near Zacatecas, Mexico. The occurrence of fresh-water shells (Unio) in the Upper Triassic of New Mexico, and the character of the vertebrate remains found there and at other points farther north, attest the non-marine character of the Triassic deposits in the Rocky Mountain region. The scanty invertebrates found in the Newark group of the east also indicate non-marine deposits. Early Jurassic (Liassic) faunas are apparently restricted to an area still smaller than that of the marine Trias.[2]

LATE JURASSIC FAUNAS

Marine fauna.—At or near the close of the Middle Jurassic the sea again invaded the continent and covered a large part of the Rocky Mountain region. It extended east to the Black Hills, south to southern Utah, and covered much of Montana, Wyoming, and Utah, with

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] A full discussion of the marine Trias may be found in the published writings of Professor James Perrin Smith. See especially *Proc. Cal. Acad. Sci.*, 3d Ser., "Geology," Vol. I, No. 10, 1904; and *Von Koenen Festschrift*, pp. 377–434, 1907.

the northwest corner of Colorado, part of Idaho, and a considerable area in British America. The fauna of this Rocky Mountain Jurassic sea is characterized by *Cardioceras cordiforme*, Cadoceras, *Belemnites densus*, and a rather varied though not large fauna consisting mostly of bivalves. It has long been recognized by Neumayr and others to be of boreal type and hence as indicating a connection either direct or indirect with the Arctic region. The fauna shows some local variations, usually associated with variations in the character of the sediments; but it appears to be essentially a unit throughout the entire area. It is believed that the deposits were all formed in one basin and within a comparatively brief period. Their maximum thickness is usually only a few hundred feet.

As there are no other marine Jurassic formations in the region and the section is known to be incomplete it is necessary to go to other areas where similar faunas occur to determine the exact position of this one in the general column. In the Upper Jurassic the following stages are recognized by De Lapparent who gives them universal application:

Portlandian { Purbeckian, Bononian }
Kimmeridgian
Sequanian
Oxfordian
Callovian

The Jurassic of the Rocky Mountain region, as far as can be deter mined from the fauna, represents the Oxfordian and perhaps the Callovian in whole or in part. That is, it is the lower part of the Upper Jurassic. In a large part of its area it rests on the Carboniferous, and the youngest marine fauna found beneath it anywhere is in the Lower Trias, while the oldest succeeding marine fauna is Upper Cretaceous. It is obvious, therefore, that neither the ancestors nor the descendants of its species are found in the same area, but fortunately its stratigraphic position is fairly well determined in the much fuller Alaskan section. On the shores of Cook Inlet the Middle and Upper Jurassic are represented by about 10,000 feet of strata with at least three distinct marine faunas[1] which are largely still

[1] Stanton and Martin, "Mesozoic Section on Cook Inlet and the Alaskan Peninsula," *Geol. Soc. Am. Bull.*, Vol. XVI, pp. 391–410.

undescribed. The strata have been almost equally divided into the Enochkin formation below and the Naknek formation above. The upper part of the Enochkin formation is characterized by a great development of the ammonite genus Cadoceras, indicating the boreal facies of the Callovian stage, while the Naknek formation contains Cardioceras near the base and an abundance of Aucella with Lytoceras, Phylloceras, etc., in the overlying beds. The fossils indicate that the horizon of the Rocky Mountain Jurassic is near the boundary between the Enochkin and Naknek formations. In other words this Rocky Mountain epicontinental sea, which W. N. Logan has discussed,[1] was drained before the deposition of the Jurassic "Aucella beds" which have such a great development in Alaska and farther south on the Pacific coast as well as in Russia and in many areas of the boreal region. Its fauna is clearly boreal, as has already been stated, and there was marine connection either directly with the Arctic Ocean, or, as the known distribution of the rocks makes more probable, indirectly through the north Pacific somewhere between Vancouver Island and Cook Inlet. There seems to have been no direct connection with the contemporaneous sea of California which had a different, though imperfectly known, fauna more closely related to middle European faunas.

After the sea had retreated from the Rocky Mountains the boreal Aucella fauna which occurs in the Naknek formation extended down along the Pacific coast into Oregon and California where it characterizes the Mariposa slate and equivalent formations, continuing through a great thickness of strata to the top of the Jurassic and passing without any striking change into the Lower Cretaceous.

In Mexico no faunas are known that belong to the Middle Jurassic, or to the Callovian and Oxfordian stages of the Upper Jurassic, but the later stages, or at least the Kimmeridgian and Portlandian, are well represented near Mazapil in the state of Zacatecas and in adjacent portions of neighboring states. Burckhardt who has recently described the fauna[2] states that it resembles the faunas of central Europe and the Mediterranean but that it also contains forms that show relationship with the Russian or boreal fauna and others that

[1] *Jour. of Geol.*, Vol. VIII (1900), pp. 241–73.

[2] Instituto Geológico de Méjico, *Boletín No. 23*, 1906.

connect it with the Jurassic of the South American Cordillera. He concludes that there must have been direct marine connection with all these regions. The most striking example of the introduction of a new element in the fauna is the intercalation of a thin Aucella bed in the midst of strata containing the Mediterranean type of fauna in the upper Kimmeridgian. The Aucella must have come in from the Pacific where, as we have seen, the boreal type of fauna extended at least as far south as middle California. The nearest recorded occurrences of Aucella in the other direction are on the east coast of Greenland and in England. On the other hand this Mexican fauna as a whole is so unlike that of California and so related to that of Europe, and the geographic position of the beds is such that connection with the Gulf of Mexico seems most reasonable. The area should therefore be mapped as included in the Atlantic sedimentation though it is probable that the Pacific waters bearing the Aucella found temporary access to it from some point south of the Gulf of California. If the exact position of this temporary Pacific connection is still indicated by sediments they have not yet been recognized.

Farther south in Mexico a somewhat different facies of the Upper Jurassic fauna found in the state of Oaxaca has been described by Felix[1] but according to Cragin[2] this has some species in common with the Malone Jurassic fauna of western Texas which on the other hand shows some relationship with the fauna of Catorce, San Luis Potosi, and hence also with that of Mazapil. The Malone fauna shows no connection whatever with the Rocky Mountain Jurassic because it belongs to a later stage and to a different province. It probably lived in an arm of the Gulf of Mexico directly connected with the area in Zacatecas and San Luis Potosi, and including the locality near Cuchillo Parado, Chihuahua, reported by Aguilera.[3] Some of the elements of the Malone fauna show decided Cretaceous affinities and thus strengthen the evidence that it is latest Jurassic.

In Europe Neumayr recognized three marine faunal provinces in the Jurassic which, as he believed, indicated climatal zones. These

[1] *Palaeontographica*, Band XXXVII (1891), pp. 172–80.

[2] U. S. Geol. Surv., *Bull. 266*, 1905.

[3] *Aperçu sur la geologie du Mexique*, p. 8, 1906.

are the Mediterranean or Alpine, the Middle European, and the boreal or Russian, each characterized by different types of ammonites and other invertebrates. For example, the ammonite genera Lytoceras and Phylloceras are abundant in the Mediterranean province, occur sparingly in the Middle European, and are practically absent from the Russian Jura. Coral reefs and important limestones also are not found in the boreal Jurassic formations.

In America there is no difficulty in recognizing a boreal fauna in the Upper Jurassic which, as we have just seen, temporarily extended far south in the Rocky Mountain region and at a later stage still farther south along the Pacific coast. It is like the Russian fauna in its essential features although it does contain the Mediterranean types Lytoceras and Phylloceras in Alaska. There is likewise no difficulty in recognizing a southern or Mexican fauna in which are commingled many of the types which in Europe are separated and considered characteristic of the Middle European and Mediterranean provinces. Finally the Mexican fauna received by way of the Pacific a few immigrants from the boreal fauna.

Variations in the lithologic development are worthy of note. Limestones form a large proportion of the sediments in Mexico while they are relatively inconspicuous in all the areas where the boreal fauna is dominant.

Jurassic (?) freshwater fauna.—The marine Jurassic beds throughout the Rocky Mountain region of the United States are immediately overlain by the continental freshwater or marsh deposits of the Morrison formation which also extend south through Colorado into New Mexico beyond the limits of the marine Jurassic beds. Its large and varied dinosaur fauna was originally assigned to the Jurassic without question, but during the last few years some paleontologists have referred it to the Cretaceous. Its stratigraphic position is consistent with either reference as the interval otherwise unrepresented comprises a considerable part of each system. Its invertebrate fauna consists of several species of Unio, Vivipara, Planorbis, etc., all of modern freshwater types which do not assist in discriminating between Jurassic and Cretaceous. The fact that the Morrison is overlain by the Kootenai on the north and by the marginal deposits of the Comanche on the south tends to place it early in the transition interval.

EARLY CRETACEOUS FAUNAS

At the beginning of the Cretaceous the two faunal provinces which have just been indicated were even more sharply defined than they had been in the Jurassic, and in each area the characteristic elements of the fauna are developed from the fauna that preceded it. The Shasta fauna on the one hand and the Comanche fauna on the other are always sharply contrasted, though each exhibited several facies. When compared with European faunas, one is in the beginning chiefly boreal and the other Mediterranean; one is associated with shales, sandstones, and conglomerates, the other, mainly with limestones.

Shasta faunas.—The boreal Aucella fauna of the Knoxville formation is the earliest one in the Shasta series. It is distributed from the Arctic coast of Alaska to southern California but south of the Yukon never extending as far east as the late Jurassic fauna did Cretaceous Aucella beds have been reported from Catorce, San Luis Potosi, Mexico, but it is probable that these are Jurassic on about the same horizon at which Aucella occurs at Mazapil.

The succeeding Horsetown fauna though at first showing a transition from the Knoxville fauna is, as a whole, remarkably distinct from it. It is characterized by the great abundance and variety of ammonites of types which in Europe are considered distinctive of the deeper water facies of the Mediterranean province. The boreal element is wanting, or at least inconspicuous. This early Horsetown fauna is much less widely distributed than the Knoxville. In its typical development it is known in a relatively small area in northern California and in Oregon. Toward the close of the Horsetown the fauna was greatly modified by the introduction of many types that show relationship with the Cretaceous faunas of southern India and also with those of Japan. This relationship was continued in the succeeding Upper Cretaceous faunas to such an extent that it is appropriate to speak of an Indo-Pacific province or region. This later Horsetown fauna was more widely distributed along the Pacific border and is well developed as far north as the Queen Charlotte Islands.

The marked change at the close of the Knoxville when the fauna ceased to have a distinctively boreal character was probably due to a northern uplift which closed Bering Strait and other direct connections between the Arctic and Pacific Oceans. The closing of these connections would modify the currents, change the climate, and permit immigration of faunal elements from other areas without any other geographic changes.[1]

Comanche faunas.—The whole of the Comanche series is here treated as Lower Cretaceous, because in the Texan area the top of the Comanche is the only natural and satisfactory major plane of division in the Cretaceous. Stratigraphic, lithologic, and paleontologic studies all lead to the same conclusion. Many European paleontologists believe that the upper or Washita portion of the Comanche is of Cenomanian age and hence referable to the Upper Cretaceous of European standards and the Mexican geologists, while adopting this view, advocate for their country a threefold division of the Cretaceous and call the upper part of the Comanche, including the Fredericksburg and Washita groups, Middle Cretaceous. These varying views as to the classification and correlation of the formations are not important in the present discussion of the succession and distribution of the faunas which are grouped under the term Comanche. These faunas show many facies varying from time to time and from place to place. There are littoral faunas, reef faunas, and deeper-water faunas, but the reef facies is perhaps the most striking and characteristic. And yet these different facies are all so intimately connected either by common species or by stratigraphic relations that it is appropriate to speak of the Comanche fauna as a whole. When the Comanche fauna is examined either as a whole or in detail it proves to be very similar to the Cretaceous fauna of the Mediterranean province in southern Europe, and it is strikingly contrasted with the Shasta fauna of the Pacific coast, although the Comanche area in Mexico closely approaches the present Pacific coast throughout that country. On a previous occasion I have called attention to the character of the differences between the Shasta and Comanche faunas.[2] They are not made up of related forms differing specifically, but they consist mainly of different classes of animals so that they present

[1] See *Von Koenen Festschrift*, p. 433, where J. P. Smith has suggested that periodic opening and closing of these connections are sufficient cause for the changes in Mesozoic and later faunas of the Pacific coast.

[2] *Jour. of Geol.*, Vol. V (1897), p. 608.

totally different facies, bespeaking very dissimilar conditions. If there had been direct and free marine connection between the two areas it is probable that the conditions could not have been so different and the faunas would have shown less contrast. That the two faunas were approximately contemporaneous and that there was no important break in the sedimentation of either area during this epoch are well determined facts. It is believed, therefore, that there was a long land mass approximately parallel to the present west coast separating the two provinces.

In considering the Comanche area, as mapped, it should be remembered that a long period during which thousands of feet of limestone were formed is represented, and that the sea was advancing toward the north. The best-known early Comanche fauna is found near Tehuacan in the state of Puebla. It has been suggested with some reason that this is possibly in part somewhat older than the Trinity group which forms the base of the Comanche in Texas. It is largely a reef fauna consisting of corals and other sessile animals with other forms that are usually associated with them. Farther north one facies of the Trinity group fauna is characterized by an abundance of Orbitolina, while another facies has more of a littoral character. Trinity strata and fossils are found as far west as Bisbee, Arizona, and north to southwestern Arkansas and southern Oklahoma.

The succeeding fauna of the Fredericksburg group also has both littoral and reef facies. The latter is characterized by an abundance and great variety of Rudistae, Chamidae, and Caprinidae with Nerinea, etc., usually occurring in very pure limestone, but this facies is in some areas repeated in the Washita group so that the two faunas are sometimes hard to distinguish. The reef facies does not reach the northern boundary of Texas and the Fredericksburg fauna as a whole is not definitely recognized beyond that line though it is possibly represented at the base of the Kiowa shale of southern Kansas.

The reef facies of the Washita fauna is not found north of southern Texas but the littoral facies extends far beyond the limits of the Trinity and the Fredericksburg into northeastern New Mexico, southern Colorado, and middle Kansas. The thin Comanche deposits in all these areas belong exclusively to the Washita group and probably to the upper Washita. They rest at some localities on the

Morrison formation and in others on older formations down to the Carboniferous. They are always directly overlain by the Dakota sandstone.

Early Cretaceous freshwater faunas.—The Morrison fauna which may possibly be Cretaceous has already been referred to in discussing the Jurassic. The coal-bearing Kootenai formation of southern Canada and Montana which is determined by its stratigraphic position and by its flora to be Lower Cretaceous has yielded a few Unios and freshwater gastropods, mostly of simple modern types. These, like the similar forms in the Morrison, are interesting chiefly from the fact that they were probably the direct ancestors of some of the modern American freshwater forms, their successors having been preserved in the rivers of the adjacent land whenever the larger area previously occupied by them was submerged in the sea.

LATER CRETACEOUS FAUNAS

Chico fauna.—On the Pacific coast the Horsetown fauna is succeeded by the littoral Chico fauna which is distributed from the Yukon River to Lower California, occurring on the lower Yukon, the Alaska Peninsula, Queen Charlotte and Vancouver islands, in middle and southern Oregon, in the Sacramento valley and the coast ranges of California to San Diego, and on the peninsula of Lower California as far south as latitude 31° 30′. There are considerable local variations in this fauna as would be expected in view of its great range in latitude. The assemblage of forms found on the Yukon is quite different from that occurring in the Sacramento valley, and still another facies is found in southern California, but these are all connected by common species so that there is no hesitation about referring both the northern and the southern facies to the Chico fauna. The fauna as a whole, like the later Horsetown fauna, is Indo-Pacific in its affinities, and is strikingly different from the faunas of the Atlantic border and interior regions of North America. Whiteaves[1] and F. M. Anderson[2] have argued for a connection during Chico time between the Pacific and interior seas, but the evidence brought forward in support of this view is based on types that have a world-wide distribution and on those that are only similar, not specifically identical.

[1] *Mesozoic Fossils*, Vol. I (1879), pp. 186–90.

[2] *Proc. Cal. Acad. Sci.*, 3d Ser., Vol. II (1902), p. 59.

In my opinion direct connection has not been proved. In time range the Chico fauna apparently began somewhat earlier and continued somewhat later than the Colorado fauna of the interior sea but it did not extend to the end of the Cretaceous, and latest Cretaceous time is probably not represented by marine deposits on the Pacific coast.

Colorado fauna.—On the Atlantic side of the continent and in the interior region the greatest marine invasion of Mesozoic time occurred after the close of the Comanche. The sedimentation began with the Dakota sandstone but the first distinctive marine fauna is found in the overlying Benton shale of the Colorado group. The Colorado fauna as a whole is easily distinguished, although it is developed in several distinct faunal zones and local facies. It is characterized by *Inoceramus labiatus* and several other specific types of Inoceramus, by certain forms of Scaphites, and by the keeled ammonites known as Prionotropis, Prionocyclus, and Mortoniceras, which are sometimes referred to Schloenbachia in the broad sense. The fauna has a very great distribution, extending from Mexico and Texas throughout the Great Plains and Rocky Mountain regions as far north as Peace River in Canada. It is considered probable, though the faunal evidence is too meager for positive assertion, that there was marine connection entirely through from the northern interior to the Arctic Ocean. No marine faunas of Colorado age are known in the Atlantic and Gulf borders east of western Arkansas, unless possibly the imperfectly known fauna of the Eutaw or "Tombigbee" sand of Mississippi belongs to its latest phase. If the Colorado sea covered that area its deposits have been overlapped by later beds. The earliest marine fauna, that of the Magothy or "Cliffwood," in New Jersey, is apparently later than Colorado.

In the eastern and southeastern parts of the Colorado sea where the later Colorado deposits are calcareous, constituting the Austin chalk and the Niobrara formation, the fauna of these beds is different in character from that of the underlying Benton shale, and the Austin fauna is much larger and more varied than that of the Niobrara though their correlation is fixed by a sufficient number of identical species. The calcareous Niobrara is characteristically developed east of the mountains in Colorado and Kansas, and northward to the Black Hills and Manitoba, but farther west and northwest the

Niobrara is represented by shale, and is not lithologically separable from the Benton. The fauna is here correspondingly modified and a number of Niobrara and Austin species are associated with an assemblage of other forms peculiar to the region, together with a few that show closer relationship with the Benton fauna.

A horizon near the top of the Benton in Texas, New Mexico, and southern Utah is characterized by an abundance of ammonites belonging to the genus Metoicoceras Hyatt, formerly referred to Buchiceras, together with a number of other forms not known elsewhere. A littoral facies of the Benton fauna is developed in Utah and western Wyoming, and locally in southern Colorado, associated with sandstones and, except in Colorado, with coal-beds.

These local or temporary differences in the Colorado fauna may be attributed to differences in depth, in proximity to the shore, and possibly to variations in climate conditioned on ocean currents. With a shallow sea and an open connection with the Arctic the southern local facies in the Benton and the Niobrara would probably correspond with the area directly influenced by the equatorial or gulf current. Certain important forms, however, like *Inoceramus labiatus* and *Prionotropis woolgari* are distributed throughout the entire area.

In the Athabasca region of northwestern Canada a peculiar ammonite fauna has been described from the Peace River sandstone, and the Loon River and Clearwater shales, all of which are referred to the Colorado group; but the question of their age and relationship should be left open until the geology and paleontology of the region are known more in detail. It has been suggested that they may be older than Colorado.

Montana fauna.—From New Mexico northward the Montana group has nearly the same distribution and extent as the Colorado group. It varies greatly in character, from all marine in some areas to largely brackish and freshwater deposits in others, and its faunas are correspondingly differentiated. A considerable element of its marine fauna is evidently derived directly from the Colorado fauna but a large proportion of it is apparently composed of immigrants from other areas, probably in part Arctic and in part Atlantic. In the north a littoral facies associated with sandstones and a deeper-water facies (the Pierre fauna) in shales may be distinguished. The littoral facies is typically developed in the Fox Hills sandstone at the top of the group but a closely similar fauna occurs at several lower horizons.

Ripley fauna.—Toward the south in New Mexico the littoral facies of the Montana fauna blends with the Ripley fauna which is well developed in the latest Cretaceous formations of Texas, Mississippi, and Alabama, and throughout the Atlantic coastal plain to New Jersey. The Ripley and Montana faunas have many species in common and many others that are closely related and yet their aspect is unlike because their dominant types are different. In the Montana fauna the genus Inoceramus is very abundant and varied and ammonoids—especially Placenticeras, Baculites, Scaphites, and other evolute types—are abundant while the Ostreidae, Veneridae, Cardiidae, etc., and gasteropoda play an unimportant rôle. In the Ripley fauna on the other hand ammonoids and Inoceramus are relatively rare and the Ostreidae, Veneridae, Cardiidae, and many types of gasteropoda, including Volutidae, are greatly developed. The Ripley fauna is more varied and luxuriant, so to speak, than the Montana and apparently indicates a warmer, or at least a more favorable climate. There was almost certainly direct connection between the areas occupied by the two faunas, but the life conditions were sufficiently different to determine distinct faunal facies. The Montana fauna probably received some of its elements directly from the Arctic, while the Ripley fauna came in from the Gulf of Mexico and the Atlantic. With the connection between the Atlantic and Pacific closed in the Mexican and Central American region as at present, the Gulf stream would give similar conditions and would distribute the Ripley fauna along the coast from Texas to New Jersey. It is noteworthy that the European fauna most closely related to the Ripley is found at Aachen in Germany and that the most natural route of migration, with such a configuration of the continent as is here assumed, would be from the American Atlantic coast northeastward to Europe.

A peculiar Cretaceous fauna, apparently contemporaneous with the Ripley, has recently been described by Böse[1] from Cardenas, San Luis Potosi, Mexico. It contains a few typical Ripley species like *Exogyra costata* and *Gryphaea vesicularis*, together with many

[1] Instituto Geológico de Méjico, *Boletín No. 24*, 1906.

corals, Rudistae, Actaeonella, etc., which suggest the Cretaceous of Jamaica. It may be considered a reef facies of the Ripley fauna.

All the late Cretaceous marine faunas that have been briefly mentioned are still typically Mesozoic, although it is true that they contain many generic types that continue on through the Tertiary. The succeeding Tertiary faunas, whether on the Pacific coast, the Gulf border, or the Atlantic coastal plain, show a very striking change from the Cretaceous faunas that immediately precede them. The specific types are practically all different.

Non-marine later Cretaceous faunas.—In the Rocky Mountain region throughout later Cretaceous time there was a great development of freshwater and brackish-water deposits alternating with marine formations. They are usually coal-bearing, and yield invertebrate faunas frequently associated with land vertebrates and plants.

The invertebrate fauna of the Dakota sandstone is too meager to be of much value. It consists of a few brackish-water species with Unio and a few other freshwater shells in other strata and at the top some marine species that probably really belong with the succeeding Colorado fauna. The freshwater species show relationship through the genus Pyrgulifera with the fauna of the Bear River formation which is apparently about on the horizon of, or a little later than, the Dakota. The Bear River fauna is distributed over a considerable area in southwestern Wyoming, and is unique among western non-marine faunas in that it contains a number of types that have left no descendants in later formations of the region. The most distinctive forms are freshwater species, but the fauna also contains brackish-water elements. The submergence beneath the Colorado sea which immediately followed the deposition of the Bear River formation seems to have been so complete in this region that the freshwater forms were not able to survive. But in the Colorado group itself along the western margin of the sea, especially in Utah and western Wyoming, there are intercalations of coal-bearing beds which contain a few Unios and other freshwater shells and brackish-water types like Ostrea, Anomia, Corbula, and Modiola, some of which recur in identical or closely similar forms at several horizons to the top of the Cretaceous.

In the Montana group there are local more or less distinctive non-marine faunas in the Mesaverde, Eagle, Claggett, and Judith River formations. The last-named formation in its typical area has a considerable fauna with a number of species that are not known in other horizons, associated with others of wider range.

The Laramie fauna, which is the last of the conformable Upper Cretaceous series, does not differ materially from the non-marine faunas that preceded it except in specific details. The brackish-water and freshwater elements of its faunas are, of course, seldom mingled in the same stratum but alternate with each other. The brackish-water species have survived from earlier formations in the same region by living in the marine waters or advancing with the sea margin when the submergence came. The freshwater types must have been preserved in the streams of the adjacent lands when marine or even brackish waters covered the larger part of their habitat. A considerable number of freshwater types were thus enabled to survive into the Tertiary and there are some Laramie *species* that continue without perceptible change in the Fort Union or earliest Eocene. With the brackish-water forms of the Laramie the case is different. They could not exist for any appreciable period much above sea-level and when the final uplift came that drained the interior region and brought the Cretaceous to a close, the last oysters and other brackish-water mollusks of the interior region died. Hence in areas of non-marine deposition where the line between Cretaceous and Eocene has not been sharply drawn, because the erosion plane that is supposed to separate them has not yet been located, the occurrence of an oyster-bed, or a stratum full of Corbula, is sufficient evidence that the rocks are still Cretaceous and below the major unconformity that separates Cretaceous from Tertiary.

The very few freshwater shells that are known from the Denver and Livingston formations in their type areas are not distinctive, but the beds which bear the Triceratops vertebrate fauna in Converse County, Wyoming, and the strata with the same vertebrates in eastern Montana, locally known as the "Hell Creek Beds," have a highly differentiated molluscan fauna of Unios, and other freshwater shells which is much more closely related to the preceding Cretaceous faunas than to that of the typical Fort Union which follows. The evidence of the invertebrates as well as of the vertebrates is strongly in favor of assigning these so-called "post-Laramie beds" to the Cretaceous.

PALEOGEOGRAPHIC MAPS

LATE MESOZOIC

BAILEY WILLIS
U. S. Geological Survey

11 AND 12. LOWER CRETACEOUS[1] (COMANCHEAN) AND UPPER CRETACEOUS[2]

In passing from the Jurassic to the Lower Cretaceous North America underwent but little change along the Atlantic border and throughout the east. It remained a low land and the coastal plain was somewhat more deeply submerged. But on the Pacific coast, on the contrary, there was pronounced movement, particularly in the Coast Range of California. A bold peninsula developed from Oregon south to Santa Barbara and, being eroded, yielded the thick sediments of the Shasta group, which were deposited in marine water east of it, in part.

In Alaska the Shastan sea appears to have invaded the Jurassic land widely, but the details are not yet known.

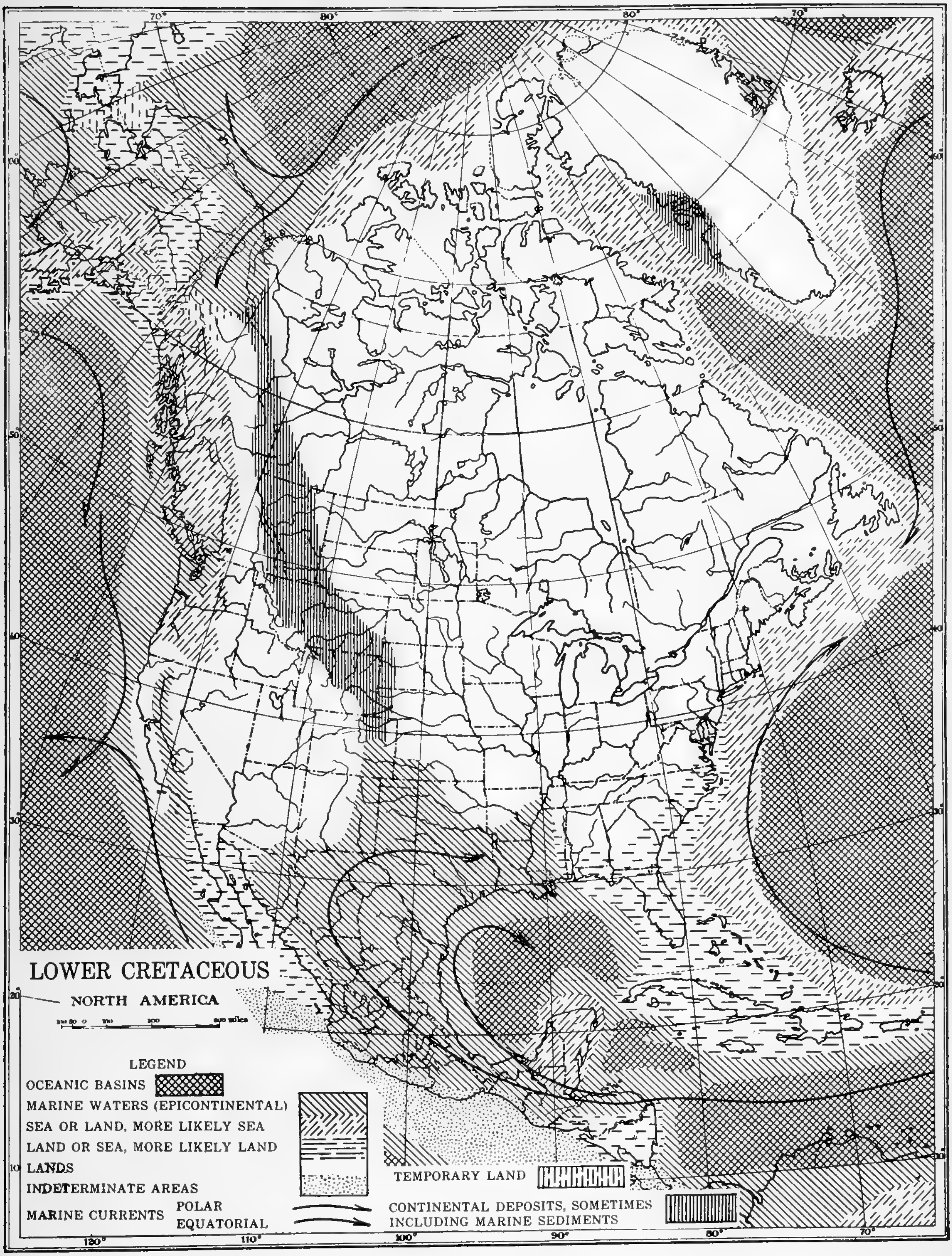
On the east of the Cordillera, from British Columbia to Wyoming, coal-bearing continental deposits (Kootenie) accumulated in a deepening trough. In Wyoming, Dakota, and Nebraska a deposit of sand (Lakota) was spread upon the plain. South of this occurs the much older Morrison formation, which is regarded as probably Jurassic by Stanton and which is overlapped by the marine Comanchean strata of the gulf. The Kootenie, Lakota, and Morrison are comprised in the area mapped as continental deposits.

