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GLACIAL FEATURES IN THE SURFACE OF THE ALPS[1]

ALBRECHT PENCK
University of Vienna

The study of river action has been very much advanced in the Alps, whose torrents give magnificent examples of the destructive and constructive action of running water. But the surface features of this great European mountain chain do not all correspond to those which we might expect after a careful study of river action. Rivers seek to establish a normal curve, which grows continually gentler down-stream. The valleys of the Alps, however, do not show such a regular grade. The floors of the headwaters show many irregularities, and gentle grades alternate with steep ones. Instead of a slope curve, there is a succession of descending steps. Farther down we find for several miles a valley floor sloping normally; this floor has been aggraded by the river and often ends in a lake basin, where the normal slope is changed into a reversed one. Most of these features are not produced, but rather are destroyed, by river action. Indeed, we see how the rivers intrench themselves in the steep parts of the stair slope, and how they fill up the lakes, which generally occupy the lower part of their valleys in the Alps. In short, their action is directed toward removing the irregularities of their courses.

There is still one other important point in which the slope of Alpine valleys does not obey those rules which control normal valleys; the law of Playfair is not applicable to them. The mouths of the lateral

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[1] This paper contains some results to which the author has arrived by researches on the Great Ice Age in the Alps, carried on together with Professor Brückner, of Halle. A detailed account of this study is given in a book entitled *Die Alpen im Eiszeitalter* (Leipzig: Tauchnitz). A part of the paper was read at the International Geographical Congress at Washington, September, 1904.

valleys are usually not accordant; they do not lie at the level of the main valley, but at a higher level; their rivers often tumble down in waterfalls to join the master-river, or they have cut into the floor of the lateral valleys a deep gorge, through which they whirl, and rush to reach the bottom of the main valley. These are the very well-known *Klammen* of the eastern, and the "gorges" of the western, Alps; and many waterfalls of this mountain chain lie at the mouths of the side valleys.

The cross-sections of our Alpine valleys are also other than what one might expect. The master-valleys have in general an extended flat bottom, at the sides of which rise very steep walls. At a certain height, steep slopes below change into more gentle ones above. Well-marked ledges separates the two slopes, and form distinct shoulders on both sides of the valleys—a condition not usually found elsewhere. That part of the valley which lies below the shoulders has often a trough-like appearance. The trough extends upward to that region in which the aggraded valley bottom is succeeded by a series of descending rocky steps, and here is often formed a very striking trough's end, by the cliff side of a high step. Above the shoulders the valley slopes are far from being regular; often they form cirque-like niches, at the bottoms of which little tarns occur. These are the *Kar* of the Alps, the "corries" of Scotland.

There are certain rules which control the occurrence of all these features. The heights at which the side valleys terminate above the main valley show a pretty regular arrangement. They describe a curve which slopes down regularly between the height above the trough end and that point where we meet with the last part of the reversed slope of the valley floor. The shoulders show a similar, but less regular, arrangement; they are also limited by the trough's end and the end of the last reversed slope of the valley floor; their height also decreases, though not regularly, between these two points. The whole arrangement leads to the conclusion that the trough has been excavated in an older valley with a higher floor; the shoulders are the intersections between the trough sides and the side slopes of the old valley. The hanging side valleys are parts of the old valley system which suffered little from erosion, and conserved their original depth. This condition is now generally accepted, since the connection of all these phenomena has been recognized, but this conclusion is not in harmony with ideas which prevailed for a considerable period, when only *one part* of the irregularities of Alpine valleys was taken into consideration.

For some time the great Alpine lakes have been regarded as the only irregularities of the Alpine valleys, and the questions of Alpine geomorphology have included only the formation of the great Alpine lakes. Of the different ways in which valley lakes are formed, only two have been considered; namely, the hypothesis of warping and the hypothesis of glacial erosion presented by A. C. Ramsay. In order to understand the former, let us assume that the lower part of a normal river slope was elevated, or the upper part was depressed. The normal slope curve then would be changed into a curve with an ascending part having a reversed slope, and the part limited downstream by this reversed slope would be filled with water so as to become submerged. This idea, first suggested by Sir Charles Lyell, and later developed further by Rütimeyer and Heim in Switzerland, helps us to understand the transformation of some valleys into lake basins; but it leads to consequences which are not supported by observations in the field. Earth-movements which could reverse the slope curve of a master-river must also affect its branches; and if a part of its curve is depressed to form a basin, the affluents of this part must also be depressed, and their lower courses must be submerged in a manner similar to the basin formed by the depression of the floor of the master-valley. Lakes formed by the subsidence of part of a river valley must digitate into the side valleys. Contrary to this, the side valleys of the great Alpine lakes are not drowned at all, but they are hanging above the lakes, and their floors show no traces of depression. The digitations we find now and then in Alpine lakes have nothing to do with the drowning of true lateral valleys; they do not stretch toward the mountains from which the side valleys come, but extend in the opposite direction. They are related to the frequent valley bifurcations, which will be considered later.

The basins of the great Alpine lakes occupy only a part of the troughs of the Alpine valleys, and every hypothesis as to their formation must deal with the trough. The trough bears every evidence of having been eroded in a former river basin, the side branches of which suffered less lowering than the main branches. This fact is now generally admitted by all who have studied the relation between the high-hanging valleys and the main valley, and it is generally acknowledged that the latter, in comparison with the former, has been overdeepened by erosive action. But there is still a diversity of opinion as to this action. Some authors, like Kilian, Garwood, and Frech, believe that it has been exercised by rivers, while the hanging valleys were occupied by glaciers and protected by them against the erosive action of water.

This idea ascribes to river-action phenomena such as are usually not developed by it. The trough does not bear the features of a common river valley; it has the width to which river valleys attain in their maturity, but it has not the normal grade which rivers always have in this phase of their development. Their slopes have the steepness of youth, as is proved by innumerable landslides occurring along them. It is a peculiar association of young and mature valley features we meet with in our large Alpine, trough-like valleys—an association which cannot be understood by the assumption of normal river action; and no attempt has been made until recently to show how it was brought about by rivers. As to the hanging valleys, however, there are not a few cases in which they were not occupied by glaciers. Therefore glacial action protecting their bottoms cannot have caused the elevation of their bottoms above those of the main valleys. The hanging valley is not a feature characteristic of glaciated regions only, the hanging mouth being confined to the latter.

He who wishes to examine the Alpine valleys in the light of river-work must not first take the valley floors into consideration; he must observe the river channels. There the law of Playfair has no application. While in the state of their maturity the surfaces of two rivers unite at the same level, their bottoms will not do so; the bottom of a larger, deeper stream generally lies deeper than that of its smaller and shallower affluent. The bottoms of side-river channels are hanging above those of the main rivers. We have here steps at the mouths, as in the Alpine valleys. While the surfaces of rivers grade down continually, their bottoms show irregularities which resemble those of the floors of some Alpine valleys. The forms of mature valleys are determined by the laws which control the *surfaces* of moving liquids, while the forms of the Alpine valleys are governed by the rules controlling the formation of the *floors* of moving liquids. Thus, instead of the law of Playfair, the law of adjusted cross-sections comes into action.

There can be no doubt what particular moving liquid or quasi-liquid is related to the features of the Alpine valleys, since it has been recognized that all the greater Alpine lakes lie in the region of the old glaciation, and later researches have proved this for all the special features of Alpine valleys. The overdeepening, with all its accompanying features—the trough, the trough's end, and the lake lying in it, with its shoulders and the hanging mouths of side valleys—is confined to the area glaciated during the Great Ice Age, and the moment you leave this area you reach the normal features of mature valleys with accordant mouths of side streams; you reach mountains whose summits are not dissected by corries. The concurrence of Alpine valley troughs and old glaciers suggests the theory of origin by glacial erosion. The theory of glacial erosion was advanced by A. C. Ramsay for the formation of the Alpine lakes. We go a great deal farther than he when we apply that theory to the formation of the far more extended feature of the troughs in the Alpine valleys, for the lake basins occupy only those parts of the troughs which extend below the lowest parts of their circumferences.

The erosive action of the glaciers has very often been denied, and is even now denied by some, while it has been at various times vigorously supported. This diversity of opinion is caused by the fact that we cannot observe how actual glaciers act upon their bottoms, their work being concealed by their icy mass. We usually see only how the glaciers transport moraines and deposit them about their lower ends. The fact that stone avalanches not rarely fall down from the side walls of a valley on the surface of a glacier suggested the idea that the material of the surface moraines is due entirely to the action of weathering exercised on those cliffs which overlook the glacier. The study of the moraines on actual glaciers, however, has revealed more clearly the fact that they cannot be entirely derived from those cliffs, but that they come in large part from the bottom of the glacier. What effects are here produced by the glacier can be observed only at those places which have been covered by the ice for some time, and then revealed again. Here we observe those very well-known *roches moutonnées*, polished and striated surfaces, which dip gently in the direction from which the glacier came, but which terminate abruptly in the opposite direction. In general, the rock surface is here limited by joints. It cannot be longer maintained that we have at those places the original surface of the rock before us. We stand rather before a quarry from which rock fragments were broken out and plucked away. This can be proved now and then by observation. At the Hornglacier in the Zillerthal Mountains, for example, I found near a *roche moutonnée* fragments which had been plucked out there and transported by the ice for some distance, slightly upward. They fitted perfectly into the quarry from which they were taken. Thus the *roches moutonnées* teach us that glaciers do not exercise a scouring action alone on their beds, as generally stated, but that they also effect a quarrying and plucking action, which is not always recognized. Therefore we will no longer call the two sides of a *roche moutonnée* "push side" and "lee side," but we prefer the expressions "scour side" and "pluck side," introduced by Shaler. Plucking forms the most important part of glacial erosion; it is exercised as well on the bottom as on the sides of its bed, and since the glacier can also transport fragments upward, it is enabled to adjust its bed to its mass and its movement.

The adjustment of its bed to its mass and movement is not confined to glaciers; the same occurs in rivers. The difference lies partly in the fact that the glaciers' beds, on account of the slowness of glacier movement, are far more conspicuous than the beds of rivers of equal capacity. The adjustment to which we refer is controlled by the necessity that through a given cross-section of a river or of a glacier must annually move the whole quantity of run-off or ice produced in the corresponding catchment basin. There is therefore a relation between the size of cross-sections (Q) and the mean velocities (V) of the liquids, on the one hand, and of area (A), precipitation (p), and evaporation or ablation (e), on the other, which may be expressed by the following equation:

$$VQ = A(p-e).$$

If there are no sudden changes either in the velocity of the moving bodies—those changes will always disappear in the course of time—or in the precipitation and evaporation or ablation of a certain region, then neighboring cross-sections will increase in the same way as the areas do. They will be nearly equal in size, if there is only a slight increase of the catchment basins between the two sections; they may be rather different if a sudden increase of the catchment basin occurs. If, for example, a river or glacier gets an important affluent, there will be a rapid increase in the size of its cross-section.

The arrangement of neighboring cross-sections is controlled by the fact that the surface of the moving liquid must have a slope. Their surfaces must continually decrease in height when we follow the direction of the movement, and where two moving fluids unite their surfaces must join at the same level. The surfaces of glaciers as well as the surfaces of rivers obey the law of Playfair, but their channels conform at the same time to the law of cross-sections. The large cross-section of a main river or a main glacier, as well as the smaller cross-sections of their affluents, have accordant surface junction, and therefore their bottoms must have different heights as long as the cross-sections are similar to each other, which is in general the case. The bottoms of side streams hang above the bottom of many rivers in the same way as the bottoms of side glaciers hang above the bottom of main glaciers. The hanging mouth is a feature of the bottom of moving liquids; the accordance, a feature of their surfaces. Since the river surfaces are the base levels of the country along their sides, they govern the heights of the bottoms of the valleys, which therefore, obey, the law of Playfair.

Every river bed shows inequalities which may be compared with the inequalities of the glacier bed. There is, however, one very marked difference. Most rivers constantly grow, and their cross-sections become therefore larger and larger. On the other hand most glaciers grow only to a certain limit; then they decrease by ablation until they terminate. Therefore their cross-sections will increase at first and then decrease. In a simple glacier the maximum cross-section will be found just at the snow-line; in a composite one, it may occur farther downward. Above and below this maximum cross-section the surfaces and bottoms of the cross-sections will approach one another until they finally coalesce. While, however, the surfaces must be arranged in a descending order, the same is not the case with the bottom. It is stated from observation that glaciers can also move on reversed slopes as long as they have a sufficient surface slope; that is, as long as the surface slope is considerably greater than the reversed bottom slope. To keep up glacial movement, it is necessary that the curves of successive cross-sections be arranged in a descending order. If we therefore, have, at the lower end of a glacier, a series of cross-sections of diminishing size, their bottoms may rise, if their surfaces slope so steeply that their centers of gravity form a continually descending line. Therefore we find in the bottoms of glaciated valleys reversed slopes, and we must expect to find them chiefly near the ends of the old glaciers. Here, indeed, most of the larger lakes of the Alps are found.

The general arrangement of the Alpine glaciation during the Great Ice Age was the following: The interior valleys of the mountain chains were filled up with enormous, flat cakes of ice, of 2,000–2,500^{m} elevation, interrupted by the higher ridges, from which deep affluents poured into the *mer de glace.* Its surface sloped down in the center very gently, and with increasing steepness toward its rim. Under this steep marginal slope lie the existing and former lake basins of the Alps. The location of their reversed slopes indicates the region where the glacier's erosive action gradually ceased. It has long been recognized that the depth of these lakes is far greater in the south than in the north, but no adequate explanation has been given. This phenomenon is consistent with the fact that the marginal slope of the Alpine glaciation at the south side of the mountains was twice or thrice as steep as on the north side; here a far greater reversed slope could be overcome by the glaciers. It must be borne in mind, however, that thick morainic deposits occur at the lower ends of the troughs. The lake basins of the Alps, therefore, are not alone formed by glacial erosion; they are partially dammed up by the thick gravel deposits which the glaciers accumulated at their ends, and this accumulation assumes, in the south side of the Alps, a far greater thickness than on the north side, because it is concentrated over a less extended area. This damming up raises the levels of the Italian lakes far higher than those of the south German lakes, and the difference of the depths of those lakes is partly caused by this difference of accumulation.

The rule of the cross-sections helps us to understand not only the formation of the lake basins in Alpine valleys, but also how the trough's upper end was formed. We usually find it where there was a confluence of the glaciers in the upper parts of a valley, where the slope glaciers united to form the valley glacier. The mass of ice, coming from this semi-circular head, was pressed here into the diameter of the same circle. Now, in order to maintain a continuous movement, an increase of velocity was necessary at this place. This increased velocity must act on the bed of the glaciers until a sufficient depth is attained. Theoretically this depth must be 57 per cent. (that is, $\frac{\pi}{2} - 1$) greater than at the semi-circle from which the glaciers came.

The cross-sections of glacier-beds are in general, as was recognized long ago, U-shaped, which indicates that a certain relation between width and depth is the most appropriate one for the glacier's movement. This U-form is, however, only constant in homogeneous rocks. In places where there are sudden changes in the nature of rocks, we meet with changes in the shape of the trough. At those places we observe that the glaciers exercise a very strong selective erosion on their bottoms. Some rocks resist more than others, and here the glacier bed shows a remarkable adjustment to the nature of the rocks. Many steps in glaciated valleys are caused by highly resistant rocks. Now and then, but not at all regularly, an increase of width corresponds here to the decrease of depth of the glaciated valley. Conversely, a sudden increase of width in a glaciated valley is often connected with a diminution in the depth of the trough.

The study of the old glaciers of the Alps reveals that, as far as their movement is concerned, they consist of two parts. In their upper parts, where they were fed by numerous affluents, there was a *confluence* of ice in the main valleys corresponding to the confluence of waters which occurs there now. In their lower parts, however, they no longer received lateral affluents. Here they spread out fan-like on the plains at the foot of the mountain chain, or even in its interior, penetrating into those valleys which afforded them no affluents.

Regions of glacial *confluence* and glacial *diffluence* are sharply separated from each other. They have nothing to do with the feeding and melting part of the glacier, and are determined only by the presence or absence of lateral affluents. The confluence and diffluence of glaciers, therefore, may occur as well in its névé region as in its region of ablation, in its feeding, or in its dissipating part (according to H. F. Reid), but generally the confluence prevails in its upper parts and the diffluence in its lower parts. On the north side of the Alps the diffluence is excellently represented by the enormous ice fans in the German Alpen-Vorland, where formerly were the glaciers of the Rhine, the Isar, the Inn, and the Salzach, while in Switzerland the diffluence was hindered by the Jura Mountains so that no regular fans were formed. On the south side, the fan-like diffluence of the ice occurred partly in the Alps, and was really restricted to it in the region of the lakes north of Milan, which we will call Insubrian lakes after the ancient country of the Insubrii, whose capital was Milan.

Everywhere where a fan-like diffluence of the ice occurred its bed shows ramifications which have a spoke-like arrangement and slope toward their center. Thus, for example, in the fan of the old Rhine glacier. Lake Constance is the center of the fan, its western termination bifurcating into lakes Uberlingen and Zell. In two similar broad furrows, the rivers Schussen and Argen approach the lake from the north and northeast. Lake Constance is the palm of the hand, its western branches and the furrows of Argen and Schussen being fingers which stretch out to the rim of the old glacier. A similar arrangement is found in the fans of the old glaciers of the Inn and the Salzach, the trough of the valleys terminating by branching in the sub-Alpine plains; and every branch is followed by a river flowing toward the Alps, in the direction from which the ice came, thus marking the reversed slope of the bottom of the different branches of the ice which formed the ice-fan. The same features reoccur where the diffluence of the glacier took place in the mountains. Lake Como bifurcates, and the Como branch has no outlet. Its waters must first flow toward the Alps to reach the outlet at Lecco. On the east side of Lake Como a branch of the old Adda glacier penetrated into the Valsassina, whose waters flow toward the Alps in order to reach Lake Como, revealing a reversed slope. A fourth finger of the Adda glacier passed over the Pass of Porlezza and reached the eastern deep part of Lake Lugano, which drains into Lake Maggiore. If the morainic deposits to the south of the eastern part of Lake Lugano were higher, that lake would discharge into Lake Como, and the relation of the eastern part of Lake Lugano to Lake Como would become very clear. It is also a finger-lake, lying around the palm-lake of Lake Como, but separated from it by a low pass.

The finger-lakes and finger-valleys, with their reversed drainage, are a very conspicuous feature in the regions of glacial diffluence. Many phenomena indicate that they were not originally there, and that their formation was connected with the diffluence of the glaciers. Lake Orta is a typical finger-lake in the region of diffluence of the old glacier of the Ticino, and has a reversed drainage. It occupies, however, a valley whose catchment basin has a peculiar arrangement, as if it would be drained toward the Po plain. It can be shown that the Lecco branch of Lake Como came very lately into use as an outlet for a branch of the Adda glacier. It can be further determined that the different fingers in the large fans of the glaciers on the north side of the Alps are younger than the gravels of the first glacial epoch. How glacial diffluence controls the formation of these features can be shown by the study of those forms which are originated by it.

When a glacier fills a valley above the height of the notches in its watershed, it flows over these notches, if it is not hindered by ice masses on the other side of the pass. By overflowing, it exercises on the pass a conspicuous erosive action, by which the pass is lowered and widened. This can be seen in all passes which have been overflowed by ice. On the St. Gotthard and on the Grimsel, ice-marks are very clear, *roches moutonnées* with their scour and pluck sides spread over the culminating surface, and little mountain tarns indicate that the glacier eroded flat basins. The longer the ice-action goes on, the more the pass is lowered; the height of the watershed is leveled down to the floor of the valley, into which the glacier pours, and a vast flat is formed which begins at the shoulders of the valleys from which the ice branched. Many Alpine passes belong to this type. They can be reached from the glacier valley only by a sharp ascent on its trough-side, while the descent into the neighboring valley is very slow. This is the case with the Monte Ceneri, which opens in the left side of the valley of the Ticino, and allows one to enter the surroundings of Lugano from the north; with the Pass of Seefeld, through which you reach the valley of the Inn south of Munich; and with the famous Pass of Reschenscheideck, through which you pass from the lower Engadine to the headwaters of the Adige. The erosion of this pass was carried so far that the floor of the pass reaches the shoulder of the Engadine, and that some old affluents of the Inn were already diverted into the Adige. A further state of erosion of an old pass is shown by the situation of Lake Orta. Here the pass has been totally leveled down, and considerable accumulations of moraines south of it force its water northward toward the Alps. Finally, in Valsassina, the long-reversed slope is independent of the terminal moraines south of it. It is a branch of the trough of the Adda valley, which extends here into a side valley where it terminates obtusely. This series of different stages shows us how the watersheds can be moved to the outer rim of the old glaciation. This state, however, has not been reached elsewhere. Its establishment depends not only on the intensity of glacial action, but also upon the original features. A pass originally very high will stand far longer than a low one. This fact must be observed in those cases where the valley, reached by a branch of the ice, is overdeepened in a way similar to the main valley. Thus, for example, that branch which branched off the glacier of the Ticino valley at the Monte Ceneri overdeepened the valleys west of Lugano, which are now occupied by the west branch of Lake Lugano, and the branch of the Adda glacier, which branched off at Menaggio, and passed the saddle of Porlezza, has overdeepened the valley of Porlezza and transformed it into the lake basin of Porlezza, which is the deepest part of Lake Lugano. He who considers only the lake basins as the results of glacial erosion will be much puzzled by the interruption of the erosive action of a glacier by a pass. On the other hand, he who follows the whole development of glacial erosion will easily recognize its great effect also on the pass traversed by the ice, and he will perhaps be aware that the erosion on the pass itself was more considerable than that which formed a basin.

The diffluence of the ice is controlled by the rule of cross-sections, as is the confluence. In the same way, as steps were formed at the places where glaciers met, other steps occur where branches occurred, for here there was a sudden diminution of the ice. There are steps of confluence in the region of confluence, and steps of diffluence in the region of diffluence. The steps of confluence are seen in the hanging mouths of side valleys; the steps of diffluence are hanging openings of those valleys which were entered by a branch of the ice. The height of both kinds of steps will generally be more considerable, the greater the difference between the main glacier and its affluent or diverting branch. Thus the step of diffluence of Valsassina east of Lake Como is higher than that of Porlezza west of this lake, and the branches of Como and Lecco divided at about the same level, since they were of nearly equal size. Here is a true bifurcation of branches, and a bifurcation of valleys follows the diffluence of the ice, if the openings of the neighboring valleys passed by the ice are so deeply eroded that they will be easily buried by the accumulation of river material which is being deposited in all overdeepened valleys since they were vacated by the ice. The bifurcation of the Rhine valley near Sargans, that of the Isère valley at Montmélian, and that of the Salzach valley near Zell am See are fine samples of valley bifurcation caused by glacial diffluence, and not, as often said, by capturing.

The establishment of a reversed drainage in consequence of glacial diffluence is very much helped by the accumulation of moraines. They surround the dissipating part of the glacier. They follow its sides as lateral moraines and surround its end as frontal moraines. In the glacier fans north of the Alps they form conspicuous landscapes. They are often watersheds between the reversed drainage of the fan and the drainage of its surroundings, which corresponds to the drainage of the ice-fan during its existence. Thus, for example, the terminal moraines of the Rhine glacier form part of the great European watershed between the northern seas and the Mediterranean. On the south side of the Alps the terminal moraines are still more conspicuous, and form amphitheaters around the ends of the overdeepened glacier beds. These are the so-called morainic amphitheaters of upper Italy, whose deposits partially dam up the Italian lakes. Those glaciers which ended in the Alps left their terminal moraines in the valleys, where they separate the reversed drainage in the region of diffluence from a peripheral drainage. The latter has been partially formed by shoving away the original rivers which descended to the ground before it was entered by the glaciers. When the ice came, they could not continue their courses and must flow along its rim. Thus they were pushed from their old courses and driven into new ones, which surround the ends of the glaciers. Many of these shoved river courses are no longer in use, having often been captured by the headwaters of the reversed drainage, as, for example, the Mangfall in Bavaria, which for a long distance flows along the terminal moraines of the Inn glacier, until it makes an elbow at the place where it was captured by a stream flowing on a reversed slope. Other shoved river courses became stable, since they were driven into the valleys of other rivers. Thus north of the old glacier of the Dran the waters of the upper valley of the Gurk were shoved by the rim of the ice into that valley which is now that of the middle Gurk, and which formerly had its own river. Here the moraine of the glacier along which the Gurk was shoved is still visible. In other cases the moraines are insignificant, especially where the glacier ended in a deep valley, and the course of shoved rivers can be traced only by the erosive action exercised along the glacier, cutting gorges into the projecting parts of the valley side. A magnificent example of such a shoved river can be followed on the left slope of the valley of the Sesia in upper Italy below Varallo. By their erosion on mountain passes, by establishing reversed slopes in their terminal regions, and by shoving the rivers coming from non-glaciated regions, the old glaciers of the Alps have profoundly modified, especially near their ends, the preglacial hydrography of the Alps.