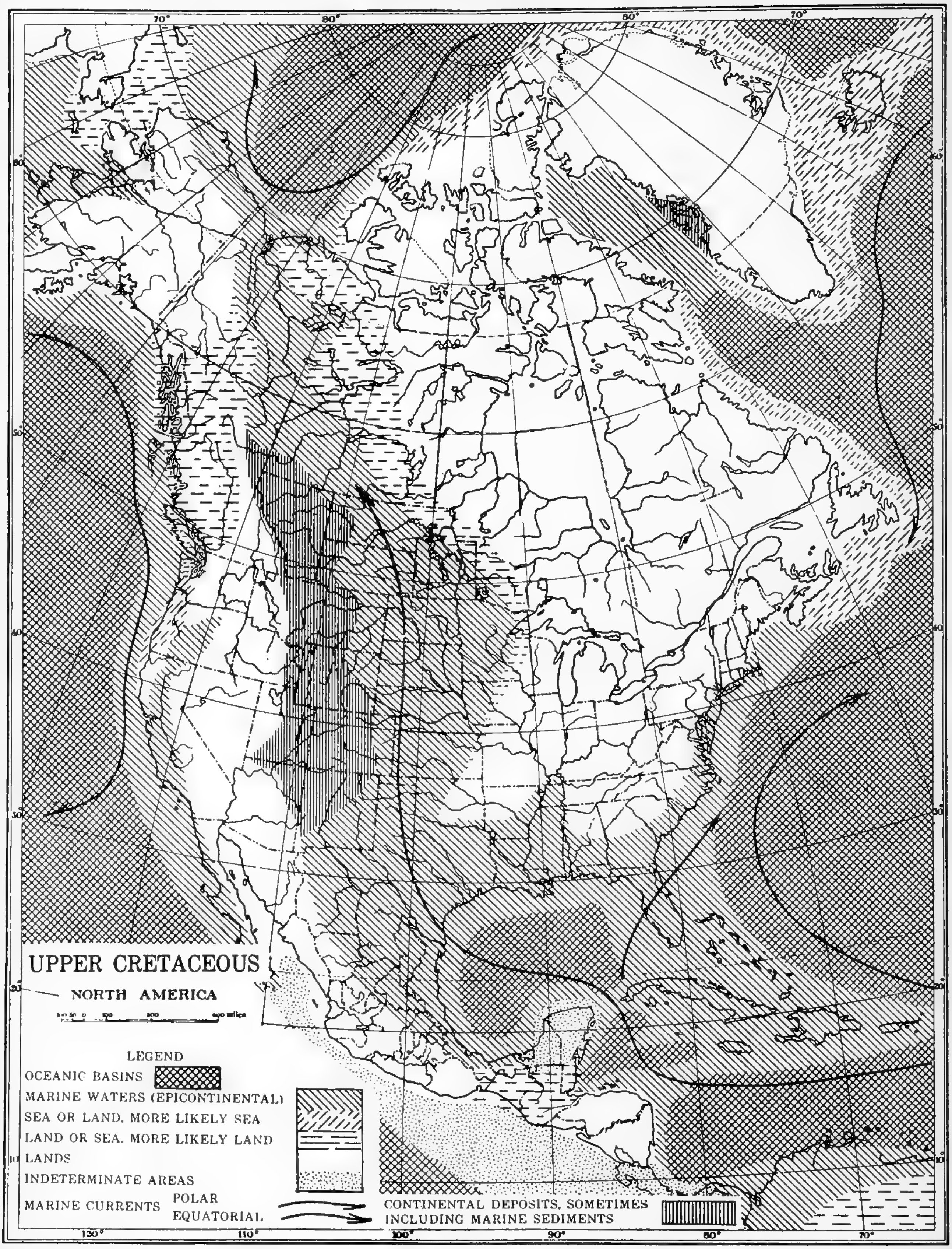
The striking feature of Comanchean geography is the expansion of the Gulf of Mexico toward the west and northwest and the deep subsidence of its floor, upon which accumulated a remarkable thickness of limestone. The unusual calcareous deposit of organic remains indicates the rich life of an equatorial ocean current.

The fauna of the Gulf of Mexico in Comanchean time is entirely unlike that of the Pacific coast. No adequate explanation of this fact

[1] Map prepared in collaboration with Dr. T. W. Stanton.

[2] Map prepared in collaboration with Dr. T. W. Stanton.


LOWER CRETACEOUS
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS


UPPER CRETACEOUS
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS
70°
80°
80°
70°
60°
50°
40°
30°
20°
10°
120°
110°
100°
90°
80°
70°

has been suggested except that a land mass diverted the ocean current. The position of the supposed land was southwest of Mexico and is indicated by the dotted area.

North America was submerged over extensive areas during the Upper Cretaceous. From Cape Cod to Texas the Atlantic and Gulf coasts of the preceding period were transgressed by the sea. From the Gulf to the Arctic marine waters spread over what is now the site of the Great Plains and in the United States that of the Rocky Mountains. The Pacific extended its limits in California and Oregon; farther north, however, from British Columbia to Alaska the land gained.

In the central West, from New Mexico to Alberta the invasion of the sea was followed by emergence of the area ruled on the map for continental deposits. The surface of the area was built up by sediments which were derived from uplands west of it, and which accumulated about as fast as the bottom sank. The area thus formed a coastal plain, extensive marshes prevailed, and the marsh deposits eventually became coal beds. Sea, marshes, and river plains alternated in sequence till near the close of the Cretaceous period, when in this Rocky Mountain area certain spots became mountains, the forerunners of the Colorado Front Range, the Black Hills, and Bighorn Mountains of today.

East of the Rocky Mountain coastal plain the marine strait prevailed to the end of the period. It divided the continent, reduced the northern land area, and admitted warm waters to the Arctic. These conditions favored the mild climate which the northern regions then enjoyed.

The eastern portion of the continent contrasted with the western. Whereas in the west rising lands were eroded, carved into hilly or mountainous landscapes, and yet became more elevated, in the east the surface was a vast plain and remained a lowland.

The close of the Cretaceous was marked by a general ebb of the seas that had prevailed over continents, possibly because the ocean basins deepened. In central western North America the land was rising also, and the combined effect was to withdraw the waters of the strait to the Gulf on the south and to the Arctic on the north.

CHAPTER X

SUCCESSION AND RANGE OF MESOZOIC AND TERTIARY FLORAS[1]

F. H. KNOWLTON

It is of course a truism to say that the transition from the Paleozoic to the Mesozoic is not, as was once supposed, an abrupt or catastrophic change, but was brought about so gradually that in many parts of the world it is often difficult, if not indeed impossible, to draw any sharp lines. Not only are the rocks lithologically similar, but a certain percentage of life-forms persisted from the one to the other, yet when each system is considered in its entirety there are apparent abundant lithologic and strongly marked biologic differences. It is my purpose to speak briefly of the floras, first of the Mesozoic and later of the Tertiary.

Triassic.—Rocks of Triassic age are known in many parts of the world and indicate two types of deposition, a fresh-water, marsh, or lagoon phase, and a marine phase. The former is only, or largely, that which has afforded a flora. The known plants of the Trias are relatively few in number. In North America we have less than 150 species, and the entire Triassic flora probably does not exceed 300 or 400 forms. Owing to considerations, physical and otherwise, concerning which there is not complete agreement, the lower portions of the Trias afford but scanty remains, and it is not until we come to the upper portion, or Rhaetic, that it can really be dignified as a flora. Our North American Triassic flora is believed to belong largely to this portion. Triassic plants have been doubtfully reported from Prince Edward Island, but they are so obviously of Permian types that they may be disregarded. The principal areas are in North Carolina, Virginia, and Pennsylvania, with relatively few in Maryland, New Jersey, Connecticut, and Massachusetts. In the west we have a doubtful plant or two from Wyoming, a considerable number from northern New Mexico, the extensive fossil forests of

[1] Published by permission of the Director of the U. S. Geological Survey.

Arizona, and a very few species from Plumas County, California. Going southward we have small collections from Sonora, from about the City of Mexico, in Honduras, Chile, and western Argentina. In other parts of the world Triassic floras have been found in England, east coast of Greenland, Spitzbergen, North Germany, southern Sweden, Italy, southwestern Spain, Persia, India, China, Tonkin, Japan, New South Wales, New Zealand, and South Africa.

What, now, are the characters of the Triassic flora? The dominant types of the Paleozoic have largely disappeared. The Lepidodendrae, Sigillariae, Calamites, Cordaites, Sphenophyllae, and Cycadofilices, so far as ascertained, have all gone, as well as a number of important genera of ferns—*Cheilanthites*, *Mariopteris*, *Megalopteris*, etc. The most notable survival from the Paleozoic is the so-called *Glossopteris* flora, which has been found with a few associated forms in Rhaetic rocks at Tonkin, the Stormberg series of South Africa, New South Wales, etc.

The Triassic flora consists essentially of equisetums, ferns, cycads, and conifers of many genera. A few forms such as *Ginkgo*, *Cladophlebis*, *Thinnfeldia*, etc., had a small beginning in the Paleozoic and expanded in the Mesozoic into large groups. But most of the flora is of distinctly Mesozoic and northern origin.

It has often been said that the plants of the Triassic are depauperate and pinched in aspect, indicating unfavorable climatic conditions. The paleobotanical facts do not altogether bear this out. In North Carolina, Virginia, and Arizona, there are trunks of trees preserved, some of which are 8 feet in diameter and at least 120 feet long, while hundreds are from 2 to 4 feet in diameter. Many of the ferns are of large size, indicating luxuriant growth, while Equisetum stems 4 to 5 inches in diameter are only approached by a single living South American species. The cycads are not more depauperate than those of subsequent horizons, nor do they compare unfavorably with the living representatives.

The complete, or nearly complete absence of rings in the tree trunks indicate that there were no, or but slight, seasonal changes due to alternations of hot and cold, or wet and dry periods. The accumulations of coal—in the Virginia area aggregating 30 to 40 feet in thickness—indicate long-continued swamp or marsh conditions, while the presence of ferns, some of them tree-ferns, indicate on the whole a moist, warm, probably at least sub-tropical climate.

Jurassic.—Coming, now, to the Jurassic, we find in the lower portion indications of a continuation of conditions which obtained in the upper portions of the Trias. The distinctive Paleozoic elements had finally disappeared, and the Mesozoic life-forms were in full swing, expanding in the middle and upper parts of the period into the abundant and widespread flora as we know it. In fact the relative uniformity and wide extension of the Middle and Upper Jurassic flora is one of the most interesting and impressive exhibits that we have. (See map showing approximate distribution of Triassic and Jurassic flora.)

There is no paleobotanical evidence indicating the presence of the Jurassic in Eastern North America. In the western interior Jurassic plant-bearing beds occur in the Black Hills, South Dakota, and the Freezeout Hills, Carbon County, Wyoming. We then pass to the Pacific coast, where we have a fine flora near Oroville, California; also northward in Trinity and Tehama counties, California, and Douglas and Curry counties, Oregon.

The following is an outline of the world distribution of the flora:

Alaska	Copper River District
	Cook Inlet
	Herendeen Bay
	Cape Lisburne
England	Yorkshire
France	Mamers—northwestern portion
Germany	Franco-Swabian area
	Northwestern area
Austria-Hungary	Steierdorf in Banat
	Crojie in Galicia
	Cracow
Italy	
Switzerland	
Portugal	
Sweden	Bornholm
	Bjuf
Spitzbergen	Cape Boheman, 78° —22′ N.
	Advent Bay, Cape Staratschin
	Green Harbor
King Karls Land	78–79° N.

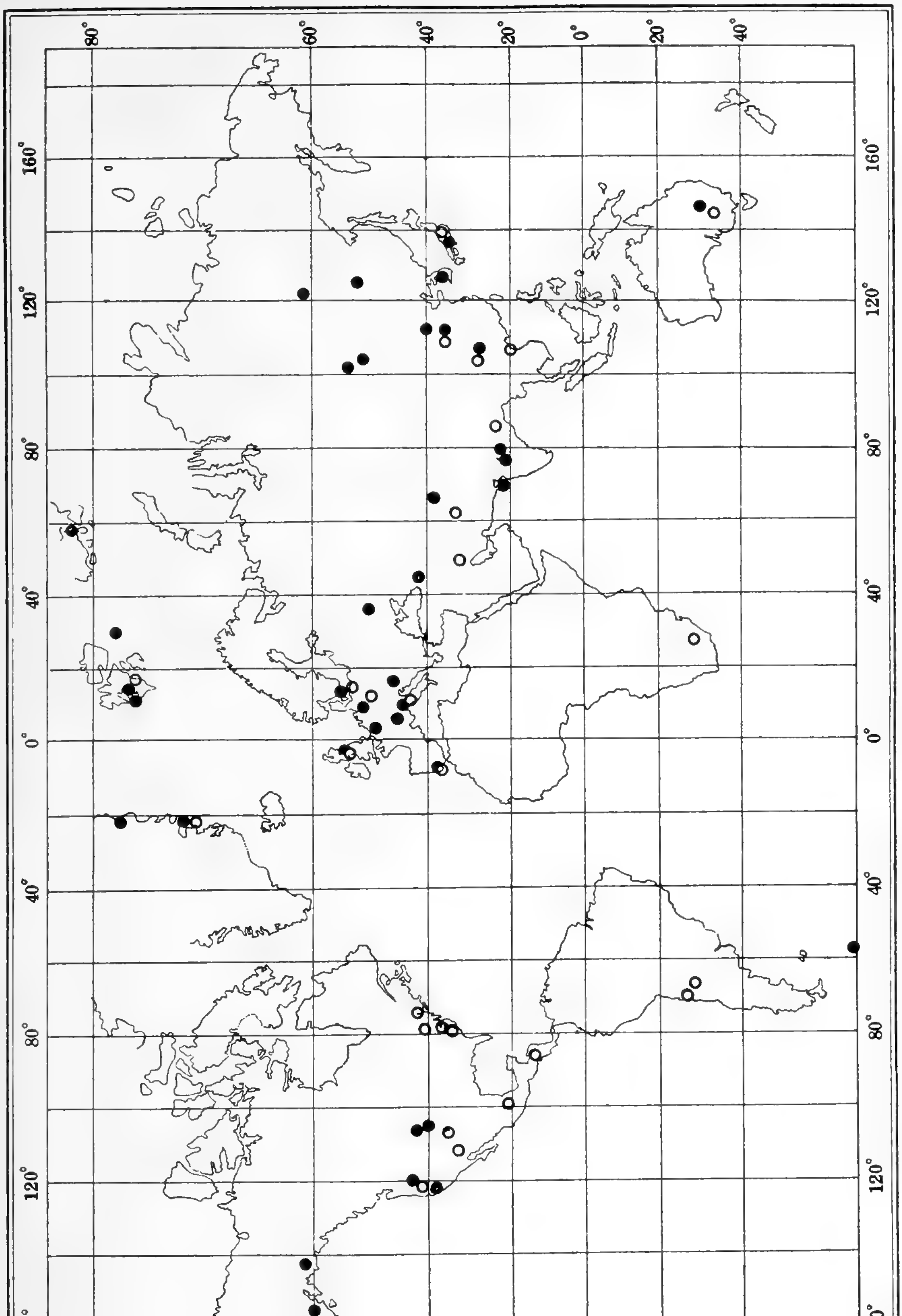


Fig. 1.—Map showing approximate distribution of Triassic and Jurassic floras.

Rings = Triassic
Dots = Jurassic

Franz Josef Land	82° N.
Greenland	Cape Stewart
	80° N.
Siberia	Ust-Balei 51° N.
	Irkutsk
	Upper Armour River
	Lena River District
Corea	
Japan	
Caucasia	
Turkestan	
India	Cutch
	Jabalpur
China	Tyrkyp-Tag
	Border Hami Desert
Australia	
New Zealand	
Louis Philippe Land	63° S.

The flora of the Jurassic, while in the main a continuation of that of the late Trias, and consisting of equisetums, ferns, cycads, ginkgos, and conifers, shows the incoming of a number of more modern types in these groups. The cycads were of course abundant and diversified, whence it has been called the age of cycads. The flora is remarkably uniform over wide portions of the world. Thus not far from 50 per cent. of the North American flora—exclusive of the cycad trunks—is the same as that found in Japan, Manchuria, Siberia, Spitzbergen, Scandinavia, or England, and what is even more remarkable, the plants found in Louis Philippe Land, 63° S., are practically the same as those from Yorkshire, England.

Some idea of the climatic conditions which prevailed at this time may be gained from the present distribution of certain obvious descendants of the Jurassic flora. Thus *Matonidium* and *Laccopteris* are represented by *Matonia* of which there are two species living in the Malay region and Borneo; *Dictyophyllum*, *Protorhipis*, *Hausmannia*, *Caulopteris*, etc., are closely allied to *Dipteris*, which has five species living in the eastern tropics; Ginkgo—so abundant in the Jurassic—has but a single living representative in China and Japan.

Climatic conditions in Jurassic.—The presence of luxuriant ferns, many of them tree-ferns, equisetums of large size, conifers, the descendants of which are now found in southern lands, all point to a moist, warm, probably subtropical climate, though in late Jurassic time the presence of well-defined rings in the tree trunks of species found in northern areas—King Karl's Land, Spitzbergen, etc.—show that there were beginning to be sharply marked seasons.

Wealden.—Immediately above what by common consent is regarded as the top of the Jurassic, is a series of fresh-water plant-bearing beds that are of quite wide extent in this country, though different names have been applied in the different areas. Thus the lower Potomac of the eastern United States (including the Patuxent and probably Arundel), the Glen Rose beds of the Trinity division of Texas, the Lakota and Cloverly of Dakota and Wyoming, the Kootenae of Alberta and adjacent Montana and extending into the Bighorn Basin of Wyoming, and the Shasta of California, and Kome of Greenland are practically equivalent in age, and correspond most closely in age with the Wealden of the Old World, which is considered to be a fluviatile or lacustrine condition of the lower Neocomian, the lowest member of the Cretaceous. The flora is a comparatively rich one, aggregating between two hundred to three hundred species, and is composed of ferns and conifers with a fair sprinkling of cycads Equisetaceae, ginkgos, etc. It shows a considerable agreement with the Jurassic, a number of species being common to the two, but on the whole its affinity is rather with the Cretaceous.

Cretaceous.—Up to the present point in the geological column the most characteristic and dominant feature of the modern flora—namely the angiosperms—has been absent. In many ways the introduction of this type of vegetation was one of the most important and far-reaching biologic events the world has known. For many years the flora of the Dakota Group and kindred floras was the oldest angiospermous flora known in this country, but as there are such a host of apparently modern types present, it was presumed that they must have had an ulterior period of development—and such proved to be the case. So far as we now know this flora appears to have had its origin in eastern or northeastern North America, in the Patapsco division of the Potomac series. Although the great majority of the plants found in association in these beds, both as regards species and individuals, still belonged to lower Mesozoic types, such as ferns, cycads, and conifers, we find ancient if not really ancestral angiosperms, and many of the same types are found in beds of approximately the same age (that is Albian) at Circal in Portugal. Although we are here much nearer the origin of the angiosperms than was before known, we are probably still some distance from their actual point of origin, but just where or when that was we do not, and may never know.

No sooner were they fairly introduced, however, than they multiplied with astonishing rapidity and in the upper members of the Potomac series—Raritan—they had become dominant, the ferns and cycads having mostly disappeared and the conifers having taken a subordinate position.

By the close of the Comanchan, or Lower Cretaceous, they had spread as far north as Alaska and Greenland, and a large number of modern genera were established.

Climatic conditions during Comanchan.—The climate over this vast area was certainly much milder than at the present time, for such well-known plants as elms, oaks, maples, magnolias, and many others were growing 72° N., in Greenland and nearly as far north in Alaska. It was at least what we would now call warm temperate.

Upper Cretaceous.—With the inauguration of the Upper Cretaceous the angiospermous flora was in full swing.

On the Atlantic border we have the Magothy, which extended from Maryland over New York, Long Island, and as far as Martha's Vineyard. The flora is a rich one, embracing about one hundred and fifty species.

In the interior, in approximately the same position, is the Dakota, which has afforded a splendid flora of over five hundred species, and occurs in Kansas, Nebraska, Wyoming, Minnesota, along the international boundary, and some of the same forms as far as central Alaska and south to Argentina.

Of the succeeding members of the Upper Cretaceous the Colorado being largely marine has but a small flora, although in southwestern Wyoming there is a small flora, made up mainly of modern types of ferns (*Gleichenia*), that finds its closest affinity in the Upper Cretaceous of Greenland.

Montana.—As this represents alternations of marine with brackish- and fresh-water conditions we have a larger flora, although the total number of known species probably does not exceed one hundred and fifty. Nothing particularly new was established at this time, the genera there being largely of older formations, though the species are mainly different.

Laramie.—As the uppermost member of the conformable Cretaceous series above the marine Fox Hills, the Laramie has had many vicissitudes of interpretation and was made to include beds now known to belong to the Montana, Arapahoe, Denver, Fort Union, etc. As logically restricted to the original definition of King, the plant-bearing Laramie is confined largely to the Denver Basin of Colorado and adjacent areas to the southward, with the probability of its being demonstrated to exist west of the mountains in Colorado, Wyoming, and New Mexico. As above restricted the Laramie flora comprises about one hundred and twenty-five species, and proves to be remarkably distinct from that of the Montana below as well as from the Arapahoe, Denver, and Fort Union above.

Tertiary.—The close of the Upper Cretaceous saw a considerable percentage of the modern angiospermous types of vegetation fully established, not only in North America but throughout the world, and the ferns, cycads, and conifers relegated permanently to a subordinate position. Certain types of dicotyledons, such, for instance, as magnolias, tulip-trees, sassafras trees, etc., had their maximum development in the Cretaceous, and in the Eocene and subsequent stages were greatly reduced until in the modern flora they are often represented by a few or even a single species of very restricted habitat. The most noticeable feature of the Eocene flora, broadly considered, is the increased number of forms that foreshadow the modern flora, a few, indeed, being still living. As examples of the latter mention may be made of the common sensitive fern (*Onoclea*) and two species of hazelnut (*Corylus*) all of which are now living in eastern North America. In late Cretaceous time the sedges (*Cyperus*, *Carex*, etc.) and grasses (*Arundo*, *Phragmites*) had but a poor representation, but in the late Eocene these groups clearly became more numerously developed both in types and species, and thus apparently made possible the rise and development of the mammalia.

Fort Union flora.—The largest and in many respects most important Eocene flora is that of the Fort Union, which is found over a vast area in the central Canadian provinces, north as far as the valley of the Mackenzie River, and south over central and eastern Montana, the western portions of both North and South Dakota, and at many points in eastern and central Wyoming and northwestern Colorado. It has recently been shown by the writer[1] that the Fort Union, extensive as it was known to be, really embraces more than has commonly been assigned to it. Conformably underlying the beds by some geologists considered as the true Fort Union, occur beds which have often been incorrectly referred to the Laramie, or its equivalents, but which are now regarded as constituting the lower member of the Fort Union formation. This lower member, which includes the so-called "Hell Creek beds" and "somber beds" of Montana, and the "Ceratops beds" of Wyoming, and their equivalents throughout much of the area above outlined, contains a rich flora which is inseparably bound to the flora of the upper member.

The flora of the Fort Union considered as a whole embraces more than five hundred species, and comprises ferns, sequoias, cedars, yews, grasses, sedges, oaks, willows, poplars in great abundance and variety, hazelnuts, walnuts, elms, sycamores, maples, a few figs, an occasional palm, and other more modern types. Whatever the conditions under which this flora grew and was entombed, it is beyond question that the climatic conditions were very different from those now prevailing in the region. But for the presence of palms and an occasional fig it might be presumed that the conditions were not greatly different from those now experienced in Atlantic North America, that is, cool temperate. This flora, which is closely similar to that in north Greenland and the valley of the Mackenzie River, undoubtedly approached from the north. The presence of palms, which are found in the lower parts of the formation, argues, on the basis of present distribution, a somewhat warmer climate, just as the numerous thick beds of lignite throughout the formation argue for extensive, long-continued, moister, marsh conditions.

The flora of the lower member of the Fort Union as at present elaborated embraces about eighty-five named species of which number about sixty-five are found in the upper member, while only sixteen of the eighty-five species are found in the Cretaceous below.

[1] *Proc. Wash. Acad. Sci.*, Vol. XI, 1909, pp. 179–238.

The unconformity of the base of these beds together with the differences in the flora, clearly and logically marks the point at which the line is to be drawn between Cretaceous and Tertiary.

In the Mississippian region in Louisiana and Mississippi we have a small Eocene flora (Eolignitic) comprising palms, evergreen oaks, magnolias, laurels, cinnamomums, etc., which appear to be most closely affiliated with small floras in northern New Mexico and adjacent Colorado, the latter in turn being most closely related to much larger post-Laramie floras in the Denver Basin of Colorado. These embrace the Arapahoe with about thirty species, and the Denver with nearly two hundred species, and are believed to be slightly older than the Fort Union—in any event, there are only about thirty species in common.

The Green River formation of upper Eocene age occupies a quite extensive area in central and western Wyoming, and has afforded a flora of some eighty species. It is very distinct from the Fort Union and other Lower Eocene floras, and shows a distinct increase of modern forms.

In the northern Pacific coast region there are a number of Eocene floras, among them that of the Swauk which occurs just east of the Cascade Mountains in Washington. This large flora is entirely different from any other in this country, and consists of types that are for the most part found in Central and northern South America, among them being palms 6 feet in diameter and in layers sometimes a foot in thickness. This shows that the palms were not sporadic or occasional, and indicates, as do many of the other things, that the climate was mild, probably subtropical. The overlying Roslin formation contains a flora that is almost entirely different from that of the Swauk, and lacking the presence of palms was probably slightly cooler than the underlying formation.

To the northward and covering a vast area in Alaska and well out on the Alaskan peninsula is the Upper Eocene Kenai formation which has afforded a rich flora of oaks, poplars, willows, hazels, walnuts, magnolias, horse-chestnuts, and maples, together with pines, spruces, cedars, and sequoias. This flora is found in British Columbia, and abundantly in Greenland, Iceland, and Spitzbergen, showing that it was of wide extent in similar northern latitudes. It is distinctly a warm-temperate flora. Another Upper Eocene flora is found in the Clarno formation of the John Day Basin, Oregon, and in the Payette formation of western Idaho. It embraces walnuts, hazels, birches, alders, oaks, elms, sycamores, maples, ashes, etc., and is temperate or warm temperate, in character.

Eocene floras in the Atlantic area are of very little importance as thus far developed.

Miocene.—The Miocene flora of North America is relatively not a large one although it comprises probably five hundred species as now known. The deposits occur often in isolated basins, widely separated, and there is usually comparatively little in common between them. A number of the more important areas may be briefly mentioned.

At Brandon, Vermont, in the midst of ancient crystalline rocks, occur small pocket-like deposits of lignite which have yielded large numbers of fossil fruits and a very few poorly preserved leaves. The fruits have been studied by Lesquereux, Perkins, and others, and about one hundred and fifty nominal species described belonging to the genera *Nyssa*, *Hicoria*, *Juglans*, *Bicarpellites*, *Cucumites*, *Tricarpellites*, etc.

At Florissant, Colorado, also in the midst of older rocks, there are small lake-bed deposits which have afforded vast quantities of plant and insect material in an admirable state of preservation. The plants number upward of two hundred species, among them being a great number of very modern types and even including not a few herbaceous forms. This flora as a whole is very unlike anything found in the region at the present day and apparently finds its closest affinity with the West Indies, though doubtless it also approached originally from the north.

Small deposits containing a Miocene flora have been found in Esmeralda County, Nevada, the Similkameen Valley, and other points in British Columbia, and in the Yellowstone National Park. The so-called Muscall beds of the John Day Basin, Oregon, and extending into central Washington, have yielded a rich flora of about eighty species, among them oaks, maples, poplars, barberry, bread-fruit trees, etc., indicating a warm, moist climate. Associated with the auriferous gravels of California is a flora of about one hundred and twenty-five species, some of which are of very modern appearance, such as *Zizyphus*, *Magnolia*, *Persea*, *Acer*, *Artocarpus*, etc.

Pliocene.—The Pliocene flora of North America is almost a negligible quantity, about the only known locality being the Falls of the Columbia River. It includes species in the genera *Woodwardia*, *Sassafras*, *Sterculia*, etc., and is very closely related to living American species.

Pleistocene.—The Pleistocene flora is better known than the last, yet we are undoubtedly only on the borderland of a knowledge of the plants of this period and their distribution. Small Pleistocene floras are known from New Jersey, Maryland, Virginia, West Virginia, North Carolina, Alabama, New York, Iowa, and Canada. The most extensive exploitation of this flora is that made in Canada in the vicinity of Montreal and Toronto, where Penhallow has been able to make out at least three stages. The species are nearly all living.

CHAPTER XI

CONDITIONS GOVERNING THE EVOLUTION AND DISTRIBUTION OF TERTIARY FAUNAS[1]

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The subject allotted me being "The Conditions Governing the Evolution and Distribution of Tertiary Faunas," I may begin by stating certain propositions which, for the purposes of this discourse, may be assumed as axiomatic.

1. A fauna is an assemblage of organic species populating a given area at one and the same epoch, and—allowances being made for the preferences of such minor groups as carnivorous, phytophagous, littoral, benthal, petricoline, and limicoline animals—having for the most part identical geographical distribution.

2. We may regard it as indisputable that the properties of the environment shown to influence a living fauna, or to control its distribution, were capable in Tertiary[2] times of exerting an analogous influence on faunas now known chiefly by their fossil remains; and, conversely, if in a fossil fauna we are able to trace certain definite features, which in a living assembly would result from a particular environment, we are justified in concluding that the fossil fauna in question was, when living, subject to the action of an analogous environment.

To illustrate this second proposition it may be said that if fig trees can now flourish and reproduce their species only in regions having a mean minimum temperature of thirty degrees Fahrenheit, and a summer mean temperature of not less than sixty degrees; and, secondly, if we find in the Tertiary leaf-beds of Greenland and Spitsbergen indications of groves of fig trees having flourished there in the Oligocene epoch; then we are likewise justified in assuming

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] The author realizes that these factors may not be entirely applicable to the faunas of pre-Tertiary epochs.

that in Greenland at that epoch the summer mean temperature did not fall far below sixty degrees, nor the winter cold maintain itself greatly below the minimum above mentioned.

Among marine animals a consensus of the evidence on record points insistently to temperature as the most important factor in determining the existence and persistence of species in a given area; and the toleration oi an organism and its progeny for fluctuations of temperature limits its geographical distribution as positively as would a material barrier. In the absence of such mortal extremes of temperature, material barriers, unless hermetically complete, really count for very little in determining distribution.

In utilizing fossil faunas as chronologic indicators of geologic time, the marine faunas are more readily utilized for the grand divisions of the scale than the land faunas, especially when the latter are characterized chiefly by fossil vertebrates. This is because the marine conditions are more uniform, less affected by meteorologic factors, and more dependent upon conditions which affect the whole hydrosphere rather than small areas of it. The struggle for life is less intense, the food supply generally more adequate, enemies less vigorous, and dangerous fluctuations of temperature far less frequent, in the sea than on land.

The same features make the land faunas more clearly indicative of minor divisions of the scale, and of the progress of organic evolution in the general region concerned; while less conclusive as to the contemporaneity of widely separated though analogous faunas.

The liability to sudden extermination by epidemic diseases, or by sharp meteorologic changes of very short duration, or even by the incursion of multitudes of small enemies, insects, or carnivora injurious to the young, is vastly greater among the land vertebrates than among marine animals. Marine vertebrates are more subject to injury from temporary causes than are the invertebrates associated with them. A marked instance of this was the destruction of the "tilefish" of the middle Atlantic coast a quarter of a century ago, if the explanation finally accepted as most probable by Professor Baird and other experts be the true one. The "tilefish" inhabited a region where the water, warmed by the proximity of the Gulf Stream, was of a moderate temperature. The combination of violent winds from a quarter which led to the forcing to the eastward of the Gulf Stream water, and to the influx of much colder water from the Polar current into the area thus vacated, was believed to be responsible for the almost total extermination of these fishes, which were found floating dead and apparently uninjured in millions on the surface of the sea, by navigators bound into New York and adjacent ports.

This temperature change which lasted at most for a few weeks would probably have had no effect whatever on the adult larger invertebrates of the same area, though to any of their larval young it might well have proved fatal. Another season would replace these, but the restocking of the fauna with "tilefish," which finally took place, required many years.

A statement of the factors which are regarded as modifying existing marine invertebrate faunas will put the student in possession of the chief factors which may have affected analogous faunas during past geologic time. My point of view is that afforded by a knowledge of conditions affecting molluscan life.

Census of species.—From a discussion too long to quote here in full,[1] I have drawn the following conclusions: That the part of the average mollusk-fauna which is capable of leaving traces in the shape of fossils, under conditions not greatly differing from those of the present day, in a region where the temperature of the sea ranges during the coldest winter month between 32° and 40° F. (which might be called *boreal*), would comprise about 250 species. In case the temperature ranged between 40° and 60° (*cool temperate*) about 400 species might be expected. With a range between 60° and 70° (*warm temperate*) we should find about 500 species, and in the *tropical* zone (70° to 80° F.) not less than 600 species; and in specially favorable localities of the tropics nearly twice as many.

Learning from the characteristic genera what zone of temperature a given fauna may have belonged to, we can with confidence predict approximately the number of species which it will prove to contain when fully explored. Of course in a single locality where the characteristic situs is exclusively mud, or rock, or fine sand, only a certain

[1] *Bull. U. S. Geological Survey, No. 84,* Correlation Papers, Neocene, 1892, pp. 25–28.

proportion of the total fauna will be represented, but these minor groups are not entitled to the designation of a fauna as used in this paper.

Relations of temperature to the fauna.—In considering the relations of temperature of the water to the fauna, account must be taken of the vertical differences. The temperature of the water at the surface differs materially from that at the bottom in most regions, where the depth is over a few fathoms. Arctic or Antarctic species may extend in cold depths of ocean for thousands of miles; while, in the warm superficial strata above them and inshore from them, a totally different assembly lives and thrives. It is easy, in the case of widely diffused northern species, when deep water dredgings have revealed the distribution, to observe in the tables the boreal forms descending with the temperatures to deeper and deeper water as they approach the tropics. That this is so generally true is satisfactory evidence that the factor of pressure, being equalized by thorough permeation of the organism, is less effective in limiting distribution than most other factors. It seems incredible that the large eggs of abyssal mollusks can go through the processes of development under a pressure of tons to the square inch; since there must be a limit somewhere to the permeability of tissues. Still it is evident that they do.

Why temperature should be so important in limiting distribution is a question which may be answered in several ways. Brooks has shown that, while the embryonic oysters (*Ostrea virginica*) are swimming at the surface of the sea, an entire brood may be destroyed to the last individual, by a fall in temperature of a few degrees, due to a cold rain. While it is not improbable that oysters from the northern part of the range of the species, say Nova Scotia, may have in the embryonic state a greater tolerance for a fall in temperature than those of a relatively warmer region like Chesapeake Bay or the coast of Florida, yet it seems likely that a certain narrow range of temperature is required for the developmental stages, and that the distribution of the species is limited to the area where such temperatures may be had during the spawning season.

Thus, for example, young Chesapeake oysters of an inch and a half in breadth may be transported to the Pacific coast, planted in suitable locations, and will flourish well, growing even faster than in their native waters. Yet of the billions of spat which these oysters have discharged into the waters of the Pacific (fifteen or twenty degrees colder than the Chesapeake at spawning time) there is not a trace left in the shape of young oysters. In spite of the best efforts of the local oystermen the Chesapeake oyster has not become acclimated.

Another way in which temperature may affect a fauna is in promoting or inhibiting the minute plant-life which forms the food of many bivalves. In all cases it is certain that a fall below a certain level of temperature is more effective upon the animals subjected to it than a corresponding rise in temperature. The first, as I have indicated, may kill; the second, merely accelerate development.

The very low temperatures nearly universal on the floor of the open ocean, and the otherwise uniform conditions that prevail there, offer favorable opportunities for wide distribution of boreal organisms. I am informed by Mr. A. H. Clark that the Antarctic Crinoidea, characterized by scaly segments, have penetrated by this road in the Eastern Pacific even to the Oregonian region; while on the opposite coast the smooth-segmented Arctic forms have been traced far to the southward.

As indicators of subaerial conditions it is obvious that littoral invertebrates are more useful than those of deeper waters, since they are more exposed to climatic changes. It may happen that a vertical section of the submarine continental slope drawn at right angles to the coast from the shore to the oceanic floor may, and in most cases will, cut through a series of different faunas corresponding to the temperatures encountered. Off Cape Hatteras the cold inshore current from the north is the haunt of a cool-temperate fauna with some boreal elements. Thirty miles off shore, in less than fifty fathoms, the fringe of the Gulf Stream protects a fauna in large part identical with that which characterizes the Bahama Banks and Bermuda. The large species of Venus, which penetrated to the north shore of the Gulf of Mexico with the cool Miocene water, have maintained themselves notwithstanding the subsequent rise of temperature and persist in these new conditions to the present day, a notable example of adaptation. On the other hand the subtropical Rangia and Corbicula, which advanced with the warm Pliocene waters far to the north of their original station, have left only sparsely scattered fossils as an indication of their invasion.

In the later Tertiaries the proportion of recent species is sufficient, taking into account the present distribution of these species, to afford the means for a very probable estimate of the temperature which prevailed during the particular portion of Tertiary time when they formed part of the fauna. An interesting example of this is afforded by a small collection of fossils obtained by Stimpson in 1865, from above the lignitic coal measures in the northeast angle of the Okhotsk Sea, in Penjinsk Gulf.[1] I have reported in full upon these fossils, and it is sufficient to say on this occasion that the climate and recent fauna of the locality are Arctic and the open water of the sea persists only for some three months of the year, while the species of fossils indicate that during their existence in the living state the annual mean air temperature, at the most moderate estimate, must have been 30° to 40° F. warmer than at present. Another instance has recently been brought to my attention. During the two seasons just past, collections have been made from the Pliocene auriferous gravels of the coast of Alaska near the town of Nome.[2] Thirty-three species have been identified of which seven appear to be new, eleven are now known living only south of the line of floating ice in winter, one is a Miocene species, and the remaining fourteen are common to the Alaskan fauna in general from the Arctic to British Columbia. This indicates clearly that during the Pliocene, when these gravels were being laid down, the climate of Norton Sound, now subarctic, was not colder than that of North Japan or the Aleutian Islands where the sea remains unfrozen throughout the entire year. This agrees well with the evidence from the marine Pliocene of the northeastern corner of Iceland, which has afforded over one hundred species, of which seventy-four are said to be common to the Crag fauna of the British Islands, corresponding to an annual mean air temperature not lower than 42° F., while it is hardly necessary to say that the present

[1] *Proc. U. S. Nat. Mus.*, Vol. XVI, No. 946, 1893, pp. 471–78, pl. LVI. The age of the fossil shells in the report upon these fossils was given as Miocene, but it is probable that like the analogous lignite deposits of the adjacent shores of America, the underlying coal measures may be referable to the Upper Eocene or Oligocene and may have been laid down contemporaneously with the American Kenai formation.

[2] Cf. *Am. Jour. Science*, Vol. XXIII, June, 1907, pp. 457, 458.

conditions in north Iceland are purely Arctic. A little patch of Pliocene at Gay Head, Mass., afforded a fragment of the genus Corbicula, now warm temperate in its distribution; while the older of the deposits at Sankoty Head, Nantucket, as well as those at Nome, show that some of the species which ranged at that period from Bering Sea to the North Atlantic are now strictly confined to temperate waters in their respective hemispheres.

I have given most of my time to the relations of temperature to faunas, as this is the most important, pervasive, and obvious factor of the modifying environment, but there are a few others which may be briefly alluded to.

The question of food is next in importance to temperature. It is true that the ocean almost everywhere is a generous provider for its inhabitants, so that only special scrutiny reveals important differences in the food supply, a large part of which is furnished by almost microscopic animals. Yet it has been conclusively shown that in places where a persistent movement brings constantly fresh supplies of food and well-aerated water, as on the continental slope washed by the Gulf Stream, or where the periodical ebb and flow of the tides do the same thing on a smaller scale—there the oceanic population flourishes with especial vigor and abundance. Near the shores a special quota of plant-feeders live, in their turn furnishing provender for carnivorous species. The distribution of plant food in the shape of algae thus governs the distribution of the phytophagous species. We find on the basalts, andesites, and recent lavas of the Aleutian chain of islands, enormous groves of kelp and meadows of olivaceous rock-weed. Whether because of something in the chemical composition of these rocks, or otherwise, the red and green seaweeds are almost wholly absent from them. However, where the granitic masses which form the core of some of the islands (and in other places stand alone, domelike in the sea) are within reach of the waves, we find a special flora of the more bright-colored algae and a special fauna dependent upon them. No matter how isolated the patch of granite, the characteristic animals recur, and in many cases reproduce in their own tints the rosy hue of the plants upon which they depend for food.

In the abysses where the absence of sunlight excludes plant life the animals are almost exclusively carnivorous and largely subsist on the abundant rain of dead organisms which slowly descends from the surface layers of the sea.

It has been customary to regard the 100-fathom line as constituting a sort of boundary between the fauna of the shores and of the deeps. This has a certain foundation in the fact that at greater depths no living algae can exist for want of sunlight. A more or less constant migration, casual or accidental, is constantly taking place between the littoral region and the deeps, but it is so slow, and the process of adaptation to the new conditions so gradual, that we may safely regard the abyssal fauna as even geologically old. I have called attention to certain features of the eastern Pacific and Antillean abyssal faunas which illustrate these remarks in the introduction to a recent monograph.[1]

Freshwater and terrestrial invertebrates are subject not infrequently to one set of influences which is rarely noticed in the open sea. This is, in the case of the limnophilous species, a change in the mineral content of the water in which they live. This is usually gradual and when injurious chiefly due to the concentration of salts (which exist in all freshwaters arising from drainage) by evaporation. In the case of many large Pleistocene lakes, of which the prehistoric Lake Bonneville may be taken as an example, this process has been carried on until the saline content of the water became so excessive that all molluscan life became extinct, as in the Great Salt Lake of Utah. A careful study of the beds of shell-marl deposited by the shrinking lake shows that the effect of the gradually increasing salinity of the water on the freshwater mollusks contained in it was to lead to a thickening and corrugation of the shell, a tendency to longitudinal ribbing, and a diminution in average size, all of which changes may perhaps be due directly to the astringent action of the salts of sodium and magnesium upon the thin and delicate margin of the mantle which secretes the additions to the shell. These characteristics become more and more pronounced as the waters become more saline, until finally the conditions become too rigorous for survival. The gradually intensified effect of the increase of salinity may be beautifully illustrated by a collection of the fossil shells from

[1] *Bull. Mus. Comp. Zoölogy*, Vol. XLIII, No. 6, October, 1908, pp. 205–12.

the successive marl beds around Great Salt Lake. Another instance, probably of the same nature, is afforded by the marls of Steinheim, in Wurtemburg, of which the mutations shown by the species of Planorbis, in particular, are described in the well-known monograph by Hyatt.[1]

A somewhat similar effect seems to be produced in the case of landshells inhabiting arid volcanic islands in windy regions. Here the astringent effect appears to be produced by the alkaline volcanic dust to which these animals living on almost bare shrubs or among sparse herbage are more or less constantly exposed. I have called attention to the conditions under which this effect seems to be produced in a paper on the landshell fauna of the Galapagos Islands.[2] This illustrates how upon animals of quite different systematic relations, similar effects, simulating an apparent convergence, may be caused by the direct action of the environment upon individuals. Paleontologically these instances are worth noting, as otherwise the forms concerned might well be regarded as belonging to totally different groups from the individuals which developed normally in an ordinary habitat.

In conclusion I may call attention to certain factors which have serious importance in modifying the fauna of a large extent of coast catastrophically, and which inferentially are to some extent responsible for the marked changes we observe in different stratigraphic horizons where we do not find indications of coincident orogenic changes.

In some regions, as the west coast of the Floridian peninsula, the strata may be slightly inclined so that the beds between which subterranean waters move have their edges beneath the sea. Torrential rains in the interior of the peninsula carry vegetable matter into the interstices of the soft limestone rocks, where it decays with the accompanying production of carbon dioxide and sulphuretted hydrogen gas. This accumulates and under the hydrostatic pressure of an exceptionally heavy rainfall is sometimes forced out beneath the sea from the edges of the submerged strata in sufficient volume to kill by suffo-

[1] "Genesis of the Tertiary Species of Planorbis at Steinheim," *Anniv. Mem. Boston Soc. Nat. History*, 1880, pp. 114, pls. I–IX, 4to.

[2] "Insular Landshell Faunas, Especially as Illustrated by the collection of Dr. G. Baur on the Galapagos Islands," *Proc. Acad. Nat. Sciences, Philadelphia*, August, 1896, pp. 395–459.

cation every living thing along many miles of coast. This has happened on the coast of Florida several times within my recollection. The repopulation of the devastated area is slow and can rarely reproduce exactly the same assemblage of animals which previously occupied that area.

Another mode in which widespread extermination of a sedentary population of invertebrates may be brought about is by the sudden appearance of vast multitudes of minute organisms like *Peredinia*. Within the last few years, both on the coasts of Japan and of California, the sea at times has been covered for miles with reddish clouds of these submicroscopic creatures. On their advent near the shore, driven by wind or currents, the shellfish, corals, and fishes are rapidly suffocated, and, if the pest continues, everything within the area it occupies will succumb. I have heard that, within two years, the Japanese pearlshell preserves on the seashore of that country have been almost wholly ruined by the organisms referred to, with the loss of hundreds of thousands of dollars, to say nothing of years of labor rendered fruitless.

PALEOGEOGRAPHIC MAPS

TERTIARY

BAILEY WILLIS
U. S. Geological Survey

13 AND 14. EOCENE-OLIGOCENE AND MIOCENE

The Eocene-Oligocene aspect of North America differed from the Cretaceous and resembled the present. The east and west were united. The Cordillera had begun its development as a system of many mountain chains, most, if not all, of which are represented in existing ranges; yet few, if any, of which have had an uninterrupted growth. They became high in the Eocene, but were greatly eroded in the Oligocene and Miocene. The volcanic activity which marks the Cordillera was very notable during the Eocene. The eastern part of the continent remained low.

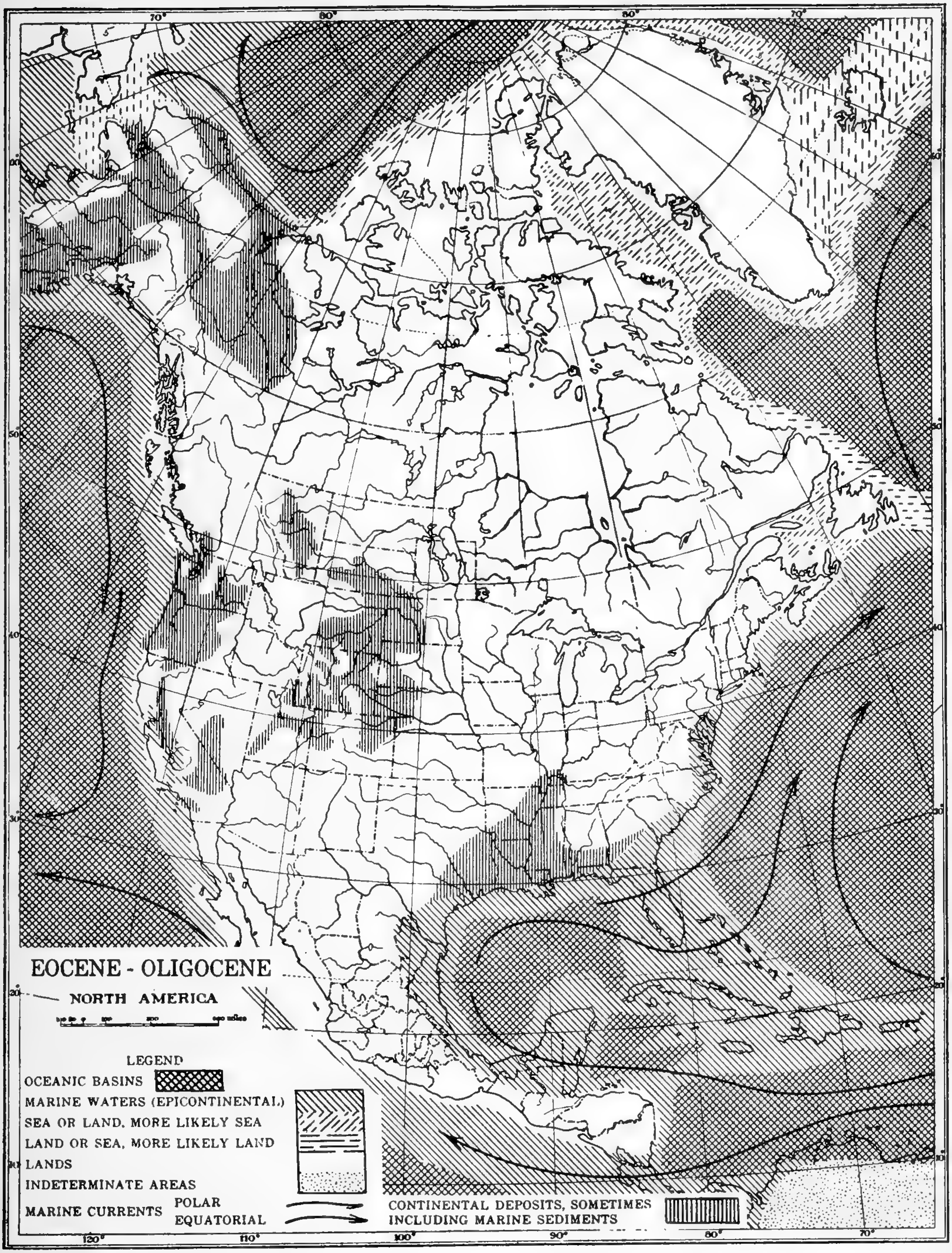
By erosion of the mountains and by contributions from the volcanoes great thicknesses of sediment accumulated in interior basins of the Cordillera. The deposits were in part fluviatile, in part eolian, in minor part lacustrine. On the map their distribution is shown by the ruling for continental deposits in the central west.

In the Gulf region and also in Alaska extensive low lands and favorable climate produced extensive marshes which are now represented by coal beds and are also indicated by the vertical ruling.

The continental connections of North America during the Eocene and Oligocene appear to have been established and interrupted, as is shown by the relations of land animals. Osborn infers that there was intermigration with Europe during the Wasatch epoch,[1] and thenceforward separation from Europe until the Oligocene, when faunistic reunion took place. These inferences are suggested on the map by the temporary lands linking Alaska with Siberia and Greenland with England.

The region of the West Indies was the seat of an embayment of

[1] Osborn, H. F., "Cenozoic Mammal Horizons of Western North America," *U. S. Geological Survey Bull. 361*, 1909.


EOCENE - OLIGOCENE
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
70°
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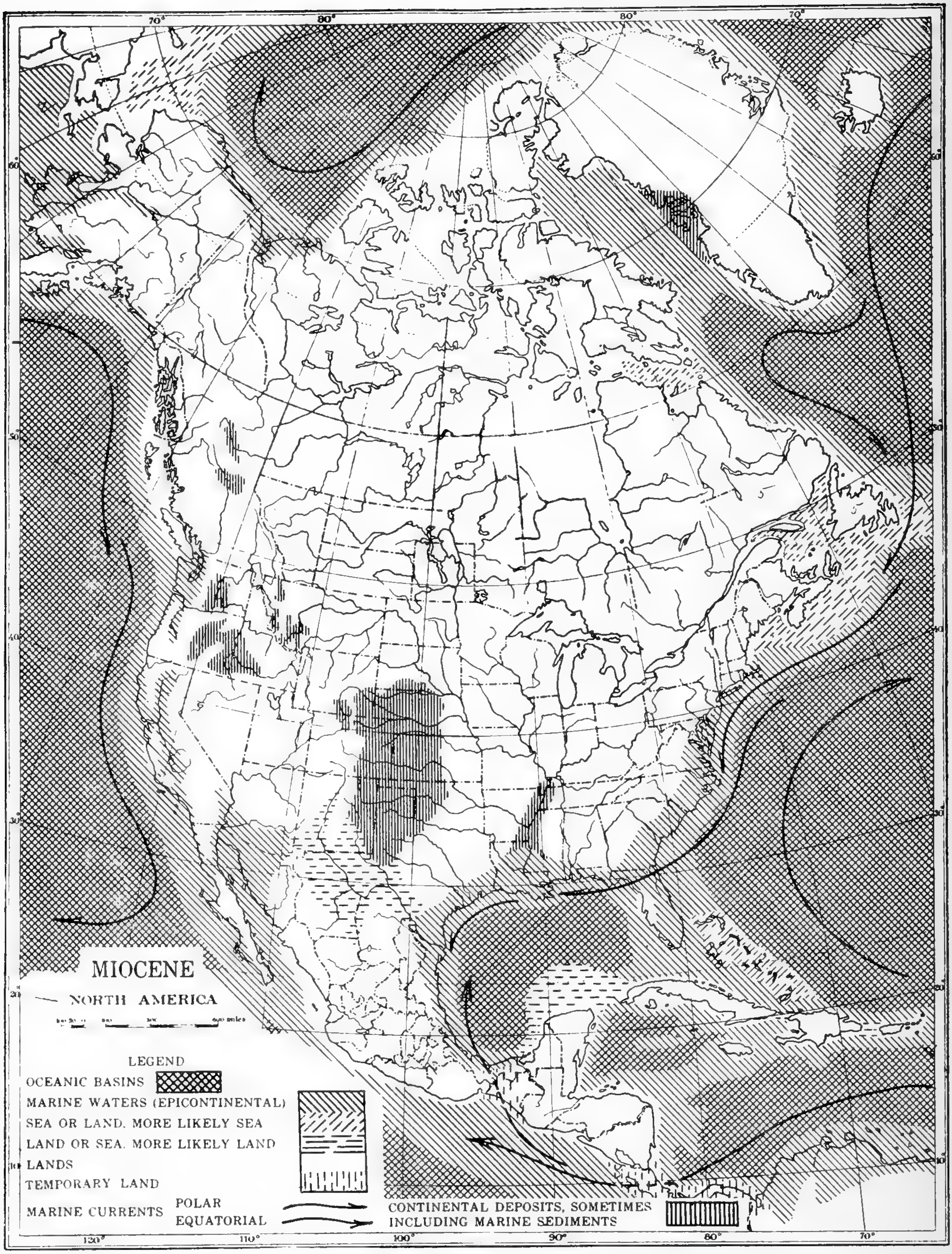
MIOCENE
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LEGEND
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MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
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LANDS
TEMPORARY LAND
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CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
120°
110°
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80°
70°

the Atlantic, beneath which was deposited the widespread Oligocene limestone, characterized by the faunas of a warm oceanic current. This fauna spread north along the southeastern coast of the United States.

I am indebted to Dr. Wm. H. Dall and Dr. Ralph Arnold for discussion of the distribution ot marine faunas and their relation to inferred currents.

In outline, North America during the Miocene resembled the continent during the Eocene. The surface was, however, less mountainous. The sites of the Sierra Nevada and of the Coast Range of British Columbia were plains or low hilly lands. The Rocky Mountains of the United States were comparatively low. In British Columbia, and thence southward through Washington, Oregon, and Nevada occurred outflows of lava, which covered many thousand square miles, but which in general were not from volcanoes. Though probably subordinate in volume of lava erupted, volcanoes were numerous and they gave off quantities of volcanic ash, which formed deposits in lakes, particularly in western Montana and British Columbia.

The elevation of the Rocky Mountains of western Montana and British Columbia by overthrust, and subsequently the development of longitudinal valleys and separate ranges by vertical displacements, probably began in the Miocene period and may have culminated during Pliocene or early Quaternary time.

In the West Indian region the close of the Oligocene period was marked by a notable disturbance, which raised a folded mountain chain from Puerto Rico to Cuba and probably continuously to Yucatan. It may also have closed the Isthmus of Tehuantepec and possibly have temporarily connected Honduras with South America. Another possible line of connection is around the eastern end of the Caribbean through the Windward Islands. If, however, such a land link united North and South America it was but temporary.

The effect of the Cuban elevation, or of some other geographic change not yet suggested, was to shut off from the northern Gulf and southern Atlantic coasts the warm currents which had sustained a rich southern fauna and to admit the cool northern waters with their appropriate life. A very pronounced faunal change, without any marked stratigraphic break in the sediments, was the result.

CHAPTER XII

ENVIRONMENT OF THE TERTIARY FAUNAS OF THE PACIFIC COAST OF THE UNITED STATES[1]

RALPH ARNOLD

CONTENTS

[1] Published by permission of the Director of the U. S. Geological Survey.

INTRODUCTION

This paper was presented as part of the symposium on "Correlation" arranged by Mr. Bailey Willis as the principal subject for discussion in Section E of the American Association for the Advancement of Science, and later continued as the main feature of a special section of the Geological Society of America, at Baltimore during Convocation Week, 1908. The paper treats in a general way of the character and distribution of the sediments laid down, and the faunas and the conditions prevailing during the Tertiary period on the Pacific Coast of North America, more especially that portion lying between Puget Sound on the north and the Gulf of California on the south. The discussion is also restricted almost exclusively to the territory directly affected by the sea, as a detailed consideration of the conditions and faunas prevailing inland belongs more properly within the province of the paleobotanist and vertebrate paleontologist. Special attention is called at several places throughout the discussion to the extraordinary localization of many of the earth-movements affecting the region under discussion and the writer wishes to advance this localization of phenomena as an argument against the too free use of diastrophism, unsupported by paleontologic evidence, as a basis of correlation.

The preparation of the paper has necessitated the correlation of the various Tertiary formations of the Pacific Coast—in fact the paper is obviously based on these correlations—and for that reason a general table of correlation is here included for reference. Lack of space prevents a discussion of the reasons for many of these correlations. Some of them differ from those previously published by the writer,[1] but for the most part they are those usually accepted by West American geologists and paleontologists.

[1] *Jour. Geol.*, Vol. X, 1902, p. 137; *Mem. Cal. Acad. Sci.*, Vol. III, 1903, p. 13; *U. S. Geological Survey Prof. Paper 47*, 1906, p. 10; *U. S. Geol. Survey Bull. 309*, 1907, p. 143; *ibid., 321*, 1907, p. 21; *ibid., 322*, 1908, p. 27.

The fourfold subdivision of the Tertiary is the one which seems best to fit the phenomena of the Pacific Coast, although for convenience of discussion in the present paper the writer has separated the upper from the lower Miocene on account of the diverse geologic histories of the two. It is obviously impossible to make exact correlations between the European and East American subdivisions on the one hand and the faunal and stratigraphic subdivisions of the Pacific Coast on the other, but by means of various direct and indirect methods it is possible, however, to make approximate correlations, and as the work progresses these approximations will be made to approach nearer and nearer to the exact. Paleontology forms the basis for the correlations, but other criteria, such as periods of widespread diastrophism and volcanic activity and profound changes in climate, have also been taken into consideration. It is well to mention here that the total thickness of Tertiary and Quaternary sediments in California approximates 25,000 feet and that within the Tertiary and Quaternary periods, relatively short, geologically speaking, as compared with the earlier divisions of the time scale, probably more distinct and profound movements have taken place on the western border of our continent than have occurred over an equal length of time in any of the preceding periods within the limits of North America.

Five maps have been prepared to elucidate the paper, each respectively representing the supposed distribution of land and water along the western border of the United States during the Eocene, the Oligocene, the lower Miocene, the upper Miocene, and the Pliocene and Pleistocene epochs. It is admitted that these maps are composites; that is, they represent the distribution not at any definite moment but throughout a period of time during which the local conditions usually changed but little relative to the changes taking place between these periods. For instance, the areas shown as subject to deposition during the Eocene are the areas over which deposits were laid down at one time or another during the Eocene epoch. In the case of certain portions of Puget Sound and elsewhere, marine conditions prevailed during the early Eocene, brackish-water conditions a little later, and freshwater or river, and coal-marsh conditions toward the close. In other portions of the same general area the conditions alternated. It is obvious, therefore, that the legends on the maps are very general. Only in those instances where the body of water indicated as fresh remained fresh throughout practically the whole of its existence is it indicated as a freshwater area on the map.