The traces of glacial action in the Alpine valleys extend beyond the limits of the trough. Near the ends of the ancient glaciers the troughs are overlooked by moraines, which now and then are located directly on the shoulders. In the interior of the mountains the striated and rounded surfaces reach far above the shoulders, and there is a very marked scoring limit which separates those parts of the valley slopes which have been buried under the ice and rounded by it, from the higher, ragged slopes, which suffered by weathering. The chamfer at the scoring limit (*Schliffkehle*) exhibits clearly a sapping action of the ice exercised along its sides, and this lateral erosion seems to have been strongest near the surface of the glacier. This condition is perhaps caused by the more brittle state of the glacier ice near its surface, while the trough indicates that the glaciers eroded intensively downward at their bottoms.

Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German *Randspalte* or *Bergschrund*, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the moving mass grinding the bottom of the glacier. By this, not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers, therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent. The bottoms of hanging glaciers may be transformd much as are the floors of main valleys which are occupied by glaciers. The rule of the cross-sections is equally applicable to them. A glacier, for example, which ends on the slope can erode the central parts of its bed below the level of its lower end and thereby establish reversed slopes. Thus the original broadly opened valley basin will be gradually changed into a sharply limited niche with a basin on its bottom. The cirquelike form originating in this way is the *Kar* or "corrie." It differs essentially from that cirque which forms the end of a valley trough, though there is often much similarity in their mere appearance. The trough's end is formed in the bed of a glacier; the corrie at the head of the glacier. The ice moves down over the cliffs of a trough's end, while it moves away from the cliff of a corrie. After having climbed over the walls of the trough's end, one arrives at a flat, formerly occupied by a hanging glacier usually surrounded by cliffs. Then one arrives at a corrie or a series of corries. An ascent of the walls of a corrie always leads one to the crest of mountains. Therefore we distinguish between cirques in valleys and cirques on slopes, between trough's ends and corries.

The forms produced by small glaciers on the slopes of the valleys vary very much. One feature is produced everywhere where the glaciers are overlooked by rocks; that is, the corrie cliff, originated by sapping. The formation of a basin at the foot of these cliffs depends on the same conditions as the formation of a basin in a valley occupied by a glacier; it is only formed where the successive cross-sections, after having increased, again, diminish—a condition which is regularly found in those glaciers which end on the slope on which they began. The true corries, with basins in their bottoms, are therefore mostly the beds of isolated hanging glaciers which did not descend far below the snow limit, and their bottoms lie nearly at the level of this limit. But if on the slopes we have glaciers which feed the valley glaciers, then we have usually to deal only with an increase of their cross-sections, and their bottoms descend without interruption somewhat below the surface of the valley glaciers. Then an *open corrie* is formed, the bottom of which often terminates rather abruptly a little below the scoring limit along the sides of the glacier valley. There are many transitions between the true, closed corrie and the open corrie; for there are many transitions between isolated hanging glaciers and affluent hanging glaciers. Now and then we find closed corries along the sides of a valley glacier, formed by its lateral affluents, which were dammed up by it. On the other hand, we find open corries as the beds of local, isolated glaciers, which lay on slopes the steepness of which was not favorable to the establishment of reversed slopes.

Closed corries prevail in the eastern parts of the Alps, where this mountain chain did not reach far above the snow-line of the Great Ice Age. Now and then we find here mountains with a single corrie or *Kar*, whose steep cliffs contrast strongly with the rounded and smoothed forms prevailing around it. Other summits are rather crowded with corries, which have eaten back so far that there is only a part of the old rounded mountain surface conserved. In other cases the last trace of the latter has disappeared, and there is a sharp crest line which separates the corries or *Kare* of opposite sides. If this crest disappears under the attacks of the glaciers, then a flat surface will be formed in the place of a former dome-shaped elevation. This surface will, however, not reach below the snow limit. Thus by the action of isolated hanging glaciers mountain summits may be degraded nearly to the level of main glaciers, so far as they lie above the snow-line.

Open corries prevail in the highest parts of the Alps, in Tyrol and in Switzerland. Their forms vary according to the height of the valley slopes above the level of the main valley glaciers. The higher these slopes are, the steeper they become, and the steeper then the slope of the bottom of the corrie. The steeper this slope, the smaller becomes the angle between it and the surrounding cliffs, and in those parts of the western Alps which reached highest above the surfaces of the neighboring valley glaciers the cliffs and the steep bottoms of the open corries nearly unite, to form very steep cliffs, the feet of which are and were constantly attacked by steep hanging glaciers formed by snow avalanches and interspersed with stones which have fallen down. The cliffs of two opposite glaciers of this kind usually intersect at a very acute angle, and form very sharp ridges whose summits are needle-like. These are the features in the Mont Blanc region, with its *aiguilles*. The height of all these sharp crests is determined by their elevation above the neighboring valley glaciers. Neighboring crests have, therefore, nearly uniform heights, and all rise in height in that direction from which the ice radiates or radiated. Therefore, seen from a distance, the centers of glaciation of the Great Ice Age, which are still today the scenes of a very strongly developed glaciation, appear as extended domes, which are very much dissected by glaciated valleys, and from which rise only a few isolated peaks, in places where the rocks resisted best the attacks of weathering. The Mätterhorn and the Gross-Glockner are types of these horns of highest resistance. They show clearly that the actual height of the sharp mountain crests of the Alps is far from being an original one. It is determined by destructive processes, the attacks of which still go on above the actual glaciers, constantly lowering the crests and the summits. The latter fact leads to the conclusion that our process of destruction is a rather modern one, for if it had lasted for a longer time, it would long ago have removed the whole of those crests projecting above the glaciers. It was believed that the crests of the mountains had been protected during the Great Ice Age by a covering of snow, and that the destruction has since begun. But the fact that the surfaces of the old glaciers served as a base-level of destruction, as the surfaces of actual glaciers do, leaves no doubt that also in the glacial period the destructive process went on. Its youth must, therefore, result from other causes, as has been believed until now. There are many reasons for assuming that the Alps were elevated during the Great Ice Age, and that this elevation was a true vertical upheaval. The youth of the high mountain crests might be caused by such a recent upheaval, still going on.

That the surfaces of the valley glaciers serve as a base-level of destruction for the hanging glaciers is a fact which corresponds to the same relation between the surfaces of side and main rivers. The other fact, that also the snow-line is such a level, helps us to understand the relation between the rates of glacial and fluviatile erosion. The snow-line becomes visible in the forms of those mountains which rise above the snow-line of the glacial period in such a way as to show that above it the destruction of the mountains went on more quickly than farther down. The sudden increase of the destruction of mountains cannot be directly caused by a sudden climatic change between the elevations below and those above that line, causing a difference of weathering. We know there is such a gradual transition of the climate in the neighborhood of the snowline, that it is very difficult to recognize the climatic features determining its position. The increase of destruction above the glacial snow-line is not due to an increase of weathering above it but is caused by the development, of a new agency, degrading land at a faster rate than the running water. This agency is the glacier ice.

Ice does not protect its bottom, as commonly believed; it attacks vigorously. These attacks become most visible where glaciated surfaces extend into the neighborhood of non-glaciated areas. There we have a continual sapping of the latter. They cannot be as easily recognized on surfaces which were totally covered with ice, for these suffer by a general degradation. Therefore mountains which have been totally covered with ice will not exhibit the same features as those which had only local glaciers. They will have no corries, and they will conserve, under their covering of ice their rounded surface;

but this will be degraded and everywhere lowered. Thus we see, besides those mountains into which closed and opened *Kare* have been gnawed, others which projected equally above the glacial snow-line, which still conserve more or less completely their preglacially rounded forms. They were totally buried under the ice.

The actual surface features of the Alps do not at all correspond to those of a water-worn mountain range. Their conformation is mostly due to ice-action, which becomes most visible where the old glaciation ceased. It shows an adjustment to ice-action which is not quite perfect everywhere, since it probably has been disturbed by earth-movement in its highest parts, and by the action of the receding ice during its oscillations in postglacial time. These oscillations have led to the deposition of morainic material at places where erosion had before been active, and to the increase of erosion at other places. They have only slightly modified the general features worked out during maximum glaciation. We must conclude, therefore, that the durations of the maxima of glaciations, surpassed considerably the times of the increase and recession of glaciation, that is, the preglacial and postglacial times.

NOTES ON SOME CARBONIFEROUS COCHLIODONTS WITH DESCRIPTIONS OF SEVEN NEW SPECIES

E. B. BRANSON
University of Chicago

The following article is the result of the writer's study of the teeth of the genera *Cochliodus*, *Psephodus*, *Sandalodus*, and *Deltodus*, in the collection of Walker Museum at the University of Chicago. In the collection are several hundred specimens of the teeth of *Sandalodus* and *Deltodus*, and more than fifty of *Cochliodus* and *Psephodus*.

The writer is under obligation to Dr. Stuart Weller for the privilege of studying the collection at Walker Museum, and to Professor C. E. McClung for the loan of specimens from the Kansas University Museum. Acknowledgment is due Professor S. W. Williston and Dr. Stuart Weller for helpful suggestions during the investigation.

Psephodus Agassiz

Cochliodus Agassiz, 1838 (*Recherches Poissons fossiles*, Vol. III, p. 174).
Cochliodus Portlock, 1843 (*Geological Report on London derry*, Plate XIV, Fig. 4).
Cochliodus McCoy, 1855 (*British Paleozoic Fossils*, p. 622).
Psephodus Agassiz, 1859 (MSS in the Enniskillen Collection).
Psephodus Morris and Roberts, 1862 (*Quarterly Journal of the Geological Society*, Vol. XVIII, p. 101).
Aspidodus Newberry and Worthen, 1866 (*Paleontology of Illinois*, Vol. II, p. 92).
Taeniodus St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 75).

A jaw of *Psephodus* with four teeth in place is preserved in Walker Museum at the University of Chicago. The full dentition of the jaw is probably not present, the front teeth having their anterior margins thick and truncated, as for articulation with other teeth. The missing anterior teeth were probably triangular in form and considerably smaller than those with which they articulate, but no place remains on the jaw for the helodoid teeth which have been so generally considered as forming a component part of the dentition of this genus.

The history of the belief in the association of helodoid teeth with the large plates on the jaw of *Psephodus* is interesting and is briefly sketched below.

The earliest mention of this supposed association is in a letter written by Captain Jones to Portlock, and published in 1843,[1] in which he says : "I think I am enabled to show that, however distinct and well marked the extremes may be, yet *Helodus planus* passes into *Cochliodus magnus*." In connection with this statement no evidence is given for its support. In publishing the results of his investigations on the arrangement of *Psephodus* teeth, Davis says in summary:

> That a row of three principal teeth increasing in size backward were attached to each cartilaginous ramus of the jaw; that the diameter of the jaw, as indicated by the groove or channel on the under surface of the teeth, diminished toward the symphysis; that a long narrow tooth was placed in front of the anterior one; and that a series of at least three helodoid teeth were placed behind it extending over the palate and increasing in size backward.[2]

The same year St. John and Worthen published the results of their studies on this genus and described an entirely different arrangement of the teeth. They conclude that—

> While the median portion of the rami of the jaw of *Psephodus* was enveloped by a moderately contorted dental plate, constituting its chief point of resemblance to *Cochliodus*, this plate was flanked on either side by a series of teeth disposed in rows from within outward similar to the occurrence of the teeth in the jaws of *Cestracion*. Therefore the solid triturating plates of *Psephodus* are not strictly homologous with the large posterior teeth of *Cochliodus*, but they are more properly designated as median teeth of the rami of the jaws [3]

In 1885 Traquair published his conclusions as to the arrangement of *Psephodus* teeth, saying:

> On the whole, I consider that view most likely to be correct which would ascribe to the mouth of *Psephodus* four large tooth plates, two above and two below, each occupying on the ramus a position similar to that of the row of the largest teeth of *Cestracion*, or of the so-called median teeth of *Cochliodus*, but that of the upper jaw differing slightly in form from the one opposed to it below. . . . . Teeth of different forms seem to have been present in the jaw, external to and in front of the large plate; those in its immediate vicinity belonging more or less to the category of *Helodus planus*. . . . . But the front of the jaw was armed

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[1] Portlock, *Geological Report on Londonderry* (1843), p. 462.

[2] *Scientific Transactions of the Royal Dublin Society*, Vol. I (1883), p. 417, Plate LV, Figs. 1–4.

[3] St. John and Worthen, *Paleontology of Illinois*, Vol. VII (1883), p. 64.

with small teeth belonging to the type which has been designated as *Lophodus* by Romanowski, and the forms *didymus* and *laevissimus*, both named as species of *Helodus* by Agassiz.[1]

During the progress of the present investigation a study of a portion of the types of *Psephodus crenulatus* and *P. obliquus*, in addition to the specimen already mentioned with the teeth in position, and described in this paper as *Psephodus legrandensis*, has led to the following conclusions: The teeth called median mandibular by St. John and Worthen[2] are posterior and correspond to the posterior teeth of *Cochliodus*. The teeth called median maxillary by the same authors are median, but not in the sense that they used the term. They articulate behind with the large posterior plates and in front with the small anterior teeth, and do not articulate with helodoid teeth, as St. John and Worthen thought. In this genus there is nothing that enables us to distinguish the maxillary from the mandibular teeth. Teeth like those called mandibular by St. John and Worthen have been found in place on the same jaw with those called maxillary. (See Plate I, Fig. 2.) All of the teeth of *Psephodus* that have been described belong in the categories hitherto known as median mandibular and median maxillary teeth, and, as before said, they occur on the same jaw.

In previous publications the commonly expressed opinion has been that helodoid teeth were present on the same jaw with the large grinding plates of *Psephodus*, although very little evidence in support of this has been forthcoming. The only evidence that seems to be of much weight in its support is that furnished by a specimen described by Traquair in 1885.[3] In this specimen forty-four helodoid teeth are preserved on the same slab with two of the large *Psephodus* teeth. It is no uncommon occurrence for teeth of different species to be preserved in close association, and the mere fact of such an association proves nothing, although, so long as no evidence to the contrary was forthcoming, it might well suggest the possibility that all the associated teeth belonged originally in the same jaw. Traquair's interpretation of the original position of these teeth in

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[1] Traquair, *Geological Magazine*, 1885, p. 343.

[2] *Paleontology of Illinois*, Vol. VII, Plate I, Figs. 1 and 2, pp. 66 and 67.

[3] *Geological Magazine*, 1885, pp. 337-44.

the jaw from their present positions on the slab shows that they are badly disarranged and might easily come from two or more specimens. He says[1] that of the two large teeth one belongs to the form called by Davis posterior, and the other to the form called median, but that they are not associated in such a way as to lend any support to that author's theory as to their arrangement. But the specimen of *P. legrandensis* furnishes positive evidence that Davis' theory in regard to the linear arrangement of the teeth is correct, with certain modifications. Only two large teeth are present in Traquair's specimen, while at least eight are necessary for the full dentition of both jaws. The teeth are so associated that Traquair concludes that the large plates occupied a position on the ramus similar to that of the median teeth of *Cochliodus*, and that helodoid teeth were arranged in front and external to them; but the specimen of *Psephodus legrandensis* before mentioned shows that such was not the position of the large plates, and that helodoid teeth could not have occupied the supposed place with reference to them.

Although the linear arrangement of the teeth of *Psephodus* postulated by Davis is in part correct, the inner margins of the teeth are placed outward in his restoration, as has been pointed out by Traquair,[2] and a glance at the dentition of *P. legrandensis* (Plate I, Fig. 2) shows that there was no place on the jaw for helodoid teeth. On each ramus of the jaw one large posterior tooth, one median tooth, usually much smaller, but in some species nearly as large as the posterior tooth, and probably one small triangular anterior tooth, are present. But instead of the teeth being arranged in a semicircle, as Davis supposed, those of the two rami touch or approach each other very closely along the median line of the long axis of the jaw.

A comparison of the dentition of *Psephodus*, as shown in *P. legrandensis*, with that of *Cochliodus* brings out certain striking similarities. The arrangement of the large *Cochliodus* teeth is similar to that of *Psephodus*, the principal difference being that they do not meet along the median line, as in *Psephodus*, but spread apart, leaving a V-shaped area. The specimen from which Newberry and Worthen drew their conclusion that helodoid teeth were associated

[1] *Ibid.*, p. 342.

[2] *Ibid.*, p. 342.

on the same jaw with *Cochliodus* teeth furnishes little evidence to support that hypothesis. The teeth are not in position, and they have the appearance of having been accidentally associated. Owen has shown[1] almost beyond question that *Cochliodus* had only three teeth on each ramus of the jaw, and more evidence than a few *Helodus* teeth found preserved in close association with *Cochliodus* teeth is necessary to demonstrate that they belonged in the same mouth. Thus it seems probable that in *Cochliodus* as well as in *Psephodus* no helodoid teeth were present in the dentition.

Psephodus legrandensis *sp. nov.*

(Plate I, Fig. 2)

A small species. Median tooth 5^{mm} broad, 8^{mm} along inner margin, 5^{mm} along outer margin. Inner posterior angle acute and produced backward; outer posterior angle obtuse, rectangular on both sides in front. Tooth strongly enrolled transversely, not arched longitudinally. Inner margins of the two median teeth parallel to each other when in position on the jaw, and approaching very closely on the median line. Posterior teeth subpentagonal in outline, 11^{mm} from posterior inner angle to anterior angle of outer edge, 6^{mm} along articular edge in median line, 8^{mm} along articular edge for anterior tooth. Teeth strongly arched longitudinally, little arched transversely, not ridged or furrowed. Enamel everywhere finely punctate. Edges not crenulate.

The posterior teeth of this species are readily distinguished from *P. crenulatus*, *P. obliquus*, and *P. placenta* by their smaller size, comparative narrowness, and greater longitudinal arching. The median teeth are more strongly enrolled transversely and proportionately narrower than those of the species above mentioned. The median teeth are distinguished from those of *P. acutus* by their smaller size, greater enrollment and the posterior angle being much less produced.

Formation and locality: Kinderhook limestone; Legrand, Iowa.

Paleontological Collection, Walker Museum, No. 10038.

Psephodus acutus *sp. nov.*

(Plate I, Fig. 1)

Type and only specimen observed a median tooth. Measurements: 10^{mm} along the inner margin, 5^{mm} along the outer margin, 7^{mm} along the posterior articular edge, 6^{mm} along the anterior articular edge. Tooth not arched longitudinally, considerably enrolled transversely. Outer and inner margins parallel.

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[1] *Geological Magazine*, 1867, pp. 59–63.

P. acutus differs from *P. legrandensis* in the posterior inner angle being much more produced, in being less enrolled transversely, in its greater breadth, and in the anterior and inner margins meeting in a slightly more acute angle. The species is a little larger than *P. legrandensis*. The surface of the enamel is everywhere finely punctate.

Formation and locality: Coal Measures; LaSalle, Illinois.

Paleontological Collection, Walker Museum, No. 10036.

Psephodus carbonarius *sp. nov.*

(Plate I, Fig. 7)

Type and only specimen observed, a posterior tooth. Measurements: antero-lateral margin, 20^{mm}; postero-lateral margin, 18^{mm}; greatest breadth, 19^{mm}. Tooth thin, strongly arched transversely and longitudinally. Trapezoidal, with antero- and postero-lateral borders about the same length. Tooth highest near the anterior angle of the postero-lateral border. From this high point the surface declines abruptly to the anterior angle of the postero-lateral border and slopes down gradually to the other borders. Surface of enamel everywhere finely punctate. Lines of growth faintly impressed or absent. Margin not crenulate.

P. carbonarius is readily distinguished from *P. crenulatus* by being much more strongly arched and lacking crenulations.

Formation and locality: Coal Measures; Newport, Indiana.

Paleontologic Collection, Walker Museum, No. 10032.

Deltodus and **Sandalodus** Newberry and Worthen

That the genus *Sandalodus* has not been sufficiently well defined to separate it from *Deltodus* is shown by the disagreement among authors concerning the genus to which the species *Deltodus grandis* and *D. complanatus* should be assigned. Newberry, who described[1] both genera, says[2] that *D. grandis* is a typical *Deltodus*, while St. John and Worthen[3] and Eastman[4] believe that it is a *Sandalodus*. Newberry contends that *D. complanatus* is a typical *Deltodus*,[5] while St. John and Worthen[6] and Eastman[7] call it a *Sandalodus*.

During the progress of the present investigation several hundred

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[1] *Paleontology of Illinois*, Vol. II, pp. 95 and 102.

[2] *Transactions of the New York Academy of Science*, 1897, pp. 297 and 299.

[3] *Paleontology of Illinois*, Vol. VII, p. 184.

[4] *Bulletin of the Museum of Comparative Zoölogy*, Vol. XXXIX, p. 198.

[5] *Op. cit.*, p. 102.

[6] *Op. cit.*, p. 184.

[7] *Op. cit.*, p. 198.

specimens of the teeth of *Sandalodus* and *Deltodus* have been studied, and one fundamental difference, perhaps of family rank, seems to distinguish one genus from the other. This difference is in the number of teeth to each ramus of the jaw, *Sandalodus* having only one tooth to each ramus and *Deltodus* having three. Only the actual finding of the teeth in place can prove this conclusion beyond all question, but the evidence in hand makes it seem more than probable. In all cochliodonts, whose full dentition is known to have more than one tooth upon each ramus of the jaw, the posterior teeth have their antero-lateral margins modified for articulation with other teeth. The teeth of *Sandalodus* have no articular edge and show no sign of other teeth having been in contact with them. No teeth of proper shape and size to fit the large plates of *Sandalodus* have been observed during the present investigation. St. John and Worthen figure and describe[1] what they call median mandibular teeth of *Sandalodus laevissimus*, but, judging from the figures, the teeth are far too much enrolled to fit the large plates of *S. laevissimus*. Furthermore, if anterior teeth were present, they should be preserved in as great abundance as the so-called posterior teeth, but, aside from those figured by St. John and Worthen, none of the kind are known, while the posterior teeth are rather common. In the Burlington limestone, where the teeth of *Deltodus spatulatus* and *Sandalodus occidentalis* are about equally common, the anterior teeth of *D. spatulatus* are numerous, though usually fragmentary; but no teeth that fit the large plates of *S. occidentalis* have been found. In regard to the dentition of *Sandalodus*, Davis says: "It does not appear probable that there was more than one tooth to each ramus of the jaw."[2] Davis believes that the mandibular teeth of *Sandalodus* differ considerably from the maxillary teeth, but in a study of all the specimens of this genus in Walker Museum it has proved impossible to distinguish mandibular from maxillary teeth, and this is true also of *Deltodus*.

There can be little doubt that *Deltodus* had three teeth on each ramus of the jaw. Owen has shown[3] that in the complete dentition

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[1] *Op. cit.*, Vol. VII, p. 166, Plate XII, Figs. 8 and 9.

[2] *Scientific Transactions of Royal Dublin Society*, Vol. I (1883), Series III, p. 436.

[3] *Geological Magazine*, Vol. IV (1867), p. 60, Plates III and IV.

of the closely allied genus, *Cochliodus*, three teeth were present on each ramus, and it has already been shown in this paper that the same is true of *Psephodus*. Davis figures one specimen of *Deltodus* dentition with two teeth in position on one ramus.[1] In discussing this specimen he says:[2]

> Connected with the posterior tooth a second one, hitherto regarded as a separate species under the name *Poecilodus parallelus*, has been found, which leaves no room to doubt that it is in its natural position, and from the character of its inside margin leads to the natural inference that a third tooth occupied the front or median portion of the lower jaw.

In all median teeth of *Deltodus* that are known the anterior edge is truncate or grooved, as if for articulation with other teeth.

Eastman says[3] that analogy of *Deltodus* with *Cochliodus*

> leads us to expect, in advance of the anterior dental plate, a series of helodus-like teeth above and below, and in front of this, at the symphysis of at least one jaw, a series of bilaterally symmetrical teeth, arched in a single plain, and corresponding to the form described by Newberry as *Helodus coxanus*.

No specimen of *Deltodus* furnishing any evidence in proof of this is known, and if, as it seems most probable, *Cochliodus* had no helodus-like teeth, there is nothing left to support such a hypothesis as to the dentition of *Deltodus*.

Sandalodus occidentalis Leidy

(Plate I, Figs. 8 and 9)

Cochliodus occidentalis Leidy, 1857 (*Transactions of the American Philosophical Society* (2), Vol. XI, p. 88, Plate V, Figs. 3–16).

Deltodus stellatus Newberry and Worthen, 1866 (*Paleontology of Illinois*. Vol. II, p. 97, Plate IX, Fig. 2 [not Fig. 3]).

Deltodus complanatus Newberry and Worthen, 1866 (*ibid.*, p. 98, Plate IX, Fig. 4).

Deltodus complanatus Newberry and Worthen, 1870 (*ibid.*, Vol. IV, Plate III, Figs. 5, 8, and 12).

Deltodus occidentalis St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 150, Plate IX, Fig. 9 [not Fig. 10]).

Deltodus intermedius St. John and Worthen, 1883 (*ibid.*, p. 153, Plate IX, Figs. 14 and 15).

Sandalodus complanatus St. John and Worthen, 1883 (*ibid.*, Vol. VII, p. 184, Plate XII, Figs. 1–4).

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[1] *Op. cit.*, Series II, Plate 52, Fig. 9.