The periods chosen for representation and as units for discussion are neither of equal length nor of equal importance, and the lines separating them are in some instances arbitrary; but it is believed that they serve the purpose of systematizing the discussion better than any other plan of subdivision. The data are incomplete and the conclusions admittedly tentative, and it is expected that future investigations will disclose new and important information, which will necessitate alterations, but the fact remains that general reports of this kind, based as they are on the present state of our knowledge, often point the way to more exact results in the future.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Messrs. Bailey Willis, J. S. Diller, T. W. Stanton, Robert Anderson, Chester W. Washburne, and several others for personal assistance in the preparation of the text and maps, and to express his thanks for the services rendered. In addition to the personal aid received, the literature relating to the subject of West Coast geology has been freely drawn on in the compilation of relevant data and in many cases proper acknowledgment for this is made in the text.

THE EOCENE PERIOD

RELATION OF THE EOCENE TO THE CRETACEOUS

Before entering into the details of the geologic history of the Tertiary it is well to consider for a moment the relations existing between the earliest Tertiary rocks and those of the Cretaceous, and to note the conditions initiating the Tertiary, as implied by these relations.

A widespread unconformity exists between the Eocene and the Cretaceous on the Pacific Coast of North America. Throughout Washington, Oregon, and certain parts of California, this unconformity is angular, while over considerable areas in California and at one locality in Oregon the unconformity may only be recognized by a more or less marked hiatus in the faunas.

It is a noteworthy fact that with one exception wherever the line between the marine Eocene formations (Martinez, Arago, Tejon, etc.) and the Cretaceous beds is marked by an angular unconformity, the underlying beds are either of lower Cretaceous (Knoxville) or middle Cretaceous (Horsetown) age, and that wherever the Eocene rests on the Chico, or upper Cretaceous, excluding the case at San Diego, the unconformity is not angular, and as far as the stratigraphic evidence goes, the two formations represent an apparently uninterrupted period of sedimentation.

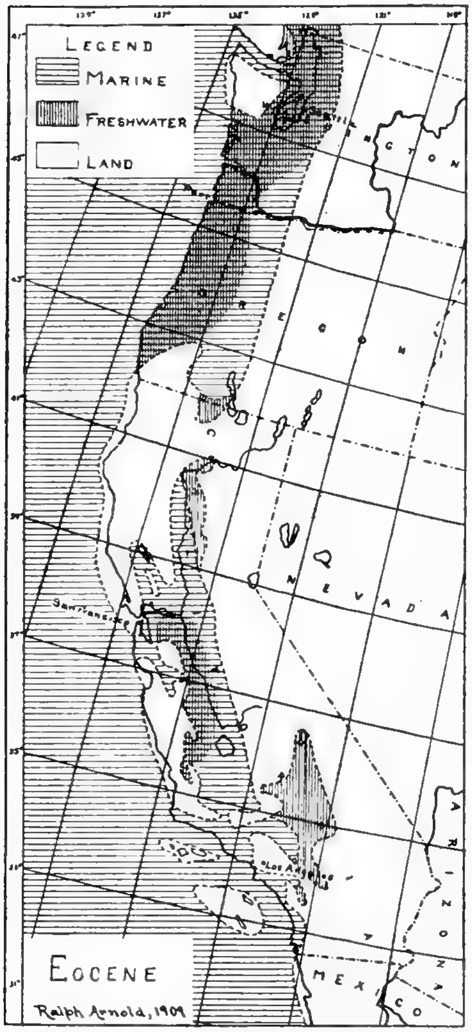

Fig. 1.—Map showing hypothetical distribution of land and water on the Pacific Coast of the United States during Eocene time.

The apparent conformability of the Eocene on the Cretaceous, together with the superficial similarity of their faunas, led Gabb and Whitney of the early California Survey to class the Martinez and Tejon formations with the Cretaceous. White, Stanton, and Merriam have, however, shown the Eocene age of the Martinez and Tejon. Of the relationships existing between these two and the Chico, or upper Cretaceous, Dr. Merriam has the following to say:

The Martinez group, comprising in the typical locality between one and two thousand feet of sandstones, shales, and glauconic sands, forms the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty species, of which the greater portion is peculiar to itself. A number of its species range up into the Tejon and a very few long-lived forms are known to occur also in the Chico. Since the Martinez and Chico are faunally only distantly related it is probable that an unconformity exists between them.[1]

[1] *Jour. Geol.*, Vol. V, 1897, p. 775.

Another fact showing the relations existing between the Eocene and the Cretaceous is the occurrence in the Eocene beds in the Roseburg region, Ore., of oysters so similar in appearance to the characteristic Cretaceous fossil, Gryphæa, that without their accompanying Eocene fauna these oysters would certainly be mistaken for Cretaceous forms.

CONDITIONS IMMEDIATELY PRECEDING AND INAUGURATING THE EOCENE

Immediately preceding the Eocene period practically all of Washington, all of Oregon excepting a small area along its southern border, the Sierran and desert region, and certain portions of the coastal belt of California were dry land. Most areas in California, and possibly also those in the Puget Sound region, which were occupied by the Chico or upper Cretaceous sea, were still under water, or at least elevated only slightly above sea-level and this without deformation of the Chico beds or subsequent erosion before subsidence. Influences, however, which markedly affected the faunas without materially influencing the sedimentation, were actively at work, and it seems likely that these influences were due to worldwide climatic changes augmented by a readjustment of ocean currents following orogenic movements. In Washington, according to G. O. Smith,

the deposition of the Cretaceous rocks seems to have been followed by an epoch in which they and older rocks were folded and uplifted. Thus was an early Cascade Range outlined, although it may be that the range had an even earlier origin. Accompanying the post-Cretaceous mountain growth were intrusions of granitic and other igneous rocks which now constitute a large part of the northern Cascades. During the time that any portion of this area was not covered by water the rocks were exposed to the vigorous attacks of atmospheric agencies. Thus, at the beginning of the Tertiary the northern Cascade region appears to have been a comparatively rugged country, although not necessarily at a great elevation above sea-level.[1]

A study of the interrelations of the Cretaceous and Eocene formations outlined in a preceding section clearly indicates that any important pre-Eocene mountain-building movements affecting the Cretaceous rocks in the California province must have taken place before the deposition of the Chico or upper Cretaceous sediments. As shown by F. M. Anderson,[2] the movements immediately preceding

[1] "Ellensburg Folio," *Geol. Atlas U. S., No. 36,* p. 1.

[2] *Proc. Cal. Acad. Sci.*, 3d ser., "Geology," Vol. II, 1902, p. 53.

the deposition of the Chico were accompanied by basic igneous intrusions. No profound movements and no volcanic activity accompanied the post-Chico (post-Cretaceous) movements in California as they did in Washington.

Steep mountains bordered the youthful Eocene sea in southern Oregon, northeastern California, and north of San Diego, and occupied portions of one or more large islands in the region of Monterey and Santa Barbara counties south of San Francisco. Elsewhere the relief of the land appears to have been comparatively low and the shore-lines with few bays or estuaries.

DISTRIBUTION AND CHARACTER OF SEDIMENTS

Rocks of marine origin and Eocene age are found at many localities throughout Washington and Oregon west of the Cascade Range, and over considerable areas of the Coast Ranges in central and southern California. Although Eocene rocks probably once fringed the greater part of the western base of the Sierra Nevada, they are now all removed by erosion or covered by later formations except at one locality near Merced Falls. For the most part the Eocene rocks of the Pacific Coast are either sandstone or shale. Conglomerate is found at the base of the formation throughout southeastern Oregon, north of San Diego, and at a few localities along the northeastern flanks of the Coast Range; and at Port Crescent, Washington, Eocene fossils are associated with tuff; but these occurrences are exceptional. Also, diatomaceous shales occur at the top of the Eocene series in the vicinity of Coalinga, Cal., where they are believed to be the source of important deposits of petroleum. Coal and other indications of shallow- and brackish-water conditions are found over much of Washington and Oregon and California, usually overlying marine Eocene beds. The maximum thickness of the Eocene sediments varies from 8,500 feet east of the Cascades,[1] 10,000 to 12,000 feet in western Oregon[2] to 9000± feet in southern California.[3]

CONDITIONS PREVAILING DURING THE EOCENE

During the early part of the Eocene, marine conditions prevailed over a considerable territory that later was covered by brackish- or

[1] G. O. Smith, *Mt. Stewart Folio.*

[2] J. S. Diller, *Roseburg, Coos Bay, and Port Orford Folios.*

[3] Ralph Arnold, *U. S. Geol. Surv. Bull. 321*, p. 21.

freshwater or swamp conditions. The regions thus affected include a large part if not all of the Puget Sound and western Oregon provinces and a considerable part of central California. How far these conditions extended eastward into central Washington and Oregon it is not possible to state owing to the covering of the Eocene by later volcanic flows. It is quite possible, however, that certain portions of the Sound country was at no time submerged under salt water, or if at all only for very short periods, for Willis states[1] that coal occurs both in the basal and upper portions of the Puget formation, which is believed to cover the period from the Eocene into the Miocene. He states further that "the physical history which is recorded in the Puget formation is one of persistent but frequently interrupted subsidence" in which "the alternation of coal beds with deposits of fine shale and coarse sandstone indicates that during this great subsidence the depth of water frequently changed." He infers "that at times the subsidence proceeded more rapidly, and that the deepened water was then filled with sediment, until the tide-swept flats became marshes, and for a time vegetation flourished vigorously in the moist lowlands," this rotation being repeated intermittently. This description of conditions is believed also to apply to much of Alaska, western Oregon, and portions of the interior valley of central California during the later Eocene. The epicontinental Eocene seas were for the most part rather shallow and in the later Eocene particularly were bordered by wide tide flats and marshes.

In the region of Lower Lake in Lake County, Cal., in the Mojave Desert immediately north of the Sierra Madre, and in the vicinity of San Diego, the early Eocene (Martinez) sea was present, but later receded and these particular areas are believed to have been dry land during the later Eocene. The Mojave Desert basin may have been covered with freshwater at this later period as lake deposits believed to be largely of Eocene age are known from the region contiguous to it. This would be in accordance with the conditions prevailing in eastern Oregon[2] and Washington[3] where great lakes existed during Eocene time immediately east of what is now the Cascade Range,

[1] *Tacoma Folio*, p. 2.

[2] J. C. Merriam, *Bull. Dept. Geol. Univ. of Cal.*, Vol. II, No. 9, p. 286, 1901.

[3] G. O. Smith, *Mount Stewart and Ellensburg Folios*, Washington.

and possibly also east of the Sierra Nevada. Erosion tending toward a base-leveling of the Sierra Nevada and other elevated portions of the Pacific Coast must have proceeded rapidly during the Eocene as is evidenced by the great thicknesses of strata laid down during the period and by the fact that high relief was not present during the Oligocene except in rare instances, although the Oligocene in general was a period of uplift for much of the Pacific Coast province.

OROGENIC MOVEMENTS AND VOLCANIC ACTIVITY IN THE EOCENE

After the deposition of the early Eocene came a period of temporary elevation, erosion, and great volcanic activity in Washington, Oregon, and northern California. Extensive basaltic eruptions through long conduits and over the eroded rock surfaces took place in eastern Washington and western Oregon, while in the region of the Olympic Mountains and eastern Oregon basalt flows and volcanic outbursts were also taking place. Eocene volcanic disturbances so pronounced in the north do not appear to have affected the Sierra Nevada nor the coastal region of California south of the Klamath Mountains.

CLIMATE DURING THE EOCENE

The faunas and floras of the Eocene indicate subtropical conditions for this period at least as far north as Puget Sound. The marine faunas of the Pacific Coast Eocene are closely allied to those of the Eocene of the southern states and the Eocene shells, *Corbicula*, for instance, as a rule belong to groups showing a predilection for warm waters. This supports the evidence offered by the floras which are of a decidedly tropical aspect. Doctor Knowlton has the following to say in connection with the flora of the Puget formation, which may be regarded as typical of the Washington, Oregon, and California Eocene:

> The lower beds [the Eocene portion of the Puget formation], on account of the abundance of ferns, gigantic palms, figs, and a number of genera now found in the West Indies and tropical South America, may be supposed to have enjoyed a much warmer, possibly a subtropical, temperature, while the presence of sumacs, chestnuts, birches, and sycamore in the upper beds [Oligocene and lower Miocene] would seem to indicate an approach to the conditions prevailing at the present day.[1]

[1] *Tacoma Folio*, p. 31.

THE OLIGOCENE PERIOD

THE OLIGOCENE A PERIOD OF ELEVATION

The Oligocene on the Pacific Coast was primarily a period of elevation and erosion over many areas which are now land. As indicated by the fine character of most of the sediment deposited during the period, the relief was not strong, except in a few regions. Outside the Washington-Oregon province there are few evidences of the period, except a more or less marked unconformity between the Eocene and lower Miocene, and these for the most part are on the extreme continental border or along the edges of the provinces of persistent subsidence. The extreme localization of the post-Eocene movements is well shown in the southwestern San Joaquin Valley where the lower Miocene and Eocene are apparently conformable and again occur within a distance of a quarter of a mile separated by a profound angular unconformity. Strata of undoubted Oligocene age consisting largely of sandy to clayey shales and carrying a characteristic marine fauna are found at many localities throughout the Puget Sound and northwestern Oregon areas and an isolated occurrence of similar beds is found in the Santa Cruz Mountains, a short distance south of San Francisco. Wherever their relations are known these beds lie conformable with the Eocene below and lower Miocene above; they therefore mark areas of persistent subsidence. A characteristic reddish to lavender formation (the Sespe), consisting of sandstone, shale, and some conglomerate found in Ventura and Los Angeles

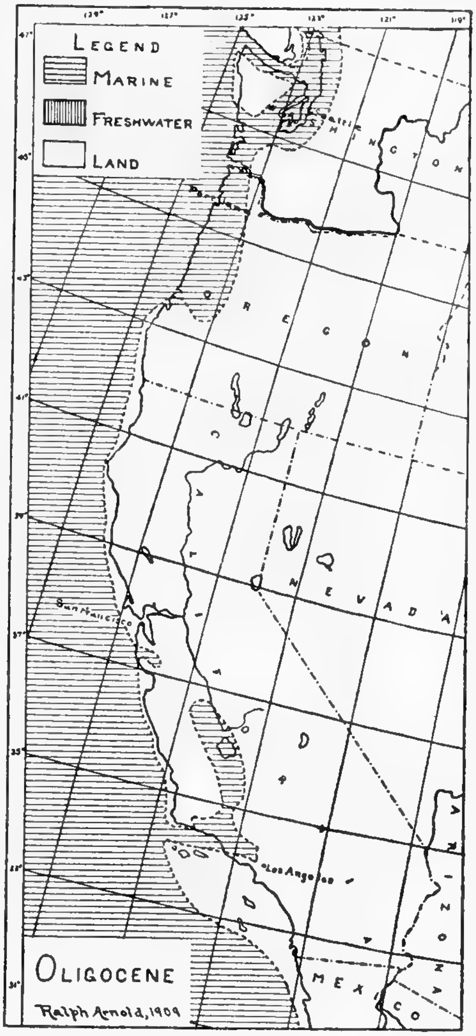

Fig. 2.—Map showing hypothetical distribution of land and water on the Pacific Coast during Oligocene time.

counties in southern California, has been doubtfully referred to the Oligocene and the map made to agree with this correlation; but it is possible this formation is Eocene.

Certain marine shales and sands underlying the lower Miocene beds in western Fresno and Kern County may also belong to the Oligocene. If so they imply that an arm of the sea remained in the San Joaquin Valley following the post-Eocene elevation that excluded marine conditions from much of the coastal belt of western America.

The total thickness of the Oligocene over the region where it has been recognized varies from over 1,000 feet in Washington to 2,300± feet in the Santa Cruz Mountains. The Sespe formation of Ventura and Santa Barbara counties, which has been tentatively correlated with the Oligocene, attains a maximum thickness of about 4,300 feet.

CONDITIONS OF EROSION AND DEPOSITION

With the close of the Arago stage (Eocene)[1] the Klamath Mountains and Coast Ranges of Oregon and California were uplifted to a moderate elevation and subjected to extensive erosion, in some localities completely removing the sediments deposited during the Eocene. With the possible exception of an area in Ventura County in southern California no mountains of strong relief contributed directly to the Oligocene sediments. In eastern Washington the great lakes which prevailed during the Eocene were elevated and the sediments which had been deposited in them were folded and eroded, the resulting detritus in addition to large quantities of volcanic ejectamenta being collected in bodies of freshwater in eastern Oregon farther south. It is thus known that with the elevation of this northern country volcanic activity still continued although on an insignificant scale as compared with the periods preceding and following the Oligocene. In California there is no evidence of volcanism in the Oligocene period.

FAUNA AND CLIMATE OF THE OLIGOCENE

What little is definitely known concerning the faunas of the Oligocene as a whole indicates their closer affiliation to the Miocene than to the Eocene. The fauna from the Oligocene of the Santa Cruz Mountains (San Lorenzo formation) and a similar fauna from

[1] J. S. Diller, *Roseburg Folio.*

Porter near Grays Harbor, in western Washington, are believed to be the oldest of the definitely known Oligocene. In these assemblages are several species showing distinct Eocene affinities; in the later Oligocene the forms are decidedly more closely allied to Miocene forms. The climatic conditions prevalent on the west coast of the United States during the Oligocene are believed to have been transitional from the subtropical of the Eocene to the more temperate of the lower Miocene.

THE LOWER MIOCENE PERIOD

CONDITIONS INAUGURATING THE LOWER MIOCENE

The Oligocene period of elevation and moderate erosion was followed by diastrophic movements of a most interesting and important character. It was during this post-Oligocene period of disturbance that definitely recognizable movements along what is now termed the great earthquake rift and associated rifts of California first took place. Although profound regional subsidence was the rule in central and portions of southern California, local movements along the faults mentioned elevated blocks of the pre-existing formations into islands, usually of considerable relief, in the region now occupied by the Coast Ranges. It is in a study of details such as the distribution of the land and water in these fault zones that composite maps, such as those accompanying this paper, become entirely inadequate and sometimes misleading. Suffice to say that beginning with the pre-Vaqueros (pre-lower Miocene) period of disturbance many of the major blocks within the general fault zone of the Coast Ranges, and to a lesser extent, the minor blocks within the major masses, were seldom at rest for more than relatively short periods up to the present day. Some folding took place during the pre-Vaqueros period, but it was local in character, such as that exhibited in the Coalinga district, and of minor importance as compared with the vertical movements of the large masses. One of the most significant facts in connection with the lower Miocene subsidence was the retention of its position above sea-level of the Sacramento Valley region at a time when the San Joaquin Valley to the south was subjected to marine conditions. This discordance of movement between the two ends of a continuous basin, which in the discussion of California geology has heretofore been considered as a unit, is believed to be related to the positive or upward-tending forces accompanying or immediately preceding the important volcanic activity which took place during early Miocene[1] time adjacent to the Sacramento Valley, and northward into Washington, but which are absent or insignificant in the region contiguous to the San Joaquin. In this connection it is also worthy of note that the greater part of the Willamette Valley was also out of water during the lower Miocene.[2]

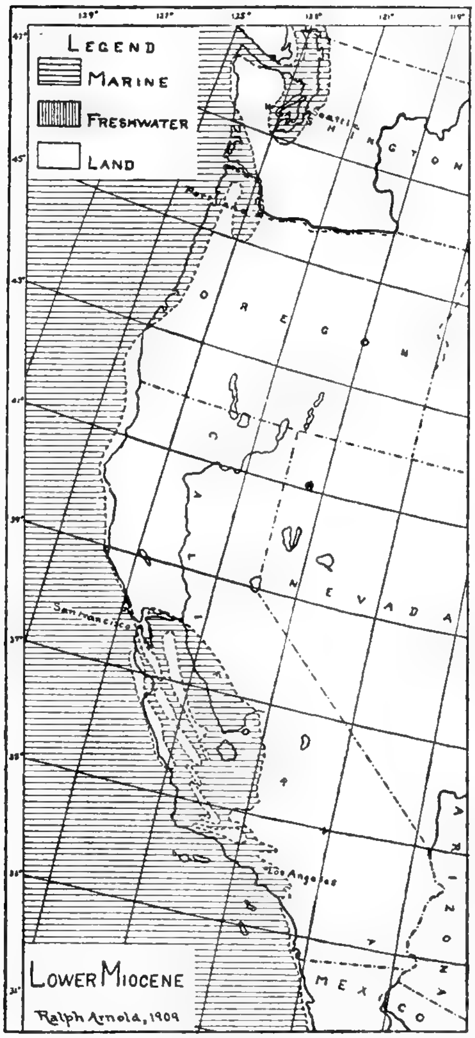

Fig. 3.—Map showing hypothetical distribution of land and water on the Pacific Coast during lower Miocene time.

DISTRIBUTION AND CHARACTER OF SEDIMENTS

The Vaqueros or lower Miocene proper, and the Monterey or lower middle Miocene epochs have been included in mapping and discussing the lower Miocene, for together they mark by subsidence the beginning of a new geologic cycle following the Oligocene elevation. Locally the Vaqueros and Monterey have totally unlike histories. The Vaqueros in the Coast Ranges of central California is characteristically conglomeratic at the base, and sandy, with minor quantities of shale, in its upper portion. In the northern part of southern California it is largely dark arenaceous shale associated with minor quantities of sandstone. The Monterey, on the other hand, is composed largely of diatomaceous material with minor quantities of sandstone, fine volcanic ejectamenta, and limestone, the last three

[1] J. C. Merriam, *Bull. Dept. Geol. Univ. Cal.*, Vol. V, p. 173.

[2] Oral communication from Mr. Chester W. Washburne.

usually more noticeable toward the base. The Modelo formation of Ventura County, the probable equivalent of the Monterey, contains two important coarse sandstone zones. In the region of Mount Diablo the Vaqueros and Monterey formations comprise alternations of sandstone and shale. In Washington and Oregon the whole lower Micoene is largely sandstone with some associated shale. A gradual gradation between the two formations is the rule, although their contact is often sharply marked and in some places is an angular unconformity.[1] The thickness of the Vaqueros is as much as 3,000 feet, that of the Monterey over 5,000 feet, a total for the whole of the lower half of the Miocene of over 8,000 feet.

CONDITIONS OF DEPOSITION

The deposition of the lower Miocene (Vaqueros) sediments was inaugurated over much of the submerged territory, along the shores of islands of sharp relief. Erosion and deposition were rapid within local basins, especially in the region from the Santa Cruz Mountains southward to San Luis Obispo County, and still there were localities within these areas of intense sedimentation where deposition was slow. It is the belief of the writer that these variations were dependent, at least in part, on the positions of the areas in question relative to the steep or low slopes of tilted fault blocks.

Over those portions of southern California, such for instance as in Ventura County, where the sea supposedly occupied the present land-area during the Oligocene, the conditions during the Vaqueros (lower Miocene) were quite different from those northward in the Coast Range archipelago. Instead of the littoral conditions accompanied by rapid and coarse sedimentation of the latter province there was in the Ventura County area deep water with slower deposition and finer sediments, especially in the earlier Miocene.

The lower middle Miocene (Monterey) shale formation is one of striking individuality, and conditions of unusual character prevailed during its period of deposition.[2] The land which had begun to subside at the beginning of Miocene time, later, at the inauguration of the middle Miocene, sank over a large part of the region of Cali-

[1] Branner, Newsom, and Arnold, *Santa Cruz Folio.*

[2] For a fuller description of the Monterey see A. C. Lawson and J. D. L. C. Posada, *Bull. Dept. Geol. Univ. Cal.*, Vol. I, pp. 22 ff.; H. W. Fairbanks, *ibid.*, Vol. II, pp. 9 ff.; Ralph Arnold and Robert Anderson, *U. S. Geol. Survey Bull. 322*, pp. 35 ff

fornia now occupied by the Coast Ranges and fairly deep water conditions became prevalent. A large area embraced between the Salinas and San Joaquin valleys and extending northward from the Antelope and Cholame valleys well toward the Livermore Valley was an exception to this general subsidence, and although much of it had been under water in Vaqueros time it was probably dry land or at least an area not subject to sedimentation during the Monterey. The wearing-away of extended land-areas ceased as they became submerged, and the material for the formation of coarse detrital deposits was no longer plentiful. Although the total thickness of the Monterey approximates a mile it is not probable that the depth of the sea at any time was as much as this, being more likely closer to half a mile.

During the period of transition between the Vaqueros and the Monterey, limestone was formed chiefly, but somewhat inclosed basins where deposits of alkaline mud were laid down apparently existed in places. Such a basin is indicated by the alkaline gypsiferous clays on the south side of the Casmalia Hills, in northwestern Santa Barbara County, probably representing upper Vaqueros.

During the early part of the middle Miocene (Monterey) time conditions were variable, calcareous and siliceous deposits alternating, probably as a result of alternating temporary predominance in the sea of organisms with calcareous or siliceous shells. As the period progressed the siliceous organisms became more predominant and remained so, making up a large fraction of the total bulk of the Monterey formation. It was an age of diatoms. These small marine plants lived in extreme abundance in the sea and fell in showers with their siliceous tests to add to the accumulating ooze of the ocean bottom, just as they are forming ooze at the present day in some oceanic waters. It is well known that diatoms multiply with extreme rapidity. It has been calculated that, starting with a single individual, the offspring may number 1,000,000 within a month. One can conceive that under very favorable life conditions, such as must have existed, the diatom frustules may have accumulated rapidly at the sea bottom and aided the fine siliceous and argillaceous sediments in the quick building-up of the thick deposits of middle Miocene time, some of which are a mile through. These diatomaceous shales are the source of some of the richest petroleum deposits of California.

VOLCANIC ACTIVITY IN THE LOWER MIOCENE

The most important display of volcanic phenomena on the Pacific Coast took place during the early and middle Miocene, and probably reached its climax at the time of the widespread post-early middle Miocene (post-Monterey) disturbances. Great volcanoes were active throughout eastern Washington and Oregon and in the Coast Ranges of California from the Santa Cruz Mountains at least as far south as the Santa Ana Mountains in Orange County. The lavas and tuffs emitted by these volcanoes, and the associated intrusions, were basic in character. Certain facies of the Monterey are believed by Lawson and Posada[1] to consist of fine volcanic ash ejected from distant volcanoes of the period.

FAUNAS AND CLIMATE OF THE LOWER MIOCENE

The marine faunas of the lower Miocene or Vaqueros are well known and of widespread occurrence in the Coast Ranges of California; those of the Monterey, owing to the peculiar character of its sediments, are meager and little understood. A general survey of the fauna, however, indicates conditions approximate to those now existing in the coastal provinces, although certain forms of southern extraction, such as large cone shells, numerous arcas, and other types, indicate possible warmer environment. The evidence of the mollusks is supported by that of the plant remains, at least in so far as it relates to the region of Puget Sound, for there, according to Knowlton,[2] the presence of sumacs, chestnuts, birches, and sycamores in the upper Puget group [probable lower Miocene] would seem to indicate an approach from the subtropical conditions of the Eocene to the conditions prevailing at the present day.

PERIOD OF DIASTROPHISM IN THE MIDDLE MIOCENE

One of the most widespread and important periods of diastrophism in the Tertiary history of the Pacific Coast was that immediately following the deposition of the Monterey or lower middle Miocene. Its effects are visible from Puget Sound to southern California. It is marked as much by readjustment, by local faulting and folding as by general movements of elevation and subsidence. In some regions the

1 *Bull. Dept. Geol. Univ. Cal.*, Vol. I, pp. 24 ff.

2 *Tacoma Folio*, p. 3.

folding and faulting were intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. In other regions low broad folds were formed during the post-Monterey disturbance, and the strata were not upheaved to a great altitude. Faulting on a most magnificent scale took place along the earthquake rift and certain other fault-zones, especially that in the Salinas Valley, and along these lines of displacement, masses of granitic rocks, which during the preceding epoch had been subject to little or no erosion, were suddenly thrust upward and left exposed to the ravages of streams that assumed the proportions of torrents in certain regions, as for instance adjacent to the Carrizo Plain in south-central California. The post-Monterey disatrophic movements in the Puget Sound province also produced sharp relief as is evidenced by the coarse sediments deposited immediately following the disturbance. The localization of movement during the period is exemplified at numerous localities in the Coast Ranges.

Throughout much of the coastal belt, and probably likewise in the interior, great volcanic activity took place during the middle Miocene, this being the last epoch of volcanism in the Coast Ranges south of San Francisco. During this post-Monterey period of diastrophism general subsidence took place over most of the areas which were under water during the lower Miocene, and, in addition, extended northward from San Francisco Bay into the Sacramento Valley and along the coast to the California-Oregon line and southward down the Willamette Valley of Oregon. A new channel was apparently opened across the northwestern end of the Olympic Peninsula, and the Colorado Desert country of southern California and Arizona which for a very long time had presumably been free from marine conditions was occupied by an arm of the sea.

THE UPPER MIOCENE PERIOD

DISTRIBUTION AND CONDITIONS OF DEPOSITION

With the possible exception of that in the Eocene the subsidence immediately preceding and extending into the upper Miocene was the most important in the Tertiary history of the Pacific Coast. As a result, the formations of this epoch occupy a very considerable percentage of the surface of the present land-area. The sediments in the southern Coast Ranges, especially, are largely derived from granitic rocks and are usually coarser at the base, becoming finer and finer toward the top, possibly indicating a subsidence greater than the concomitant sedimentation. Exceptions to the rule of coarse basal sediments are not uncommon, however, and in the Santa Cruz Mountains and also in eastern Monterey County, Cal., the unconformable deposition of fine shale directly upon older rocks is a well-marked phenomenon. This, of course, indicated a sudden and rather deep submergence of the areas in question at the initi ation of the upper Miocene. Conditions favoring the life of diatoms, so marked in the Monterey, continued over part of the Monterey diatomaceous shale territory during the upper Miocene (Santa Margarita and Fernando formations). The areas of maximum deposition during the period were apparently on the southwestern side of the San Joaquin Valley in western Fresno County and in central Ventura County, Cal., where thicknesses of over 8,000 feet of sediments, belonging largely to the upper Miocene, occur.

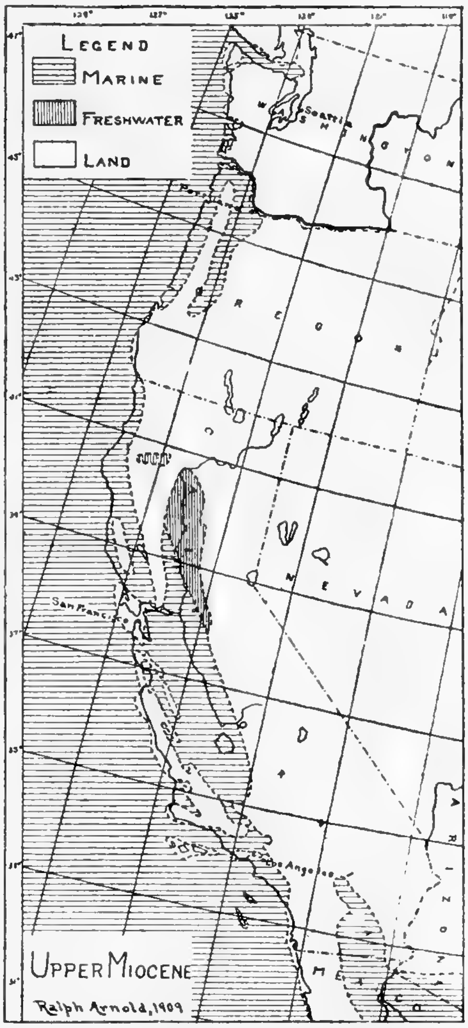

Fig. 4.—Map showing hypothetical distribution of land and water on the Pacific Coast during upper Miocene time.

EROSION AND VOLCANIC ACTIVITY

The peneplanation of the Klamath Mountains and the Sierra Nevada was probably completed during the upper Miocene, the detrital material from these land areas forming the great deposits in the San Joaquin and Sacramento valleys and the coastal belt of northern California. Erosion was practically continuous in these first-mentioned areas from the beginning of the Eocene, but the final approach toward base level was probably not attained until the close of the upper Miocene. Volcanic activity had ceased on the Coast Ranges south of San Francisco during the inauguration of the upper Miocene, and had become subdued if not suppressed in the coastal belt to the north. In Oregon[1] and possibly also in the vicinity of Mount Diablo, east of San Francisco, in northeastern California, and in Washington volcanoes still persisted.

FAUNAS AND CLIMATE OF THE UPPER MIOCENE

The upper Miocene as here mapped and described embraces several formations, each carrying a more or less well-defined fauna. The most characteristic of these, in the order of age, are the Santa Margarita, typically developed in San Luis Obispo and Monterey counties, Cal., the Empire of Oregon, and the San Pablo of the San Joaquin Valley. All three of these indicate conditions approaching those of the present day, though leaning toward warmer climates. Toward the end of the Miocene and the beginning of the Pliocene, the forerunners of the upper Pliocene sub-boreal invasion which was to come, began to be felt. A cool-water fauna is found in the uppermost Etchegoin (upper Miocene) formation in the Coalinga district, this being followed by a freshwater fauna. In the lower Pliocene faunas of southern California are the last representatives of certain unique species of Pecten which were abundant in the upper Miocene of central California, but which migrated southward during the late Miocene, and became extinct before the Pliocene in the territory where they formerly had been so abundant. The abundance of huge oysters, pectens, and certain subtropical echinoid types in the Santa Margarita implies shallow, rather warm, water—these conditions being due in part, at least, to the local sheltered bodies of water which occupied the southern Coast Ranges during that period. The Empire fauna, best developed along the edge of the open upper Miocene ocean, extended from at least as far north as the Straits of Fuca to the region of the Santa Cruz Mountains and possibly farther south.

The strong resemblance between the Etchegoin fauna of the

[1] J. C. Merriam, *Bull. Dept. Geol. Univ. Cal.*, Vol. V, p. 173.

Kettleman Hills in southern Fresno County, Cal., and the Carrizo Creek beds of the Gulf province of southeastern California has led to the correlation of the latter with the former, although the writer's first examination of the Carrizo Creek fossils led to his placing them tentatively in the lower Miocene.[1] This correlation of the beds with the upper Miocene seems best to fit the conclusions based on other criteria such as faunal relations, character of sediments, sequence of geologic events in this province, etc.

THE PLIOCENE AND QUATERNARY PERIODS

CONDITIONS OF DEPOSITION AND CHARACTER OF SEDIMENTS

Sedimentation was continuous from the Miocene through the Pliocene and on into the Quaternary over large areas along the Pacific Coast, but there was a marked change in the conditions surrounding the deposition at various times within this long period. In a limited coastal belt, marine conditions marked the Pliocene and Quaternary as well as the upper Miocene, while farther inland freshwater, possibly alternating with short brackish-water or even marine, conditions prevailed during the Pliocene and Quarternary. This change from marine to lacustrine environment in the basin provinces of the Coast Ranges was probably brought about by two causes: first, a gradual elevation of the whole coast, and second, as suggested by Newsom,[2] movements along the earthquake rift and other faults in which certain of the blocks were elevated, forming barriers across pre-existing channels between the interior basins and the ocean. Faunal evidence indicates that those basins farthest inland, such as the San Joaquin Valley, became fresh possibly earlier in the Pliocene than those nearer the sea, such as the Santa Clara Valley basin.

The marine Pliocene deposits consist largely of fine sand and soft shale, and sometimes marl, while the freshwater sediments usually include considerable thicknesses of coarse, more or less incoherent gravels, hardened silt and sands. The maximum thickness of the marine Pliocene is attained in the Merced section immediately south of San Francisco, where approximately 4,000 feet of strata of Pliocene age are exposed. The greatest thickness of freshwater

[1] *Science*, N. S., Vol. XIX, 1904, p. 503.

[2] "Santa Cruz Folio," *Geologic Atlas U. S.*, 1909.

Pliocene occurs along the southwestern border of the San Joaquin Valley in western Fresno and Kings counties where the Tulare formation, largely of Pliocene age, attains a thickness of about 3,000 feet.

DIASTROPHISM AND VOLCANISM IN THE PLIOCENE

The most important movements inaugurating the Pliocene seem to have been an elevation of the Sacramento Valley and certain portions of the coastal belt of northern California and Oregon and the closing of the connection between the south end of the San Joaquin Valley and the southern California province. Although sedimentation was practically continuous from the Pliocene into the lowest part of the Pleistocene over much of the Pacific Coast, there is in parts of southern California a sharp line of unconformity between the Pliocene and Pleistocene. The extreme localization of the movements producing this unconformity is well exemplified at San Pedro, near Los Angeles, where the Pleistocene is separated from the Pliocene by an angular unconformity at Deadman Island, while half a mile distant on the mainland the same formations are perfectly conformable. Volcanic activities of a more or less complicated nature took place in certain portions of northern and central California during the Pliocene, while in the same period and probably up to a very recent date certain areas in the Sierra Nevada and Cascades have felt the effect of volcanism to a marked degree.

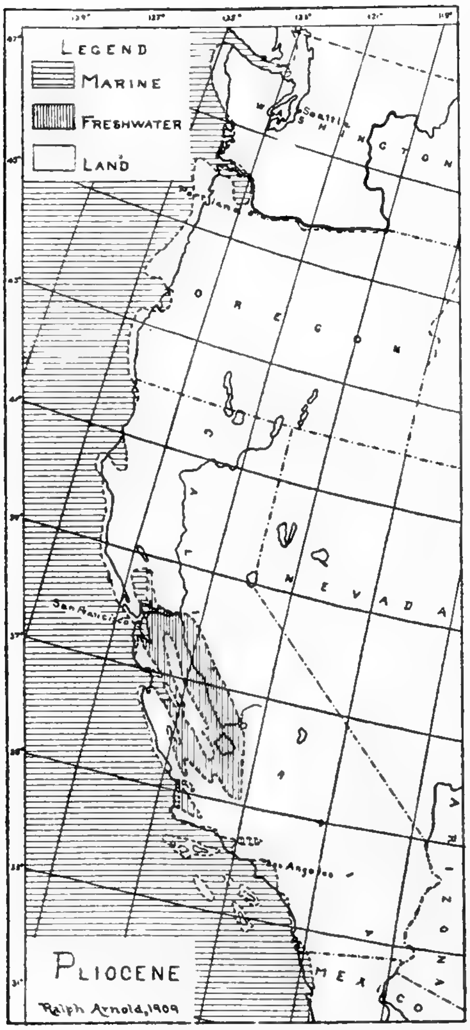

Fig. 5.—Map showing hypothetical distribution of land and water on the Pacific Coast during Pliocene time.

DIASTROPHISM IN THE QUATERNARY

Important and more or less widespread periods of diastrophism later than the one terminating the Monterey (middle Miocene) period of deposition occur in the Pleistocene. Up to the time of the discovery of certain indisputable evidence[1] regarding the Pleistocene age of beds affected by certain of these latest mountain-forming movements, the diastrophism had been considered as closing the Pliocene and initiating the Pleistocene. Minor movements producing local unconformities took place in central and southern California at various times during the Pleistocene in addition to the more far-reaching disturbances in the same epoch. The latest diastrophism, including the elevations and subsidences of the coast line, the recent movements along the earthquake rift, etc., are familiar to all. The localization of many of these movements is known already; the localization of many more of them will, it is believed, become clear when they are studied in detail.

FAUNAS AND CLIMATE OF THE PLIOCENE AND PLEISTOCENE

The faunas of the Pliocene and Pleistocene freshwater deposits are closely related and in some cases almost identical to the living faunas of the same province, while the marine faunas, on the other hand, indicate profound variation of environment, at least as regards temperature. Dr. Philip P. Carpenter[2] was the first to point out the cold-water faunas of the upper Pliocene and lower Pleistocene of the Pacific Coast. His conclusions have been strengthened by later workers, and in addition it has been shown that the latest Pleistocene faunas of the same region are of a type more tropical than those now inhabiting the shores of the Pacific Coast of the United States. It is thus evident that the warm temperature of the upper Miocene gave place to cooler conditions just before or at the beginning of the lower Pliocene, and to sub-boreal conditions in the upper Pliocene and lower Pleistocene. The later Pleistocene showed a very marked increase in oceanic temperature over the lower Pleistocene, even approaching subtropical warmth, and this, in turn, being followed by the conditions now prevailing. At some time during the upper

[1] *Mem. Cal. Acad. Sci.*, Vol. III, 1903, pp. 53–55.

[2] *Ann. and Mag. Nat. Hist.*, 3d Ser., Vol. XVII, 1866, p. 275.

Miocene and Pliocene, conditions prevailed favoring the migration of similar faunas into Japan and California or intermigration between the two. This is shown by the close similarity of certain pectens found in the upper Miocene in California, in still later beds in Alaska, and in the living fauna of Japan. The general resemblance of the late Tertiary faunas of California and Japan also favors this conclusion.

SUMMARY AND CONCLUSIONS

SUMMARY

Following the period of elevation and erosion at the close of the Cretaceous, the Eocene was inaugurated by a subsidence below sea-level of the greater part of western Washington and Oregon and the western part of central and southern California. Volcanic activity was pronounced in the early and middle Eocene. Later in the Eocene brackish- and freshwater conditions prevailed over the same area, and extended over much of Alaska. The fauna and flora of the Eocene were tropical to subtropical. The Oligocene was a period of elevation with marine conditions restricted to a much smaller area than in the Eocene. The fauna was transitional with stronger affinities toward the Miocene. The lower Miocene marked a widespread subsidence in the coastal belt which was followed by a period of mountain building and great local deformation, volcanism, etc. The Miocene faunas and floras indicate conditions comparable with those of the present day, or possibly a little warmer, except at the very close, when cool conditions began to prevail. The upper Miocene was a period of subsidence, with ideal conditions for maximum deposition of sediments in local basins. During Pliocene and early Pleistocene time there was a continuation of many of the upper Miocene conditions, except that marine environment gave place locally to freshwater. The marine fauna of the upper Pliocene and lower Pleistocene indicates sub-boreal conditions in southern California, followed by conditions in the middle or later Pleistocene more tropical than those of today. A period of elevation and considerable local deformation in the early Pleistocene inaugurated the present conditions on the Pacific Coast. Many of the movements occurring throughout the Tertiary were of local extent, and, for that reason, correlation on a basis of diastrophism, unsupported by paleontologic evidence, is extremely hazardous.

CYCLES OF DIASTROPHISM

The period of the Tertiary uplift of the last worldwide cycle of diastrophism has been marked by two complete subcycles in the Pacific Coast of North America. The first was begun with gradual submergence in early Eocene, was continued by a gradual elevation in the later Eocene when marine conditions gave place to brackish- or freshwater conditions, and was completed by the epoch of uplift and erosion in the Oligocene. The second was initiated by submergence in the Miocene, was continued by the gradual elevation in the Pliocene, when, as in the later Eocene, freshwater conditions supplanted marine, and has been practically completed by the Quaternary uplift which marks the present position of the continent.

PERIODS OF MAXIMUM ELEVATION AND SUBSIDENCE

The periods of marked elevation were the Oligocene, late Pliocene, and Quaternary; the periods of maximum subsidence were the middle Eocene and upper Miocene; the periods of greatest volcanic activity were the middle Eocene and the middle Miocene. It is noteworthy that the periods of maximum volcanic activity were practically coincident with the periods of maximum subsidence in adjacent areas.

CHANGES IN CLIMATE

The climate was tropical to subtropical in the Eocene, transitional from this to warm temperate in the Oligocene, warm temperate in the Miocene, transitional from this to sub-boreal in the lower Pliocene, sub-boreal in the upper Pliocene and lower Pleistocene, and warm temperate in the later Pleistocene.

DIASTROPHIC PROVINCES

The study of the Tertiary history of the Pacific Coast shows the following positive elements or areas of persistent uplift in the coastal belt: The Olympic Mountains; a more or less uncertain, probably disconnected, belt along the western part of Washington and Oregon; the region of the California-Oregon line and thence eastward toward the Blue Mountains of southeastern Washington; the Santa Lucia Range, south of Monterey Bay; the region north and northeast of

San Diego; and the Peninsula of Lower California. The Sierra Nevada and Sierra Madre and San Bernardino and San Jacinto mountains may also be considered in the same class. The region of Santa Catalina and San Clemente islands off southern California belong to an area about which little is known previous to the Miocene, although it is the belief of the writer that they are in a belt of more or less persistent uplift.

The negative elements or areas of persistent subsidence are: Puget Sound; the Willamette Valley; the San Joaquin Valley, and the Sacramento Valley to a less degree; central Ventura County; and, since the Eocene, the Salinas Valley, and the vicinity of Los Angeles.

Coalinga District	Ventura County	Los Angeles County	San Diego Region
Alluvium	Alluvium	Alluvium	Alluvium
Stream Deposits	—Unconformity—	San Pedro	San Pedro —Unconformity—
		—Unconformity—	
		Beds at Deadman Is.	
Tulare			
	Fernando	Beds at Third St. Tunnel and Temescal Canyon Fernando	San Diego
—Unconformity—			
Etchegoin —Unconformity—			Beds at Carrizo Creek
Jacolitos			
Santa Margarita			
	—Unconformity—	—Unconformity—	
	Modelo		
—Unconformity—			
Vaqueros	Vaqueros	Puente	
—Unconformity—			
	Sespe (Oligocene ?)	Sespe (Oligocene ?)	
			—Unconformity—
Tejon			
	Topatopa		Martinez or Tejon
Chico		Chico	

Table of Tentative Correlations of the Tertiary Formations of California, Oregon, and Washington

Ralph Arnold January, 1920

Era	Period	Epoch	Standard California Section	Central Washington	Western Washington	Eastern Oregon	Western Oregon	Mount Diablo Region	Santa Cruz Mountains	San Luis Obispo	Santa Maria District	Coalinga District	Ventura County	Los Angeles County	San Diego Region
Cenozoic	Quaternary	Recent	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
		Pleistocene			Vashon										
			San Pedro				Marine Sands	Marine Sands Unconformity	Marine Sands Unconformity	Marine Sands Unconformity	Marine Sands Unconformity	Stream Deposits	Unconformity	San Pedro	San Pedro Unconformity
			Unconf.		Admiralty									Unconformity	
			Unconf.												
	Tertiary	Pliocene												Beds at Deadman Is.	
			Merced			Rattlesnake		[illegible]	(Merced (Santa Cruz	[illegible]					
								Unconformity				Tulare			
			San Diego					[illegible]						Beds at Third St. Tunnel and Temescal Canyon	San Diego
									[illegible]		Fernando		Fernando	Fernando	
					Unconformity	Unconformity						Unconformity			
		Miocene					Empire								Beds at Carrizo Creek
			San Pablo		Beds at [illegible] Bay			San Pablo [illegible]		Unconformity		Etchegoin Unconformity			
			Unconformity	Ellensburg								Jacalitos			
					[illegible]			Beds in Contra Costa County	Santa Margarita	(Pismo (Santa Margarita		Santa Margarita			
			Santa Margarita												
			Unconformity	Yakima Basalt	Unconformity	Columbia River Basalt		Unconformity	Unconformity	Unconformity	Unconformity		Unconformity	Unconformity	
			Monterey		Beds at			Monterey	Monterey	Monterey	Monterey		Modelo		
					Port Blakeley		[illegible] Sandstone		Unconformity			Unconformity			
			Unconformity		[illegible]										
			Vaqueros					Vaqueros	Vaqueros	Vaqueros	Vaqueros	Vaqueros	Vaqueros	Puente	
									Unconformity			Unconformity			
		Oligocene	Unconformity		[illegible]	Unconformity	[illegible]								
			San Lorenzo		[illegible]	John Day	[illegible]		San Lorenzo		Sespe (Oligocene?)		Sespe (Oligocene?)	Sespe (Oligocene?)	
			Unconformity	Unconformity		Unconformity									Unconformity
							[illegible]								
		Eocene	Tejon	Manastash	Beds at [illegible]		[illegible]	Tejon			Tejon	Tejon			
				Unconformity									Topatopa		Martinez or Tejon
				Roslyn											
			Martinez	Unconformity	Beds at [illegible]		[illegible]	Martinez	[illegible]						
				Swauk	Beds at [illegible]										
Mesozoic	Cretaceous	Upper Cret.	Unconformity	Unconformity		Unconformity	Unconformity			Unconformity					
			Chico			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Chico		Chico	
		Lower Cret.					[illegible]				Knoxville				

CHAPTER XIII

CORRELATION OF THE CENOZOIC THROUGH ITS MAMMALIAN LIFE

HENRY FAIRFIELD OSBORN
American Museum of Natural History, New York City

The sea borders of the United States may be correlated with each other and with those of Eurasia in Cenozoic times through their invertebrate life, but for the vast interior of the American continent we must depend chiefly upon the mammals and in a less degree upon the reptiles, fishes, insects, and plants. I foresee great aid through these latter sources, but it is clear that the mammals will always afford the chief means of correlation, since in all parts of Europe mammal-bearing formations alternate with marine shell-bearing formations.

The standard divisions of Cenozoic geologic time will always be those established in Europe. The problem set before the paleontologists of our country is therefore to compare and establish our time divisions as closely as possible with the European standards. For this reason since 1899 I have been pursuing an exact investigation of the sequence of mammalian life in America and in the European Tertiary formations, and have enlisted the co-operation of many European and American paleontologists in the hope that such precise data may be obtained as to secure common understanding and usage of chronologic terms in the two countries.

Previous to 1898 scattered attempts at the correlation of European horizons *inter se* were made by Dawkins, Schlosser, Osborn, Depéret, and others, but it was not until June, 1905, that there began in the *Comptes rendus* a remarkable series of papers by Depéret entitled "L'évolution des mammifères tertiaires," covering with fulness the whole subject of the succession of mammalian life in Europe, the correlation of all the known horizons, with theories as to the migrations between the continents of Eurasia, North America, and Africa. I am not in accord with Depéret on many of these theories but I accept in full his correlation of the mammal-bearing horizons on the continent, together with his subdivisions of geologic time.

Similarly in America there are the pioneer correlations of Leidy of the American formations with each other and with those of Europe, followed with increasing precision by those of Cope, Marsh, Scott, Clarke, Dall, and Osborn. In 1899 Matthew published *A Provisional Classification of the Freshwater Tertiary of the West*, and this together with his *Faunal Lists of the Tertiary Mammalia of the West*, published in 1909, afforded the American bases for Osborn's *Cenozoic Mammal Horizons of Western North America*, published in 1909, in which for the first time the succession of the mammalian life of the New and Old Worlds is closely compared.

In the meantime increasingly accurate field methods, especially in the horizontal recording of levels after methods introduced by Osborn, Hatcher, and Wortman, have resulted in the subdivision of the old "formations" of Leidy, Cope, and Marsh into successive *Life-zones* similar to those long in use in invertebrate paleontology. These life-zones are obviously as important in questions of time as they are in questions of phylogeny or descent; they narrow down the old correlation standard of the comparison of similar specific and generic stages to different levels; they add greatly to the possibilities of precise comparison in respect to the newer data of correlation, such as detailed evolution of related forms, the simultaneous introduction of new forms by migration, the predominance or abundance of certain forms, the convergence and divergence of American and European faunas.

Putting together all these facts of various kinds, the first result is the proof that the mammalian life of Eurasia and America in Tertiary times passed through a series of grand phases of union, of divergence, of reunion, and perhaps again of divergence. There are seven of these phases.

In the *first*, in Basal Eocene times, we find North America, Europe, and possibly South America peopled with archaic mammals of Mesozoic ancestry.

In the *second* faunal phase, of Lower Eocene times, we observe the first modernization, which occurs simultaneously in Europe and North America, by the invasion of many modern families of mammals, which intermingled with the archaic; the life of Europe and North America continues to be very similar.

In the *third* faunal phase, beginning in Middle Eocene times, the mammals of America and Europe gradually diverge and undergo an independent evolution with little or no faunal interchange; at the close of the Eocene the two faunas are very far apart.

In the *fourth* faunal phase, beginning in Lower Oligocene times, there is a sudden reunion of New and Old World life. At the same time there occurs in both countries a second very surprising modernization apparently by the further invasion of modern forms from the north.

A *fifth* faunal phase occurs in the Middle Miocene, when there is a fresh reunion in the New and Old Worlds by the arrival in America of the proboscideans and the short-limbed rhinoceroses.

Then follows a long period of independent evolution in the two countries until in the Middle Pliocene we enter a *sixth* faunal phase, in which a close land connection with South America is re-established, after an interval of separation reaching back into Eocene times.

Finally a *seventh* faunal phase occurs in Pleistocene or Glacial times, when all the larger North American mammals become extinct, as well as the south American invading stocks, while North America is replenished by a large fauna from Eurasia.

It will be noticed that these phases are in no way coincident either with the greater or with the lesser time divisions, for the obvious reason that these time divisions have all been established on the basis of the evolution of invertebrate life in Europe.

EOCENE

Basal.—The very opening of the Eocene furnishes one of the most brilliant examples of the possibilities of precise correlation through vertebrate life. Changes occurring in the interior of the American continent may be compared precisely with those along the northern coasts of France and Belgium. In each case great forms of reptilian life persist to the very close of the Cretaceous; the conditions of the American "Laramie," "Hell Creek," or Ceratops beds are similar to those of the Danian or Maestrichtian of Belgium; both mark the abrupt termination of the Age of Reptiles; both are overlaid by beds

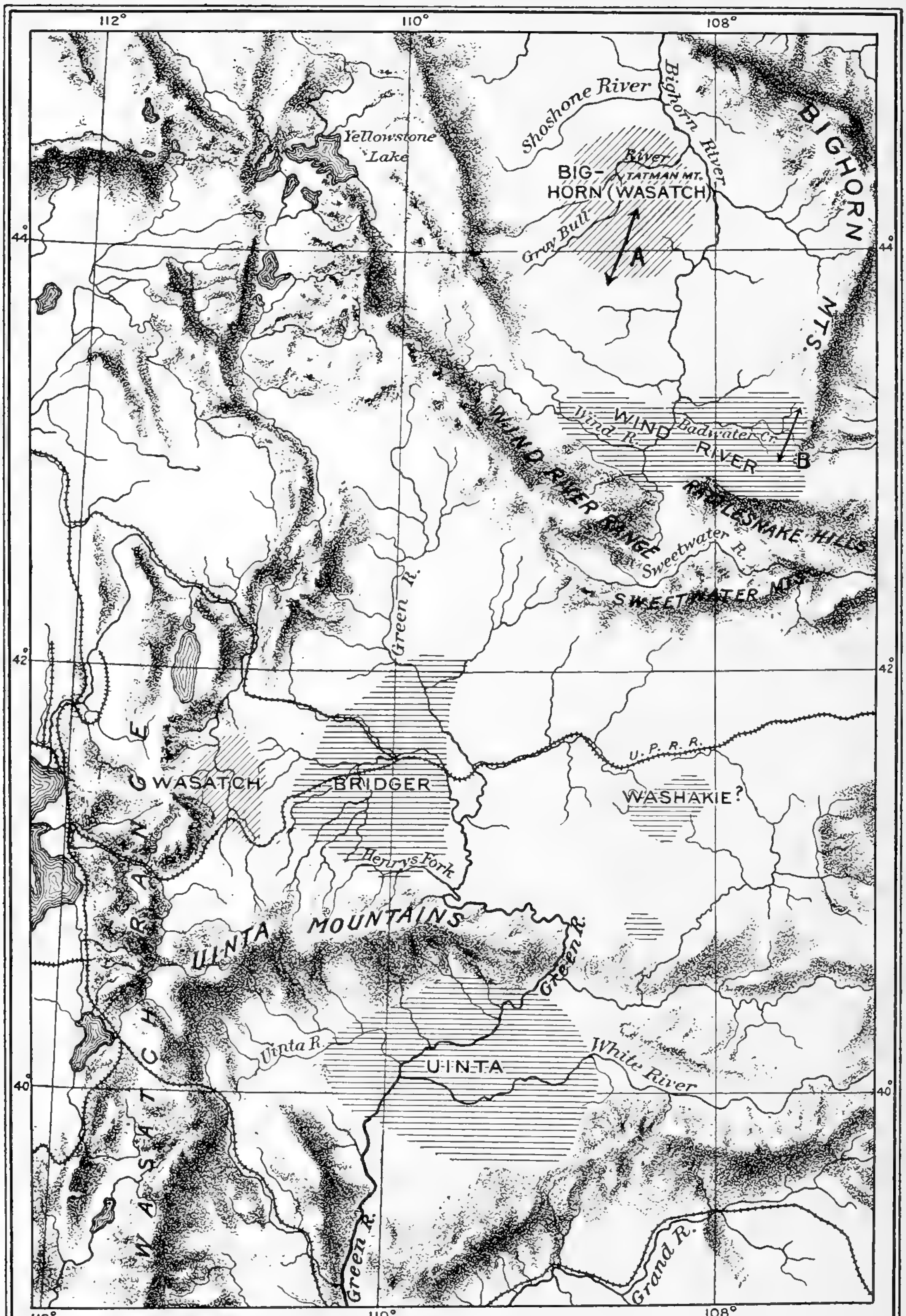

FIG. 1.—Map of southwestern Wyoming and northern Utah, showing partial areas of the Wasatch, Wind River, Bridger, and Uinta formations. Extensive areas of the Wasatch are purposely omitted. A, B, lines of sections by F. B. Loomis.

containing a number of very distinctive types of archaic mammals mingled with those of distinctive reptiles (*Champsosaurus*) found alike in the Puerco of Mexico, the Fort Union of Montana, the

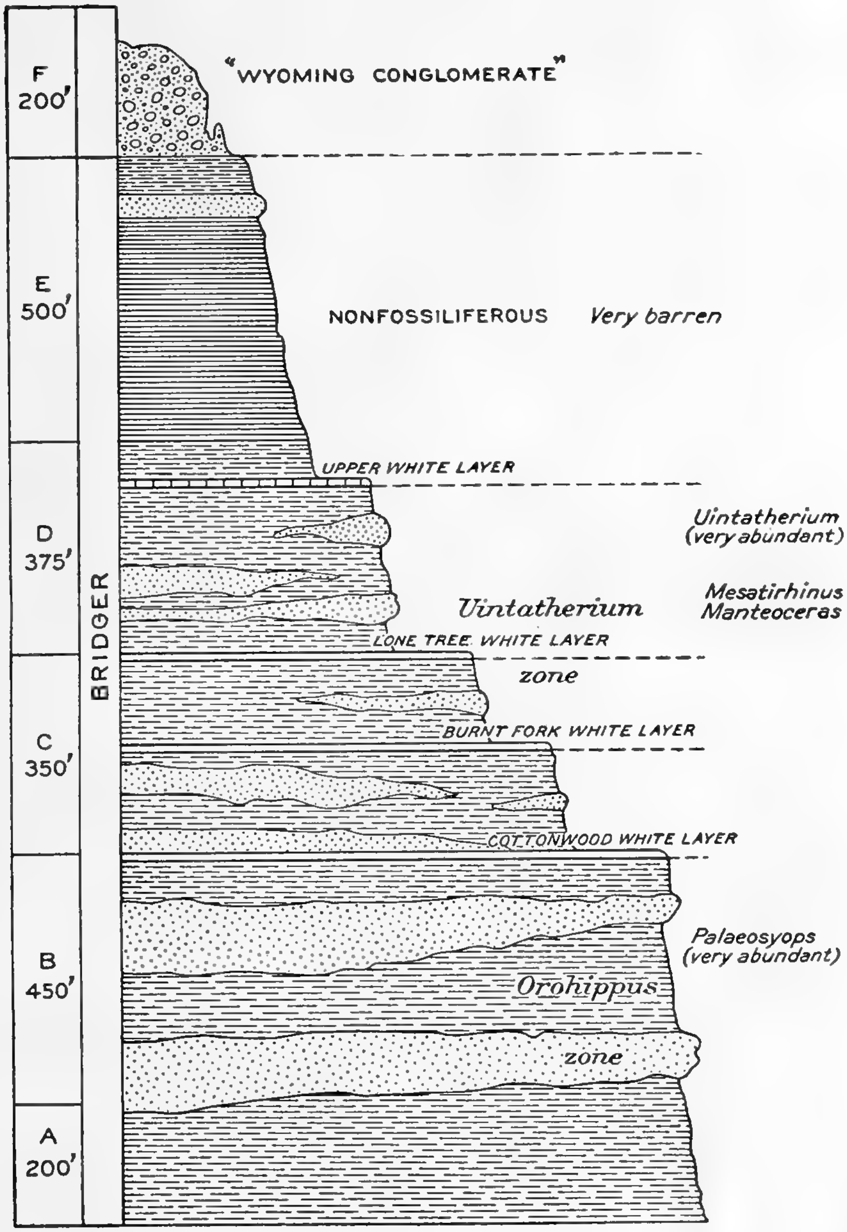

FIG. 2.—Columnar section of the Bridger formation, Henrys Fork, western Wyoming. After studies by Matthew and Granger, 1902.