[2] *Ibid.*, p. 430.

[3] *Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 200.

Deltodus complanatus Newberry, 1897 (*Transactions of the New York Academy of Science*, Vol. XVI, p. 298, Plate XXIV, Figs. 1–7).

Deltodus occidentalis Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 200, Plate 4, Fig. 38, and Plate 5, Fig. 53).

Sandalodus complanatus Eastman, 1903 (*ibid.*, p. 198).

Teeth triangular in outline. In teeth of average size, 40–60^{mm} long, postero-lateral border about 1^{cm} longer than antero-lateral. The outer end terminates in an acute point; the inner end has the inner angle obtuse, the outer angle acute. Tooth slightly arched longitudinally and transversely, but, as compared with associated species, flat and thin. A low, broad ridge extends from the obtuse angle of the inner end to the outer end. From this ridge the surface declines very rapidly to the thin antero-lateral border and gently toward the postero-lateral border. Alation broad, slightly upturned. Enameled surface smooth and polished, everywhere finely punctate. Lines of growth usually not well marked. Antero-lateral border not modified for articulation with other teeth, usually straight or slightly convex.

S. occidentalis differs from *D. spatulatus* in being much less arched both longitudinally and transversely, and in having the ridge, which is not as high as in *D. spatulatus* extending from the obtuse angle to the outer end very close to the antero-lateral edge, instead of at some distance from it, as in *D. spatulatus*. The surface of the tooth declines rapidly to the antero-lateral border from the top of the ridge, and gently toward the postero-lateral border, while in *D. spatulatus* the stronger slope is toward the postero-lateral border. Antero-lateral margin not concave, as it is in *D. spatulatus*.

This species is referred to *Sandalodus* because there is evidently only one tooth to each ramus of the jaw. As has been stated, the large teeth have no articular edge, and although they are numerous in the Burlington limestone, no teeth have been found that could occupy the position of the median or anterior teeth as present in the dentition of *Deltodus*, *Cochliodus*, and *Psephodus*.

In examining a large number of fragmentary teeth of *Sandalodus complanatus* and *Deltodus occidentalis*, it was found impossible to distinguish one species from the other, and, after examining more than a hundred well-preserved teeth, the conclusion was reached that the two groups of teeth represented a single species. In large collections they grade into each other to such an extent that it is impossible to separate them, but it is not difficult to understand how they came to be described as two distinct species from scanty material.

Eastman says[1] he is convinced that "the teeth figured as *Deltodus complanatus* in the posthumous paper of Newberry are fragments of *D. occidentalis*." These specimens are now preserved in the collection of Walker Museum, and as two of them are practically complete, there is no reason why Newberry should have identified them incorrectly, and with the union of the two species both Newberry and Eastman are correct in their conclusions.

Formation and locality: Kinderhook, Burlington, and Keokuk limestones; Iowa, Illinois, and Indiana.

Sandalodus emarginatus *sp. nov.*

(Plate II, Figs. 1, 2 and 3)

A very large species. The dimensions of the type specimen are: 95mm along the antero-lateral border, 65mm along the inner end, 110mm along the postero-lateral border, 26mm in thickness at the thickest part. Strongly arched longitudinally and transversely. Alation strong, extending out 40mm from the postero-lateral border. At the place where this alation diverges from the main part of the tooth there is a strong notch which extends to the middle of the alation in a line parallel with the main axis of the tooth. The anterior border of the alation is gently convex to near the outer angle, where it is strongly convex. The alation is thick and strong, does not turn up at the outer angle, and has a sharp ridge extending from the outer angle to the middle of its base, the sharpness of this ridge being due to the worn condition of the tooth near the inner border. Rings of growth show faintly on this worn surface. Inner end of tooth gently convex near the antero-lateral border, gently concave near the postero-lateral border. Inner posterior angle slightly obtuse. Outer end curved abruptly downward, and probably wound once and a half on itself as in *Sandalodus laevissimus*.

S. emarginatus differs from *S. laevissimus* in being more strongly arched both transversely and longitudinally, in being thicker and stronger, in having a strong notch where the alation diverges from the main part of the tooth, and in the alation being thick, convex upward, and not turning up at the point:

The types of *S. emarginatus* are two specimens, one of which is almost perfect, only a small part of the initial coil being absent; the other has lost part of the initial coil and half of the alation.

Formation and locality: Keokuk limestone; Keokuk, Iowa.

Paleontological Collection, Walker Museum, No. 10059.

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[1] *Op. cit.*, 1903, p. 198.

Sandalodus alatus Newberry and Worthen

(Plate I, Figs. 3–5)

Deltodus alatus Newberry and Worthen, 1870 (*Paleontology of Illinois,* Vol. IV, Plate II, Fig. 6, p. 368).

Deltodus alatus Woodward, 1889 (*Catalogue of Fossil Fishes in British Museum,* Part I, p. 199).

Deltodus spatulatus Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College,* Vol. XXXIX, p. 198).

In a paper published in 1903 (*loc. cit.*, p. 198) Eastman gives *Deltodus alatus* as a synonym of *D. spatulatus.* The specimens of *D. alatus* teeth in the collection of Walker Museum are all more or less fragmentary, but they present the following characters which serve to distinguish them from *D. spatulatus.* The pores in the enamel are much larger and fewer in number. The average number per square millimeter being four in *D. alatus* and seven in *S. spatulatus.* The postero-lateral border of *D. alatus* teeth has a broad, thin alation extending its full length. Near the outer end this alation is much broader than the accompanying ridge. In the posterior teeth of *D. spatulatus* the alation is not broad, but it is thick, and it disappears near the outer end. *D. alatus* teeth have a thin, narrow alation along the antero-lateral border, while the antero-lateral border of *D. spatulatus* teeth is thick, has no alation, and is modified for the attachment of other teeth.

This species is referred to *Sandalodus* because it seems to have but a single tooth to each ramus of the jaw.

Formation and locality: Keokuk and Burlington limestones; Iowa and Illinois.

Sandalodus porcatus *sp. nov.*

(Plate I, Fig. 14)

Type a single incomplete tooth. Length along antero-lateral edge, 34^{mm}; breadth above alation, 14^{mm}; greatest thickness, 10^{mm}. As the outer part of the alation is missing, its full dimensions cannot be ascertained. Tooth very thick and strong at the inner end, but becoming thin along the antero-lateral border near the outer end. The postero-lateral border is thick from the outer end to the alation, but becomes quite thin along the margin of the alation. The alation resembles that of *S. emarginatus* in being convex upward and very thick and strong. It occupies considerably more than half the postero-lateral border of the tooth, and diverges from this border at an angle a little greater than 100°. Tooth strongly arched longitudinally and transversely, excepting at the outer end, where the transverse arching is much less than in *S. laevissimus* and *S.*

emarginatus. The transverse arching near the inner end is much stronger than in any other species of *Sandalodus*. The outer end was probably enrolled as much as in *S. laevissimus*, but the enrolment is partially broken away. Enamel punctation so fine that it can with difficulty be detected with the naked eye. The tooth is peculiar in having a sharp ridge along the higher part running from the outer end to the inner. From the antero-lateral border six small ridges with sharp crests pass upward and forward, joining the large ridge at the top. The posterior one of these ridges is quite strong, but they decrease in size progressively toward the anterior end of the tooth, and the anterior one is very faintly marked. No lines of growth are present.

This species differs from *S. emarginatus* in the presence of the ridges above mentioned, in its greater transverse arching near the inner end and lesser transverse arching near the outer end, in the relative width of the alation, in the fineness of the enamel punctation, and in its size.

Formation and locality: St. Louis limestone; Salem, Ind.
Paleontological Collection, Walker Museum, No. 10050.

Sandalodus latidens *sp. nov.*

(Plate I, Fig. 11)

Teeth of medium size, comparatively broad, not arched longitudinally, little arched transversely. Pointed at the anterior end. The antero-lateral margin forming a strong curve, the postero-lateral margin straight for 12^{mm} from the outer border, then diverging to form a prominent shoulder, rounded at the outer part. This shoulder extends out 8^{mm}, and from its point the postero-lateral margin passes backward in a straight line, converging slightly toward the main axis of the tooth, until it approaches the posterior border, where it curves inward and meets the antero-lateral border in the line of the main axis. Surface of enamel coarsely punctate. Lines of growth showing as delicate color markings, with no ridges present. Greatest length of tooth, 48^{mm}; greatest breadth, 27^{mm}.

The breadth, shape, and punctation of this tooth are probably of generic value, but it is here placed provisionally with *Sandalodus*, as there can be little doubt that there was only one tooth to each ramus of the jaw.

Formation and locality: Keokuk limestone; Keokuk, Iowa.
Paleontological Collection, Walker Museum, No. 10035.

Deltodus spatulatus Newberry and Worthen

(Plate I, Figs. 10, 12, and 13)

Deltodus spatulatus Newberry and Worthen, 1866 (*Paleontology of Illinois*, Vol. II, p. 100, Plate IV, Fig. 7).

Deltodus spatulatus Newberry and Worthen, 1870 (*ibid.*, Vol. IV, Plate III, Fig. 11).

Cochliodus costatus (*pars*) Newberry and Worthen, 1870 (*ibid.*, p. 364, Plate III, Fig. 12 [not Fig. 10]).

Deltodus spatulatus Newberry, 1879 (*Annual Report of the Geological Survey of Indiana*, p. 346)

Deltodopsis? convolutus St. John and Worthen, 1883 (*Paleontology of Illinois*, Vol. VII, p. 165, Plate XI, Figs. 11 and 12).

Cochliodus costatus (*pars*) St. John and Worthen (*ibid.*, p. 167).

Deltodus latior St. John and Worthen (*ibid.*, p. 145, Plate IX, Figs. 11 and 12).

Deltodus spatulatus Newberry, 1897 (*Transactions of the New York Academy of Science*, Vol. XVI, p. 292, Plate XXIX, Figs. 8–11).

Deltodus spatulatus Eastman, 1903 (*Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, Plate IV, Figs. 41 and 42; Plate V, Fig. 55).

In the collection of Walker Museum are several nearly perfect specimens of *Deltodus spatulatus* teeth from the Keokuk limestone, and a large number of more or less complete specimens from the Burlington limestone. Those from the Keokuk are generally much better preserved than the ones from the Burlington. On the Keokuk specimens a few lines of growth are usually present, but the Burlington specimens rarely have lines of growth developed. One specimen from the Keokuk is remarkable for the great development of the outer end of the tooth. It curves downward and backward, lacking about 100° of forming a complete circle. From the fact that this curved part is very slender, and consequently would rarely be preserved, it is possible that it was generally developed to a much greater degree than has formerly been supposed. The complete outer end or antero-lateral margin has not been observed in any of the teeth from the Burlington limestone.

A study of these specimens substantiates Eastman's view[1] that *Deltodopsis? convolutus*[2], and the narrow, strongly enrolled teeth called by Newberry and Worthen *Cochliodus costatus*[3] are probably the median or anterior teeth of *Deltodus spatulatus*. A great many

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[1] *Bulletin of the Museum of Comparative Zoölogy at Harvard College*, Vol. XXXIX, p. 199.

[2] St. John and Worthen, *Paleontology of Illinois*, Vol. VII, p. 165, Plate XI, Figs. 11 and 12.

[3] *Ibid.*, Vol. II, p. 364, Plate III, Fig. 12 ? (not. Fig. 10).

teeth of this character have been found in the Burlington limestone. They are usually fragmentary, but fit the posterior teeth of *D. spatulatus*, and there are no other posterior teeth from that formation with which they can be classed.

Formation and locality: Kinderhook, Burlington, and Keokuk limestones; Illinois, Iowa, and Indiana. Numerous in the Burlington and rare in the Kinderhook.

Deltodus attenuatus *sp. nov.*

(Plate I, Fig. 6)

Tooth triangular in outline. The type specimen measures 22^{mm} along the antero-lateral border, 27^{mm} along the postero-lateral border; inner margin, 15^{mm}. Tooth slightly arched longitudinally, little arched transversely. A ridge runs from the acute angle of the posterior border to the anterior border. The tooth slopes down abruptly from this ridge to the postero-lateral border, excepting at the posterior angle, where there is an alation that turns upward. The postero-lateral border is very thin. Toward the anterior border there is no depression, the rest of the tooth being the same height as the ridge. The antero-lateral margin is very thick at the inner end, but thins out toward the outer end. The posterior inner angle is obtuse, the posterior outer angle acute. The surface of the enamel is very finely punctate throughout.

This species differs from *Deltodus angularis* (*Orthopleurodus carbonarius*) St. J. and W. in being much narrower and thinner, much less arched both longitudinally and transversely, and in the character of the ridge.

The type specimen, a posterior tooth from left mandible or right maxilla, is from the Coal Measures near Kansas City, Mo. It is now in the collection of the University of Kansas.

PLATE I

FIG. 1.—*Psephodus acutus* sp. nov. Median tooth of left mandible or right maxillary.

FIG. 2.—*Psephodus legrandensis* sp. nov. Dentition of one jaw; anterior teeth restored in outline.

FIGS. 3–5.—*Sandalodus alatus* N. and W. Fig. 4 shows the alations on both sides of the tooth. Fig. 3 has the alations restored in outline. Fig. 5 shows the characteristic punctation of the teeth.

FIG. 6.—*Deltodus attenuatus* sp. nov. Posterior tooth; anterior end and part of alation restored.

FIG. 7.—*Psephodus carbonarius* sp. nov. An almost perfect posterior tooth.

FIGS. 8 AND 9.—*Sandalodus occidentalis* Leidy. Fig. 8 shows the characteristic shape of the anterior edge of the teeth of this species. Fig. 9 shows posterior end of tooth; anterior end restored from more perfect specimens.

FIG. 11.—*Sandalodus latidens* sp. nov. A perfect tooth.

FIGS. 10, 12, AND 13.—*Deltodus spatulatus* N. and W. Figs. 10 and 13 show the characteristic shape of antero-lateral edge of the teeth of this species; anterior end restored. Fig. 12 shows the shape of the posterior end of the teeth of this species; anterior end restored.

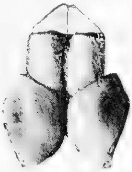
FIG. 14.—*Sandalodus porcatus* sp. nov. Tooth with part of anterior end and alation restored.

PLATE II

FIGS. 1–3.—*Sandalodus emarginatus* sp. nov. Fig. 1, top view of complete tooth. Fig. 2, antero-lateral edge of same tooth; outline to show relation of postero-lateral edge. Fig. 3, postero-lateral edge of same tooth.

Plate I

1



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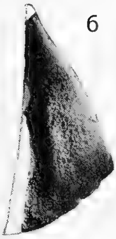

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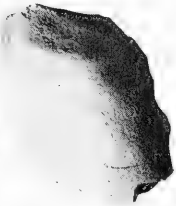

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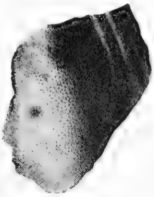

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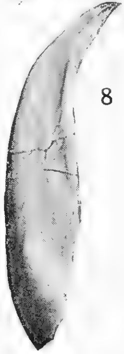

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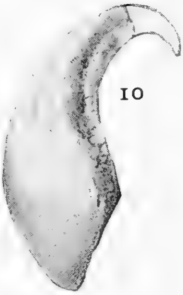

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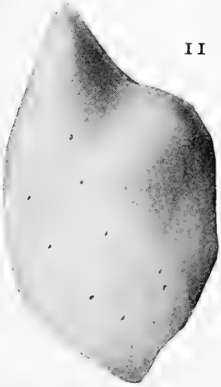

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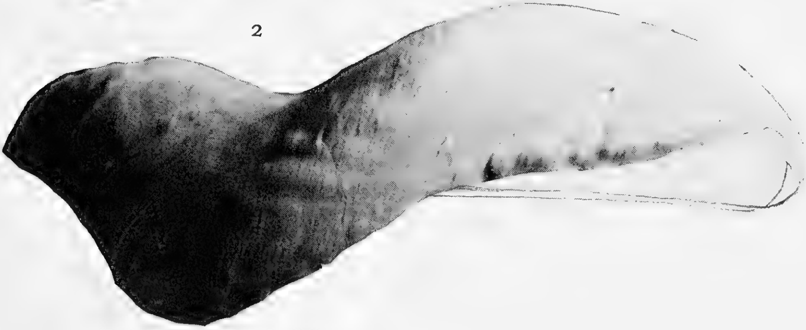

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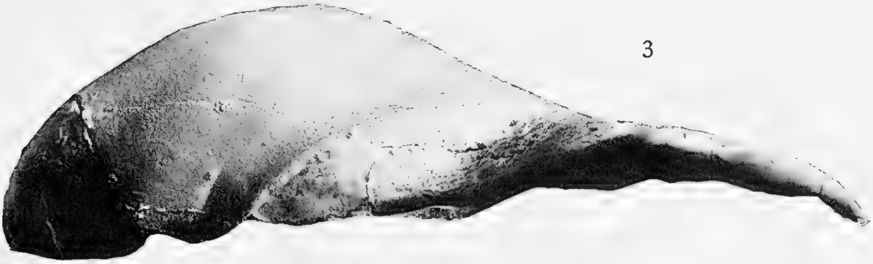

LAMINATED INTERGLACIAL CLAYS OF GRANTSBURG, WIS.

[WITH CHRONOLOGICAL DEDUCTIONS.]

CHARLES P. BERKEY
Columbia University

GRANTSBURG, Wis., is in Burnett county. The St. Croix River forms the western boundary of the county, separating it from Minnesota. Two large streams enter the St. Croix from the east; one, known as Clam River, crosses the central portion of the county, and the other, Wood River, crosses well toward the south. Both, in their lower courses, cut entirely through the capping drift deep into a stratified clay deposit that forms the subject of this paper.

At all points the clays lie beneath a later and coarser sheet of either modified drift or till, or both. This capping varies in thickness from a few feet to possibly 50 feet, or even more. Yet the general surface of the country is extremely level over large tracts. Swamps and so-called meadows of immense size are a common feature. But the remainder of the district known to be underlain by the clay bed is typical sand barrens. That the clays extend also beneath the adjoining morainic belt forming the southeastern margin of the sand tract is indicated by characters in the deposits themselves, although their actual presence in that direction is not a matter of observation.

Extent.—One margin of the deposit is near the mouth of Wood River. The thickness there at its best exposure is only 5 feet. The broad St. Croix valley then cuts into this margin, and beyond no trace of the clays has yet been found. Exposures on Clam River lie 15–18 miles northeastward from those to be seen on the Wood. A total thickness there of over 40 feet seems to indicate that the margin in that direction is still some distance away. The same is true of the eastward extent, as noted above, while toward the west the broad St. Croix valley has destroyed the southern portion, at least on that side. There is, however, at one point on the west side of the St.

Croix, on Snake River about 6 miles above its mouth, a deposit of laminated clays that might be interpreted as a marginal facies, but with no intervening exposures there is doubt about this connection.

Although exact boundaries, therefore, are not known, an extent of at least 20 miles north and south, and a width of 10–15 miles, are certain. Thus the area known to be underlain by these clays is about 250 square miles. The probable area is still greater, but in some directions the margins are hopelessly buried beneath heavier glacial deposits.

Thickness.—At Grantsburg 15 feet of the stratified clays are exposed in the workings of the Terra Cotta Brick Co. Mr. Ira C. Jones, the manager, at the writer's suggestion, bored entirely through the deposit, and reports a total of 35 feet at that point. There is, however, at the same place clear evidence of the removal of some of the topmost material by later ice-advance. How much should be accounted for in this way no one can tell, but the original thickness was certainly more than 35, and probably less than 40, feet.

Near the mouth of Wood River, as noted above, the same deposit is 5 feet thick.

On Clam River, with 40 feet exposed, the deposit is not entirely cut through. An undulating habit of the lowermost laminæ, however, seems to indicate proximity to the floor.

Character.—These clays are all strongly laminated. The laminæ vary in thickness from a mere film to several inches in different parts of the deposit, but are comparatively uniform in any particular zone. Their average thickness in the upper part of the deposit is about a quarter of an inch. The average thickness nearer the middle is about one-tenth of an inch. Less uniformity is observable near the top than in any other zone.

The lamination is extremely regular and approximately horizontal. Small crumplings or bunchings occur, but are rare.

The general color is red from top to bottom. On closer inspection, however, the laminæ are seen to be of two types—a deep red one, and a gray, which alternate without exception throughout the deposit.

Very perfect water-sorting is evident from a study of these individual laminæ. The gray ones are comparatively coarse-grained, containing maximum diameter of 0.06^{mm}. Diameters of 0.02 to

0.03^{mm} are very common, while of course there is much finer matter. The red laminæ are composed of extremely fine grains and flakes. There are no grains at all comparable to the sizes given above. Average diameters are less than 0.002^{mm}.

The passage from one type to the other is sometimes gradual and sometimes abrupt. As a rule, the gradual changes hold for all cases in passing upward from a gray to a red lamina. The abrupt changes are noted in passage upward from a red to a gray one. Evidently there is some sort of unity between each gray lamina and the overlying red one throughout the series.

Taking, therefore, the double lamina—*i. e.*, a gray and the succeeding red one above—as a unit, the following facts obtain: The most irregular lines in the lamination are at the very base of the gray laminæ. There are sinuosities on a small scale that simulate erosion unconformities. The coarsest grains seen anywhere in the material are in these small embayments along this line. There is an occasional streakiness of the gray laminæ with the finer red material, but not uniformly developed. The change to red, in rising from the base of the gray lamina, takes place very gradually and gives a much more even line or band than that at the base. The change to red color is no more marked than the change to finer and finer grain. There is no streakiness in the red layers.

At Clam River there is some modification of these characters. The proportion of gray material is greater. The upper 20 feet of that deposit are decidedly gray and sandy. Lower down, however, the red layers assume their accustomed character, relations, and importance, and are of even more than the usual thickness.

Composition.—Much of the clay matter is so extremely fine that identification in the grain is of doubtful accuracy. Among the coarser fragments quartz is most abundant. Feldspar, garnet, tourmaline, mica, and kaolin are also recognized. As a whole, the gray laminæ are extremely siliceous, while the red are by strong contrast argillaceous.

"Clay dogs," small limy concretions, occur in the upper part of the deposit at Grantsburg.

Chemical analysis shows a higher percentage of lime and magnesia than would be expected from the color of the material. Iron, however, is prominent enough to overcome their effects, so that the burned wares are all red.

Where successive laminæ are so divergent in characters, it is evident that there might be considerable difference in chemical analysis from different samples. For ordinary brick-making purposes the material is mixed as thoroughly as possible with the equipment of the plant. Such a mixture would best represent the composition of the deposit as a whole. Nearly all the work yet done has been upon the upper zone of about 15 feet. Two samples out of this zone give the following results in a partial analysis. No. I is mixed material and fairly representative. No. II is from the uppermost layers.

	I	II
Silica, SiO_2	58.52%	64.76%
Alumina, Al_2O_3	14.98	15.45
Iron, Fe_2O_3	7.92	4.86
Lime, CaO	5.26	4.22
Magnesia, MgO	3.39	4.02
Water, H_2O	7.92	5.96
	97.96	99.17

This leaves a balance of 2.04 and 0.83 per cent., respectively, for the undetermined constituents.

Economic value.—With moderately thorough mixing the Grantsburg laminated clays make common stiff mud brick of excellent quality. The fineness of grain and plasticity aid in producing an unusually smooth finish. With hard burning the product is remarkably strong. The colors are all classed as red, but exhibit considerable range of shades, the hardest-burned lots being darkest in color. Likewise the more exposed margins have darker color, so that systematic setting of the kiln with this result in view produces a variegated ware that is considered attractive.

All wares require a temperature of about 2,000° F. in burning. The upper beds of Clam River are too sandy for use as clays at all. At all other points, however, with careful mixing the material is valuable for clay wares. Vitrified bricks have been made by the company now operating at Grantsburg which seem to duplicate the most approved paving quality. Ornamental terra-cotta, however, is the most promising line of development to which this clay lends itself.

In practice the chief problem is to secure complete intermixture of the two types of laminæ. They have very different shrinkage and fusibility. When the mixing is thorough, however, the result is a clay of superior quality and capable of use in higher grades of wares.

Geological relationships.—Evidence as to the age and origin of this deposit has been in part involved in the preceding description. The laminated clays rest upon a thick accumulation of red glacial till of typical late Wisconsin character. At the mouth of Wood River this is well exposed. Occasional horizontal markings seen here throughout a thickness of about 40 feet of this till are thought to indicate standing water during its deposition. On the St. Croix, half a mile away, this same till in turn rests upon the eroded surface of white and yellow friable Cambrian sandstone.

Everywhere above the clays rests a sand or till capping, or a mixture of both. It contains coarse sand in greatest quantity, but also gravel and bowlders. At the clay pits near Grantsburg, the overlying gravelly till also contains an occasional pyritiferous and carbonaceous nodule very like those sometimes seen in lignite horizons. There are also numerous chunks, angular fragments, of laminated clay, of the size of small bowlders which, in connection with the furrowed or uneven surface of the clay deposit itself, argues a plowing up of some of this material by subsequent advance of glacial ice. The capping drift does not show water marking, and is of variable thickness, with occasional typical morainic aspect. Wherever the surface is level for any considerable area the sloughs and meadows are found. These are a surprising phenomenon in a country that appears to be all sand, but no doubt the effective bottom is formed by the underlying laminated clay beds.