Thanetian of northern France. Thus we believe the opening of the Tertiary admits of close correlation in the Old and New Worlds. The succeeding rich Puerco-Torrejon mammalian life of New Mexico, so far as known, parallels that of the Thanetian (including the

Cernaysian) stage of northwestern Europe. It is all *Paleocene*, or Basal Eocene.

Lower.—The beginning of the Lower Eocene is clearly defined in the Rocky Mountain region and with equal sharpness in northern France and Belgium by the appearance of *Coryphodon*, and by the

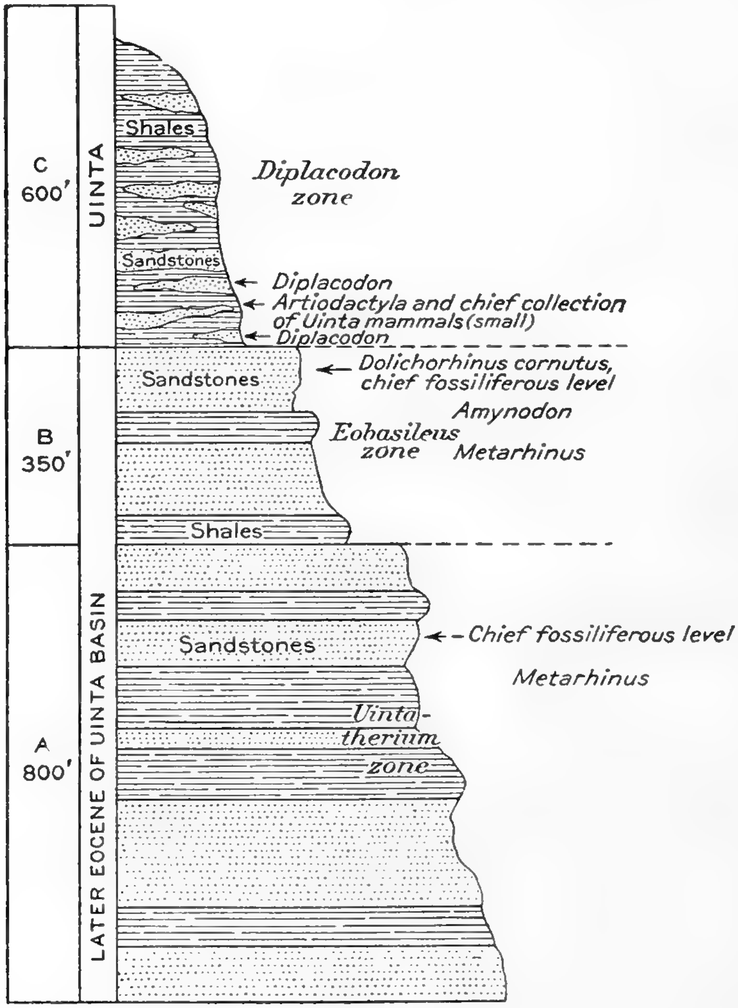

FIG. 3.—Columnar section of the Uinta formation, northern Utah. In A and B the diagram does not properly represent the irregular nature of the so-called sandstones and clays, which are probably in part coarser and finer volcanic-dust deposits. Modified from notes by O. A. Peterson, 1894. Faunistic studies by Osborn.

opening of the second faunal phase with its advent of modernized life. Our Lower and Upper Wasatch correspond respectively with the Sparnacian and Ypresian stages of France. It is represented in deep and fairly rich exposures in northern New Mexico and in western, central, and northern Wyoming.

The Wind River of central Wyoming together with the Lower Huerfano near the Spanish Peaks of Colorado marks the upper life-zone of *Coryphodon* and may prove to correspond closely with the Ypresian of France. In the Rocky Mountains the Wind River is readily distinguished by the survival of a number of characteristic Lower Eocene types (*Coryphodon, Phenacodus*) and the fresh arrival of a number of equally characteristic Middle Eocene types (uintatheres, titanotheres). It is consequently an ideal transition fauna. Unfortunately the formations believed to be of corresponding age in France are poor in mammal remains.

From this time on to the summit of the Eocene we are passing into the third faunal phase, or divergence and independent evolution of the life of Europe and America. Consequently close correlation is almost impossible; at no period in the Tertiary were the Nearctic and Palearctic faunas so widely separated.

Middle.—With the American Bridger, 1,800 feet in thickness, we enter the Middle Eocene and broadly compare the Lower Bridger with the Lutetian and the Upper Bridger with the Bartonian of France. The precise survey of the life-zones of the Bridger by Granger and Matthew marks one of the greatest advances of recent times.

Similarly under the direction of the present writer the Washakie of central Wyoming has been surveyed precisely by Granger, proving that the Lower Washakie is identical in age and in its mammalian life with the Upper Bridger and broadly corresponds with the Bartonian, or closing stage of the Middle Eocene of France. We are now in the Uintatherium Zone, all the famous discoveries of Cope and Marsh having been made at this level. Here belongs also the beginning of the Uinta deposition of northern Utah.

We now pass into the Eobasileus Zone of the Upper Washakie and the Middle Uinta, in which the long-headed uintatheres described by Cope as *Eobasileus* and *Loxolophodon* occur mingled with remains of highly specialized Eocene titanotheres. This is apparently the lower level of the Upper Eocene and is broadly comparable with the Ludian stage of France.

Upper.—The succeeding Ligurian stage of France may be paralleled with the upper, or true Uinta, the Diplacodon Zone of Marsh.

The zonal type is a large titanothere with well-developed bony horns, transitional in many characters to the Lower Oligocene titanotheres; in fact, the summit of the thick Diplacodon Zone of 600 feet will probably prove to coincide with the base of the White River Group on the great plains. Quite recently, during the summer of 1909, the much-desired sequence of Oligocence and Eocene strata was discovered by Mr. Granger of the American Museum expedition. The Diplacodon Zone has been discovered in the Wind River region of Wyoming underlying the Titanotherium Zone.

The Ligurian stage of France is that of the famous Gypse de Montmartre discovered by Cuvier, full of paleotheres and anoplotheres, a mammal fauna totally distinct from that of the Rocky Mountain region.

OLIGOCENE

Lower.—The Oligocene opens in the New and Old Worlds with the fourth faunal phase and second modernization, which since it affects alike Europe and America probably indicates a fresh migration from the great unknown northern, or Holarctic region. With this migration close faunal resemblance is re-established with western Europe, and thereby comes a welcome means of geologic correlation; in other words, we may with considerable confidence consider that the base of the White River group was nearly coincident with the inferior Tongrian of France. Sixteen new families of mammals appear in America, all of them still existing, and seventeen modern, or still existing, families appear in Europe. This momentous faunal change in North America is partly attributable to the fact that this is our first glimpse of the life of the Great Plains.

Middle.—The Lower Oligocene, or Titanotherium Zone, most accurately surveyed by Hatcher, is succeeded by the Middle Oligocene or Oreodon Zone, broadly comparable with the Superior Tongrian and Stampian of France, both containing similar types of amphibious rhinoceroses and many other mammals. One of the chief points of interest here is the sharp separation discovered by Matthew between the plains-living mammals buried in the so-called clays, or finer deposits, and the forest-living mammals buried in the coarser intrusive river sandstones.

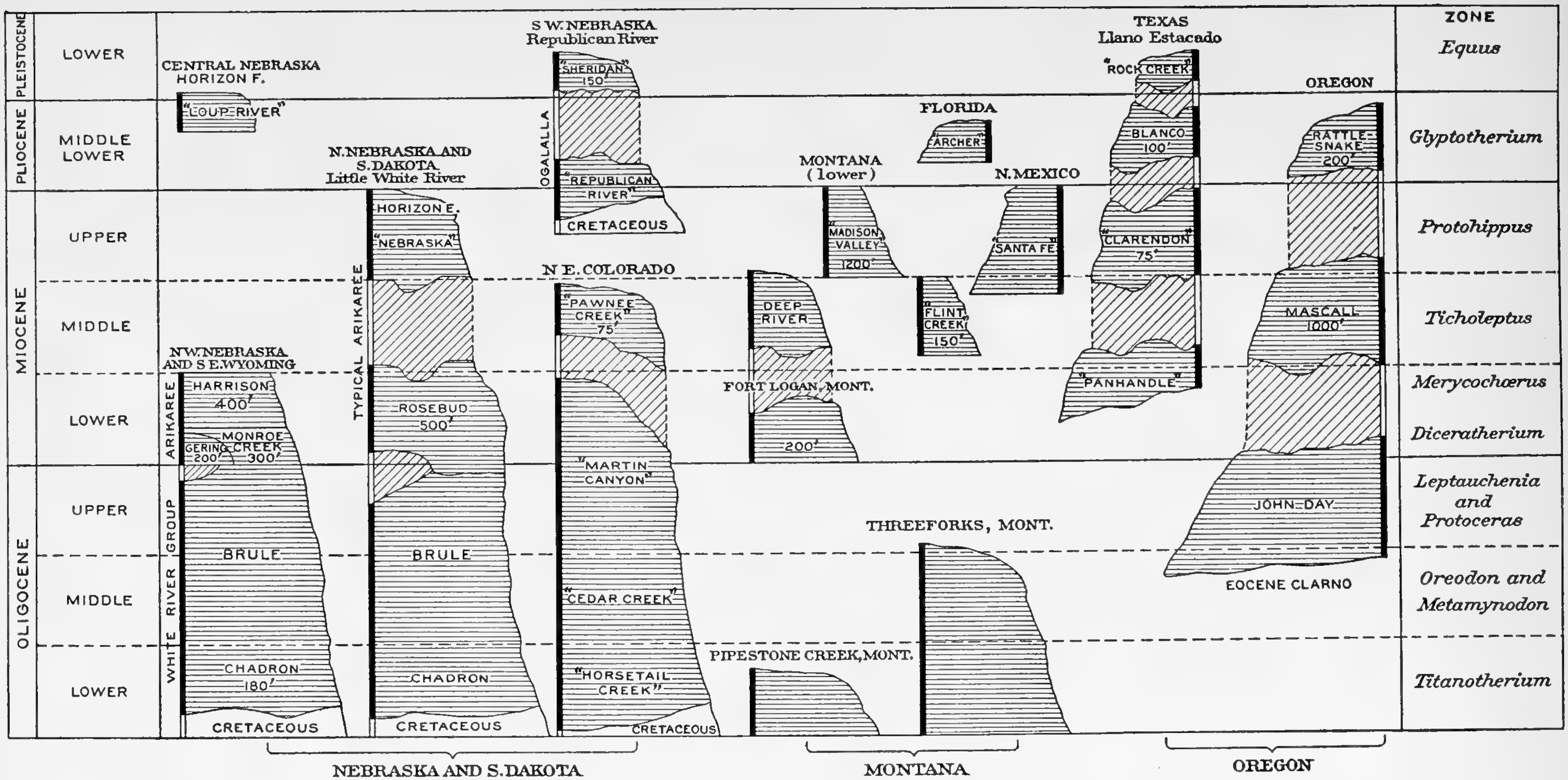

FIG. 4.—Provisional correlation of some of the chief epicontinental Oligocene-Pleistocene deposits and formations of the West in which fossil mammals have been recorded. Unlike the sections in the other figures, these sections are not represented to scale; they are purely conventional. After W. D. Matthew and H. F. Osborn, 1907.

Upper.—The close of the Oligocene takes us into the John Day tuff deposits of Oregon, and is generally parallel with the Aquitanian Stage of France, typified by St. Gérand-le-Puy. It is the Diceratherium Zone, or the climax of the evolution of the pair-horned rhinoceroses in both countries. We pass also into the Upper Merycochoerus Zone at the summit of the John Day and at the base of the Arikaree formation extending along Pine Ridge of South Dakota. Here we are again in difficulty in determining just when the American Oligocene should be regarded as closing and the Miocene as beginning. An abundance of diceratheres and entelodonts still betokens Oligocene times, but it is possible that we may be in the Miocene. This is one of the doubtful points requiring further investigation.

MIOCENE

The solution of the Lower and Middle Miocene sequence in America through the discoveries of Hatcher, Peterson, and of Matthew marks another great advance of recent years.

Lower.—There is no question that in the Upper Arikaree, the Upper Harrison of Hatcher, and the Upper Rosebud of Matthew we are fairly in Lower Miocene times corresponding with the Burdigalian of Europe. There is now considerable faunal difference between the New and Old Worlds. The Proboscidea certainly enter Europe at this time, and one of the debated points is when they first appear in North America.

Middle.—The Vindobonian, or Middle Miocene of Europe, divided into the three successive stages of Sansan, Simorre, and St. Gaudens, is again with considerable confidence compared with the Deep River of Montana, and the Pawnee Buttes of Colorado, through the researches of Scott and Matthew. Here we enter the fifth faunal phase, marked by fresh migrations and the first undoubted appearance of the proboscideans and short-limbed rhinoceroses in America, both arrivals from the Old World. Physiographic changes are indicated in evidence of increasing summer droughts, numerical increase of animals adapted to plains-living and the semi-arid conditions, in the disappearance of most of the browsing types. The correlation is, however, by no means close at present, because the life of Europe and the great American plains is of different local habitat.

Upper.—In the Upper Miocene, however, we are again somewhat more confident in correlating our Hipparion and Procamelus Zone, the "Loup Fork" of early writers, with the Pontian or Pikermi stage of Europe typified by the wonderful advent of the plains fauna of Asia which spreads all over southern Europe, probably into Africa and the far East of southern Asia and China.

PLIOCENE

It is difficult again to demarkate the close of our Miocene and the beginning of our Pliocene. For the first time in American Tertiary history an invertebrate paleontologist (Dall) comes to our aid through discovering that the mammals of the Alachua Clays of Florida overlie certain true Lower Pliocene molluscs. The mammals of these clays are comparable to those of the Republican River of Kansas, and we are consequently disposed to place the latter in the Lower Pliocene. It is at least a more recent phase than the "Loup Fork," and is hence distinguished as the Peraceras Zone, from the presence of a number of broad-skulled hornless rhinoceroses.

Lower.—Of undoubted Lower Pliocene age is the recently discovered Snake River deposit of western Nebraska, the Neotragocerus Zone, and the Virgin Valley and Thousand Creek of Nevada. The arrival at this time of true Old World tragocerine and hippotragine antelopes from Asia, as identified by Matthew and Merriam, is one of the most noteworthy discoveries in recent paleontology. These antelopes may prove to demarkate our Lower Pliocene, in which case the Republican River will be pushed back into the close of th Miocene because it certainly does not contain these Old World forms.

The Lower Pliocene, or Plaisancian, of Europe is represented by the mammalian life of Casino, which is very sharply demarkated from that of Pikermi.

Middle.—The Astian, or Middle Pliocene, life of France, typified at Roussillon and Montpellier, is broadly comparable with the Blanco of Texas, where we enter the sixth faunal phase, marked by the invasion of South American armored edentates, or glyptodonts, into the southern United States. These deposits are accordingly known as the Glyptotherium Zone. They mark a great advance upon those of the Republican River.

PRELIMINARY CORRELATION

		EUROPE	ASIA	NORTH AMERICA
PLIOCENE	Upper	SICILIAN	Siwaliks	"Loup River"
	Middle	ASTIAN	Siwaliks	Blanco
	Lower	PLAISANCIAN	Siwaliks	Thousand Creek Rattlesnake and Republican River
MIOCENE	Upper	PONTIAN	Manchhar	"Loup Fork" Madison Valley Clarendon
	Middle	VINDOBONIAN	Manchhar	Deep River Pawnee Buttes Mascall
	Lower	BURDIGALIAN		Arikaree "Upper Harrison" Rosebud
			AFRICA	
OLIGOCENE	Upper	AQUITANIAN		Harrison (Lower) John Day White River(Upper)
	Middle	STAMPIAN		White River (Middle) Brulé Clays
	Lower	SANNOISIAN	Fayûm	White River (Base) Cypress Hills Pipestone Creek Chadron
EOCENE	Upper	LUDIAN	Fayûm	Uinta (Upper and Middle) Washakie (Upper)
	Middle	BARTONIAN		Uinta (Lower) Washakie (Lower) Bridger (Upper)
		LUTETIAN		Bridger (Lower) Huerfano (Upper)
		UPPER YPRESIAN		Bridger (Lower) Huerfano (Upper) Green River
	Lower	LOWER YPRESIAN		Huerfano (Lower) Wind River Wasatch (Upper)
		SPARNACIAN (Upper Landenian of Belgium)		Wasatch (Lower)
		UPPER THANETIAN (=Cernaysian) (Lower Landenian of Belgium)		Torrejon Fort Union
	Basal	LOWER THANETIAN		Puerco Fort Union
CRETACEOUS	Uppermost	DANIAN = Maestrichtian (Terrestrial) (Marine)		Hell Creek

Upper.—The Upper Pliocene, or Sicilian, stage of Europe, typified by the Val d'Arno fauna of northern Italy, is hardly comparable with any American horizon. We are here on the border-line between Pliocene and Pleistocene, and a great deal of research is still needed. The Peace Creek deposits of Florida (Dall) may help us because here we discover an Equus and an Elephas Zone overlaid by marine Upper Pliocene molluscs. Rather primitive forms of Equus and Elephas are also characteristic new arrivals of the Upper Pliocene, or Sicilian, stage of Europe. The same doubt applies to the little-known "Loup River" of Nebraska, in which *Equus* and *Elephas* were discovered by Leidy many years ago.

PLEISTOCENE

Perhaps the most striking determinations which await the mammalian paleontologist are those which close comparison of the Pleistocene stages in the New and Old Worlds will afford. In Europe we have four great series of correlation data, namely:

The geologic succession of the glacial depositions;

The faunal succession especially among the higher mammals;

The evolution of stone implements of human manufacture;

Stages in the skeletal evolution of man.

In America the two kinds of data connected with the evolution of man are entirely wanting, and we are thrown back on the geologic and the faunistic divisions; consequently close comparison in these two lines of evidence common to both countries is all the more necessary. In Europe it is possible to distinguish four grand faunistic phases, namely:

The first early Pleistocene fauna, Eolithic Stage of culture;

Second or mid-Pleistocene fauna, Eolithic and early Paleolithic Stages;

Third or Upper Pleistocene fauna, late Paleolithic Stage;

Fourth, post-Glacial fauna, Neolithic Stage.

From close study of the Pleistocene life of North America there is promise of correlation with Europe through identification of American with European glacial and interglacial periods, through the discovery and identification of interglacial faunas, as in the Aftonian and Toronto deposits, through the careful recording of the time of extinction of native types and of the time of arrival of new types to demarkate our Pleistocene also into great successive life-zones.

The chief progress made thus far (1909) is that we begin to recognize the following divisions of American life:

Early and mid-Pleistocene life of the plains, *Equus* Zone;

Mid-Pleistocene life of the forested regions, *Megalonyx* Zone;

Life of the maximum cold period, *Ovibos* Zone;

Life of post-Glacial times, Zones of *Cervus* and *Homo.*

Especially interesting is the coincidence of the maximum cold period, or *Ovibos,* Musk Sheep, Zone of America, with the maximum cold period, or *Elephas primigenius, Rangifer tarandus* Zone of Europe.

It is obvious that we should never expect to discover as clear demarkation of the life-zones in America as in Europe because of the vast refuge areas of the mammals in the south. In Europe the glacial advances are sharply punctuated by the appearance and disappearance of species. In America apparently such appearances and disappearances are gradual.

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CHAPTER XIV

PHYSICAL GEOGRAPHY OF THE PLEISTOCENE WITH REFERENCE TO THE CORRELATION OF PLEISTOCENE FORMATIONS

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The character of the changes which marked the transition from the Tertiary to the Quaternary were somewhat unusual, though not unique as they were once believed to be. Great as these changes were, they were probably not equal in magnitude or importance to the changes which marked the transition from one great era of the earth's history to another. The significant changes at the close of the Tertiary are those which had to do (1) with the height and extent of the land and, perhaps as a result of these changes, (2) with profound alterations of climate, bringing on (3) glaciation on an extensive scale, and causing (4) migrations and mutations of life.

I. THE PHYSIOGRAPHIC CHANGES

The changes in altitude which affected the North American continent late in the Tertiary have not, in most places, been worked out in such detail as to lead to numerical results in which implicit confidence can be placed; but the general tenor of the evidence is harmonious, and the main conclusions are probably correct in their general terms. They may be summarized briefly as follows:

1. In the eastern part of the continent, the land is generally thought to have stood higher than before by some few hundred feet. If the more extreme views of a few of the geologists who have studied this question are accepted, the excess of elevation over the present was a few thousand feet.

2. In the larger part of the Mississippi basin, the gain in altitude was considerable, though still on a relatively moderate scale. In the eastern and central parts of the basin it is probably to be measured by a few hundreds of feet, rather than by figures of a larger denomina-

tion. There is some reason for thinking that the important topographic features of the central Mississippi basin are chiefly of late Tertiary and post-Tertiary origin, developed from a late Tertiary peneplain now represented by the summits of the higher hills and uplands of the region, a few hundred feet above the general level in which the present valleys are sunk. It is true that these summits have sometimes been interpreted as remnants of a Cretaceous peneplain; but this conclusion is not firmly established, and the alternative suggested above is entitled to consideration.

3. In the west, the relative uplift in the closing stages of the Tertiary and early Pleistocene was greater. The estimates of the late Tertiary and post-Tertiary uplift here at one point and another range from several hundred feet to several thousand feet. The figures are most definite and perhaps most satisfactory near the Pacific coast. In southern California, the uplift at this time has been estimated at 1,500 feet; in northern California, 1,500 to 2,000 feet; and in the Sierras at 3,000 to 6,000 feet. In Oregon, Pleistocene marine fossils are found up to elevations of 1,500 feet, while in and about the Cascade Mountains of Washington, an elevation of several thousand feet, maximum, seems to be well established.

In British Columbia, the relative upwarp of the corresponding time has been thought to reach an amount comparable to that of the Cascade Range, while, farther north, most of the estimates point to less extensive changes. The old peneplain which is now at an elevation of 6,000 to 9,000 feet in Washington and British Columbia, is thought to descend to 4,000 or 5,000 feet farther north. While the age of the deformation which brought the former peneplain of these northern lands to its present position has not been fixed with precision, the best opinion seems to place it, or at least its initiation, in the late Pliocene and early Pleistocene.

Students of the western interior have reached no general agreement as to the amount of late Tertiary and Quaternary change of level, but there is general agreement that the land of that region was notably higher at the close of the Tertiary, and later, than it had been before. The increase in the height of the land amounted, perhaps, to a few thousand feet in some places, but was probably far from uniform.

4. In the West Indies and Central America, the interpretation of facts and supposed facts seems to be more or less uncertain. Spencer would make the amount of change of level in the West Indies within this general period very great, even 8,000 to 11,000 feet higher than now. Hill would have some portions of Cuba at least 2,000 feet higher than now at or since the close of the Tertiary, and the Barbadoes 1,100 feet higher at about the same time, while Hershey thinks the Isthmus of Panama has been bowed up 1,000 feet or so since the beginning of the Pleistocene.

If even the more moderate of these figures are correct, it appears that the average relative increase in the altitude of the continent must have amounted to several hundred feet at least. This amount of elevation must have been adequate (1) to increase erosion by streams greatly, this increase resulting both from (*a*) increase in precipitation, and (*b*) increase in gradient of the streams; (2) to lower in some slight measure at least the average temperature of the land, and to increase its range; and (3) to reduce the amount of vegetation on the average, both because of (*a*) the unfavorable change in temperature and (*b*) the more rapid erosion.

Outside of North America, similar changes seem to have been in progress. Thus in South America, such determinations as are at hand point to an elevation approaching 3,000 feet at a maximum on the west coast of South America, since the late Tertiary. Changes of similar import, and perhaps of comparable extent, are indicated by the facts reported from other continents, though for all but Europe, the facts are meager. In Europe, changes of level at the close of the Tertiary were not everywhere great, but about the borders of the Alps, the increase of elevation is estimated by Penck and Brückner to have been 300 to 500 meters.

It should be noted that the deformations of this time were more important in affecting the height of the land than in affecting its area. Yet from the evidence of existing floras and faunas, it seems probable that the up-swelling of the contiguous parts of America and Asia were sufficient to connect them by way of the Aleutian Islands. Shaler and Spencer have urged reasons for thinking that Florida and Cuba were connected in the late Pliocene or early Pleistocene, but this conclusion cannot be said to be established. In Europe, within the same general period of time, England has probably been joined to the continent, and southern Europe to Africa. Submerged valleys on the northwestern coast of Europe, if interpreted in the usual way, indicate elevations several hundred to a few thousand feet greater than those of the present, enough, if some of the estimates are correct, to have connected Europe with Greenland and North America. If such a connection existed, it must have entailed changes in oceanic circulation sufficient to have affected the climates of high latitudes in an important way.

The very considerable changes at the beginning of the Quaternary were followed by a great succession of changes as the period progressed. Some of them reinforced the changes just sketched, and some of them were of the opposite phase. Oscillations of level during the Quaternary have been more carefully worked out along the coast of northern Europe than in America. Unexpectedly enough, evidence seems to point to greater depression during the glacial epochs than during the interglacial. The amount of the determined oscillations of level during the Quaternary range from a few feet to a few hundred feet.

II. EFFECTS OF PHYSIOGRAPHIC CHANGES ON CLIMATE

In many parts of the earth, as in the interior and eastern part of North America, in Europe, and elsewhere, the increase of elevation at the end of the Tertiary was probably not sufficient to be of great importance climatically, in a direct way. In other regions, as in the western part of North America, on the other hand, the gain in height was probably sufficient to produce considerable effects directly.

In an indirect way, the effect of the increase of average altitude of land on climate may have been much more considerable. Erosion was stimulated by the increase of altitude and by the decrease of vegetation due to the causes already mentioned. The increased rate of erosion led to the removal of the residual earths and alluvium which may well have accumulated on the surface to very considerable thickness, and the removal of these materials from the surface exposed the underlying rock to decay.

If changes in the constitution of the atmosphere are to be regarded as the cause, or as even one cause of climatic change, the increase of erosion at the close of the Tertiary would have led to an increased consumption of carbon dioxide, and so may have been responsible for the initial step in the series of changes which brought on the glacial climate. Though it is, perhaps, too early to affirm that the increased altitude of the land at this time was the basal cause which led to the cold climate which followed, this is a hypothesis toward which students of glacial geology are looking with much hope.

If the increased height of the land led to increased erosion, and so to increased consumption of carbon dioxide, the reduction of the amount of this gas in the atmosphere would have lowered the temperature everywhere. The resulting decrease in the temperature of the sea would have led to an increased solution of carbon dioxide from the atmosphere, thus depleting the atmospheric supply still further, and this, in turn, reacted upon the temperature and became a cause of its further reduction. This cause, therefore, once in operation, must have continued with increased effectiveness until the decay of rock was checked by decrease of altitude or temperature, or by the accumulation of ice-sheets which protected the rock beneath from ready carbonation.

III. THE DIRECT IMPORTANCE OF THE ICE-SHEETS THEMSELVES

Irrespective of the cause of the glacial climate, the covering of six million or more square miles of land in the northern hemisphere with ice hundreds and thousands of feet in thickness was in itself an extraordinary event which might well serve as an important landmark in geologic history. The ice-sheets, and especially the remarkable successions of ice-sheets, might appropriately be emphasized as proof of one of the most remarkable climatic incidents in the history of the earth, so far as now known. But apart from its great climatic significance, each ice-sheet meant the relatively rapid superposition upon the northern continents, over the great areas indicated, of a new layer of rock, the ice, which for tracts of millions of square miles must have had a thickness exceeding a thousand feet, and perhaps a thickness of several thousand feet. The aggregate volume of this new rock, superposed on the northern parts of the northern continents, was such that it could only have been measured in terms of millions of cubic miles. The withdrawal of its substance from the sea effected a corresponding lowering of its surface, an appropriate extension of land, and an increase in its height above the sea.

Though this great body of rock new-laid upon the lands was temporary in its character, primarily because of the low temperature at which its substance assumed the liquid form, it was of great importance, from a geologic point of view, in more ways than one.

1. In the first place, the loading of millions of square miles of land with such a weight must have had an appreciable effect upon crustal movements, if the doctrine of isostasy has validity, and its disappearance, under climatic conditions which developed later, must have produced movements of the same class, but of opposite phase.

2. Again, the development of the ice-sheets put a virtual stop to the processes which had been in operation over six millions of square miles of the land, and set other processes into operation in the same places. Thus the normal phases of river work were suspended, most rivers within the ice-covered area ceasing to flow altogether. The usual phases of rock weathering and decay were practically stopped over the same areas, areas which, in the aggregate, were a very considerable fraction of the surface of the land. On the other hand, a new process of erosion was substituted for the old—erosion not restricted chiefly to the removal of decayed rock.

3. The changes in erosion were hardly greater than those in sedimentation, for instead of the assortment and separation of decayed material into its several physical classes before deposition, fine sediments and coarse, largely of undecayed material, were left promiscuously commingled. Thus on a large scale and over enormous areas deposits were made which were unlike those of comparable extent at any other stage of the earth's history, unless at times when climates were similar.

4. It should be noted further that the changes in the processes of erosion and sedimentation—changes in kind as well as in rate—were not limited to the areas actually covered by the ice, or even to the areas affected by drainage from it, or by icebergs which floated out beyond its edge. Modifications of erosion and sedimentation were felt in all areas affected, directly or indirectly, by the change of climate.