It is clear that the clay deposit was accumulated some time in the late Wisconsin stage of the Glacial period. Heavy deposits of Wisconsin till preceded the clays, and there was a readvance of the ice covering the whole area again after the laminated clays were laid down. The thin cap left by this last advance, and the little disturbance of previous deposits, argue a place at the immediate close of the stage for this locality.

The larger development of sands immediately upon and after the deposition of fine clays of so great extent seems to indicate a long-continued assorting of materials, carrying the fine matter forward and leaving the coarser behind, until a final movement of the chief agency brought them both together a second time—but this time in separate beds. The prevailing sandiness of the upper portion of the laminated deposit at Clam River leads one to regard that direction—*i. e.*, the north or northeast—as nearest to the general supply. This is the region also that constitutes the typical sand barrens of northern Wisconsin. The long, assorting process must have been as prominent a genetic factor with them as the type of bed-rock from which they were obtained.

The laminated clays.—The laminated clays are no doubt a lake deposit. The uniform succession of laminæ, the relationship between the red and gray, and the constancy of their characters lead one to look for some uniformly periodic cause of formation.

The presence of comparatively large grains throughout the gray laminæ shows a continuance of supply of new material during its accumulation at least, while the presence of some streakiness of finer red matter occasionally in them indicates fluctuations or lulls within this period of supply.

The absence of all large fragments in the red laminæ, their uniformity of succession, and their gradual increase in fineness of grain seem to argue a period of complete cessation of supply from without and complete protection from disturbances.

This periodic supply, then, must mark either successive storms or successive thawings of neighboring glacial ice. If the latter, then the period is seasonal, and each unit of lamination, a gray and a succeeding red layer together, represents a year of time. On this supposition, the summer thawings of the glaciers furnished silt to the lake then covering the Grantsburg area, and left behind great quantities of coarser materials to be later spread as the poorest of northern soils. Winters checked the supply, coated the lake with ice, and in this quiet season the finest sediment settled down in the uniform red laminæ of the clay deposit.

The deposits themselves have further evidence on this point. It is scarcely conceivable that a supply controlled by spasmodic periods, such as storms, could produce uniformity either in thickness or in distribution. Variations would be expected to be notable and frequent, and at random with occasional breaks of a much more pronounced character. On the contrary, at any given horizon the thicknesses are comparatively uniform and there are no breaks of a higher order than those of the single unit. If, furthermore, the succeeding laminæ represent seasonal supply from a more or less proximate ice margin, succeeding seasons might be expected to give fairly equivalent results, greatest uniformity being developed when the ice margin is distant, and greatest variation when the ice is nearest. Other things being equal, when the supply is near by, a greater quantity of matter would reach the lake in a given season, and in connection with the general tendency or character of the season there ought to be more irregularity and greater thickness of deposit. In terms of the clays themselves, the laminæ of the middle zone should be most uniform and of least average thickness, while those of the top and bottom zones should be most variable. This is easily seen to be true in the deposit. The greatest irregularities are near the top. With a retreat of the ice margin to near its maximum withdrawal the middle zone of laminæ must have been laid down. A seasonal interpretation accords well with the facts. Even the streakiness seen in the thicker gray layers makes room for storms or other fluctuations within the season itself, and supports the other interpretation for the more uniform breaks.

If the seasonal interpretation may be regarded as established, it remains only to compute the number of units of deposition in order to estimate the number of years the deposit was in accumulating. This done, we need but to connect this episode in the general ice-retreat with its proper limitations in order to get the force of its bearing upon postglacial history.

Time estimates.—For computation a gray and red lamina together make a unit and represent one year. At Grantsburg the deposit is now 35 feet thick, and was originally greater. There are an average of four units to the inch, or forty-eight to the foot, in such portions of the bed as can be critically examined at that point. There are then approximately 1,680 units in the total thickness. It seems fair to conclude from the above computation that the interglacial lake, producing the laminated clays at Grantsburg, existed 1,700 years, and that the accompanying minor retreat and readvance of the ice-margin consumed the same length of time.

The whole problem of time relation to geologic process is a difficult one. There is no very satisfactory formula for the solution of either a process or an interval in so exact terms as years. The most successful attempts at such solution are for the interval between the final withdrawal of the ice from particular localities and the present time. For the vicinity of Buffalo by means of Niagara Falls, and for the vicinity of Minneapolis by means of St. Anthony Falls, careful estimates have been made and are widely known: In both cases, however, there are variable factors capable of modifying any particular result seriously, and even multiplying the lower estimates many times. The lowest estimates are in general those either published earliest or those which pay the least regard to possible variation of the factors. But there is so far no more precise estimate as to this interval, or any part of it, from any other source.

It is believed, however, that the Grantsburg clay beds furnish just such data, and that, so far as they go, they are more precise than the two familiar examples cited above.

The interval covered by this estimate of 1,700 years measures only one of the minor oscillations of the Lake Superior ice-lobe. In its whole retreat from St. Anthony Falls to the highlands of its source there were doubtless several similar fluctuations. Evidence of this in part is the great development of terminal moraines piled across the region, and the occurrence of similar laminated clay beds at other localities. It would seem as though the time actually required for the retreat of the ice from St. Anthony Falls to Lake Superior alone must have been at least as great as the smallest estimates formerly made for the whole postglacial interval.

Summary.—A laminated clay bed 35 feet thick is exposed on Wood and Clam Rivers in Burnett county, Wisconsin.

The area estimated to be underlain by this deposit is more than 300 square miles in extent.

Excellent bricks are being made, and the material is capable of more uses.

The deposit is of lake origin fed by melting glacial ice.

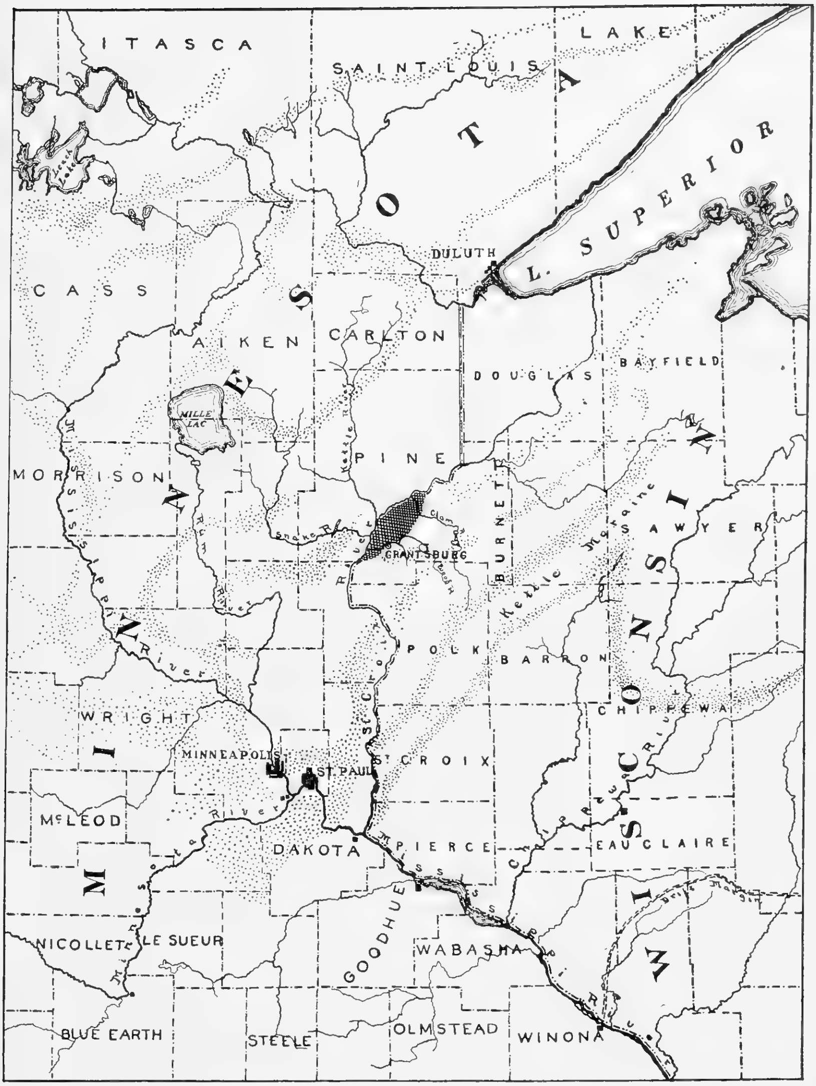

FIG. 1.—Region about the head of Lake Superior, showing location of the Grantsburg clay deposit, and its general relation to the major terminal moraines of the vicinity. (Compiled from the maps of the Minnesota and Wisconsin State Surveys.)

Its age is late Wisconsin stage of the glacial period, and is in a minor way interglacial.

The character of lamination is considered to indicate a seasonal accumulation. Each unit of lamination, therefore, measures a year.

The total thickness of the deposit divided by the average thickness of the unit of lamination gives a number equivalent to the length of time occupied in its accumulation. This is approximately 1,700 years.

If correct at all, the above furnishes a more precise measure for a part of the postglacial interval than is obtained from any other source. The part of this interval involved is but one of the minor fluctuations of the retreating ice in the vicinity of Grantsburg, Wisconsin.

Evidence from this source is opposed to the lowest estimates of postglacial time as computed from Niagara and St. Anthony Falls.

THE NEW MADRID EARTHQUAKE[1]

EDWARD M. SHEPARD
Springfield, Mo.

CONTENTS

GENERAL STATEMENT

Several papers, recently published, have shown an awakening interest in the region called the "sunk lands" in southeastern Missouri and northeastern Arkansas, which, as an older writer has stated, presents one of the few examples on record of the incessant quaking of the ground for several successive months far from any volcano; but so far as the present writer has been able to find, no theory or suggestion as to the probable cause of the violent phenomena exhibited in the region of New Madrid, either at the time of, or subsequent to, the period of greatest violence, has been proposed.

During the summer of 1904 the present writer had an opportunity, in connection with an investigation of the artesian waters of Missouri for the United States Geological Survey, to make several trips into the region, in one of which he was accompanied by Mr.

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

M. L. Fuller, under whose general direction the study of the artesian waters was conducted. The trips presented numerous opportunities for the observation of earthquake phenomena, often still clearly visible, and for studying their possible connection with artesian-water conditions. It is with a view to calling attention to this relation that the present paper is prepared.

PHENOMENA OF THE EARTHQUAKE

All writers on this subject refer to the earthquake as having been widespread in the then thinly settled region of the Mississippi basin, and express surprise at the exhibition of such violent phenomena occurring so far from the seacoast or volcanoes, and so distant from regions where the earth's crust is known to be in an unstable condition.

Description of the earthquake.—The circumstance of the earthquake has been graphically described by various observers, and an excellent collection of statements in regard to it has been published by Dr. G. C. Broadhead.[1] In order that the phenomena may be more vividly recalled by all, we quote from these extracts:

> A letter from L. Bringier, which had been published in the *American Journal of Science, Vol. III, 1821*, states that the shock was felt for 200 miles around. There seemed to be a blowing out of the earth, bringing up coal, wood, sand, etc., accompanied with a roaring and whistling produced by the impetuosity of the air escaping from its confinement, which seemed to increase the horrid disorder of trees being blown up, cracked, and split, and falling by thousands at a time. The surface settled, and a black liquid rose to the belly of the horses, which stood motionless, struck with panic. Afterward the whole surface remained covered with holes, which resembled so many craters of volcanoes, surrounded with a ring of carbonized wood, and sand which rose for about 7 feet. A few months after, these were sounded and found to exceed 20 feet in depth. Now it is covered with ponds and sand hills or monticules, which are found where the earth was formerly lowest. There seemed to be a tendency to carbonization in all vegetables soaking in the ponds, produced by these eruptions. A lake was produced 27 miles west of the Mississippi, with trees standing in the water 30 feet deep.

Another interesting account[2] of the earthquake is given by Godfrey LeSieur, an old inhabitant of New Madrid County. He says that—

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[1] *American Geologist*, August, 1902.

[2] Switzler, *History of Missouri*, and Campbell, *Gazetteer of Missouri.*

The first shock came at 2 A. M., December 16, 1811, and was so severe that big houses and chimneys were shaken down, and at half-hour intervals light shocks were felt until 7 A. M., when a rumbling like distant thunder was heard, and in about an instant the earth began to totter and shake so that persons could neither stand nor walk. The earth was observed to roll in waves a few feet high, with visible depressions between. By and by these swells burst, throwing up large volumes of water, sand, and coal. Some was partly coated with what seemed to be sulphur. When the swells burst, fissures were left running in a northern and southern direction, and parallel for miles. Some were 5 miles long, 4½ feet deep, and 10 feet wide. The rumbling appeared to come from the west and travel east. Similar shocks were heard at intervals until January 7, 1812, when another shock came as severe as the first. Then all except two families left, leaving behind them all their property, which proved to be a total loss, as adventurers came and carried off their goods in flat boats to Natchez and New Orleans, as well as all their stock which they could not slaughter. On February 17 there occurred another severe shock, having the same effect as the others, and forming fissures and lakes. As the fissures varied in size, the water, coal, and sand were thrown out to different heights of from 5 to 10 feet. Besides long and narrow fissures, there were others of an oval or circular form, making long and deep basins some 100 yards wide, and deep enough to retain water in dry seasons. The damaged and uptorn country embraced an area of 150 miles in circumference, including the old town of Little Prairie [now called Caruthersville], as the center, a large extent on each side of Whitewater, called Little River, also both sides of the St. Francis in Missouri and Arkansas. Reelfoot Lake, in Tennessee, sank 10 feet.

Features of the earthquake area.—This disturbed area extends from a point south of Cape Girardeau for 200 miles to a locality north of Wynne, Ark., and reaches from the eastern bluffs of the Mississippi to the foothills of the Ozarks a distance of from 30 to 40 miles. It includes most of Lake County, Tenn., a number of counties in southeastern Missouri, and several in northeastern Arkansas. Dr. W J McGee, in his paper on "A Fossil Earthquake," states that—

> With a single exception, the traveler by steam packet on the lower Mississippi finds the river flanked by alluvial banks so low that during great freshets they are overflowed all the way from Cairo to the Gulf, save where protected by natural or artificial levees.

The exceptional area he describes as a low dome, which bulges upward 20 or 25 feet above the general level of the alluvial plain. This dome

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[1] *Bulletin of the Geological Society of America*, Vol. IV, pp. 411–13.

is made up of a series of more or less parallel ridges, swamps, and shallow lakes. Where the Mississippi River cuts through it the banks exhibit large deposits of sand and alluvium underlaid by a thick bed of tenaceous blue clay—the Port Hudson clay. Not only is an unconformity exhibited between the alluvium and clay deposit, but from New Madrid nearly to Osceola the bed of clay has an irregular, wave-like outline, and in places is abruptly faulted. Stumps are frequently seen imbedded in it, occasionally in a series, one above the other, extending from below low-water mark to a height 25 feet above that mark.

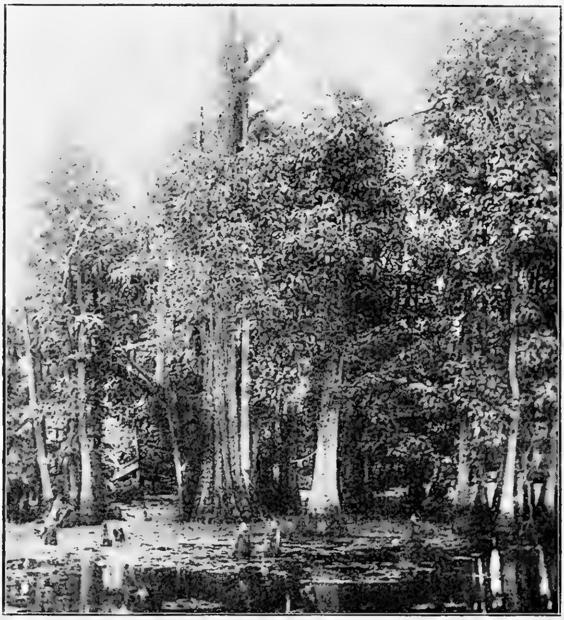

Fig. 1.—View on swamp bordering Varney River, near Kennett, Mo. (Photographed by M. L. Fuller.)

McGee calls attention, in his paper, to the dry bayous that squarely and obliquely enter Reelfoot Lake—a sunken lake in Tennessee, saying that "when this occurs there is no sign of delta-building, and both channels and natural levees may be traced long distances in the lake." He also says: "This absence of deltas indicates that the uplift or deformation occurred suddenly."

A careful study of the whole district of the dome indicates that it has been lifted above the general alluvial plain of the Mississippi. We have spoken of the narrow, more or less parallel, ridges, alternating with narrow, irregular lakes and swamps. Frequently the line between the swamp and ridge is abrupt and terrace-like. Near Gayoso a striking example of this configuration occurs. Here the general level of the ridge breaks abruptly in a straight line, and drops some 4 or 5 feet to the general level of the swamp, forming what even the countryman recognizes as a fault scarp, and describes as "the place where the land sunk."

FIG. 2.—East side of Varney River, below Kennett, Mo. (Photographed by M. L. Fuller.)

The streams which flow through this district are very tortuous and generally, though not always, follow the line of the swamps. Instead of flowing into the Mississippi, they usually flow at a slightly divergent angle, and empty into the St. Francis. There is a strong and decided slope southwestward through this area from the Mississippi to the White River, the valley of the latter being there decidedly lower than the valley of the Mississippi. A large amount of water flows southwestward through this area, and it is noticeable that, while the vegetation has the characteristic luxuriance of the swamps, the water is relatively clear, pure, and cool, and alive with bass and other game fish supposed to inhabit only those waters which are moderately pure and cool. It is further remarkable that the bottoms of these streams are usually hard and sandy, with little or no muck, as is usually so common in swamps.

The elongated lakes are, as a rule, shallow, although there are some exceptions. Reelfoot Lake, in Tennessee, for example, is from 20 to 25 miles long, and from 4 to 5 miles wide, with a depth of from 20 to 30 feet. Its area is perhaps doubled in time of high water. It is deeper at the northeast than at the southwest end. The water of this lake, as well as of the others in the area under consideration, is clear and pure, and not yellow and turbid, like the waters of the Mississippi. On this lake one may float over submerged treetops, and on Golden Lake, near Wilson, Ark., as well as on others in the district, the same submergence of trees may be observed. Tyronza and Crooked Lakes are both sunken lakes fed from below by clear and relatively cool water, Crooked Lake being irregular in depth, with many deep holes in the bottom. Mr. C. B. Bailey, of Wynne, Ark., to whom the writer is indebted for personal guidance through a portion of this district and for many valuable notes, states that Little Black Fish Lake, near Parkin, Ark., 1 mile long and 200 feet wide, has a depth of from 50 to 60 feet. The water is clear and cool, and hunters sink their venison into it for preservation. Other lakes in the vicinity are shallow, being only from 5 to 15 feet deep. It is noticeable that these sunken lakes vary decidedly in the amount of subsidence. Maximum amounts are found in Reelfoot and Crooked Lakes, where the forests are entirely submerged. In others we find the timber but half-buried, and in still other instances the surface is lowered but a few feet. Several miles west of Kennett, in the swamps on the Varney River, the line of sinking is marked in a most interesting way. To the east of a north-and-south line at one point in the swamp, the timber grows tall and erect, in its normal position, while on the west it appears to be submerged to a depth of from 10 to 15 feet. There are areas where the land has been sunken, the timber killed, and the depression partially refilled with flood deposits, upon which has sprung up a new vegetation of a character entirely different from the old. In the Big Bay district, north of Wynne, Ark., the dry bayous are covered with stunted trees of willow and honey locust, while on the slightly higher land on either side are the giant cypresses and gums.

Fault scarps.—The fault scarps are a striking feature of the country, especially in the Big Bay district. Two nearly parallel lines of cracks having an east-and-west trend are found near the mouth of Fortune Creek, where it empties into the St. Francis. Others in the same vicinity have a northeast-and-southwest trend, with a present depth of about 4 feet. One of these cracks, illustrated in the photograph (Fig. 3), has growing from it a tree which is probably seventy-five years old.

FIG. 3.—Fault scarp, ten miles north of Parkin, Ark., in the Big Bay district.

Ejection of sand.—Another feature of this region, and one which will be referred to later, is the large amount of white sand that constitutes the surface of the New Madrid district. Passing down the Mississippi River from St. Louis, the amount of sand on the banks is not relatively large. On entering the sunken district, we find a small amount of coarse sand, which is evidently derived from the breaking down of the Ordovician and Cambrian sandstones of the country above, and proceeding southward we find a steady increase in the amount of fine white sand which, everywhere forms the surface of the flats, reaching a maximum thickness in what is called the "sand slew" country, at the southern end of the area under discussion, 20 miles north of Wynne. The land here is frequently too poor to support much vegetation. There is little or no loam, and arid patches of sand are common. Along the edges of the cracks and fault scarps large deposits of sand are frequently found. Another peculiar feature of the country which should be mentioned is the presence of "sand blows"—low mounds of fine white sand mixed with small pieces of lignite. These mounds are 3 or 4 feet high, with a diameter of from 20 to 100 feet, and are frequently slightly hollowed in the center. They are scattered over the whole district, and the sand is so pure that it will not support vegetation, and consequently barren patches mark their site.[1]

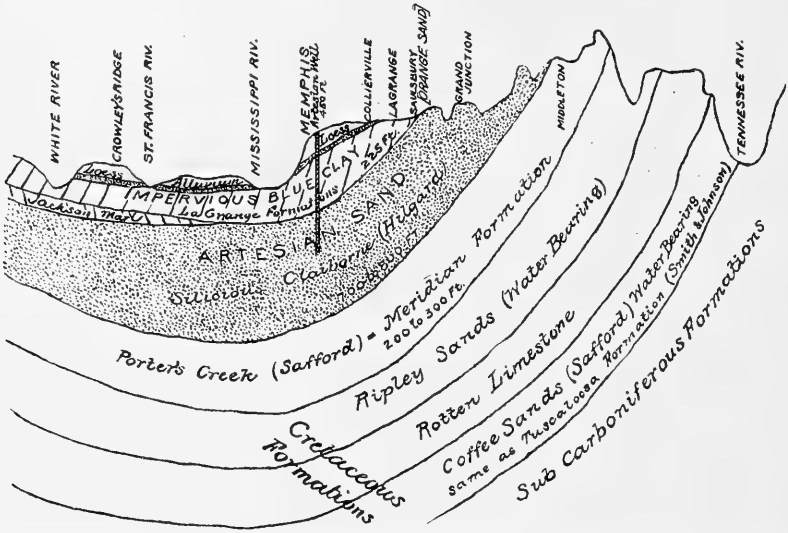

FIG. 4.—An east-and-west geological section through Memphis, Tenn. Vertical scale exaggerated about 250 times. The Orange Sand (LaFayette formation) lies between the Artesian Sand and the Impervious Blue Clay of the diagram. (From J. M. Safford's report to the Artesian Water Co., of Memphis, Tenn.)

ASSOCIATED ARTESIAN CONDITIONS

The Mississippi Valley forms a strong artesian basin between the Tennessee Mountains and the Ozarks. Referring to the geological section and map adapted from the report on *The City Water Supply of Memphis*, by Safford, it will be noticed that loess covers

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[1] The inhabitants claim that wells driven in these "sand blows" give a better quality of water.

Crowley's ridge on the west, and the bluffs on the east side of the valley, while sand and alluvium cover the area under discussion. Beneath the loess is from 6 to 40 feet of Lafayette gravel, followed by a layer of impervious blue clay—the La Grange formation, which varies greatly in thickness, and averages from 100 to 225 feet. Under this impervious blue clay is from 10 to 40 feet of Orange sand, and below this is found the great water-bearing sand, the Silicious Claiborne, or the La Grange sand of the La Grange formation of Hilgard, which varies in thickness from 600 to 800 feet. This deposit of sand, which is finer in texture above and below than in the middle, and which is intercalated with thin beds of clay and a considerable amount of lignite, is a reservoir in which the waters from the Tennessee Mountains and the Ozarks meet under great pressure. Beneath this sand is found from 200 to 300 feet of Porter's Creek (Safford), or Meridian, formation, and under the last is about 250 feet of Ripley sands, another water-bearing formation, the source of the artesian waters of Jackson, Miss., while still lower is the Rotten limestone overlying the Coffee sands, which, in turn, rest unconformably upon the Sub-Carboniferous.

Numerous drill-wells through and around the sunken district develop the fact that the wells of the region do not flow, but that the water rises to or very near the surface, while those on the border of this district are mainly artesian, or flowing, wells. Starting at Memphis, where there are 140 flowing wells, and going northward along the border of the district, a flowing well 628 feet deep is encountered at Dyersburg, Tenn.; one 840 feet, at Hickman, Ky.; one 930 feet, at Wystaff, Ky.; several over 800 feet, at Cairo, Ill.; one 626 feet, at Mound City, Ill.; one 710 feet, at the mouth of Cash Creek, Ill.; one 62 feet, at Pocahontas, Mo., north of Cape Girardeau; one 900 feet, at Campbell, Mo.; and one 480 feet, at Parkin, Ark., west of Memphis.

In the sunken area which is encircled by these flowing wells there are non-flowing wells at Terrell, Ark., 860 feet; north of Memphis, 800 feet deep; at Deckerville, Ark., 700 feet; at Caruthersville, Mo., 428 feet; at New Madrid, Mo., 200 feet; and at Sikeston, Kennett, and Marked Tree, Mo. The waters in the flowing well at Cairo are probably derived from the St. Peter's sandstone.

Here we find the anomalous condition of a great artesian basin where the wells flow in a circle surrounding the center, but rise to the surface only on the low ridges within this circle. The constant and vast seepage along fault lines and low places, accomplished by springs to be later described, keeps down the stronger artesian pressure which is seen on the outer borders of the area.[1]

Sand brought up in wells.—Messrs. W. G. Lanhan and W. C. Davis, engineers for the Memphis Water Co., state that of 141 wells that have been sunk in Memphis nearly all flow when they are not pumped, and that the altitude to which the water rises, when not pumped, is 218 feet above Biloxi, Miss. These gentlemen both say that there is a continuous flow of fine sand carried up to the surface by the water of all these wells from depths varying from 450 to 600 feet. A brass strainer, with openings one hundred-and-fiftieth of an inch in width, is placed in the bottom of each well, and this is so rapidly worn by the sand that it has to be replaced in from three to five years. Every precaution is taken to keep this sand from the valves and piston rods of the pumps. The wells are tapped at depths of from 40 to 60 feet, and the water is conveyed by large brick tunnels 5 feet high to a central reservoir well at the pump station. The sand collects so rapidly in these tunnels that they must occasionally be cleaned out. One tunnel was found nearly filled with sand deposited from the water.

Mr. Henry Moss, of New Madrid, Mo., was connected with the Missouri River Commission some twenty-five years ago, when a series of wells was sunk along the river and on the islands from Lister's Island, 20 miles north of New Madrid, to Fort Pillow, near Osceola, Ark.—a distance of about 90 miles. These wells were bored from 125 to 200 feet deep, and he states that the sand and water would shoot up into the pipes to within 30 feet of the surface, the sand frequently clogging the bottom of the pipe.

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[1] The writer is greatly indebted to Mr. W. B. Johnson, of Memphis, Tenn., for various sections and data relating to the wells of this district. He calls attention to the similarity in composition of the waters on the east side of the basin; also to the purity of these waters, which undoubtedly have their source in the Tennessee Mountains. These are in striking contrast to the waters on the west side, which are generally saline, and which have their source in the Ozarks. He further states that the La Grange sands at Memphis are 800 feet thick, while at Pine Bluff, Ark., they are only 40 feet.

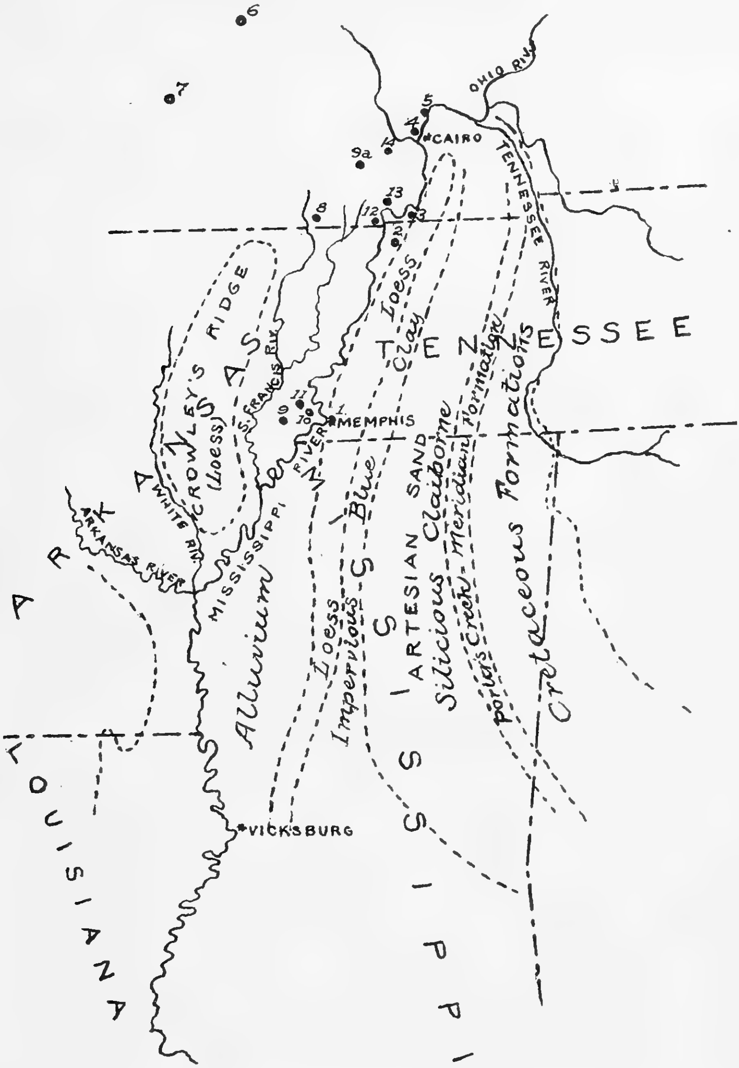

FIG. 5.—Plan showing the outcrop of geological strata east and west of Memphis. Scale: 1 inch = 90 miles. (Adapted from J. M. Safford's report to the Artesian Water Co. of Memphis, Tenn.) Flowing wells occur as follows: (1) Memphis, Tenn.; (2) Dyersburg, Tenn.; (3) Hickman, Ky.; (4) Cairo, Ill.; (5) Mound City, Ill.; (6) Pocahontas, Mo.; (7) Grandin, Mo.; (8) Campbell, Mo.; (9) Parkin, Ark.; and non-flowing wells at (10) Terrell, Ark.; (11) Deckerville, Ark.; (12) Caruthersville, Mo.; (13) New Madrid, Mo.; (14) Sikeston, Mo.

Sand brought up by springs.—We have noted the character of the water in the sunken lakes and streams—its clearness, purity, and temperature—and that the streams, where sounded, seem to have a hard, sandy bottom, and a general absence of muck. We have further referred to the great volume of pure water that is everywhere flowing out of this sunken district, and also to the abundance of game fish which only thrive in pure spring water. That typhoid fever is almost wholly unknown in this district is another fact bearing on the purity of its water supply. The people drive a pipe with a strainer 10 or 15 feet into the sand, and obtain an abundance of reasonably pure water, which they pump to the surface.

A careful study of these streams, especially along the St. Francis, the Little Tyronza and the Big Bay, reveals the fact of the constant escape of water from below through small openings surrounded by little cones of sand. This is noticeable for miles along the St. Francis and in the Big Bay district, especially on the bluff side of the streams.

Deep-seated water, then, is constantly coming to the surface, bringing with it fine sand from below. It is probable that old fault lines through the clay permit this constant discharge, which must slowly and steadily produce an undermining of the clay layer by the removal of the sand below. A glass of water taken from the springs, though seeming quite clear, will deposit, in a few minutes, a fine film of sand at the bottom. Mixed with the little sand-cones that surround the spring outlets are minute particles of lignite, which further indicate the deep source of these waters.

The soil is generally very thin, especially in the southern part of this district, where the sand deposit is thicker, and the surface sand, for several inches, is destitute of the fine particles of lignite, the absence of which is partly due to the action of surface waters in carrying the lighter particles away. Earthworm castings, however, wherever found, show the presence of the lignite. This sand that is spread over the greater portion of the sunken district, in size of grain, structure, general appearance, and association with lignite, closely resembles the drill samples obtained from the Silicious Claiborne, or La Grange formation, and justifies the conclusion that it has been thrown up from below.

A careful microscopical study of these sands confirms this impression. Under the microscope we find them to be made up of varying mixtures of small, beautiful, rounded, incoherent, water-worn grains of quartz, ranging from limpid or pellucid to perfectly transparent, glass-like particles. Occasionally, rounded grains of red, yellow, or black jasper occur, and in all samples fragments of lignite are seen. The samples studied were obtained from the artesian wells at Memphis, the small springs scattered over the district, the fault scarps, and many localities throughout the whole sunken area. The apparent identity of the surface and artesian sands is very plain.

Source of sand covering surface of "sunk area."—Testimony from various witnesses establishes the source of much of the sand distributed over this area. Eliza Bryan, of New Madrid, in a letter to Lorenzo Dow, dated March 22, 1816, speaks of the awful darkness of the atmosphere, which was saturated with sulphurous vapor, and of the fact that during all the hard shocks the earth seemed horribly torn to pieces, while the surface of hundreds of acres was from time to time covered over, for various depths, with the sand that issued from the numerous fissures. She says: "Some of these fissures closed up immediately after they had vomited forth sand and water. What seemed to be coal was thrown up with the sand in some places." A. N. Dillard, of New Madrid, stated to Professor J. W. Foster that the shocks continued from twenty to thirty months, and that in every instance the motion was from the west or southwest. He said: "Fissures would be formed from 600 to 700 feet long, and 20 to 30 feet wide, *through which water and sand spouted 40 feet high.*"[1]

Mr. Timothy Flint published in his *Book of Recollections* that "a tract near Little Prairie, now called Caruthersville, became covered with water 3 or 4 feet deep, and when the water disappeared there remained a stratum of sand." Further, that "there were two classes of shocks—those in which the motion was horizontal, and those in which it was perpendicular."

In the description by Godfrey LeSieur, given on a previous page, attention is called to the large volume of water, sand, and coal that was thrown up. Dr. Hildreth, in Wetmore's *Gazetteer of Missouri*, states that—

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[1] Italics are the writer's.

> The earth on the shores [of the Mississippi River] opened in wide fissures, closing again, and water and mud, in huge jets, were thrown higher than the treetops. The atmosphere was filled with a thick vapor or gas. . . . . The sulphurous gases discharged during the shocks tainted the air, and the river water, for 150 miles below, could not be used for a number of days.

Hon. Lewis F. Linn, of the United States Senate, states in a letter concerning this earthquake that "the earth rocked to and fro, vast chasms opened from which issued columns of water, sand, and coal, accompanied by hissing sounds."[1]

To sum up the testimony of most observers, we have emphasized the fact that the disturbance came from the west; that the ground rolled in great waves; that numerous fissures were formed; that great volumes of "sulphurous vapors," water, sand, and lignite were thrown up at various heights; that large areas were covered with water, the subsidence of which was marked by a thick coating of sand; that these shocks continued for nearly three years; and that the waters of the Mississippi receded for several minutes.

Further, we find today that large volumes of water are constantly coming to the surface as springs in this district; that these springs are numerous along the lines of fissure; that deep artesian wells around this region bring up this same variety of sand with lignite, some, as at Memphis, when first sunk, ejecting large chunks of the lignite; that the sand and lignite brought up in the deep wells are similar to the same substances brought up by the innumerable springs that feed the lakes and streams of this district, and that they are apparently the same as that which surrounds the blow-holes and fault scarps, and which covers, as with a vast sheet, the considerable areas in the sunken district.

Relation of the earthquake to artesian conditions.—If one studies the phenomena of the earthquake as seen by the observers quoted in this article, he cannot help being impressed with the fact that the conditions as described are identical with what would be expected to occur from the undermining of the clay horizon by the slow and continuous removal of large bodies of sand. In this process of undermining a time would come when a slight disturbance would destroy

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[1] The above quotations are taken from Dr. Broadhead's collection of letters and documents relating to the earthquake, published in the *American Geologist* for August, 1902.

the equilibrium, and when the great pressure of the artesian water below would burst forth, causing the elastic clay roof to undulate, with the resulting earth-waves and ejections of water, sand, and lignite so vividly described by numbers of eyewitnesses of the catastrophe. The first disturbance, relieving, to a degree, the artesian pressure, would be followed by a temporary equilibrium, which would be succeeded by other periods of disturbance, as described.

RECENT EARTHQUAKES

This region has for many years been subject to slight earthquake shocks. A year rarely passes without their occurrence, the last one having as recent a date as September, 1904. In August, 1903, houses were shaken and dishes rattled, the phenomena lasting about ten minutes, and being accompanied by a roaring sound underneath. This earthquake was rather severe near Charleston, Mo., where a pond 3½ miles from the town was greatly enlarged by the sinking of adjacent land. The disturbance was attended by the throwing up of a considerable quantity of fine white sand. Mr. W. M. Timbs, a railroad conductor, stated that on October 5, 1895, quite a severe earthquake occurred in this region. At this time, south of Belmont, the water flowed from the driven pumps in this vicinity, and brought up sand and particles of coal, the pumps continuing to flow for a month. Numerous small cracks were formed on the prairie, from which sand and particles of coal were ejected. The writer's attention was called to the fact that one or more of these earthquake shocks occur each fall, being more frequent at that season of the year than at any other time. This might be accounted for by the low water in swamps, streams, and ponds following the dry season characteristic of the country—a condition which would give decreased pressure at the surface and offer least resistance to the artesian pressure below. Observers state that these shocks are always accompanied by a roaring noise and a waving of the ground.[1]

Some of the intense local disturbances in the Charleston, S. C.,

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[1] Mr. W. S. Randall, of Poplar Bluff, Mo., informs the writer that in a well sunk there to a depth of 700 feet, a number of years ago, the water rose to within 15 feet of the surface. A twelve-horse-power engine could lower it only about one inch; but after a severe earthquake shock, about three years ago, the well was nearly ruined, and since then furnishes barely enough water to run a factory.

earthquake district, which is also an artesian district, may have been due to the long and slow undermining of superincumbent beds by the removal of sand by artesian pressure. Visitors to this region have informed the writer that large quantities of sand were thrown up at various places during the shocks, and that springs bringing up sand still issue from the fissures thus made, similar to those described in the Big Bay district.

COMPARISON WITH CONDITIONS NEAR SHREVEPORT, LA.

Several visits to the region around Shreveport, made a number of years ago, revealed a condition similar to those of the New Madrid area, and suggested the probability of the agency of earthquakes in producing the lakes, swamps, and deposits of sand so characteristic of this portion of the state of Louisiana. Shreveport is likewise an artesian region, and in its geological structure is similar to that of New Madrid. Sunken lakes covering forests occur there, as described by Lyell,[1] who calls attention to these sunken lakes as illustrating the changes now in progress in the earth's crust. In the Red River region of Louisiana he mentions Lake Bistineau, which is 30 miles in length and from 15 to 20 feet deep, and on which one may float over a submerged forest. He also refers to Black, Caddo, Spanish, and Natchitoches Lakes, and does not agree with Darby's view that the gradual elevation of the bed of the Red River by the accumulation of alluvial material has raised its channel and caused its waters, in flood time, to flow up the mouths of some of its tributaries and to convert parts of their courses into lakes. Lyell says that—

> Most probably the causes assigned for the recent origin of these lakes are not the only ones. Subterranean movements . . . . have altered the levels of various parts of the basin of the Mississippi.

Mr. A. C. Veatch says in a paper on the Shreveport area:[2]

> The valley region above Shreveport is possibly unique in the respect that changes, which usually occupy great periods of time, and whose full story can only be learned by deduction, have taken place here within a few years. Lakes have been formed and destroyed; streams formed and abandoned; waterfalls produced to destroy themselves; new streams formed out of parts of the beds of old ones; and temporary reversals of the drainage system have been effected.

[1] Lyell, *Principles of Geology*, Vol. I, p. 457.

[2] Geological Survey of Louisiana, *Report for 1899*, p. 152.

On p. 159 of this same report we read:

> Connected with Sodo Lake by Big Willow Pass is Ferry or Fairy Lake. It differs from Sodo by having hills on both sides; being exactly the same type as Cross Lake, a lake occupying an old stream valley. Ferry Lake is quite shallow, with a narrow line of deeper water winding irregularly through it. This lake is rendered particularly interesting by the large number of cypress and oak stumps standing upright in it, even in the deepest water.

The same author says further, on p. 185:

> On the recent origin of the lakes in the upper part of the valley there can be little question. A number of planters of Red River bottoms have repeated to me the old Caddo Indian tradition that about 150 years ago the land now occupied by Sodo Lake was an oak ridge, that all the water flowed in a narrow cypress-fringed bayou in the center, and that the filling of the valley was sudden, as if by an earthquake.

PRIMARY CAUSE OF THE NEW MADRID EARTHQUAKE

As to the primary cause of the New Madrid earthquake, it is difficult to make any statement. It may have been due to the readjustment of fault lines in the Ozarks, or to a similar cause in the Appalachians. It would seem more likely to have been the former, as the fault scarps in the Ozarks frequently have an appearance that does not betoken great age and, further, slight earthquake shocks, which observers described as coming from the west, have been noticed.

As to the cause of the great local disturbance in the New Madrid region, there can be no doubt that it was due to the great artesian pressure from below, which slowly undermined, for centuries, the superincumbent beds of clay by the steady removal of the sand through innumerable springs. A slight earthquake wave would destroy the equilibrium of a region thus undermined, resulting in the sinking of some areas, and the elevation of others, thus producing such conditions as were described by various observers who witnessed the castrophe of 1811.

The escape of gas resulting from decaying organic matter may have had something to do with the certain phenomena of the earthquake, and would certainly account for the presence of so-called "sulphurous vapors" and gases referred to by so many observers in their accounts of the earthquake.

CONCLUSIONS

The facts here given present an explanation of the elevation and depression of the land in the New Madrid region that has not before been recognized, and the writer believes that they form a satisfactory explanation of the phenomena which have so long puzzled those who have attempted to solve the problem of the great local disturbance at New Madrid. If this is so, they may also explain similar instances of subsidence and elevation in other regions that have been little understood, and will demonstrate, for the artesian waters of the globe, a wider influence as a geologic agent than has hitherto been ascribed to them.

STRUCTURES OF BASIN RANGES

CHARLES R. KEYES
New Mexico School of Mines, Socorro, N. M.

Several memoirs recently published have awakened a new interest in the geotectonics of the Great Basin region. The main structural features about which discussion centers appears to be whether the Basin ranges are the result of normal faulting and form "block" mountains; or whether the "block" aspect is only apparent, in reality the "block" originally being a sharp asymmetric fold, in which subsequent erosion wears off the steeper limb faster than the other.

In the elucidation of the arguments by specific example, it is unfortunate that some of the illustrations selected have not been chosen with greater discernment. It is now well understood that some of the instances noted furnish the most conclusive proofs of directly the contrary of the purpose for which they were cited. Without entering into detail in regard to many of these cited examples from other parts of the Basin region, it seems pertinent at this time to call attention briefly to certain features displayed in the New Mexican part of the field. These may help to explain similar phenomena in other districts.

The geologic sequence in central New Mexico is especially noteworthy on account of the almost complete absence of the Lower Paleozoic rocks and the enormous development of the Cenozoic strata. The important member of the sequence above the Proterozoic metamorphics is the Upper Carboniferous limestone which attains a normal thickness of 2,000 feet.

In all of the mountain ranges of central New Mexico, appearing as tilted blocks, the crests of which rise 3,000–5,000 feet above the bases, the great Carboniferous limestone forms the backslope, usually reaching to the summit. On the opposite or steep face of the ridges the Proterozoic clastics and schists, which usually stand on edge, are exposed for a vertical distance of 2,000 feet, or more. Above the Carboniferous limestones at the foot of the mountains are Red Beds and then Cretaceous sandstones.

No evidence has yet been found that would indicate that any of these numerous mountain blocks were produced by folding. All observations go to show most conclusively that only faulting is involved. The sedimentaries of some of these mountains, however, are often folded and closely corrugated. Thrust-planes are plainly visible. Numerous other indications point to tremendous compression at some time or other. But the period of compressive action has been found to be a very different one from that during which the present mountains were formed. The compression took place long before the existing mountain blocks reared their heads above the vast surrounding plains. Chronologically this period of compressive conditions was manifestly after the Carboniferous, because the rocks of this age were involved; but it was before the late Cretaceous, since Cretaceous strata are as clearly not affected.

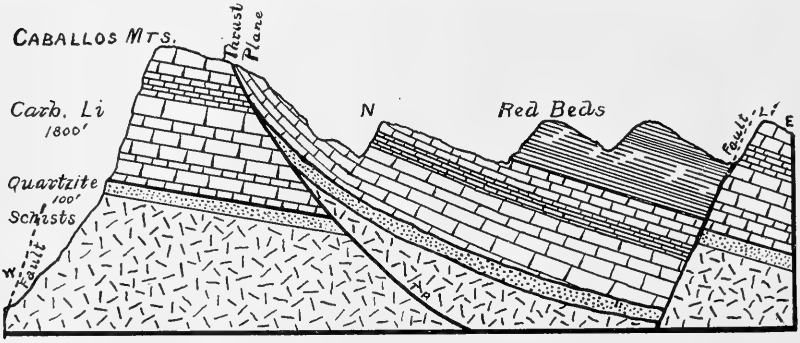

FIG. 1

In the Sierra de los Caballos, in south-central New Mexico, the geological sections are particularly instructive. Near the highest point of the range, known as Timber Peak, the scarp is over 3,000 feet high and displays an excellent exposure of the rocks throughout this entire vertical distance. The transverse section shown a short distance to the north is represented in the diagram, Fig. 1. The heavy line *T. P.* indicates the position of an exceedingly well-displayed thrust-plane. Along it the beds are highly contorted. The entire limestone is badly shattered and traversed by large and small crevices which are now cemented by calc-spar. The inclination of the thrust-plane is now rather steep, but, as will appear subsequently, this is due partly to the fact that the present position of this structure is not the original one. Since its formation the thrust-plane also has been tilted in marked degree. In point of time, the formation of the thrust-plane long antedates the uprising of the present mountain blocks.

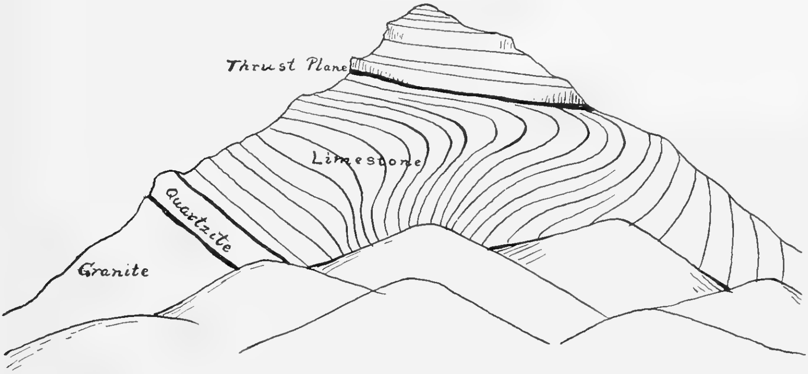

FIG. 2

A few miles to the north, in the same range, is another lofty point called Caballo Peak. There are clearly shown in this place the limestone beds completely overriding the lower beds, the first mentioned now reposing nearly horizontally on inclined strata. Fig. 2 is a sketch of the peak as it appears from the south.

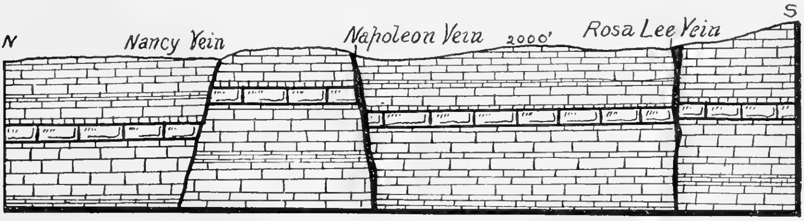

FIG. 3

Another system of faults, the age of which is quite recent, also exists. These dislocations run transverse to the other two and to the axis of the range. As they appear in the canyon walls (at *N*, Fig. 1), a sketch of them (Fig. 3) is annexed.

There are, then, in the Sierra de los Caballos at least three very distinct periods of faulting. The first was before the formation of the present mountain ridge; a second was coeval with its formation; and the third was long subsequent to its uprising.

Were it not for exceptionally clear evidence to the contrary, casual examination could very easily lead to the conclusion that the Caballos mountain range was produced by sharp folding and that the crest of this asymmetric fold was removed through erosion. This deduction is a quite natural one, especially when, in a view from the summit of the range, there are clearly shown the strata dipping eastward forming a broad syncline and coming up again with westerly dips in the great San Andreas Mountain block, 30 miles beyond.

It so happens that in the instance under consideration we now know enough of the general geological history of the region to give us a good insight into some of the actual conditions that have existed. It has recently been shown[1] that the Upper Cretaceous of central New Mexico rests in marked unconformity upon the older rocks. The period during which conditions existed for folding of the strata was, already stated, later than the laying down of the Carboniferous limestones and later than the deposition of the "Red Beds," as these were all involved.