The great ice-sheets, with the recurrent disturbance which they probably occasioned in the crust of the earth and the lesser changes in the surface of the ocean; with their recurrent inhibition of the usual processes of erosion and sedimentation over great areas; with their recurrent modification of these processes over other great areas beyond the ice-sheets themselves; and with their recurrent inauguration on a large scale of processes of erosion and sedimentation which were unusual, might, without consideration of further changes of an indirect character, furnish adequate bases for important time divisions. Especially is this the case since the influence of the ice-sheets must have been felt in a physical way, throughout most if not all the earth.

IV. CHANGES IN LIFE

The great changes in the physical processes which this on-coming of the ice-sheets brought into operation, effected corresponding changes in life and in the processes which depend on life. In the first place, the total amount of land life must have been greatly reduced. If account be taken of mountain glaciation in both hemispheres as well as of the ice-sheets, it is probably within the limits of truth to say that conditions became so far inhospitable as nearly to eliminate land life from about one-seventh of the land of the globe, and to have rendered conditions relatively inhospitable over a still larger area. The effect upon the life of the sea is less easily stated, but it also must have been great, for the average reduction of the temperature of the sea must have been considerable.

The crowding of land life off 8,000,000 square miles, more or less, must have tended to concentrate it upon the land which still remained hospitable, and to decimate or exterminate those forms which could not migrate readily. Migration must have been forced upon the sea life as well as upon that of the land, and the shifting of the zones of both must have resulted in a shifting of the sites of organic deposition, perhaps especially of the sites where limestone was made. At the same time, the rate at which it was formed, the whole earth considered, was probably much reduced.

It would seem, from the series of physical changes sketched, that very profound changes in life should have followed, but it must be confessed that, in spite of the conditions which it would seem must have been favorable for great destruction of life, and for imposing great modifications upon that which survived, statistical evidences of the changes which followed are less impressive than would have been expected. The data at hand do point to extensive migrations, but not to the exterminations and profound modifications which might have been anticipated. It seems impossible to think that the changes of climate which drove musk oxen to Kentucky and Virginia, and Arctic plants and reindeer to the lowlands of central Europe and to the Mediterranean, were without very profound biologic significance, unless the life of the earth had reached a condition of far greater stability than that of earlier times, when lesser physical changes seem to have produced greater biological changes.

One of the features of the late Tertiary land life, and especially of the floras, seems to have been the great extent to which types were mingled. This mingling of tropical or sub-tropical forms with temperate and boreal ones seems to have begun as early as the middle of the period. The oscillations of climate which marked the Pleistocene seem to have had a sifting influence upon the migratory forms, and to have forced them to special adaptations and habitats as the period progressed. This is suggested, for example, by the floras of America and Eurasia. Gray pointed out long ago that the forest flora of the eastern part of North America is more like that of Japan than like that of the western part of our own continent. In Europe, the north-south and south-north migration of the floras as ice-sheets advanced and receded was interfered with by the east-west mountain ranges and by the seas bordering Europe on the south. In eastern Asia and America, on the other hand, the back-and-forth migration of the floras was facilitated by the greater continuity of land between high and low latitudes, and in America at least, by the absence of east-west mountain ranges. In the western part of the United States, the irregular topography made repeated latitudinal migrations of the floras more difficult than in the eastern part, though perhaps less difficult than in Europe. In eastern Asia and in eastern America, where migration was relatively easy, the forest flora is much larger than in Europe or western North America. Thus Atlantic America and Pacific Asia have each 66 genera of forest trees, while Pacific America and Europe have but 31 and 33 genera respectively, and the number of species is approximately in keeping with the number of genera.

Vulcanism has been regarded as a factor which decreased the flora in the western part of North America as compared with the eastern; but since the floras were much the same throughout the Tertiary in all northern lands, and since the climax of Cenozoic vulcanism came as early as the Miocene, the importance of this factor in impoverishing the Pleistocene life of the western part of the United States may be questioned. Furthermore, it has little or no application to Europe, where the flora was equally reduced.

The to-and-fro movements of the land faunas and floras must have introduced an elaborate series of superpositions, giving an elaborate, orderly, and unusual succession. The record of this succession has not been worked out in its completeness, and unfortunately there is little chance that it will be worked out in its fulness unless by the most persistent care. In the regions which were glaciated repeatedly, the advance of each ice-sheet destroyed, in most places, the record of the successive floras and faunas which had lived since the preceding retreat, so that, within the area glaciated, the succession of successions is hardly likely to be found in its entirety in any one place, and perhaps not in all places. Outside the area which was glaciated, especially near the borders of the regions occupied by the successive ice-sheets, there is better chance that a complete record of the biological changes may have been preserved. The peat bogs of such regions might be expected to give complete records if they had endured continuously since the time of the first glaciation; but peat bogs are themselves temporary, and it is perhaps too much to expect that complete record of the migrations of life during the successive epochs of the glacial period will ever be found at any one place.

The records, however, of the post-glacial peat bogs are such as to give some indication of the results which would probably be found if all the migrations could be ascertained. Thus in Scandinavia and Denmark, we have a succession of post-glacial floras, the first corresponding in a general way to the present vegetation of the tundra, the second a forest vegetation dominated by the birch and poplar, the third a forest vegetation dominated by pines, the fourth, one dominated by the oak, etc., the fifth a flora similar to that of the Black Forest Mountains, indicating a temperature warmer than that of today for the same region, and finally, a southward retreat of the last flora to its present latitude. The first five members of the succession seem to correspond with the half of a normal interglacial series. If this interpretation is correct, this series of five floras would be nearly doubled with the on-coming of another glacial epoch, and this doubled series must have been repeated, substantially, several times in the course of the long succession of glacial epochs. Fragments of interglacial records have been found both in America and Europe. In a few cases they are full enough to encourage the hope that when their number is duly increased, they may be pieced together into consistent wholes. It is too much to expect that they will ever be as complete as the record of post-glacial life.

It is not now apparent just how far biologic or paleontologic data of the Pleistocene, except for their record of climatic changes, are to be significant in correlation. Aside from the mammals, changes of species have been insignificant. Even among mammals, it is not clear that the dying-out of species in one locality was contemporaneous with the disappearance of the same species in other localities. A stratigraphic basis for this interpretation would be needed before it could be accepted. So far as all other forms of life are concerned, the paleontologic record of one interglacial epoch must have been essentially identical with that of another, if the intervals were equally long and mild.

Perhaps more help in correlation may be looked for in another direction. Intercontinental migrations, it would seem, must have been virtually restricted to interglacial epochs. The times when species first appeared in a given region may therefore prove to be much more significant in correlation than the times when species died out.

Something perhaps may be hoped for in the careful study of the records of oscillations of level, during the period; but it seems clear that different parts of the same continent have suffered minor or even considerable deformations, independently of others. If it were established that opposite sides of an ocean basin were less independent in this respect—a doctrine for which much might be said—the movements on opposite sides of an ocean basin might be a hopeful line of research; but it cannot, at the present time, be said to have led to important conclusions.

It would appear that only through a combination of stratigraphic, climatic, paleontologic, and orogenic studies, carried out in greater detail than they have yet been, can important results in the correlation of Quaternary formations be reached, between widely separated areas.

PALEOGEOGRAPHIC MAPS

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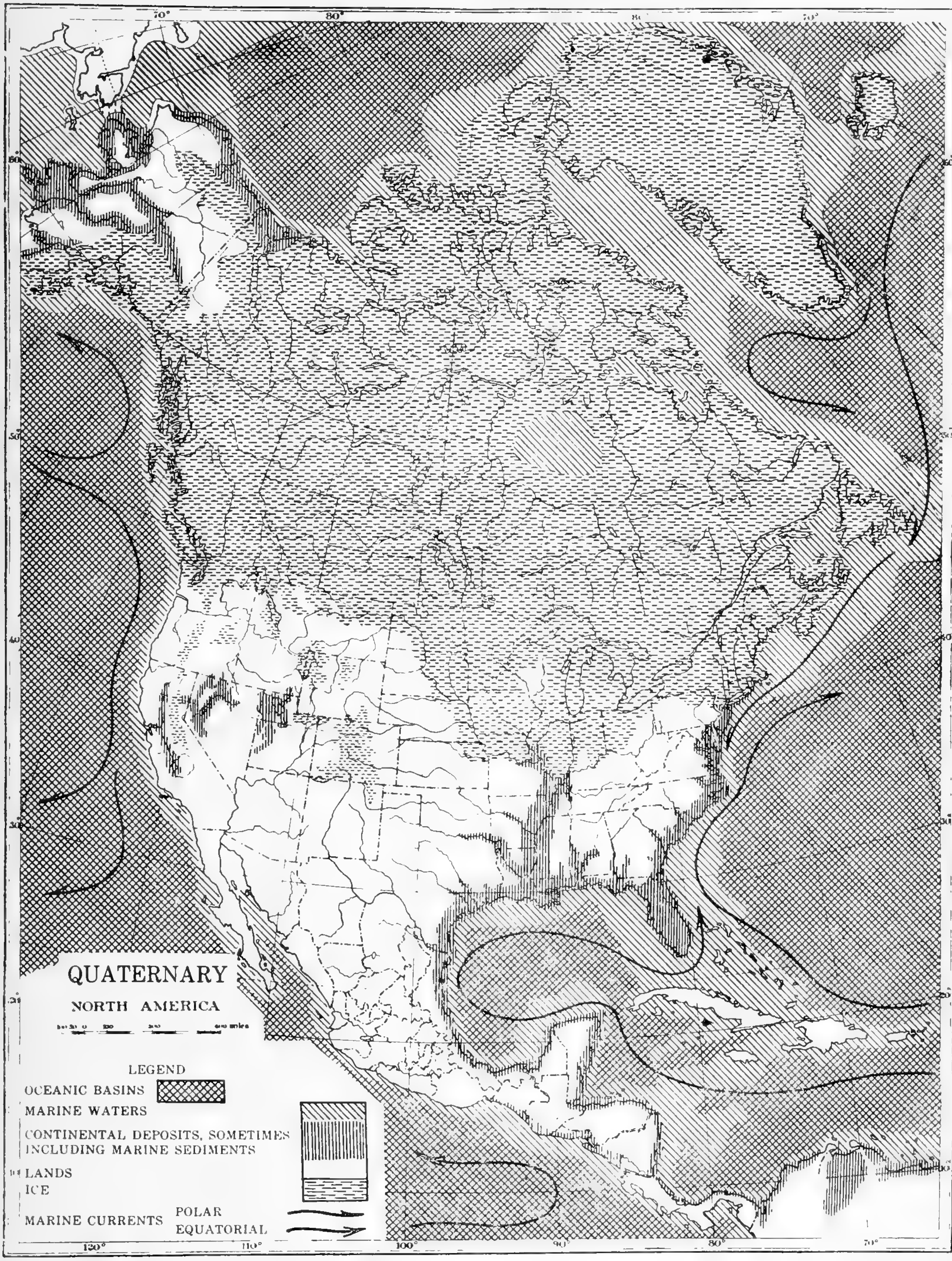
15. QUATERNARY NORTH AMERICA

North America during the Quaternary presents very unusual features. The land area is large. The margin of the continental plateau is now somewhat submerged, but probably has not been so throughout the period. Marine embayments are not extensive, except Hudson Bay, which is a fair example of the smaller epicontinental seas that have spread over various parts of the continent in the past. Mountain systems that are great in extent and height have grown from the places of the early Tertiary ranges of the Cordillera, which had been deeply eroded before the Pliocene. The Appalachian Mountains, which began to rise above the plains of eastern America possibly as early as the Eocene and which toward the close of the Miocene had ceased to grow at something less than half their present greatest height, have been raised to their existing altitudes during the Quaternary.

These mountain features of North America are paralleled or exceeded in other continents and the period is thus characterized as one during which the forces that raise mountains have been decidedly active.

In late Tertiary time great differences of climate developed. The equatorial, temperate, and polar zones became much more unlike than they ever had been, according to the geologic record. The Quaternary is distinguished by the development, the advances, and retreats of several ice sheets, whose combined areas are shown on the map. The expanse of ice was at no one time so great, but the entire area shown as ice was covered at one time or another, and some parts of it several times successively, by continental glaciers.

The developments of topography and climate, including polar refrigeration and corresponding modifications of oceanic conditions, have greatly changed the environment of plants and animals, and have resulted in special phenomena of competition and adaptation, through which existing forms have been evolved.


QUATERNARY
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
LANDS
ICE
MARINE CURRENTS POLAR
EQUATORIAL
120°
110°
100°
90°
80°
70°

CHAPTER XV

ORIGINATION OF SELF-GENERATING MATTER AND THE INFLUENCE OF ARIDITY UPON ITS EVOLUTIONARY DEVELOPMENT

D. T. MACDOUGAL

Any attempt at an interpretation of a desert landscape, with its diversity of forms, isolation of individuals, and scarcity of organic matter in the soil, leads inevitably to a consideration of the theoretical conditions which would be necessary in the origination of the physical basis of life, its development into organisms known to us in the living and fossil state, and also of the possibilities of the occurrence of a re-generation at the present time.

From almost every excursion which the biologist has made into this inviting field of speculation on which he has called to his aid various extreme or unusual intensities of the factors to be taken into account, he has been ruthlessly recalled by the geological historian with the reminder that the general composition of the atmosphere, its pressure, the temperatures, and other conditions prevalent on the earth's surface were uniform and continuous with those now encountered and not widely different, in their total departure, in any stage of terrestrial development in which life might have originated.

Now we are not able to discover that living or self-generating matter is actually being formed anew on the earth's surface at the present time, and in the absence of positive evidence we are compelled to say that all life now in existence must have descended from forms which had their ultimate origin in other times and under other conditions than those now prevalent.

A consideration of the phyletic aspects of fossil and living forms of plants yields but little, which might serve as an indication of the conditions under which the earlier forms developed. Even the earliest remains include such advanced types as the ferns and cycads. The amount of progress represented by the derivation of the gametopetalous seed-plants from these, in comparison with the preceding evolution, is quite insignificant, while even the simpler forms of animals and plants are to be considered as types widely divergent from primitive self-generating matter, being removed from it by the slow but sure advances of untold millions of years of development.

It is, therefore, as if we had observed the events and objects of yesterday and were called upon to read the history of the past century. In the search for supporting ideas upon which to base speculation, two conceptions serve as encouragement for a renewed attack upon this fascinating problem. One is embraced by Chamberlin's planetesimal theory of the growth of the earth and the attendant modification of surface conditions, which necessarily showed a complex widely different from the present, and the other is one, growing in favor with physiologists, to the effect that the essential activities of living matter rest upon catalysis, and enzymatic processes, with the characteristic reaction velocities directly affected by internal and external limiting factors. The protamic nucleus may be taken to represent the first form in which self-generating matter might be said to have the characters of protoplasm, but previously to its synthesis there must have occurred an increasingly complex series of carbon compounds, with hydrogen, oxygen, nitrogen, sulphur, and phosphorus, while iron, calcium, magnesium, and potassium are also involved in its activities at the present time. That these main constituents were present in the atmosphere at partial pressures of varying intensity, and that unstable carbides, nitrates, phosphides, and sulphides brought by infalling planetesimals were passing into more stable unions with the formation of hydrocarbons, ammonia, hydrogen phosphide, etc., is suggested by Chamberlin, and the possible interactions and combinations might result in the synthesis of very complex substances, well up toward the simpler forms of living matter. The hypothesis formulated by him also assumes that the surface of the earth was unworn piled talus, but little of which had gone into solution. The development of the hydrosphere moistening this layer, and forming pools and small bodies of water all exposed to the light of the sun, together with the variations in temperature, partly due to the heat of impact of infalling bodies, the influence of magnetic fields induced by bodies circulating about the earth determining the paths of ions and electrons traversing them, and other states of ionization, due to radioactivity, would all be possible factors contributory to a synthesis that might form a beginning of the physical basis of life. Any resulting thermo-catalyzer would be a possible agent for self-organization, and in the development of an organic type its characteristic activities would consist in the degradation, or reduction of the potential energy of the medium or substratum and the oxidation of the acquired substances. Living matter is in fact a thermal engine in which the oxidation is, comparatively, exceedingly slow.

FIG. 1.—Mud-volcanoes of Lower California, in and around which unusual opportunities for chemical combination are offered by the conditions of temperature and pressure.

No process observable by available physiological methods suggests the origination of living matter, yet it seems quite probable that combinations similar, analogous, or even identical with the earliest forms might be produced in the laboratory, in inclosed spaces or under special conditions. Doubtless compounds of much greater intricacy have been made, but while we might make such substances, yet it would be extremely difficult for us to furnish the supply of material and the continuance of conditions which would permit this matter to exercise its initial functions of self-generation to any appreciable extent. The starting of a strain of living matter which might perpetuate itself and evolve into differentiated forms will long remain one of the most difficult feats which confronts the experimenter. The tests and criticisms which have been applied to the results of the few essays that have been made for the production of bodies which would be self-maintenant in a suitable medium, have been, for the most part, misdirected. Thus in the consideration of the hitherto unsuccessful efforts to produce bodies simulating some of the properties of self-generating matter, tests for the physical and chemical properties of protoplasm as well as for phenomena of the cell have been applied, regardless of the fact that the cell probably stands removed by a million years of evolution from the simple living material which first took shape, and represents, in fact, simply a successful form of organism and by no means the only possible morphological organization.

Such misuse of criteria has doubtless operated to curb research and discourage experimentation, and while it may have seemed soundly conservative for Kelvin to say:

> But let not youthful minds be dazzled by the imaginings of the daily newspapers that because Berthelot and others have thus made foodstuffs they can make living things, or that there is any prospect of a process being found in any laboratory for making a living thing. . . . . There is an absolute distinction between crystals and cells. Nothing approaching to the cell of a living creature has ever yet been made,[1]

yet the actual accomplishment of self-generating matter is, as suggested above, a theoretical possibility in the laboratory. The provision of a proper nutritive environment would present greater difficulties than the construction of a thermo-catalyzer capable of sustaining itself in a proper medium.

After growth and decay, the next most important property of living matter is that of irritability, of impressibility, and of accommodation to environment. The basic substance of protoplasm endured because of a capacity for withstanding the current range of temperature and insolation, and this endurance was made possible by fairly automatic adjustments, one of the simplest of which is encountered in recognizable form in living plants today in the decrease of water content, consequent upon the cooling of protoplasm. Few

[1] *Nature*, XXXI, 13, 1904.

adjustments are so simple, and, of course, more complicated ones became possible as atomic group after atomic group was added to the constituency of living matter.

Along with these acquisitions the feature of the rhythmic action which has become so characteristic and important for the living growth is to be considered, and this with contractility is dependent upon surface tension, viscosity, etc.

So far the properties suggested are those common to all living forms, but there must have ensued many differentiations of living matter, of which we have two survivals in plants and in animals. It seems probable that the first specialization resulted from the formation of substances in some of the living masses which converted radiations of certain wave-lengths into heat and other forms of energy active in promoting the reduction processes. A fortuitous movement toward such specialization may indeed have been the factor that made for survival in an environment of decreasingly available supply of chemical energy. The highest development of this power of absorption of light rays is to be assigned to chlorophyll, but preceding the formation of this very intricate and unstable substance there may have occurred a series of other compounds acting as heat-absorbent screens, of which the reddish and bluish pigments of the lower algae are surviving examples. Many disintegration products constituting the reds and blues of plant tissues sustain physical relations of a similar character to sunlight.

It is not possible to formulate any rational conception of living matter without including its environmental relations. These become of the utmost importance at the moment of formation of self-generating matter, and it may be assumed with perfect safety that of all the possible synthetic processes only those which ensued in the presence of a medium which furnished substances suitable for building material could survive. Furthermore, when the accumulation of this material and its specialization is considered it is apparent that successful origination occurred only on solid or semi-solid substrata rather than in undifferentiated solutions in open waters. Still an abundance of this liquid would be of great importance to the colloidal masses which we may think of as the earliest living things, and, as will be shown presently, water has continued to be the most important of all of the things affecting development especially with regard to the vegetal organism. The first method of multiplication of individuals or colloidal masses undoubtedly consisted of simple fragmentation resulting from the accumulation of a mass too great to be held together by surface tension, and the separation of these masses must have been accomplished, or made possible by flotation which continues to be one of the most efficient agencies in the dissemination of plants, a fact specially emphasized by the results of our studies upon the revegetation of the Salton Basin.

An early specialization of structure probably rested upon the reduction of portions of the self-renewing colloidal masses from the suspended condition of a sol to the condition of a gel, and doubtless the limiting membranes of protoplasmic masses depend upon this process. Likewise some form of centrum resulted from congelation processes by activities of a nature elementary to the relations of the nucleus and cytoplasm in the modern cell.

Wherever portions of the colloidal mass came into contact with solid substances gelation or aggregation ensued, and the masses of material thus differentiated would give form and stability in place, representing the earliest form of anchorage organ. In this as well as in other features of the plant, evolutionary development was slow so long as the monotonous conditions of an aquatic habitat were to be met. Very simple processes or extrusions from a cell or coenocyte of this general nature are still to be encountered among certain algae.

As soon, however, as it was left stranded by the disappearance of the shallow waters in which it may have lived, or was lifted above the water level by any means, the diversified conditions encountered by the organism, including desiccation, exercised a differentiating effect on the root-organ scarcely less marked than those which may be ascribed to the same agency in the shoot. The necessity for anchorage was no less, but now the nutritive substances no longer bathed the entire body but were present only in hygroscopic solutions on the soil particles with a vertical distribution not uniform, and with much horizontal irregularity. Survival depended upon the formation of specialized tracts for absorption, and conduits for the transport of solutions from the organ of fixation to other parts of the living mass. It is to be noted, however, that the modern root arose anew from the vegetative axis, and is therefore not directly derived from the primitive anchorage organs described.

The present occasion does not warrant a discussion of the evolutionary development of the vegetal organism from the colloidal mass to the gametophyte, now represented by the prothallium of ferns and their allies. Neither is it necessary to recall details of plant anatomy further than to point out that the earlier forms of plants, co-ordinately with the monotonous conditions offered by their acquatic habitats, showed no differentiation of tissues comparable with that of the axis of the modern seed-plant, and that their flattened bodies were for the most part closely appressed or adherent to the substratum. The development of the sexual type of reproduction in such forms had been followed by a habit of formation of the sexual organs separately, perhaps some distance apart on the upper or lower surfaces of the body. In the functionation of such organs the two kinds of protoplasts representing the sexual elements would be set free at the surface of the body and accomplish union while swimming freely, or in higher stages of development, the one representing the egg-cell would remain in place, while the fertilizing protoplast, or spermatozoon would find its way to it. In either case free water was absolutely necessary for reproduction. The body of the plant might be partially or completely immersed, or it might have only a thin film coating the surface, through which the sexual elements must move, but in either case the plant could not survive away from the margins of streams, seas, and lakes, or up out of the moist lowlands, or beyond the borders of rainy regions.

The thallose forms carrying on sexual reproduction do not appear to have been capable of the morphological development which might have gained them independence from the water, and this freedom was gained only after a secondary, asexual generation came into existence.

In the general movement which finally resulted in a land flora, the fertilized egg held in the body of the thallus would germinate in place, developing into a vegetative structure (the sporophyte) unlike the thallus which bore the egg. Then cells were cut off, or separated from the body of this alternate generation, known as the sporophyte, which had the power of developing into thalli like the original. Now the germination and growth of these asexually produced spores could proceed in the absence of free water, and in ordinary soil in which all of the water present was represented by the hygroscopic layer coating the minute particles of which it is composed.

Even with this development, however, plants could not get very far from the water, since this element in a free state was still necessary for the activities of the gametophyte, or sexual generation. The sporophyte, however, continued to increase in size and to wax in importance in the life-cycle of the species, until finally its body was much larger than that of the gametophyte. This feature is well illustrated by the tree ferns in which the sporophyte is a massive plant while the prothallium, or sexual generation, is a small thallose structure only a few millimeters across.

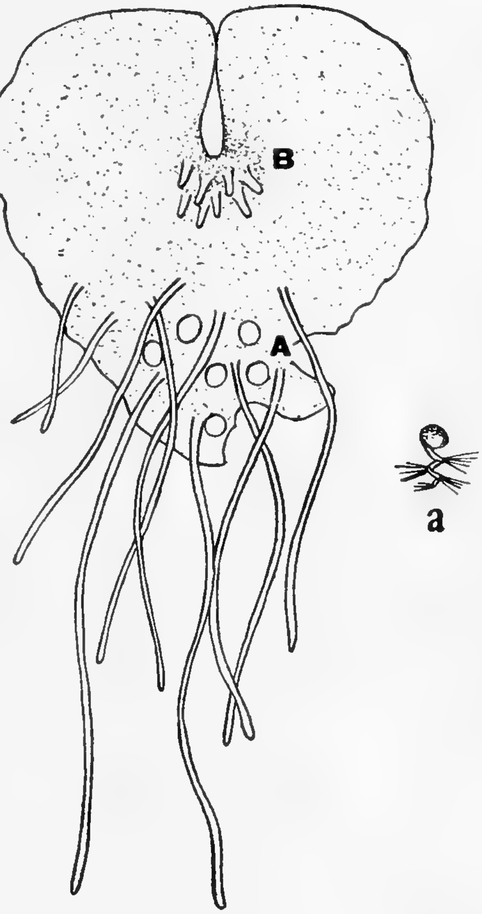


FIG. 2.—The gametophyte, or sexual generation of a fern. Reproduction is accomplished by the movement of a sperm (*a*) from the antheridium *A* to the archegonium *B* where it fuses with the egg, accomplishing fertilization. The sperm swims through a thin film of water which may be present. The absence of the film by aridity is unfavorable to the reproduction and continuation of this type of vegetation. The germination of the egg produces the sporophyte or fern plant ordinarily known (see Fig. 3).

Eventually, however, the spores formed by the sporophyte, capable of living on dry land, were germinated in place, giving rise to sexual individuals, which were also held and nursed in the tissues of the sporophyte. Then in completion of the movement, accessory structures, including the pollen-tube, were formed, by which the sexual reproductive elements might be brought together independently of external conditions. By these steps the seed-plant originated and vegetation became truly and wholly able to occupy the land—a most momentous change, and one of great importance in connection with the general subject under consideration.

Temperatures alone have been unduly drawn upon in the interpretation of distributional features of ancient and existing floras, a fact made more plainly apparent by recent observations at the Desert Laboratory, in which it has been found that several species range over a vertical mile. Such species endure cold of $-35°$ C. and have a growing season of less than a hundred days in the more boreal or alpine portion of their ranges, while in the southern or lower localities inhabited by them, temperatures of 48° C. may be encountered; the growing season extending over 300 days; the thermometer going below the freezing-point not more than 12 hours during the entire year.

It is with no surprise, therefore, that it is learned that there is no single feature in the structure and functionation of plants that with perfect assurance may be connected with the influence of temperature alone, although alpine and polar floras bear a distinct aspect by reason of a combination of conditions of moisture, insolation, duration of the seasons, and course of the humidity.

While temperature is not in itself a direct factor in shaping the general trend of evolutionary development in plants, yet it is indirectly concerned by the influence exerted upon precipitation, and the relation of the amount of the rainfall to the possible evaporation. The great changes in the climatic pattern of the surface of the earth, both in this and preceding periods, produced by whatever cause, may be taken to have affected vegetation chiefly through the humidity and desiccation effects, which not only determined the range and habitats of the species, but also played a predominant part in shaping the general development of the vegetal organism.

It will be profitable therefore to analyze the changes accompanying a modification of a climate toward or away from the desiccation of a region and the response of the flora to such altered conditions of environment. To do this most effectively let us suppose that the rainfall in New York, Pennsylvania, Labrador, Iowa, or Florida were reduced to one-fourth of the present amount by a gradual decrease through a long term of years. In the lower levels of the region affected, the total production of organic matter would be greatly lessened and consequently the amount of humus would decrease; wind erosion would remove much of this from its place of formation and by this means alone the distribution of many species would be totally altered. The soil moisture would ultimately be so depleted that the surface layers would show as great a proportion as the underlying layers, carrying an excess during seasons of precipitation, a fact that would have the profoundest influence upon the native vegetation, determining not only the habit of the root-systems, the form of the shoot, but also becoming a factor in distribution, and giving a new form to the competitive struggle among the organisms in a locality. The change in precipitation would result in the formation of long outwash, detrital slopes, or bajadas, giving new habitat conditions, and a further differentiation would consist in the surface accumulation of soil salts, giving alkaline and saline areas upon which halophytic, or saline plants flourish. The lessened relative humidity would result in modification of foliar surfaces, make necessary for survival special structures in seeds and spores, and would be followed by a more intense insolation by reason of the non-absorption of some portions of the spectrum, and lastly the course of the temperature of the soil would change with the depletion of the humus and the altered water relations.

If desiccation ensued as a result of simple horizontal reduction of the precipitation, in a region with an unbroken surface lying at nearly the same level, the effect would be sweeping, monotonous, and with an almost total absence of selective effect that would mean extermination, or change in a flora *en bloc*. The majority of interpretations of the paleontological record assume such results. It is to be seen, however, that desiccation in a region with diversified topography and great differences in level would result in great differentiation, and if to this reduction is added the restriction of the rainfall to one or two brief seasons or to limited periods a maximum of effect may be expected.

The development of desert conditions in the manner described over a region of any extent would entail the least disturbance on mountain summits, where, by reason of the lowered temperature and the facilities for condensation, the evaporating power of the air would remain lowest. The original, or pre-desert forms would be able to maintain themselves on such elevated slopes with but little adjustment. Similar survivals might ensue along the lower drainage lines, where the underflow in streamways and washes might support a moisture-loving vegetation as it does in southwestern Africa and southwestern America. So much for survival by localization. A second manifestation would be shown by restriction of seasonal activities. The rate of evaporation on the lower levels might be lessened by lower temperatures during the winter season and at this time rapidly acting annual plants might carry through their cycle of activity, remaining dormant in the form of heavily coated seeds during the warmer, dryer period of the year. Perennials with deciduous leaves might display a coincident activity. This survival of moisture-loving plants in a region of pronounced desert character is most marked, however, in places where the precipitation occurs within definite moist or rainy seasons, such as the great Sonoran desert in which two maxima of precipitation occur, separated by periods of extreme drought. Both the winter and the summer rainy seasons are characterized by the luxuriant growth of broad-leaved annuals, which might not be distinguished from those of any moist region. Some species are active during the summer season, and others during the winter, while a smaller number perfect seeds during both seasons. A number of perennials parallel this activity of the annuals with the result that in the most arid parts of Arizona, according to the unpublished researches of V. M. Spalding, half of the native species are in no sense desert plants, requiring as much moisture for their development as do those of Maryland, Michigan, or Florida. The desiccation of a region is seen therefore not to result directly in the extermination of moisture-loving types, but rather to the reduction of their relative or numerical importance and a limitation of their activities to limited periods, or moist seasons.