A number of observations lately made emphasize the character of the events which took place in the region during early Cretaceous times, and the great importance of the unconformity at the base of the Cretaceous of the region. That during this period the older rocks were greatly disturbed over wide areas is amply attested by the almost vertical "Red Beds" (Carbo-Triassic) overlain by horizontal Cretaceous, as is seen at Tejon, south of Santa Fé, in Sandoval county;[2] the highly inclined Carboniferous limestones, on either side of high trachyte dikes on which recline nearly horizontal Cretaceous sandstones on the Chupadera Mesa, in eastern Socorro county;[3] and the position of the Cretaceous on the older formations in the Caballos Mountains in Sierra county; as well as in other localities. The unconformity represents a great land surface; and during the interval for which it stands the strata of the region were folded and eroded off to a plain-like surface before being later covered by sediments.

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[1] *American Journal of Science* (4), Vol. XVIII (1904), pp. 356–58.

[2] *Ibid.*, p. 357.

[3] *Ibid.*, p. 358.

Attention is especially called to these facts for the reason that in some instances cited relative to the structure of Basin ranges it is quite manifest that the proper local interpretations have not been made. It is probable that a large number of other cases will be found to be illy chosen for purposes of type illustration. The observations made in the Sierra de los Caballos are suggestive of similar phenomena occurring in other districts. Critical evidence on the points emphasized is much desired from many other ranges. When once secured, it may do much towards correcting some very erroneous present interpretations.

A generalized geological cross-section of a part of the Basin region of New Mexico more clearly illustrates the type of mountain structure under consideration (Fig. 4).

FIG. 4

In all of these ranges there are abundant evidences of marked compression producing the phenomena of folding and thrusting. Yet in every instance thus far observed the period of this movement is found to be long prior to the elevation of the present mountains.

There is another very deceptive feature connected with the formation of the block-like mountains of the New Mexican portion of the Basin region. At the foot of the steeper slope the strata are often found tilted at a high angle, and inclined away from the range. The attitude of the beds easily suggests, at first consideration, the possibility of the mountain ridges being a sharp anticline, with the center completely removed through erosion, leaving the limbs of the arch unequally exposed. This condition might be readily fancied because of the fact that the greater part of the height of the mountains, 3,000–4,000 feet, is usually composed of massive crystallines and schists, and the crest and backslope of the limestones.

There are strong reasons for believing that this phenomenon, instead of being ascribed to folding of the asymmetrical type, should be considered an accompaniment of normal faulting. Only the faulting is on a gigantic scale—a scale very much larger than is usually met with. When the hade is steep, the strata on the down-throw side to a greater or less degree commonly lag, until a considerable zone is produced in which the strata become highly inclined, and in many cases stand even nearly vertically. A typical case is represented below:

In a smaller way we find the same lagging structures accompanying the faulting in coal mines. It is a fact well known to the miners that when the dip lessens a down-slip is soon to be expected.

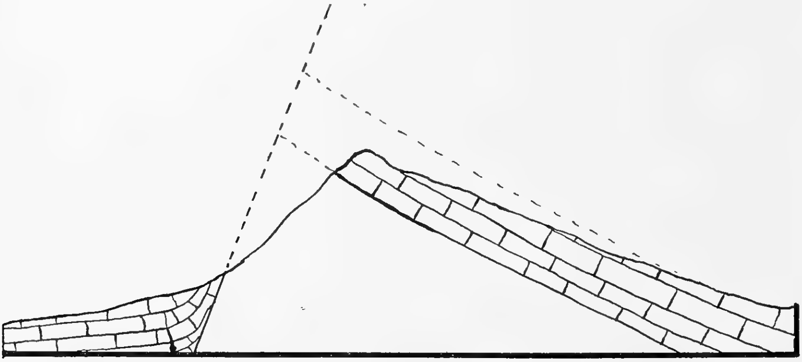

FIG. 5

There is a theoretical reason for believing that in the region under consideration normal faulting, instead of folding, is to be expected to explain the origin of the New Mexican mountains of the Basin district. The principle was clearly set forth by LeConte[1] as long ago as 1889, when discussing the Nevada region between the Sierra Nevada and the Wasatch Mountains.

As considered there and in his textbook of geology[2] this author appears to have regarded the area in question as a region which was subjected to slow and general uprising, but continually adjusting itself through normal faulting in great blocks. By the tilting which these blocks suffered mountain ranges were produced on the elevated edge, and on the depressed side were formed valleys which were subsequently filled with sediments.

[1] *American Journal of Science* (4), Vol. XXXVIII (1889), p. 259.

[2] *Elements of Geology*, 5th ed. (1904), p. 242.

In the late account of the Humboldt region in Nevada, Lauterback[1] dissents somewhat from the view of the simple tilted block idea, and is inclined to believe that the mountain-block and the valley-block are distinct. This appears often to be the correct interpretation in the New Mexican part of the Basin region.

The physiographic development of the New Mexican region appears, briefly to be as follows: About the beginning of Tertiary time the area lying between what is now the Gulf of California and the Gulf of Mexico must have been a vast low-land plain elevated but slightly above sea-level, and having faint relief features. A large part of the plain was a surface worn out on the beveled edges of Cretaceous and older strata, as is, even at the present day, still clearly discernible in its remnants. The Las Vegas plateau, the Llano Estacado, the bolson plains of central New Mexico, and some of the less-broken plains of eastern Arizona appear to belong genetically together. To the east and west of the vast area thus outlined there had been formed, from the sediments derived from the planing off of the central land area, a broad submarine platform. When later in Tertiary times the general bowing up of the region began to take place, the great plain that had been formed was partly a peneplain of destructional land origin and partly a constructional plain of marine origin.

During the period of uprising folds were extensively developed, and the compression was so intense that in many cases thrust-faults were formed. Many low mountain ridges were probably produced at this time. Subsequently, as if the upward movement had been too extensive, the compressive force gave way to one of tension. Normal faulting on a grand scale occurred, producing the numerous short monoclinal or "block" mountains of the region.

Several important points bearing upon Basin Range structures appear to be reached in the present connection:

1. The determination of the most obvious structures of any particular mountain region is not sufficient and is not critical evidence; the time of the formation of the structures is an all-important consideration. When the younger strata are removed from the mountains, the structures of the older rocks may tell a very different story. In some

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[1] *Bulletin of the Geological Society of America*, Vol. XV (1904), p. 343.

instances mentioned by Spurr the younger strata would seem to be entirely wanting. In many New Mexico ranges the great Carboniferous limestones form the major portion, and they give evidence of an older and very different record of events from that which includes the uprising of the present mountain blocks.

2. The structures of each mountain range must be determined separately and upon the evidence which it alone presents. Even in neighboring ranges one may disclose a history very much longer and older than another.

3. In the New Mexico area orogenic movement, while more or less rhythmic in character, was doubtless continuous since Paleozoic times. At least three periods of marked activity have been recognized.

4. Modern ranges, the "block" mountains rising out of the Basin plains, in which the Mesozoic strata are eroded from the summits, are likely to have the structures of the first period of orogenic movement (early Cretaceous) most in evidence, and the later effects may be less strongly emphasized. In the specific cases of New Mexico this period was one of folding and overthrusting.

6. Modern mountains, around which there are late lava flows, are likely to show the effects of the third (Pleistocene) movements. These are chiefly normal faulting.

THE CLASSIFICATION OF THE UPPER CRETACEOUS FORMATIONS AND FAUNAS OF NEW JERSEY[1]

STUART WELLER
The University of Chicago

Since the organization of the present Geological Survey of New Jersey, three classifications of the Cretaceous formations of the state have been proposed and have been published in the reports of the Survey. The first of these, elaborated by Professor Cook during his administration as state geologist, was published in 1868.[2] At that time the practice of naming geological formations by geographical names was not usually adopted by working geologists, and the successive beds were designated by names suggested by their lithologic characters. Above the "plastic clays" since known as the Raritan formation two major series of beds were recognized, the "clay-marl" series below and the "marl" series above. The discrimination of the beds of the "marl" series, as first described by Cook, has not been changed by any of the more recent investigations, but a closer study of the "clay-marl" series has led to the discrimination of a series of beds not recognized by Cook. In his interpretation of the stratigraphy of the southern portion of the area, however, Cook, in the absence of accurate topographic maps, fell into one error on account of his failure to recognize the disappearance of his "red sand" formation in that direction, and the consequent continuity of the "lower" and "middle" marl beds. To the south he identified a bed now known to belong in the "clay-marl" series, with the "lower marl" of Monmouth County, and considered the bed now known to represent the combined "lower" and "middle" marls, to be the continuation of the "middle" marl alone.

In 1891 Professor W. B. Clark entered upon a study of the Cretaceous beds of New Jersey, and the results of his work are published in the *Annual Reports* of the Survey for 1892, 1893, and 1897. The

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[1] Published by permission of the State Geologist of New Jersey.

[2] *Geology of New Jersey*, 1868, p. 241.

two essential differences between his classification and that of Cook are in the position of the major dividing line between what are, roughly speaking, Cook's "clay-marl" and "marl" series, and in the interpretation of the "yellow sand" formation above the "middle marl." In place of Cook's lithologic names, however, Clark substituted a series of geographic names in accordance with more modern usage. In a more recent paper Clark[1] has made some modification of his earlier interpretation of the beds, notably in the position of the lower boundary line of his lower or Matawan division in the region adjacent to Raritan Bay. In this paper he has excluded the Cliffwood clays from the Matawan, thus bringing the basal line of the Matawan to conform exactly with the base of Knapp's Merchantville clay.

During his study of the Pleistocene deposits under the direction of Professor R. D. Salisbury, Mr. G. N. Knapp found it necessary to make close study of the underlying formations of Cretaceous age. In the course of this study he was able to discriminate a series of five distinct formations in the old "clay-marl" series of Cook. Each one of these formations was found to be marked by constant lithologic characteristics, but at that time the paleontologic characters of the beds had not been investigated. These formations were traced by Knapp and carefully mapped entirely across the state from Monmouth to Salem Counties. A description of the beds, especially in relation to the soils to which they give rise, was first published by Professor Salisbury in the 1898 *Report* of the Survey,[2] and geographic names were applied to them, viz., Merchantville, Woodbury, Columbus, Marshalltown, and Wenonah. A fuller description of the lithologic characters of these formations has been given by Dr. H. B. Kümmel in the recent *Clay Report* of the Survey.[3]

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[1] *American Journal of Science*, 4th series, Vol. XVIII, pp. 435–40.

[2] *Annual Report of the State Geologist of New Jersey*, 1898, pp. 35, 36. It may be said that the tracing out of the Cretaceous beds was no part of Professor Salisbury's plan. It was done by Mr. Knapp because the several beds of the "clay-marl" series sustained very definite relations to the Pleistocene formations. The names published at this time were not published by Professor Salisbury for the purpose of making a new classification of the Cretaceous, but merely because the soils could best be described in connection with these several subdivisions.

[3] Geological Survey of New Jersey, *Final Report*, Vol. VI, pp. 152–61.

These three systems of classification have been arranged side by side in the accompanying tables, in order that they may be easily compared one with the other.[1] At the time of publication of Cook's classification, although a large number of Cretaceous fossils had been described from New Jersey, little was known of the actual distribution of the fossil species in these beds, except in the case of the conspicuous shell beds which can be recognized continuously across the state. Cook's classification may therefore be considered as being based almost exclusively upon the lithologic characters of the beds. Before Clark's classification was proposed, however, Whitfield's[2] two important volumes upon the paleontology of the Cretaceous formations of New Jersey had been published, and Clark gives long lists of fossil species in his papers as representative of the faunas of his major divisions, so that his classification was founded, at least in part, upon paleontologic data. Knapp's subdivisions of the "clay-marl" series are professedly based upon the lithologic characters alone.

During the field seasons of 1903 and 1904 the writer has been engaged in an investigation of the paleontology of these Cretaceous beds and has accumulated a large amount of information in regard to the faunas of the successive formations, especially those of the "clay-marl" series, and in the following pages an attempt will be made to point out the bearing which this new evidence has upon the classification of the formations and faunas.

In his Matawan division, Clark has recognized two formations, the Crosswicks clays and the Hazlet sands. The Crosswicks clays correspond exactly with Cook's "clayey green sand," and with Knapp's two formations, the Merchantville clay-marl and the Woodbury clay; while the Hazlet sands correspond in Monmouth County with Cook's "laminated sands" and with Knapp's two formations, the Columbus sand and the Marshalltown clay-marl, as well as with

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[1] In this table Cook's classification of the beds in Monmouth County is recognized. His understanding of the stratigraphy in the south was incomplete, and in that portion of the area he considered Knapp's Marshalltown formation as the equivalent of the "lower marl" and the Wenonah as the equivalent of the "red sand," the true Red Bank sand and the Tinton beds being absent there.

[2] *Paleontology of New Jersey*, Vols. I and II; also *Monographs of U. S. Geological Survey*, Vols. IX and XVIII.

a portion of the Wenonah sand. In his faunal lists Clark does not differentiate the fauna of the Crosswicks clays from that of the Hazlet sand, but gives a single generalized list of species as the fauna of the whole Matawan. As a matter of fact, there is considerable community of characters among the faunas of all five formations recognized by Knapp in the "clay-marl" series, except only the fauna of the upper beds of the Wenonah sand in the southern portion of the area, enough, at least, to make their inclusion in one major division fully justifiable. The two cephalopod genera, *Placenticeras* and *Scaphites*, characterize the whole series of beds, either one or both being present at every locality where fossils have been extensively collected, while neither of them has been detected in the higher beds. There are, however, sharp distinctions between the faunas of the successive formations recognized by Knapp, and these faunal characters are easily recognizable throughout the whole extent of the beds across the state, wherever fossils have been found. In the discrimination of these faunal zones of the "clay-marl" division, however, it is not safe to assert that any particular species is absent from any one of the faunas, and bare lists of species, without some statement of the abundance of the forms noted, might not in all cases show the characteristic features of the different faunules. The combined faunas of the whole series of formations, and even including those to the summit of Clark's Monmouth division, really make one unit of a larger order. The constant recurrence of various species and groups of species, in this entire series of faunal zones, indicates that somewhere along the Atlantic border they lived continuously. As local conditions of environment changed from time to time, the dominant characteristics of the local faunas changed, and it is such changes, for the most part but not wholly, that are recorded in the faunas of these New Jersey formations.

The Merchantville clay is characterized by the abundance, among other species, of *Axinea mortoni*, *Idonearca antrosa*, *Trigonia eufaulensis*, and *Panopea decisa*. In the Woodbury clay these same species are conspicuous for their absence or great rarity. In a collection from the Woodbury clay in Monmouth County, including sixty or more species and many hundreds of individuals, a single specimen of *Idonearca* and a single *Axinea mortoni* were found; while, on the other hand, *Cyprimeria*, *Lucina cretacea*, *Breviarca*, *Cancellaria subalta*, and others which were rare or entirely absent from the Merchantville, are the commonest species of the fauna. Furthermore, this same faunal distinction between the two beds holds as sharply in the region opposite Philadelphia as in Monmouth County. The faunal lists of the Matawan, heretofore published, omit many of the most abundant and widespread species of the Woodbury clay, and are predominantly of Merchantville species, so that the Matawan fauna as previously recorded is somewhat incomplete.

The Columbus sand has as yet not yielded a single fossil, and is perhaps entirely barren. The Marshalltown formation, however, in its more southern extent is abundantly fossiliferous, although in Monmouth County no fossils have yet been found. Near Swedesboro the fossils in this bed occur in a remarkably perfect state of preservation and in great numbers. A large *Trigonia*, probably *T. mortoni*, is represented by hundreds of individuals, and associated with this species are *Cyprimeria sp.* and *Idonearca vulgaris* in abundance. In this fauna the large and ponderous specimens of *Gryphaea vesicularis* and *Exogyra costata*, with innumerable specimens of a variety of *Ostrea larva*, are a conspicuous faunal element for the first time, foreshadowing, perhaps, the Navesink fauna. The whole complexion of the fauna is different from either the Merchantville or the Woodbury, although certain species are present which occur also in one or both of these lower faunas.

Between the Marshalltown clay-marl and the "lower" or Navesink marl there is a well-marked sand bed 40–60 feet thick. In Monmouth County it is, on the whole, a fine micaceous sand, with some clay laminæ and locally near its base with thicker clay lenses. Locally its upper portion is a coarser quartz sand, with a commingling of glauconite near the marl bed. In the southern counties it is predominantly a coarse quartz sand with some disseminated glauconite, the fine micaceous phase being inconspicuous or even perhaps entirely absent. This formation Knapp called the Wenonah sand.

In Monmouth County Clark's Hazlet sands correspond exactly with Cook's "laminated sand," and almost exactly with Knapp's three formations—the Columbus sand, Marshalltown clay-marl, and the Wenonah sand—the upper few feet of the latter being apparently

Cook, 1868		Clark, 1892–1904		Knapp-Kümmel, 1898–1904	Weller, 1905	
Upper Marl	Ash Marl Green Marl	Manasquan	Manasquan Marl	Upper Marl (in part)	D	Manasquan
Yellow Sand			Yellow sand, later referred to the Miocene	Lime sand (including Yellow Sand)	C	Long Branch
Middle Marl	Yellow limestone and lime-sand	Rancocas	Vincentown			Vincentown
	Shell layer Green Marl Chocolate Marl		Sewell	Middle Marl (Sewell)		Sewell
Red Sand	Indurated green earth	Monmouth	Red Bank Sand	Red Sand (Red Bank Sand)	B	Tinton
	Red Sand Dark micaceous Clay					Red Bank
Lower Marl	Marl and Clay Blue shell Marl Sand Marl		Navesink Marl	Lower Marl (Navesink Marl)		Navesink Mt. Laurel
Clay Marls	Laminated Sands	Matawan	Mount Laurel Sand	Wenonah Sand	A	Wenonah
			Hazlet Sand	Marshalltown Clay-Marl		Marshalltown
				Columbus Sand		Columbus
	Clayey Green Sand		Crosswicks Clay	Woodbury Clay		Woodbury
				Merchantville Clay-Marl		Merchantville

excluded. In the southern counties the Hazlet sands correspond only with Knapp's Columbus and Marshalltown, all of the Wenonah being excluded. The line, therefore, between the Matawan and Monmouth, as these two divisions were defined in 1897, is a line running diagonally across Knapp's Wenonah sand, from near the summit of that formation at Atlantic Highlands to its base in Gloucester and Salem Counties. This lack of agreement between the two interpretations was apparently due to Clark's interpretation of the relations of the coarse, quartz-sand phase of the Wenonah which he called the Mount Laurel sand. In regard to this formation he said:

> They have a thickness of about 5 feet in the vicinity of Atlantic Highlands, which slowly increases to the southward, until in the region to the east of Philadelphia they have increased to over 25 feet. Beyond that point they increase more rapidly throughout the southern counties, reaching 50 feet in Gloucester County and fully 80 feet in the vicinity of Salem.[1]

In New Jersey the lithological change at the top of the Wenonah is much more marked than that at its base, and for this reason the Wenonah sand was grouped by Knapp and Kümmel[2] with the underlying rather than the overlying beds. In effect, therefore, two positions for a major dividing line in this portion of the section have been suggested: (*a*) diagonally across the Wenonah sand; and (*b*) at the top of the Wenonah sand.

The recent paleontological studies cast some light upon this problem, even although they do not definitely settle it.

The Wenonah sand, so far as known at present, carries two different faunas. One of these has been found in Monmouth County, and at two localities from which extensive collections have been made over one hundred species have been recognized. This is very different from that in the overlying Navesink marl, and for the present will be referred to as the Wenonah fauna, although ultimately it may be best to give it a different name. The other fauna occurs in Gloucester and Salem Counties, and will be described in connection with that of the Navesink marl.

At one of the localities where the Wenonah fauna has been found the fossils occur in a coarse ferruginous sand at a distance of 9 feet

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[1] *Annual Report of the State Geologist of New Jersey*, 1897, p. 183; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 334.

[2] *Loc. cit.*

beneath the base of the Navesink marl. The other locality is in a fine, more micaceous and argillaceous bed, immediately beneath the marl.

In this Wenonah fauna there is a return of many Merchantville and Woodbury species, among them being *Trigonia eufaulensis*, *Axinea mortoni* and *Panopea decisa*. *Idonearca* is also present, but is much less conspicuous than in the Merchantville or the Marshalltown. Among the Woodbury species which occur in the Wenonah fauna, may be mentioned *Cymella bella*, which, although rarely present in the Merchantville, was much more conspicuous in the Woodbury fauna. *Leptosolen biplicata* is one of the very common forms in the Wenonah fauna which was present both in the Woodbury and the Merchantville. The ponderous *Gryphaea* and *Exogyra* of the Marshalltown fauna are absent, but *Ostrea plumosa* is sometimes a very common species.

The faunal change in passing from the Wenonah to the Navesink formations in Monmouth County is far greater than the change in passing over the line between any two of the formations below. In the fauna of the Navesink marl a new factor is introduced which is entirely foreign to the earlier faunas of the area, the most characteristic species of this new element being the cephalopod *Belemnitella americana* and the brachiopod *Terebratella plicata*, both of which are especially abundant and characteristic of this zone. We also find a recurrence of the massive *Gryphaea vesicularis* and *Exogyra costata* which characterized the Marshalltown beds below, but the *Exogyra* is usually less abundant than in the earlier fauna. *Ostrea larva* also occurs in great abundance, as it did in the Marshalltown fauna, but it is a somewhat different variety of the species. In place of the cephalopods *Placenticeras* and *Scaphites* of the "clay-marl" faunas, *Nautilus dekayi* occurs in this fauna and also in the fauna of the Red Bank sand next above. In the fauna of the beds just beneath the base of the Navesink marl, *Placenticeras placenta* occurs more frequently than in any other bed of the New Jersey Cretaceous, associated with many other species common also to the Merchantville or Woodbury formations. These facts, taken together with the marked lithological change at the top of the Wenonah, are strong evidence for placing the major dividing line in this portion of the New Jersey Cretaceous at the base of the Navesink marl in Monmouth County. But there are other facts to be considered.

One of the most characteristic faunal features of the Navesink marl is a conspicuous shell bed about 12 feet above the base of the marl in Monmouth County. It is usually about 1 foot in thickness, and is composed almost exclusively of the shells of *Gryphaea vesicularis* and *Ostrea larva*, with occasional specimens of other pelecypods and gasteropods. At the base of the Navesink in Monmouth County there is sometimes an arenaceous, more or less abundantly fossiliferous bed, which Cook designated as the "sand-marl." At Atlantic Highlands this bed is 3 or 4 feet thick, and is evidently the bed which Clark mentioned in his description of the Mount Laurel sand at that locality, and which Knapp regarded as forming the top of his Wenonah sand. In passing to the southward this arenaceous basal member of the Navesink seems to become more and more conspicuous, replacing higher and higher beds of the green-sand marl, until at Mullica Hill it extends up to and even includes the conspicuous shell layer of the formation. This arenaceous facies of the Navesink frequently abounds in fossils, although they are usually imperfectly preserved casts, and the fauna is always characterized by the typical Navesink species *Belemnitella americana.*

It is believed that Clark's conception of the Mount Laurel sand formation has grown out from this changing facies of the Navesink to the southward, and, in the absence of sufficient data concerning the fauna of the beds immediately beneath those with the *Belemnitella* fauna, he has extended the Mount Laurel formation downward to include the entire sand bed to the top of the Marshalltown clay. On the other hand, Knapp and Kümmel have extended the Wenonah formation upward to include all the sand to the south, so that their upper boundary line of that formation marks a higher and higher geologic horizon in that direction. From the standpoint of the faunas the major division line in this portion of the Cretaceous beds must be drawn where the *Belemnitella* fauna is introduced, and although the Wenonah fauna of Monmouth County has not yet been detected in the more southern portion of the area, neither has the *Belemnitella* fauna been observed in the lower portion of this Mount Laurel-Wenonah sand, 18 feet beneath the top of the sand being the lowest horizon where the *Belemnitella* fauna has been seen in New Jersey.

With this interpretation it is possible that both the terms, "Mount Laurel" and "Wenonah," should be retained in the nomenclature of these beds, the Wenonah for the sand formation beneath the beds bearing the *Belemnitella* fauna in Monmouth County and for the southern continuation of the same beds, while the name "Mount Laurel" will designate the arenaceous facies of the Navesink which becomes more and more conspicuous to the south. These relations, however, complicate the task of mapping the beds in the southern portion of the New Jersey area, because of the juxtaposition of the two arenaceous formations whose separation can be based only upon the presence or absence of the *Belemnitella* fauna. However, further observations upon these beds must be made before the relations here suggested can be considered as established.

The fauna of the Red Bank sand is to some extent a recurrence of the faunas of the beds beneath the Navesink marl, *Trigonia eufaulensis*, *Axinea mortoni* and other species of the Merchantville, Woodbury, and Wenonah formations being commonly present. Some species, such as *Perrisonota protexta* and *Corbula crassiplica*, which were present, although usually rare, in one or more of the "clay-marl" formations, become much more abundant in the Red Bank. The fauna is characterized everywhere by the large shells of *Gryphaea vesicularis* and by *Ostrea larva*, species which were abundant in none of these lower formations except the Marshalltown; but they never form such a shell bed as that which occurs so commonly in the midst of the Navesink marl. Other elements in the fauna are also inherited from the Navesink, although the two most characteristic Navesink species, *Belemnitella americana* and *Terebratella plicata*, have nowhere been observed in the fauna.

In none of the classifications as published, except Cook's, is any special recognition given to the hard, glauconitic, indurated sand bed at the top of the Red Bank, although it was briefly referred to by Clark, and has been carefully mapped by Knapp. This bed, called by Cook the "indurated green earth," marks a definite horizon and yields a fauna which especially characterizes it throughout its entire extent. The most characteristic member of this fauna is the large ammonite *Sphenodiscus*, which has frequently been collected from this horizon, but has not been observed elsewhere. Another very characteristic species is *Trigonia caerulea*, which has been seen only in this formation, and almost everywhere the beds furnish numerous crustacean claws probably belonging to the genus *Callianassa.* A fine exposure of this formation occurs at Tinton Falls, N. J., where this hard bed, 22 feet thick, is responsible for a waterfall in a tributary of the Swimming River, and the name "Tinton beds" may be used to designate the formation. The fauna of the Tinton beds is much more closely allied to the faunas of the beds below than to those above, many of the earlier species being present, while *Terebratula harlani*, the most characteristic species of the next higher division, has never been observed.

Judging from their faunas, the three formations—Navesink (including that portion of the underlying sand with the *Belemnitella* fauna), Red Bank, and Tinton—constitute together a major division of the entire Cretaceous series, comparable in rank with the five formations of the "clay-marl" series, and Clark's name "Monmouth" very nearly expresses the limits of the division.

The Rancocas division of Clark, if some modification of interpretation be admitted, is another natural paleontologic division, characterized by the brachiopod *Terebratula harlani*, but the later investigations of the New Jersey Survey have thrown much light upon this portion of the Cretaceous section. The Sewell marl rarely contains fossils except at its summit, where a very constant shell layer of about 5 feet thickness occurs, being made up almost exclusively of the shells of *Gryphaea vesicularis* and *Terebratula harlani.* The Vincentown formation consists in large part of calcium carbonate furnished by immense numbers of several species of bryozoans. The remains of echinoids are also more or less common, and in the past some very fine specimens of these fossils have been found in this formation. The Vincentown fauna, however, is so different from that occurring at the summit of the Sewall marl that, were it not for the relationships of the "yellow sand" fauna, which combines both elements, one would scarcely be justified in including the Sewell and the Vincentown under one larger division.

In Cook's original classification of the Cretaceous beds of New

Jersey the stratigraphic position of the "yellow sand" was considered to be above the "lime sand" or Vincentown formation of Clark, and it was believed to be intimately related to that formation. But Clark, from his published statements, seems to have been somewhat uncertain in regard to the relationships of this bed.[1] It appears that, while at first he was inclined to follow Cook in including the "yellow sand" in the Cretaceous, yet at a later date he arrived at a different conclusion and considered the beds to be of Miocene age.

A careful search by the writer, in company with Knapp, disclosed good fossils in the "yellow sand" at several localities, and fragments of fossils may be found in the formation at almost every exposure. At the base of Gold Hill, one mile south of Eatontown, *Terebratula harlani* and *Gryphaea vesicularis* occur in abundance, and with them fragments of spines and plates of echinoids, and broken bryozoans. At California Hill, near Deal, fossils occur near the summit of the formation in abundance, *Terebratula harlani* again being the most common form, associated with several species of pelecypods. In the bank of the Manasquan River, at New Bergin Mills, one and one-half miles west of Farmingdale, this formation is well exposed in an unweathered condition, and contains a somewhat larger percentage of glauconite than in the other localities mentioned. Fossils are exceedingly abundant at this locality, some layers of the sand being filled with bryozoan remains, with some echinoids, the fauna being essentially that of the Vincentown lime-sand. In other beds at the same locality, fragments of *Terebratula harlani* were observed.

I have interpreted these fossils as definite evidence that the sand in which they occur is of Cretaceous age, and is to be correlated with the Vincentown lime-sand. If it be thought worth while to designate the "yellow-sand" facies of this formation by a separate name, it may be called the "Long Branch sand," as has been suggested by Knapp.

Clark's contention that the "yellow sand" is Miocene in age is based upon the supposition that the present position of the included fossils is not their original position, but that they have been washed

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[1] *Annual Report of the State Geologist of New Jersey*, 1892, p. 205; *ibid.*, 1893, p. 338; *ibid.*, 1897, p. 186; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 336; and *Annual Report*, 1897, p. 190; also *Bulletin*, Vol. VIII, p. 340.

out from their original place of deposition, and have been redeposited in these sands in Miocene time. This interpretation, however, seems to be untenable on account of the stratigraphic relations of the beds, on account of their geographic distribution, and on account of the difference in character between these beds and the dark clay beds which form the base of the undisputed Miocene in the adjacent region. Furthermore, wells drilled to the south of the outcrop of the "yellow sand" show the presence of a similar arenaceous bed beneath the Manasquan marl.

If the reference of these beds to the Cretaceous is correct, it shows that the *Terebratula harlani* zone has a much greater vertical range in New Jersey than the shell bed at the summit of the Sewell marl, in this respect corresponding with the conditions in Maryland where, Clark says, "the *Terebratula harlani* is no longer limited to its former horizon at the top of the Sewell marls, but occurs frequently within and even at the top of the lime-sands."[1]

As regards the "upper" or Manasquan marl of Clark, there is no difference of opinion, except as Clark's earlier interpretation of the "yellow sand" affected the lower limits of the formation in his original definition. The fauna differs in most of its species from the lower faunas, *Caryatis veta* and *Crassatella delawarensis* being two species usually found in this horizon and not observed elsewhere. The bed is especially characterized by the large number of sharks' teeth it contains. The higher beds of the "upper marl," separated by Clark as the Shark River formation, are recognized, by everyone who has studied them, as of Eocene age, and therefore they need no further consideration here.

From the view-point of the writer, the arrangement of the formations, as expressed in the fourth column of the table on p. 76, seems best to express the true faunal relationship of the beds. With the exception of the Tinton beds and the Long Branch sand, no new names are introduced. For the designation of the four major divisions the letters A, B, C, and D are used, instead of Clark's four names "Matawan," "Monmouth," "Rancocas," and "Manasquan," these divisions being strictly faunal, while Clark's names were proposed to designate stratigraphic divisions.

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[1] *Annual Report of the State Geologist of New Jersey*, 1897, p. 189; also *Bulletin of the Geological Society of America*, Vol. VIII, p. 339.

In conclusion, the following summation of results in connection with recent investigations upon the Cretaceous formations and faunas of New Jersey may be made.

1. Cook's classification fully differentiated all the beds of the "marl" series that have been recognized since his investigations were carried on, but the "clay-marl" series has been more fully divided since his work was completed. He was in error, however, in applying his classification to the southern counties.

2. In the discrimination of beds, Clark's classification is in the main that of Cook, his contribution being a modernization of the older classification by the introduction of geographic formation names for Cook's lithologic names, and a grouping of the formations into larger divisions.

3. In so far as the discrimination of beds is concerned, Knapp's differentiation of the "clay-marl" series is a distinct advance over the earlier classification.

4. A study of the paleontology of the "clay-marl" formations of Knapp shows them to be as fully differentiated by their faunas as by their lithologic characters.

5. For both faunal and stratigraphic reasons, the "indurated green earth" of Cook is separated from the Red Bank sand, and is recognized as a distinct formation to which the name Tinton beds is applied.

6. The "yellow sand" is regarded to be of Cretaceous age, as originally interpreted by Cook, and its fauna to be the equivalent of that of the Vincentown lime-sand.

Reviews

Maryland Geological Survey, Miocene. By William Bullock Clark, State Geologist, 1904. 2 vols. (1) Text pp. 1–543 and Plates I–IX; (2) text pp. 1–127 and Plates X–CXXXV.

This volume is an admirable example of the results to be attained by the co-operation of numerous experts organized to elaborate the various aspects of a single problem in geology. Much separate and individual work had already been done on the Miocene deposits of Maryland when this survey began. Under the leadership of Dr. Clark, new collections and new surveys were made, and with the literature and old collections at hand, and by an exhaustive study of the Miocene, its stratigraphy and its faunas, with refiguring of old forms and descriptions of new, a concise but exhaustive monograph of the Maryland Miocene has been produced, interesting to any intelligent reader.

The introductory part is contributed by Dr. Clark. Dr. G. B. Shattuck, who, assisted by other members of the survey, has personally conducted the stratigraphic study in the field, writes the geological part and the discussion of early literature. In this portion is found an exhaustive list of species with their local distribution in eighty-eight separate stations, and general distribution into the five zones into which the Miocene is divided (viz., Calvert, zone 17 [lower bed], and zone 19 [upper bed] of the Choptank [as a whole] and the St. Mary's formations).

Dr. W. H. Dall writes the chapter on the relations of the Miocene of Maryland to that of other regions and to the recent formations. Dr. Dall supplies at the end of this part a valuable list of the species characteristic of the North American Miocene, by which he means "the species which occur only in the Miocene and occur in it from top to bottom . . . . not at every horizon . . . . they have existed throughout the Miocene somewhere, and disappear with the inauguration of the Pliocene" (see p. cliii).

The "Systematic Paleontology" is written by different authors, each taking the group of fossils to which he has given special study. Dr. E. C. Case, Dr. C. R. Eastman, E. O. Ulrich, R. S. Bassler, T. W. Vaughan, Dr. R. M. Bagg, Jr., Dr. Arthur Hollick, Mr. C. S. Boyer, Dr. G. C. Martin, Dr. L. C. Glenn, and Dr. W. B. Clark, each discuss one or more groups of either animals or plants.

A comparison of the Miocene of America with that of Europe suggests to Dr. Dall the following:

> The differentiation of faunas was well established before the beginning of the Tertiary, and Eocene faunas in America show American characteristics clearly, as compared with those of Europe. Other differences, suggesting migrations, occur in the relative time of appearance of certain groups; as, for instance, in America, the first influx of Nummulites is in the upper beds of the lower Oligocene, just as they were about to disappear from the European fauna, where they had flourished in myriads at an earlier epoch, though then unknown west of the Atlantic. Thus we may expect and shall find, on an inspection of the American Miocene, both differences and points of agreement. As in Europe, so in America, the Miocene was a period of elevation of plication of the earth's crust with its attendant vulcanism, of denudation of the recently elevated areas, and the formation of extended areas of sediment, formed chiefly of clays, sands, and marls, either consolidated into shales and sandstones, or remaining less compacted. The elevation of middle America and the Antillean region, in harmony with that of southern Europe, seems to have been more or less constant, since no marine Miocene beds have been definitely recognized in this area, and the antecedent Oligocene sediments were elevated several thousand feet, North and South America were united, the island of Florida became attached to the Georgian mainland, and the continent of North America on the whole assumed approximately its present outlines. Some modification of the coast line or sea bottom, supposedly in the vicinity of the Carolinas or possibly connected with the elevation of the Antilles, diverted the warm currents corresponding to the present Gulf Stream so far off-shore in the early part of the Miocene as to permit of the invasion of the southern coast lines by a current of cold water from the north, bringing with it its appropriate fauna and driving southward or exterminating the pre-existent subtropical marine fauna of these shores. This resulted in the most marked faunal change which is revealed by the fossil faunas of the Atlantic coast of America subsequent to the Cretaceous. A cool-temperate fauna for the time replaced the subtropical one normal to these latitudes, and has left its traces on the margin of the continent from Martha's Vineyard Island in Massachusetts south to Fort Worth inlet in east Florida, and westward to the border of the then existing Mississippi embayment.
>
> The deep embayment of the Chesapeake region in Maryland and Virginia has retained the largest and least-disturbed area of the marine Miocene sediments and given its name to them, as typical, on the Atlantic coast, of the faunal remains of this character, which they contain. Contrary to the conditions existing in Europe, in America no marked invasions by the sea or extensive depressions of continental land are characteristic of Miocene time, though in special localities the Miocene sediments transgress the remnants of the Eocene.

Regarding temperature conditions Dr. Dall writes:

We may therefore conclude (1) that the temperature conditions governing the fauna of the Maryland Chesapeake were those of the temperate rather than the boreal or subtropical faunas of the present coast; and (2) that the temperature of the Chesapeake embayment was on the whole somewhat warmer than at present. This is what the genera represented also indicate. Between the several horizons of the Maryland Chesapeake there is but very slight indication of any temperature difference; so far as there is any, it points toward a progressive but slight cooling of the water from the Calvert to the St. Mary's; while the subsequent Pliocene was doubtless accompanied by a change in the opposite direction, a rise of temperature being indicated by the changes in the fauna.

H. S. W.

Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, in Indian Territory and Oklahoma. By JOSEPH A. TAFF. With an Appendix on Reported Ore Deposits of the Wichita Mountains, by H. FOSTER BAIN. (Professional Paper No. 31, U. S. Geological Survey.)

This paper treats of the geology and physiography of the mountains named in the title. In both mountain regions there is a core of pre-Cambrian igneous rock. These rocks are much the same in both regions. The principal varieties in the Arbuckle Mountains are granite, quartz-monzonite, aplite, granite-porphyry, and diabase. In the Wichita Mountains gabbro is present, besides most of the above.

The lowest sedimentary rocks of the Arbuckle Mountain region are referred to the Middle Cambrian, and the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous systems are all represented. The successive formations are conformable up to the top of the Mississippian. There are unconformities between the Mississippian and the Pennsylvanian, between the Pennsylvanian and the Permian, and between the Lower and Upper Cretaceous. The rocks have been considerably deformed and displaced by folding and faulting.

In the Wichita Mountains the oldest sedimentary rocks are likewise referred to the Middle Cambrian. The other systems represented are the Ordovician and the Permian. The intervening Silurian, Devonian, and Carboniferous beds are supposed to be buried by the Red Beds. The structure of the Wichita Mountains is comparable to that of the Arbuckle Mountains; that is, the beds are deformed both by folding and faulting.

The physical history of the region is outlined as follows: The mid-Carboniferous (Mississippian?) rocks were uplifted and folded, resulting in mountain conditions; but before the end of the Carboniferous (Pennsylvanian?) these mountains were worn down to moderate relief, and before the Cretaceous they were reduced to a peneplain. The earliest peneplain represented in the region is, therefore, of pre-Cretaceous age.

There is a lower peneplain, partially developed, probably of Tertiary age, which cuts the Cretaceous as well as older rocks, and its surface is 100 to 400 feet below that of the Cretaceous peneplain. A still later cycle of erosion has been begun, and the valleys are now developing new plains 200 feet or so below the Tertiary peneplain.

In the Wichita Mountains, there is nothing to indicate the date of the deformation more closely than that it was somewhere between the Ordovician and Permian; but, in view of the similarity of the structure and of the stratigraphy in the two mountain systems, it is regarded as probable that the deformation in the Wichita Mountains occurred at about the same time as that of the Arbuckle Mountains.

With reference to the reported ore deposits in the Wichita Mountains, an elaborate series of tests of materials collected by Dr. Bain shows nothing of economic importance.

R. D. S.

"On the Evolution of the Proboscidea," *Philosophical Transactions*, London (B), Vol. CXCVI, pp. 99–118.

"The Barypoda, a New Order of Ungulate Mammals," *Geological Magazine*, October, 1904, p. 481.

Of the numerous discoveries of Eocene vertebrates from Africa within the past few years none are of more interest than certain forms referred to the Proboscidea by Dr. Andrews, of the British Museum. He has shown very clearly several of the early stages in the evolution of these animals from small-skulled animals with an almost typical eutherian dentition, the first premolar only being wanting, and the second incisor, the tusk of the elephant only moderately developed and not at all porrected. Hitherto the earliest of the Proboscidea known are from the lowest Miocene of France. the order reaching America in the upper Miocene times. That Africa was the original home of this order of ungulates now seems assured.

Another paper of interest by the same author is that in which he defines a new order of ungulates from the Eocene of Africa, which he has called the Barypoda, a group somewhat intermediate between the Amblypoda (Dinocerata) and the Proboscidea.

S. W. W.

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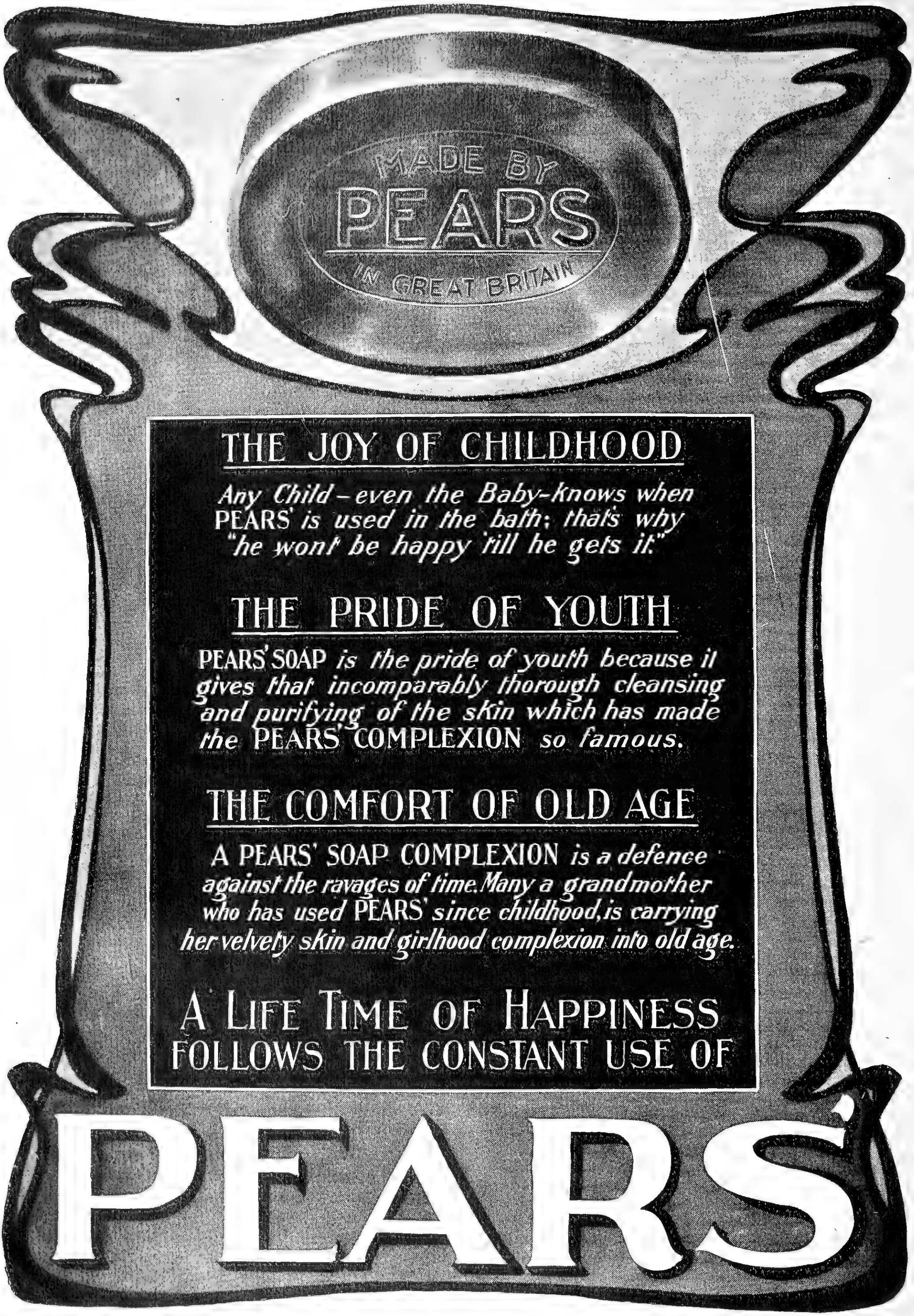
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REPORT OF THE SPECIAL COMMITTEE FOR THE LAKE SUPERIOR REGION

TO C. WILLARD HAYES, ROBERT BELL, FRANK D. ADAMS, AND CHARLES R. VAN HISE, GENERAL COMMITTEE ON THE RELATIONS OF THE CANADIAN AND THE UNITED STATES GEOLOGICAL SURVEYS

INTRODUCTORY NOTE BY C. R. VAN HISE

The report below of the special committee on the nomenclature and correlation of the geological formations of the United States and Canada is the first joint report of the geologists of the two countries. Before the death of Dr. G. M. Dawson, formerly director of the Canadian Geological Survey, I had correspondence with him in reference to joint field-work in the Lake Superior region. It was agreed between us that such field-work should be undertaken, but his untimely death occurred before anything was done.

After Dr. Dawson's death I continued correspondence upon the subject with Dr. Robert Bell, acting director of the Canadian Geological Survey. As a result of this correspondence, December 22, 1902, Dr. Bell wrote to Dr. C. D. Walcott, director of the United States Geological Survey, suggesting a conference in reference to the mutual interest of the two Surveys. This letter led to the appointment of a committee—consisting of C. W. Hayes and C. R. Van Hise, for the United States Geological Survey, and Robert Bell and Frank D. Adams, for the Canadian Geological Survey—to consider all questions as to the successions of formations, and as to nomenclature, which concerned the two Surveys.

This committee, with C. W. Hayes as chairman, met for the first time at Washington, January 2, 1903. At this meeting several special committees were appointed to consider different districts along the international boundary. For the Lake Superior region the following committee was appointed: for the United States, C. R. Van Hise and C. K. Leith, of the United States Geological Survey, and A. C. Lane, state geologist of Michigan; and for Canada, Robert Bell and Frank D. Adams, of the Canadian Geological Survey, and W. G. Miller, provincial geologist of Ontario.

August 3, 1904, this special committee met in the Marquette district of Michigan, and during the six weeks following visited successively the Gogebic, Mesabi, Vermilion, Rainy Lake, Lake of the Woods, Animikie, and original Huronian districts. After finishing the field-work, a report in preliminary form was drawn up.

In December, 1904, another meeting of the special committee was held at Philadelphia, further to consider the report, all members of the committee being present except C. R. Van Hise. At this meeting the report of the subcommittee was completed as given below.

REPORT OF THE COMMITTEE

Your special committee on the Lake Superior region, during the months of August and September, 1904, visited various districts in the Lake Superior country, their purpose being to ascertain, if possible, whether they could agree upon the succession and relations of the formations in the various districts, and could further agree upon a nomenclature appropriate to express the facts. The districts visited were the Marquette, the Penokee-Gogebic, the Mesabi, the Vermilion, the Rainy Lake, the Lake of the Woods, the Thunder Bay, and the original Huronian of the north shore of Lake Huron. Aside from the regular members of the special committee, for parts of the trip other geologists were with the party. Dr. C. W. Hayes, geologist in charge of geology, United States Geological Survey, and a member of the general committee, was with the party for the Marquette, Penokee-Gogebic, Mesabi, Vermilion, and Rainy Lake districts. Professor A. E. Seaman was with the party for the Marquette, Penokee-Gogebic, Rainy Lake, Lake of the Woods, and Thunder Bay districts. Mr. J. U. Sebenius was with the party for the Mesabi district, Mr. W. N. Merriam, for the Mesabi and Vermilion districts; Mr. W. N. Smith, for the Thunder Bay district; Mr. E. D. Ingall and Mr. T. D. Denis, for the Lake Huron district. The knowledge of these men was of great assistance to the committee.

In the following pages we shall give the successions and relations of formations which we believe to obtain for each of the districts visited, and give our opinion as to the major correlation of the rock series of the various districts, so far as this can be safely done, and the nomenclature which seems to best express the facts.

For each district, unless otherwise specified, the succession will be considered in descending order. In giving the successions for the various districts, we shall use, for convenience, the names suggested by geologists who have done the detailed work in the districts, without thereby expressing any opinion as to their appropriateness or their advisability.

In the Marquette district we found the upper series there exposed to be as follows: (1) Michigamme slate and schist, and (2) Ishpeming formation. Locally within the Michigamme slate, and apparently near its base, is an iron-bearing horizon. The Clarksburg volcanics, said to be a local phase of the Michigamme formation, were seen at Champion. The basal member of the Ishpeming formation is the Goodrich quartzite. This series, called the upper Marquette series by the United States Geological Survey, has at its base a pronounced unconformity, marked by extensive beds of conglomerate having materials of diverse character. The dominant fragments of the conglomerate at the localities visited are from the Negaunee formation to be mentioned below. The next series is the Middle Marquette series, consisting of (1) the Negaunee formation, (2) the Siamo slate, and (3) the Ajibik quartzite. In the publications of the United States Geological Survey this series was not separated from the series next mentioned, but the work of Professor Seaman has shown that there is a pronounced unconformity, marked by strong basal conglomerates at the bottom of the Ajibik. Below this unconformity is the Lower Marquette series, consisting of (1) the Wewe slate, (2) the Kona dolomite, and (3) the Mesnard quartzite. At the places where we saw the succession there is a belt of slate between the Kona dolomite and the Mesnard quartzite of such thickness that it might possibly be mapped as a formation if the exposures were more numerous. The members of the United States Geological Survey think that this slate is probably general for the district, as it shows wherever the exposures are continuous from the dolomite to the quartzite. At the base of the Lower Marquette series is an unconformity, marked by conglomerates bearing fragments of all the kinds of rocks seen in the underlying series. Two classes of fragments are especially abundant. These are (1) tuff, greenstone schist, and many kinds of greenstones which belong to the so-called green-schist series of the district, and (2) various kinds of granite and gneissoid granite. Adjacent to the state road south of the city of Marquette the actual contact was seen between the two series, the basal conglomerate resting upon the green schist. The great variety of materials in this conglomerate and the well-rounded character of the fragments left no doubt in the minds of the members of the party that there is a great structural break at the base of the Lower Marquette series.