Two types of vegetation may be definitely connected with arid conditions, representing as they do the morphogenic action of water which has been a predominant one in the development of the seed-plants. In one form the chief operation has been one of reduction and protection of surfaces. Leaves have been reduced to linear vestiges representing various parts of the foliar organ, branches to spines or short rudiments as in certain Fouquieriaceae,

FIG. 3.—(Above) Tree-fern in a moist tropical forest in Jamaica, in which such plants survive. (Below) Dense carpet of borages and other annuals which grow from seed during the rainy season in the Tucson desert. These plants are similar in habit and structure to those of a moist region.

stomata show special constructions, and all parts of the shoot heavily coated and hardened; root-systems have been extended horizontally and the individuals thus isolated, being more or less accommodated to soils containing a large proportion of salts. The spinose, stubby, and switchlike perennials which result from such action are characteristic of low, inclosed desert basins, like the Salton, and those of southern Africa, and central Asia, where the scanty rainfall does not occur within such regular limits as to make distinct moist seasons.

The second form of desert vegetation is one in which the absorptive function has become highly developed and the capacity gained for conserving the surplus water taken up during the moister seasons. The Cactaceae are the most prominent representatives of this type in North America, and some of this group, as well as other species representing a wide range of families, have the capacity for sufficient water to meet the needs of the individual for a decade, while forms are known which might carry out their cycles of reproduction for a quarter of a century by the use of the surplus accumulated within their bodies. Such succulents display not only the reduction of the shoot and of the foliar surfaces together with induration of the epidermis, but have also this capacity for accumulating water and are hence desert plants par excellence, representing the apex of specialization to desiccation.

As a total result of the slow desiccation of any region, therefore, a very important proportion of the flora would consist of moisture-requiring species, or mesophytes, and the remainder would be included in two classes, the spinose forms with reduced shoots and roots, and the succulents with atrophied shoots, but with the additional development of storage structures in some organ of the shoot or root. The total number of species within an arid region is not less than that of the most densely closed tropical area, but the number of individuals is less, the interrelations of the individuals and species are not identical, and the competitive struggle for existence is of a nature widely different from that of a tropical forest. Increase in aridity tends to localization in distribution, and increase in humidity to diffuseness.

Evidence of the existence of xerophytes in previous periods of desiccation is extremely scanty. Calamites and lycopods with a slender central cylinder and a thick inclosing cylinder of thin-walled tissue have been alluded to in this connection, but these great

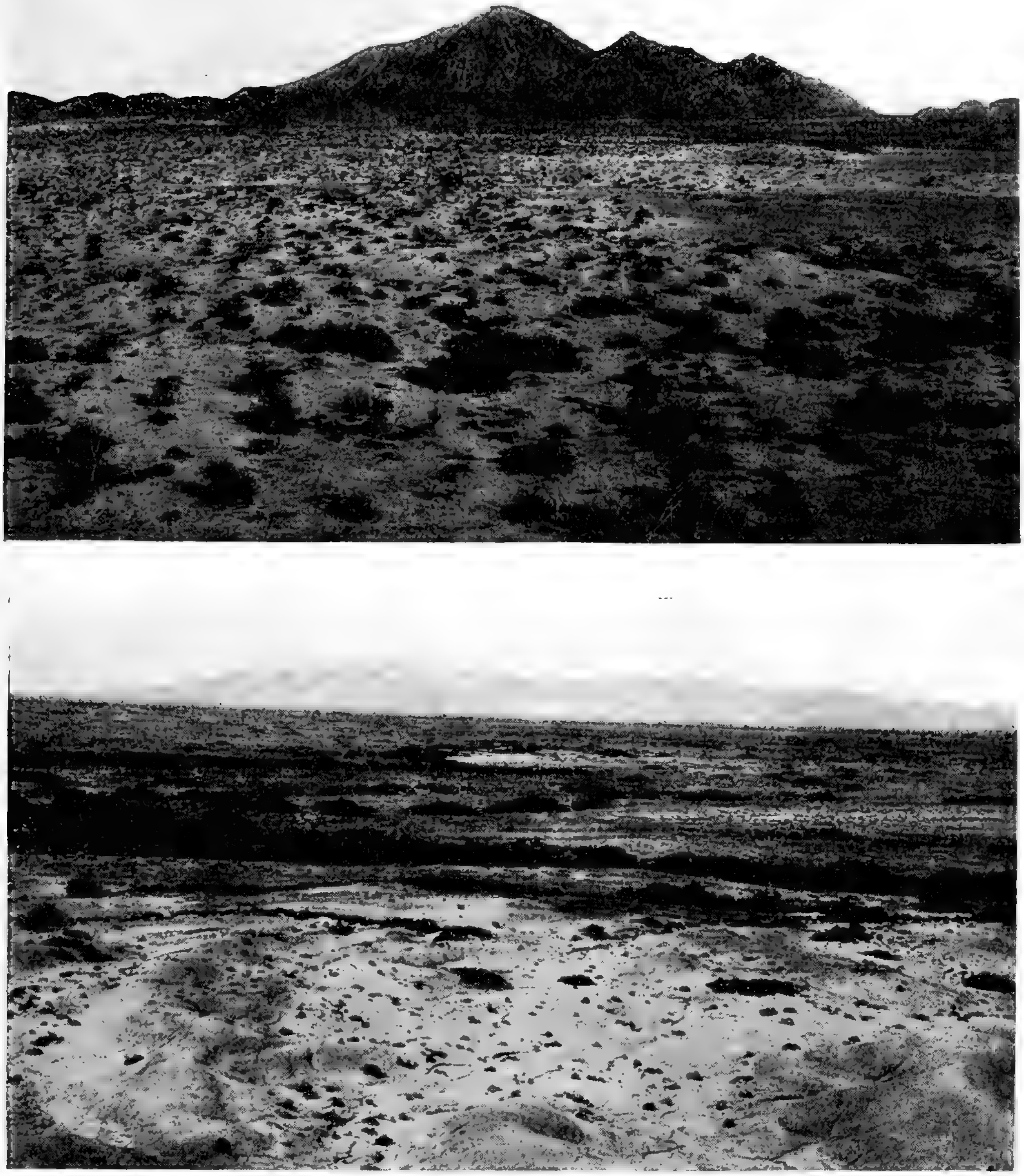


FIG. 4.—Aspect of the vegetation in regions with no well-marked rainy seasons of regular recurrence. (Below) The bolson of Las Vegas, Nevada. (Above) Bajadas of minor range of mountains near the shore of the Gulf of California, San Felipe Bay. The plants comprise spinose forms with very reduced shoots and leaves, which have not developed storage capacity.

sporophytes probably stood in swamps, or at least were hygrophytic in habit, and by the requirements of their separated gametophytic reproduction could not exist on land areas independently. It is also to be noted that many forms peculiar to swampy areas at the present time display reduced shoots and leaves of a specialized structure due to the action of certain constituents in the substratum, that they are known as "swamp xerophytes" and if brought to light as fossils might give the impression of having lived in an arid climate.

FIG. 5.—Types of plants from the Tucson desert, where two distinct yearly periods of maximum precipitation occur. In addition to the morphological reduction of the shoots and leaves, the capacity for the accumulation and retention of water has reached an enormous development. A group of sahuaros (*Carnegiea gigantea*) on the left; a single bisnaga (*Echinocactus Wislizenii*) on the right. The last-named plant has a supply sufficient for a dozen years' activity in its tissues.

The leaves of conifers very probably represent a specialization adapted to existence in a dry atmosphere, yet it is notable that the greater majority of surviving species live in soils in which the occurrence of moisture is not that of the desert.

The swollen stems of the Bennettitales offer the strongest suggestion of desert forms, and their structure and reproduction would make possible their maintenance as independent inhabitants of the dry land.

It is true, of course, that desert conditions are not favorable for fossilization, yet many opportunities for such action undoubtedly occur in the carrying and burying action of the torrential floods of desert streamways, while wind-blown deposits might preserve the more indurated forms. Many of these and the skeletons of the Cactaceae would seem well adapted for preservation in this manner, although no remains have yet been uncovered. The view that such forms are of recent origin, within the present period of advancing desiccation, would predicate a very great phylogenetic activity unprecedented perhaps, but by no means impossible.

The actual relationship between plants and their environment is by no means a settled question and since this and related problems are to be discussed in detail at the Darwin memorial session of this meeting, this subject will not be considered here farther than to say that it is unsafe to asssume that any organism has undergone adaptation and fitting specialization in direct somatogenic response to any set of environic factors, and that admissible evidence on such matters is extremely difficult to obtain.[1]

The operations of factors lessening the supply of water to any region would of course result in greater aridity in some places than in others and the movements of xerophytic forms established in these to other contiguous areas dried out later would be a matter in which the direction of the winds, streamways, movements of animals, and position of mountain barriers would play a determining part.

The recession of large expanses of water included in a desiccating region, such as has occurred in the great basins in Utah and Nevada, and in the bolsons to the southward and eastward in New Mexico, Chihuahua, and Arizona would present special conditions. The rate at which the waters of such inland seas might recede, however, would be such that the advance of vegetation to cover the immersed areas would be quite as rapid as that necessary to follow a receding ice-sheet or a change of climate due to any cause. Thus our observations on the Salton Lake show that beaches a mile in width are bared

[1] *Fifty Years of Darwinism.* New York: H. Holt & Co., 1909.

within a year, while the agencies most effective in their revegetation are combined wind action and flotation.

Many areas, such as the central basin of Asia, the American desert, the Eyre Basin in Australia, and southern Africa, offer clear examples of the effect of desiccation upon the vegetation of a region, but when we proceed to the consideration of the probable happenings when an arid region receives an increasing precipitation, our speculations must be based wholly on experimental evidence of the physiological behavior of plants under known conditions.

Here, as in the decrease of the supply of water, no mass movement or extermination of a flora is to be taken for granted. Many highly specialized succulents extremely local in their distribution would undoubtedly quickly perish with the progression of a climate bringing an excess of moisture; alterations in temperature would not exercise such violent action upon plants of wider range, however. That both together might not totally exterminate a type of succulent is shown by the existence of cacti in tropical rain-forests and on the high northern plains of Nevada, Idaho, and Montana. If plants of wider latitudinal distribution are taken into consideration it may be seen that with an advance of polar climate to the southward the extermination of a species in the northern part of its range would be coincident with additions to the eligible area on the southward. If the land area were limited or if mountain barriers intervened, such dissemination would of course be impracticable and the forms involved would soon perish. These features must be taken into account in an interpretation of the flora of the inclosed basin of central Asia, which, so far as the meager information available shows, is extremely poor in the higher succulent desert types, a characteristic also of the Death Valley and of the Salton Basin in North America.

The unfavorable influence of increasing moisture upon the xerophytic forms of a region would also include effects of an indirect character. Soil temperature and moisture relations would undergo great alterations, humus would increase, and other changes would ensue, entailing conditions which their specialized structures would be unfitted to meet. Furthermore, succulent and spinose plants being advanced types, their retrogressive evolution to conform to moist conditions would be a process resulting in enormous loss of species. Some spinose types would seem to offer the best morphological features for such a change.

Perhaps the most inportant of all of the altered conditions brought about by increasing moisture, however, would be the total transformation of the competitive struggle for existence. Animals would no longer play the predominating rôle as in arid areas. The number of individuals representing the constituent species of a flora would be multiplied a hundred fold, perhaps a thousand fold, and once more the amount of food material offered to animals would decrease their total importance as a factor in selection, while the intensest crowding between shoots would once more be resumed and horizontal differentiation of associations such as that in forests would ensue.

The element of a desert flora which would respond most readily to ameliorated aridity would, of course, be the hygrophytic annuals and perennials, which had survived the period of desiccation in their refuge of the rainy seasons, and in the moist areas along streamways and on elevated peaks. These would quickly occupy the greater part of the surfaces available for plants to the great intensification of the inter-vegetal struggle for existence. As these hygrophytes survived in the moist situations and the moist seasons of an arid period, so the surviving xerophytes in a moist period would find refuge in restricted habitats on talus slopes, rocks, and sand in which the soil-moisture relations would be best suited to their specialized structure and might display their seasonal activity during a period of the year in which the precipitation was least.

Briefly restating the principal ideas touched upon, it may be said that Chamberlin's prothesis of the planetesimal aggregation of the outer portions of the earth and the attendant conditions, together with current theories as to the catalytic nature of the essential activities of protoplasm, makes possible rational speculations upon the origination of self-organizing matter.

The passing of nitrates, phosphides, carbides, and sulphides into more stable combinations might readily result in the formation of thermo-catalysts, one type of which survived in the later forms of living matter. Similar combinations do not appear to be taking place at the present time, and their accomplishment experimentally is attended with difficulties not yet surmounted.

The part of the evolution of living matter which may be brought under observation in living forms or preserved material represents very advanced stages and the cell is separated by a wide range of development from the colloidal masses in which self-generating matter first took form. The construction of substances which might use or transform energy other than that of chemical structure represents the first differentiation between the animal and vegetable organisms.

Plants were necessarily confined to aquatic or hygrophytic habitats as long as their history included the free gametophyte, and a land flora became possible only with the development of the sporophyte culminating in the derivation of the seed-plants. In this and in subsequent history the water-relation has played the predominating morphogenic rôle.

The desiccation of a region occupied by a land flora would entail a complex series of changes in climatic and other environmental factors which may be followed by extermination or differentiation of the flora. This differentiation, which would ensue most readily in regions of diversified topography, with an absence of barriers preventing distributional adjustments, would include localizations of habitats, seasonal restriction of activity, and transformation of the competitive struggle for existence from one chiefly among plants to one between plants and animals.

The surviving flora would include an important proportion of mesophytes or hygrophytes, while the arid conditions might be followed by the development of two types of xerophytes, succulents, and spinose forms.

The amelioration of desert conditions would mean a reversal or shifting of various environic factors, the whole favoring the increase in the number of individuals representing the mesophytes, the widening of their habitats, and the institution of the fiercer competition among plants. Such changes would force a retrogressive development on the xerophytes, exterminating many, restricting the range of all, and would result in the survival of a few under conditions wholly foreign and antagonistic to those in which their characteristic qualities originated.

In all attempts to correlate ancient floras and interpret the climate of formations, especially with regard to aridity, the following features are to be taken into account:

Vegetation of diverse lower types might cover moist lowlands, make a profuse growth along streams, or clog extensive stretches of shallow waters in seas and lakes, but only seed-plants could occupy dry land. It is to be borne in mind that the forms representing this advanced type must have constituted a small proportion of the vegetation for a long period after their origination. Their present predominance must be a very modern feature. Furthermore, the dissemination of new forms proceeds somewhat slowly and it is by no means to be taken for granted that the existence of seed-plants, as denoted by fossil remains, is to be taken as an indication that such plants occupied or covered great continental areas. Soil conditions would be a very important factor in such distribution.

The distinction between the vegetation of a region in alternating moist and arid epochs may not easily be made, since as has been pointed out the fossilization of the flora of the Arizona Sonora desert would probably result in material richer in moisture-requiring plants than in xerophytes The morphological features of the forms preserved would offer the most valuable evidence, and the presence of a single xerophyte among a hundred forms requiring moisture would be of great significance.

The final stages in the differentiation of the land flora, by which spinose and succulent xerophytes have come into existence, seems to have been reached within very recent times. No fossil remains of desert plants have yet been recovered. Some of the forms which have the aspect of xerophytes must have grown in moist regions by reason of their method of reproduction. Some of the cycads and the conifers may be regarded as being most suitable of the older types for existence under arid conditions. The fitness of these plants is due almost wholly to features of the shoot, and the known features of their root-systems offer nothing suggestive of adaptability for the characteristic soil conditions of the desert.

CHAPTER XVI

DIASTROPHISM AS THE ULTIMATE BASIS OF CORRELATION

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There are many and diverse views relative to the nature and the causes of diastrophic movements. To keep as largely as may be on common ground, most of these divergencies of view may be set aside as immaterial to our present purpose. We may all agree that the fundamental factors of the case are a lithosphere with a deformable surface, a liquid, covering part of this surface and determining erosion and sedimentation, and a gaseous envelope. We may easily agree that the outer part of the lithosphere is solid and has a sufficient measure of rigidity to maintain the surface inequalities. I do not see that we need to agree as to the causes of deformation. In some sense, I do not see that we need even to agree as to just what the absolute movements were, i. e., I do not see that it is material for us here to know whether the deformative movements were shrinkages, or expansions, or lateral shifts, provided we agree as to the general nature of their effects on the agencies at work on the surface of the lithosphere. We do not need to entertain the same conception of the nature of the earth's interior, if we are at one as to the working conditions which have prevailed on its surface.

No doubt we can easily agree on the present great working factors: (1) abysmal basins occupying about two-thirds of the earth's surface, bordered by terrace faces rising at angles of 2° to 5° for say 12,000 feet to a quite definite terrace-angle about 100 fathoms below the sea-level; (2) continental platforms whose upper faces slope gently up from this angle to the coast-line and thence ascend into the various reliefs of the land. If we thus agree that the upper face of the continental platform is bounded by the edge of the continental shelf, and that this edge is equally the boundary of the abysmal basins, whether the waters overlap the edge or not, we may also agree that the edge of the oceanic waters, whether they agree with the edge of the abysmal basins or not, form the chief line of demarkation between the great erosions and the great depositions the world over. It is not the only line of such demarkation, to be sure, for degradation gives place to aggradation at many other local horizons, but in this discussion let us agree to deal only with factors of the larger order and to neglect incidentals; let us deal with body deformation, rather than local or provincial warpings. We all recognize further that the sea-level is not only a dividing plane between two great divisions of physical agencies, but between two great biological divisions.

To this list of agreements, there are two other propositions which we cannot add quite so unhesitatingly, because we need to weigh them well, and if we cannot all agree respecting them, we must agree to differ, for they are fundamental to the further discussion. These relate to the effects of body deformation on the relations of land and sea.

If deformation were confined to the abysmal bottoms and were compensatory, no effect would be felt on the relations of land and sea. If deformation were confined wholly to the interior of the continents, it would be similarly ineffectual. Deformations so limited are, however, likely to be only provincial, and fall outside our discussion.

There remain two conceptions of general or body deformation between which choice must be made. In the one, the deformations are supposed to be indifferent to their predecessors, and to disregard the configurations produced by previous deformations. Their successive effects upon continental outlines and basin capacities are thus heterogeneous and the combined results irregular and uncertain. It is not clear to me how they can be made a very trustworthy basis of systematic correlation. The submergent phase of one continent or fraction of a continent may, in this case, be contemporaneous with the emergent phase of another continent or fraction of a continent, and the progress of events on one continent is as likely to be contrasted with those of another continent as to fall in with them co-ordinately.

According to the other view, deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results co-ordinate. If, for example, the first depression of the abysmal basins was due to the superior specific gravity of the basin-bottoms, this specific gravity remained and participated in the next deformation. If the continental masses, at the outset of continental formation, were relatively low in specific gravity, this low specific gravity was handed down to later periods and helped to renew deformation of the same phases in the same regions. Under this view, ocean basins and continental elevations tended toward self-perpetuation. It is not assumed that this prevented shell crumplings, provincial warpings, or block movements of diverse phases within the continental or the abysmal areas, for these might obviously be necessary effects of the general deformative movements, or at least inevitable incidents connected with the dynamics lying back of them.

A choice between these two conceptions is imperative to this discussion, as they lie at the parting of the ways in the interpretation of the larger events of geologic history. I accept the second view with much confidence. It should be more fully qualified respecting the incidental accompaniments just mentioned, but time does not permit.

According to this view, each great diastrophic movement tended toward the rejuvenation of the continents and toward the firmer establishment of the great basins. The distinction between continent and basin must not, however, be interpreted on the superficial ground of the water-line, for the water-line merely shows that the basin is over-full, just full, or under-full, as the case may be. The average water-line undoubtedly helps to give a definite terrace border to the abysmal basin, but the water-line freely abandons this and often is far from coinciding with it.

The base-leveling processes have shown that they are able to lower the continents approximately to the sea-level in a fraction of geologic time. The continents would therefore have long since disappeared, if they had not been rejuvenated by renewed relative elevation or the withdrawal of the sea. I am able to find no evidence of lost continents. There are submerged margins, and matter has been carried continent-ward from denuded borders. There are some submerged dependencies and inter-continental connections. There are also some rather deeply submerged ridges that probably connected the present continents at remote stages in their history. In the earlier eras, when the differentiation of platforms and basins was less advanced, ridges which have since been submerged are perhaps recognizable. In the interpretation of the earlier periods, these should probably be restored as continental connections. In the earliest known ages, these may have been rather numerous and their combined area considerable, but these seem to me to be only qualifying features which, by the natural place in evolution which they fill, support, rather than weaken, the general conception of a systematic succession of deformations in which the offspring of each is the parent of the next, and in which both continents and ocean basins were progressively segregated and unified.

I trust that many of you will agree that, in general, the relatively upward movements of diastrophism have been located continuously in the continents, and the broad downward movements continuously in the ocean basins, and that, setting aside incidental features, the dominant effect of the successive diastrophic movements has been to restore the capacity of the ocean basins and to rejuvenate the continents. This conclusion seems to me to be strongly supported by the general course of geologic history, wherein sea-transgressions and sea-withdrawals have constituted master features. Perhaps our firmest ground for this conviction is found in the present relations of the continents and the sea basins. If heterogeneity had dominated continental action in the great Tertiary diastrophisms, the results should stand clearly forth today. Some continents should show recent general emergence, while others should show simultaneous general submergence. The dominant processes today should be those of depressional progress, on the one hand, and those of ascensional progress, on the other. As a matter of fact, all the continents are strikingly alike in their general physiographic attitude toward the sea. They are all surrounded by a border-belt, overflowed by the sea to the nearly uniform depth of 100 fathoms. These submerged tracts are all crossed by channels, implying a recent emergent state. None of the continents is covered widely by recent marine deposits, and yet all show some measure of these. Wide recent transgressions in one part do not stand in contrast with great elevations in another. Even beyond what theory might lead us to expect, when we duly recognize the warpings incidental to all adjustments, the recent relations of the continents to the seas conform to one type. The 10,000,000 square miles of continental margin, now submerged, is distributed around the borders of all the continents with a fair degree of equability. May we not, therefore, agree that in the world-wide phases of diastrophic movements, the basins have been additionally depressed and the continents repeatedly rejuvenated.

It is important that we should agree, or agree to disagree, on one further point. Have diastrophic movements been in progress constantly, or at intervals only, with quiescent periods between? Are they perpetual or periodic? The latter view prevails, I think, among American geologists. This view has acquired especial claims since base-leveling has come to play so large a part in our science, for it is clear that the doctrine of base-leveling is specifically inconsistent with the doctrine of perpetual deformation, for the very conditions prerequisite to the accomplishment of base-leveling involve a high degree of stability through a long period. The great base-levelings, and the great sea-transgressions, which I think are little more than alternative expressions for the same thing, have, as their fundamental assumption, a sufficient stability of the surface to permit base-leveling to accomplish its ends. Shall we not therefore agree that there has been periodicity in the world-warping deformations? Let this not be held with such exclusiveness that we fail to recognize duly the effects of the adjustment of minor stresses, at other times. These may be preliminary or after-effects of the larger movements, or they may be due to local stresses more or less independent of the general body-stresses. These quite certainly have been present, and have produced intercurrent departures from the strict tenor of the great systematic movements.

If there is need for additional argument on periodicity, it may be found in theoretical considerations, but these we have tried to avoid in the main. Whatever we may regard as the fundamental agencies that give rise to those stresses in the earth which are precedent to deformations, we may easily all agree that the earth opposes some resistance to deformation. There is certainly some rigidity in the body of the earth. According to the fundamental laws of rigidity, the deforming stresses must reach a certain magnitude before a movement can start. Now, if we recall that every such deformative movement, affecting a free surface, in its very nature, throws the resisting crust into an attitude of relative weakness, it follows that, with such progressive easing, the movement will go on until the stress is accommodated and a state of equilibrium essentially restored, after which another period of accumulation is prerequisite to another movement.

If we are agreed on the periodicity of great deformations, it clearly follows that in a quiescent state the base-leveling of the land means contemporaneous filling of the sea basins by transferred matter, and hence a slowly advancing sea-edge which is thus brought into active function as a base-leveling agent. This water movement is essentially contemporaneous the world over, and is thus a basis for correlation. *The base-leveling process implies a homologous series of deposits the world over.* At first these represent the conditions immediately following continental rejuvenation. Later they are succeeded by the deposits representing the modified conditions to which the first stage gives rise, and so on through the series up to the climacteric ones when base-leveling has reached its greatest development. After this a declining series follows. The deposits of the more advanced stages of base-leveling are, as now well recognized by most American geologists, markedly different in physical constitution and physiographic aspect from those of the earliest stages of continental rejuvenation. The criteria for discrimination between these earlier and the later members of the series are indeed of the collective rather than the individual type; they have character as distinctive assemblages of criteria rather than as single or isolated criteria, but they are perhaps all the safer for this composite character.

Correlation by base-levels is one of the triumphs of American geology; correlation by its complement, transgressive deposits on a base-level, may easily be added, and perhaps on quite as firm or even firmer physical grounds. If we add the biological element the case is immeasurably strengthened, for correlation by cosmopolitan faunas, the very best of faunas for the purpose, is added to the physical correlation. Migration at the climax of base-leveling and sea-transgression is freer and more prompt than at other times. Correlation to the foot, as by an unconformity, may not be practicable, but the precision of correlation by unconformities has more apparent than real value, for the different parts of the same unconformity vary much in time. All distant correlations involve some measure of inexactness, and the more frankly it is made obvious, the less its liability to mislead.

Correlation by general diastrophic movements takes cognizance of four stages: (1) the stages of climacteric base-leveling and sea-transgression, (2) the stages of retreat which are the first stages of diastrophic movement after the quiescent period, (3) the stages of climacteric diastrophism and of greatest sea-retreat, and (4) the stages of early quiescence, progressive degradation, and sea-advance.

(1) The characteristics of the climacteric stage of base-leveling and sea-transgression need little further characterization here, for the function of base-levels is known to all American geologists and the function of great sea-transgression to every stratigrapher and paleontologist. We have in base-leveling conjoined with sea-transgression, just that combination of agencies which is competent to develop the broad epicontinental seas of nearly uniform depth requisite for an expansional evolution of shallow-water life. At the same time, it furnishes broad pathways around and across the continental surfaces for wide migrations and the comminglings that lead to cosmopolitan faunas of the shallow-water type.

(2) The stages of initial diastrophism and sea-retreat find their criteria in the deposits that spring from an increased erosion of the deep soil-mantles accumulated in the base-level period, in the effects of increasing turbidity, in the lessening areas suitable for the shallow-water life, and in the limitation of migration.

(3) The climacteric stages of diastrophism are marked by the stress of restrictional evolution among the shallow-water species; by increased clastic deposition in land basins, on low slopes, and on sea borders, by great land extension, but often, perhaps dominantly, by diversity of land surface and by liability to climatic severities and diversification. Areally, land life is favored, but it is hampered by the climatic and topographic diversities, and these may prove graver obstacles to migration and intermingling than even the tongues of sea that previously traversed the land surface. Correlation by glaciation in these stages is likely to prove a valuable adjunct, but we

must first test our criterion, for we are not as yet quite sure that contemporaneity of glaciation is inferred on reliable grounds. The shallow-water life of the diastrophic stages is driven into narrow border tracts and into local embayments, and is thus forced into special adaptations and into narrowly provincial aspects.

(4) The early stages of quiescence and of base-leveling, with advancing seas, are peculiarly fruitful in biological criteria, for they are marked by re-expansions of the narrowly provincial shallow-water faunas of the previous stages. The progressive development of these provincial faunas and their successive unions with the faunas of neighboring provinces, as these come to coalesce by means of the progressive sea-advances, form one of the most fascinating chapters in life evolution, and give some of the most delicate of criteria for correlation.

This rough outline is quite too meager duly to set forth the criteria of correlation connected with the stages of general diastrophism. It rather suggests them than sets them forth.

It remains to consider the precedence among themselves of the three factors, diastrophism, deposition, and life development.

We are accustomed to look to the life record as our chief means of correlation. Its very high utility is quite beyond discussion. Thoughtful students, however, recognize that the paleontological record is based, in an essential way, on stratigraphy and that it is corrected and authenticated by the precise place the life is found to occupy in the stratigraphical succession. Stratigraphy and paleontology thus go hand in hand, each sanctioning the other. *Diastrophism lies back of both and furnishes the conditions on which they depend.* The relationship is not reciprocal in any radical sense. The life does not, in any appreciable way, affect diastrophism. Deposition has been thought to be related to mountain-folding. Erosion in one area and deposition in another has been assigned as an initial agency in deformation. While some influence of this kind may be conceded, I think it is rather a localizing influence than a fundamental one. If wrinkling must take place from other causes, quite possibly previous erosion here and deposition yonder may localize the wrinkling. But that is quite apart from fundamentally causing the wrinkling. Reasons are growing yearly in cogency why we should regard the earth as essentially a solid spheroid and not a liquid globe with a thin sensitive crust. I think we must soon come to see that the great deformations are deep-seated body adjustments, actuated by energies, and involving masses, compared to which the elements of denudation and deposition are essentially trivial. Denudation and deposition seem to me clearly incompetent to perpetuate their own cycles. It seems clear that diastrophism is fundamental to deposition, and is a condition prerequisite to epicontinental and circum-continental stratigraphy.

Diastrophism thus seems to me fundamental both to stratigraphic development and life development. Diastrophic action seems to be the forerunner of both these standard means of correlation. It therefore seems to be the ultimate basis of correlation. The criteria of this correlation include at once its own specific criteria, the criteria of stratigraphy as dependent on diastrophism, and the criteria of paleontology as modified by the direct and indirect effects of diastrophism.