The lowest group of the Marquette district is a very complex one, which has been designated as the Basement Complex. It consists of two classes of material—the greenstone-schist series, and the granites and gneissoid granites. The greenstone schist series is especially well known through the description of the late George H. Williams, found in *Bulletin 62* of the United States Geological Survey. This series is designated on the maps of the *Marquette Monograph* as the Kitchi and Mona schists. Intrusive in the green schist series are great masses of granite and gneissoid granite. No evidence was seen by the party that any of the granites intrude the sedimentary series above the green-schist series, although Seaman thinks in one place a small mass of granite does intrude the Lower Marquette series. It is believed that the great masses of granite of the district antedate the three series here called Upper, Middle, and Lower Marquette.

In the Penokee-Gogebic district the highest rocks seen are the Keweenawan traps and interbedded sandstones, the bedding of which dips at a high angle to the north. No actual contact between the Keweenawan and the next underlying series was seen, but north of Bessemer, below the Keweenawan, the next formation is the great Tyler slate formation of the Penokee series, while at Sunday Lake the Keweenawan rests directly on the iron-bearing formation which is stratigraphically below the slate. This relation led the party to infer the existence of an important unconformity between the two. The Penokee-Gogebic, or iron-bearing series, consists of (1) the Tyler slate, (2) the Ironwood formation, and (3) the Palms slate. This Palms slate was seen to rest directly upon granite south of the Newport and Palms mine. At the former locality there is no conglomerate at the base. At the latter locality there is a conglomerate at the base of the slate which, besides containing granite detritus, also contains many cherty fragments supposed to be derived from the next underlying sedimentary series.

East of the Presque Isle River the lower sedimentary succession of the Penokee-Gogebic district was visited, here consisting of (1) cherty limestone and (2) quartzite. The quartzite dips to the north at a moderate angle and rests upon green schist. The two formations were seen in direct contact for a hundred feet or more. The cleavage of the green schist abuts against the bedding of the quartzite at right angles. The quartzite near its base passes into a conglomerate, which, just above the contact becomes very coarse and contains very numerous well-rolled fragments of the immediately subjacent schist. The unconformity at the base of the quartzite could not be more pronounced.

The party nowhere saw the relations of the limestone-quartzite series just described and the Penokee-Gogebic series proper, but they have no reason to doubt the conclusion of the United States Geological Survey that the limestone-quartzite series is the inferior one.

The relations of the green schist, called Mareniscan by the United States geologists, and the granite, which together constitute the basement upon which the determined sedimentary series of the district rest, were not studied by the party. The United States geologists hold that the relations are perfectly clear, and that the granitic rocks are intrusive in the green schist.

In the Mesabi district the succession of the Mesabi series is as follows: (1) Virginia slate, (2) the Biwabik iron formation, and (3) the Pokegama quartzite. This series dips at a gentle angle to the south. At the base of this series at Biwabik is a conglomerate which rests upon a series of slates and graywacke, the latter in nearly vertical attitude. The unconformity between the two is most pronounced. The slate and graywacke where crossed has a considerable breadth. It flanks a green-schist series. The slate and graywacke formation adjacent to the green-schist is conglomeratic. Many of the fragments of the conglomerate are from the underlying green schists. At the locality visited it could not be asserted that the break between the slate-graywacke formation and the green-schist series is great, although nothing was seen which is contrary to this view. The granite constituting the Mesabi range is reported by the United States geologists as intruding both the green-schist and the slate-graywacke series, but not the Mesabi series. At the east end of the district a newer granite is reported as intruding both the Mesabi and the Keweenawan series, and in the central portion of the district small areas of granite porphyry are reported as antedating the slate-graywacke series.

In the Vermilion district the Upper series, where seen, consists of (1) Knife slates and (2) Ogishke conglomerate. The Ogishke conglomerate contains very numerous fragments of all the underlying formations noted—porphyries, green schists, iron formation, granite —and we have no doubt that there is a great structural break at the base of the Ogishke. The series below this unconformity, the Vermilion series, consists of (1) the Ely greenstone and (2) the Soudan formation. The Ely greenstone is the dominant formation. It is mainly composed of green schists and greenstones, many of which show the ellipsoidal structure described by Clements. The other important formation of the Vermilion series is the Soudan iron formation. The structural relations of the Ely greenstone and the Soudan formation are most intricate. No opinion is here expressed as to their order. The Ely greenstone and the Soudan iron formation are cut by porphyries, and, according to the reports of the United States Geological Survey, are cut in a most complex way by the great northern granite, but the localities illustrating this were not visited. It is worthy of mention that the United States geologists report granite as intruding the Knife slates and Ogishke conglomerates in the central parts of the district, especially in the vicinity of Snowbank Lake, but this locality was not visited by the party.

In the Rainy Lake district the party observed the relations of the several formations along one line of section at the east end of Shoal Lake and at a number of other localities. The party is satisfied that along the line of section most closely studied the relations are clear and distinct. The Couchiching schists form the highest formation. These are a series of micaceous schists graduating downward into green hornblendic and chloritic schists, here mapped by Lawson as Keewatin, which pass into a conglomerate known as the Shoal Lake conglomerate. This conglomerate lies upon an area of green schists and granites known as the Bad Vermilion granites. It holds numerous large well-rolled fragments of the underlying rocks, and forms the base of a sedimentary series. It is certain that in this line of section the Couchiching is stratigraphically higher than the chloritic schists and conglomerates mapped as Keewatin. On the south side of Rat Root Bay there is also a great conglomerate belt, the dominant fragments of which consist of green schist and greenstone, but which also contain much granite. The party did not visit the main belts colored by Lawson as Keewatin on the Rainy Lake map, constituting a large part of the northern and central parts of Rainy Lake. These, however, had been visited by Van Hise in a previous year, and he regards these areas as largely similar to the green-schist areas intruded by granite at Bad Vermilion Lake, where the schists and granites are the source of the pebbles and bowlders of the conglomerate.

In the Lake of the Woods area one main section was made from Falcon Island to Rat Portage, with various traverses to the east and west of the line of section. The section was not altogether continuous, but a number of representatives of each formation mapped by Lawson were visited. We found Lawson's descriptions to be substantially correct. We were unable to find any belts of undoubted sedimentary slate of considerable magnitude. At one or two localities, subordinate belts of slate which appeared to be ordinary sediment, and one belt of black slate which is certainly sediment, are found. In short, the materials which we could recognize as water-deposited sediments are small in volume. Many of the slaty phases of rocks seemed to be no more than the metamorphosed ellipsoidal greenstones and tuffs, but some of them may be altered felsite. However, we do not assert that larger areas may not be sedimentary in the sense of being deposited under water. Aside from the belts mapped as slate, there are great areas of what Lawson calls agglomerate. These belts, mapped as agglomerates, seem to us to be largely tuff deposits, but also include extensive areas of ellipsoidal greenstones. At a number of places, associated and interstratified with the slaty phases are narrow bands of ferruginous and siliceous dolomite. For the most part the bands are less than a foot in thickness, and no band was seen as wide as three feet, but the aggregate thickness of a number of bands at one locality would amount to several feet.

We could discover no structural breaks between the above formations of the Lake of the Woods. The various classes of materials —slates, agglomerate, and ellipsoidal greenstones—all seem to belong together. In short, these rocks in the Lake of the Woods seem to us to constitute one series which is very largely igneous or volcanic in origin, but does, as above mentioned, contain some sediments. This series in the Lake of the Woods area is the one for which the term "Keewatin" was first proposed for the greenstone series, Lawson giving as one reason for proposing this name the statement that there is no evidence that these rocks are equivalent with the rocks of Lake Huron described by Logan and Murray as Huronian.

The ellipsoidal greenstone-agglomerate-slate series is cut in a most intricate way by granite and granitoid gneiss, which constitute much of Falcon Island at the southern part of the Lake of the Woods and a great area north of the Lake of the Woods. These relations between the granite and Keewatin were seen on the northwest part of Falcon Island and on a small island adjacent. They were also seen north of Rat Portage. At the latter place the rocks adjacent to the granite are banded hornblende and micaceous schists, very similar to the banded rocks of Light House Point, at Marquette. At Hebe Falls the granite and Keewatin series are seen to be in actual contact, the Keewatin being apparently intruded by the granites, although the relations have often been interpreted as conformable gradations. Going north along the Winnipeg River, the relations between the two series become perfectly clear. Great blocks of the Keewatin are included in the granite, the masses varying from those of small size to others of enormous bulk. Also the two have intricate relations, which have perhaps been best described as *lit par lit* injection. In short, the relations are those so well described by Lawson for this area.

In the Thunder Bay district we visited especially the areas about Loon Lake and Port Arthur. In the Loon Lake area the succession is as follows: The top series is the Keweenawan, here consisting of sandstone above and conglomerate below, with interbedded basic igneous flows or sills. Below the Keweenawan is the Animikie. The contact between the Keweenawan and the Animikie was seen at two places. At one of these there is an appearance of conformity, but at the other the eroded edges of the Animikie iron-bearing formation are traversed by the Keweenawan beds. At one contact the base of the Keweenawan rests on the Animikie slate, interstratified with the iron formation, and at the other on one of the members of the iron-bearing formation. At both localities the conglomerate at the base of the Keweenawan bears detritus from the underlying series, including both the slate and the iron-bearing formations of the Animikie. The Animikie succession which we saw near Loon Lake includes two phases of the iron-bearing formation with an interstratified belt of slate. The Animikie here has in general rather flat dips, although locally they become somewhat steeper.

Near Port Arthur the higher slate member of the Animikie was visited by a portion of the party, and on previous occasions had been visited by the other members. This is the formation which is agreed by all to rest upon the Animikie iron formation. It is notable as containing the intrusive sills called by Lawson the Logan sills.

At one place near Loon Lake a test pit has been sunk to the bottom of the Animikie, and here at the base of the formation is a conglomerate bearing fragments of the next underlying series—a graywacke slate. This graywacke slate covers a large area, shows cleavage at a high angle, and is evidently an important formation in the district.

The party has no doubt that there is considerable unconformity between the Keweenawan and the Animikie, and a very important unconformity between the Animikie and the graywacke slates.

A portion of the party went north from Port Arthur to see the green-schist and granite series. This was found, but seen only in small volume at the particular area visited. At other times several members of the party have visited larger areas of this green-schist and granite complex north and northwest of Port Arthur in Gorham, Conmee, and other townships, and in the green schists they found an iron-bearing formation analogous in character to the Soudan formation of the Vermilion district. The granites are intrusive in the greenstones.

At no place were the relations between the graywacke slate series below the Animikie and the green-schist granite complex observed.

In the original Huronian area—i. e., the area described by Logan and Murray as extending from near Sault Ste. Marie along the north shore of Lake Huron to Thessalon and northward — we examined a number of crucial localities. At the first of these, about five miles from Sault Ste. Marie, near Root River, we studied the relations of the conglomerate, mapped as lower slate conglomerate by Logan, with the granite. The conglomerate is in a vertical position. We found the upper horizon of the conglomerate near the road to be of moderate coarseness, and to contain many fragments of green schist, greenstone, and granite. The granite fragments increase in prominence and size toward the north, and at the north end of the exposure we have a great granite conglomerate. After an interval of a few paces we found to the north a red granite similar to many of the fragments of the conglomerate. The party has no doubt that the conglomerate rests unconformably upon the granite. This conglomerate, while mapped by Logan as lower slate conglomerate, appears to be above a limestone next to be mentioned, and has been connected by Van Hise and Leith with rocks like the red quartzite belonging above the limestone, and they believe it to be the upper slate conglomerate rather than the lower slate conglomerate, although the overlapping recent lake deposits prevent the connection by actual areal tracing. A short distance east of the point where the conglomerate is next to the granite and north of the great mass of the conglomerate is a belt of limestone which continues east for perhaps half a mile. North of this limestone is conglomerate, and still to the north, granite. This northern conglomerate is very similar to the conglomerate south of the limestone, and two interpretations are possible as to its position: it may be regarded as the lower slate conglomerate under the limestone, or it may be regarded as an equivalent to the conglomerate south of the limestone, being repeated by an anticline or possibly a fault. The limestone has a steep dip to the north, and, accepting either alternative, it must be regarded as overturned.

We next visited the abandoned limestone quarry north of Garden River station. Here we found the conglomerate, marked by Logan as the upper slate conglomerate, within a few paces of the limestone. This conglomerate is in all respects similar to the average of the conglomerates before mentioned, except that it contains very numerous limestone fragments. The party has no doubt that the limestone formation was laid down, and that a considerable erosion interval occurred before the deposition of the conglomerate upon the limestone. The slate-conglomerate belt north of the limestone was examined, and while it was not found in contact with the limestone, it was seen to increase in coarseness as the limestone is approached, and across the little ravine which separates the conglomerate from the limestone it was found to contain numerous limestone fragments. We therefore conclude that the rock on each side of the limestone is the upper slate conglomerate, the structure probably being anticlinal, possibly with faulting. This conclusion suggests that the same relation obtains at the Root River locality above described.

On the limestone point on the east side of Echo Lake we found the following ascending succession, with monoclinal dip to the southeast: (1) white or gray quartzite, grading through graywacke into (2) a thin belt of conglomerate not exceeding twenty feet in thickness and containing numerous granite fragments. Above the conglomerate is (3) limestone in considerable thickness, and over this (4) the upper slate conglomerate. This last is a thick formation. The upper conglomerate is very coarse near the limestone, and becomes finer in passing away from the limestone along the lake shore. Like the conglomerate near Garden River, it bears very numerous limestone fragments, the evidence of which is beautifully seen at the lake shore, where the water has dissolved many of them completely and others in part. The ledge thus presents a deeply pitted surface, many of the pits being several inches in depth.

On the west side of Echo Lake we ascended the prominent bluff next north of the west limestone point, and here found the formation nearly horizontal, but dipping slightly into the hill. The quartzite in this position composes the greater part of the bluff. A short distance from the top we found the quartzite grading upward into a graywacke-like rock, and this into a conglomerate which contains granite and green-schist fragments; indeed, it is typical slate conglomerate. This conglomerate is only a few feet in thickness, and above it appears a siliceous limestone, and above this, normal limestone like that of Garden River and the east side of Echo Lake. The total thickness of the limestone here seen was probably not more than fifty feet, and of the conglomerate below, not more than thirty feet. The lower five hundred feet or more of the bluff is the white quartzite.

The other bluffs on the west side of the lake were not visited by the party, but Leith, Seaman, and Van Hise have examined each of these bluffs, and found the succession above given to obtain upon each prominent bluff, with the exception that on the next bluff to the north the limestone is wanting, so far as observed. The limestone is also in greater force on some of the other bluffs, but is always subordinate in thickness to the quartzite. It thus appears that the great formation on the west side of Echo Lake is the quartzite; that the limestone above appears, not as a single belt, but as a number of synclinal patches often capping the hills; and that the conglomerate showing both north and south of the limestone is a very thin formation between the quartzite and the limestone, and is, therefore, the lower slate conglomerate.

Our observations from Root River to Echo Lake convince us that there is a considerable structural break in the Huronian. The upper series includes the following formations of Logan, viz.: white quartzite, chert, and limestone, yellow chert and limestone, white quartzite, red jasper conglomerate, red quartzite, and upper slate conglomerate. The lower series includes the lower limestone of Logan and the lower slate conglomerate, white quartzite, and gray quartzite. North of Thessalon the two series are represented by Logan and Murray as being separated by a fault. Here the distribution may be explained by the unconformity mentioned, but it is also entirely possible that the relations are due to faulting or to both unconformity and faulting.

Four miles east of Thessalon on several islands off the coast is a great conglomerate, mapped by Logan and Murray as gray quartzite. This conglomerate was found to rest unconformably upon the granite, the actual contact being observed upon one island opposite the northwest quarter of Sec. 12 of the Township of Thessalon. The fragments in the conglomerate are well rounded and are largely granite, but there are also numerous pebbles and bowlders of greenstone and green schist. On several islands adjacent to the conglomerate the massive granite includes many fragments of greenstone and green schist, showing the granite to be intrusive into a greenstone formation. Thus in the complex against which the conglomerate rests we have a source both for the granite and greenstone pebbles and bowlders. To the northwest the conglomerate grades up by interstratification into a quartzite. About a quarter of a mile west of the conglomerate, near the north end of a point, the quartzite is found to become a fine conglomerate, and to rest against greenstone which is cut by a large granite dike. The greenstone shows ellipsoidal parting. The granite dike strikes toward the conglomerate and the quartzite, but it dies out into a depression showing no rock, which continues to the quartzite some fifty or sixty feet distant. The quartzite and conglomerate strike directly across this depression, showing continuous exposures, and are not cut by granite. The relations here are believed by certain members of the party to show clearly that the quartzite and conglomerate rest unconformably upon the greenstone, but other members felt that this conclusion is not certain. The conglomerate and gray quartzite are cut by greenstone dikes. Similar rocks also cut the Thessalon series referred to below.

The rocks called green chloritic schist by Logan (*3c*) will here be called the Thessalon series. This series consists of ellipsoidal greenstones, amygdaloids, agglomerates, and massive greenstones. No undoubted sediments were observed in the series. The relations of the Thessalon series to the granite were observed southeast of Little Rapids, and it was found that the granite cuts the greenstone series in an intricate fashion. The belt of gray quartzite, mapped as extending inland for a number of miles between the Thessalon series and the granite, was found to be absent at this locality. Two or three miles east of Thessalon, felsite and granite in considerable masses were found to intrude the Thessalon series. At one place several felsite or granite dikes were observed to cut both the agglomerates and ellipsoidal greenstones. From the relations observed, the party had no doubt that the conglomerate islands east of Thessalon belong unconformably upon the granite, and they think it probable (Van Hise would say highly probable) that the quartzite and conglomerate rest unconformably upon the Thessalon series, mapped as green chloritic slate by Logan and Murray. It is regarded as probable that the white quartzite below the lower slate conglomerate northwest of the Thessalon series which is adjacent, and is shown by its dip to rest upon the Thessalon series, is separated from that series by an unconformity, but no direct evidence of such relation was observed.

The Thessalon series should be excluded from the Huronian if, as believed, the unconformity just mentioned exists. If this series be excluded, the Huronian of Lake Huron consists of two series, an Upper Huronian and a Lower Huronian. The Upper Huronian extends from the top of the series, as given by Logan and Murray, downward to and including the upper slate conglomerate; and the Lower Huronian extends from the main limestone formation to the gray quartzite, including its basal conglomerates. In the area mapped by Logan on the north shore of Lake Huron the Laurentian consists of granite and gneissoid granite, with subordinate inclusions of greenstone.

We do not feel that our examination of the Lake Superior region was sufficiently detailed to warrant an attempt at correlation of the individual formations of the various districts. There are, however, certain general points which seem to be reasonably clear, and about which there is no difference of opinion between us. These are as follows:

There is an important structural break at the base of the Keweenawan. The term "Keweenawan" should include substantially all of the areas which have been thus mapped, or mapped as Nipigon, by the Canadian and United States Surveys, and the State Surveys of Michigan, Minnesota, and Wisconsin.

Below the Keweenawan is the Huronian system, which in our opinion should include the following series: In the Marquette district, the Huronian should include the Upper and Lower Marquette series, as defined in the monographs of the United States Geological Survey, or the Upper, Middle, and Lower Marquette series, as given in the previous paragraphs. In the Penokee-Gogebic district, the Huronian should include the series which have been called the Penokee-Gogebic series proper, and the limestone and quartzite which have local development, and which we visited east of the Presque Isle River. In the Mesabi district, the Huronian should include the Mesabi series proper, and the slate-graywacke-conglomerate series, unconformably below the Mesabi series. In the Vermilion district, the Huronian should include the Knife slates and the Ogishke conglomerates. In the Rainy Lake district, the Huronian should include that part of the Couchiching of the south part of Rainy Lake which is limited below by basal conglomerate as shown at Shoal Lake. In the Thunder Bay district, the Huronian should include the Animikie and the graywacke series in the Loon Lake area. In the original Huronian area, the Huronian should include the area mapped by Logan and Murray as Huronian, except that the Thessalon greenstones should probably be excluded.

Unconformably below the Huronian is the Keewatin. The Keewatin includes the rocks so defined for the Lake of the Woods area and their equivalents. We believe the Kitchi and Mona schists of the Marquette district, the green schist (Mareniscan) of the Penokee-Gogebic district, the greenstone series of the Mesabi district, the Ely greenstones and Soudan formation of the Vermilion district, the part of the area mapped as Keewatin by Lawson in the Rainy Lake district not belonging structurally with the Couchiching, and probably the Thessalon greenstone series on the north shore of Lake Huron, to be equivalent to the Keewatin of the Lake of the Woods, and, so far as this is true, they should be called Keewatin.

For the granites and gneissoid granites which antedate, or protrude through, the Keewatin, and which are pre-Huronian, the term "Laurentian" is adopted. In certain cases this term may also be employed, preferably with an explanatory phrase, for associated granites of large extent which cut the Huronian, or whose relations to the Huronian cannot be determined.

The following succession and nomenclature are recognized and adopted:

Cambrian—Upper sandstones, etc., of Lake Superior
Unconformity
Pre-Cambrian
Keweenawan (Nipigon)[1]
Unconformity
Huronian { Upper (Animikie)
Unconformity
Middle
Unconformity
Lower }
Unconformity
Keewatin
Eruptive contact
Laurentian

Alphabetically signed by the committee as follows:

Frank D. Adams,
Robert Bell,
A. C. Lane,
C. K. Leith,
W. G. Miller,
Charles R. Van Hise,
Special Committee for the Lake Superior Region.

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[1] Dr. Lane dissents as to the position of the Keweenawan as follows:

"The use of pre-Cambrian above does not imply unanimity in the committee with regard to the pre-Cambrian correlation of the Keweenawan—a topic the committee as such did not investigate."

THE ACCORDANCE OF SUMMIT LEVELS AMONG ALPINE MOUNTAINS: THE FACT AND ITS SIGNIFICANCE[1]

REGINALD A. DALY
Ottawa, Canada

CONTENTS

THE STATEMENT OF SUMMIT-LEVEL ACCORDANCE

Neither statistics nor eloquence are required to recall one principle in the interpretation of lofty, alpine mountains; their student must be content to attack their mighty problem in a piecemeal fashion. The alps of the world are tangles in structure and the stony records of tangles of prodigious events. It is no wonder that their form has so long baffled the evolutionist. He has often had to turn back from the attempt to carry into the high mountains the same ground principles of land-building and land sculpture which have of late years been so successfully explaining the simpler forms of the land.

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[1] Published by permission of the Canadian commissioner, International Boundary Surveys.

If, then, advance in the interpretation of the world's great ranges can be really made in any one direction, such advance must be welcomed as a step toward the distant, ultimate goal of complete knowledge of the earth. Not only for the sake of the single study itself, but perhaps still more for the sake of putting no obstacle in the way of related interpretations, it is well that close scrutiny be fixed on every such subordinate theory. No further reason is necessary for additional field-work on a problem now in discussion concerning the physiography of mountains, namely, the meaning of the generally observed accordance of levels among the higher summits of an alpine range.

The word "accordance" is used advisedly. "Equality" of heights is not meant by those observers who have given the question the best attention. For limited areas "subequality" of the summits is a fact, but over wider stretches, and especially over the whole of a single range, even subequality fails, and the accordance takes the form of sympathy among the peaks whose tops in companies or in battalions rise or fall together in imaginary surfaces often far removed from the spheroidal curve of the earth. In general, the imaginary surface which will include the higher summits of peaks and ridges in an alpine range has the form of a low arch, highest in the interior of the range and elongated in the direction of the main structural axis of the range. Subordinate, but usual and systematic, complications in the form of this imaginary surface are found in transverse crenulations which alternately depress and raise the surface from its average out-sloping position on the margin of the great arch. The axes of these transverse depressions are often suspiciously coincident with existing drainage courses.

There is, then, at least one orderly element in the "chaos" or "tumbling sea" of mountains visible from a dominating point in any one of a goodly number of alpine ranges. The accordance of summit altitudes has been noted in the Alps, in parts of the Caucasus, in the Pyrenees, in the Sierra Nevada of California, in the Alaskan ranges, in the Canadian Selkirks and Coast Range, and in the American Cascade Range.[1]

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[1] In the present paper the term "alpine range" is used to signify a range possessing not only the rugged, peak-and-sierra form of the Swiss Alps, but, as well, the internal

The fact of accordance is established, while the theories of explanation are very various. That they need critical examination and sifting is clear, not only for the sake of the important fact of accordance itself, but also for the reason that these theories involve widely diverging views on great physiographic revolutions. Geological history in long chapters is thereby as expressly implied as it would be by the interpretation of purely stratigraphic evidences, illustrating over and over again the truth that both classes of evidences are required in building up a complete history of the earth. Not only do these theories involve premises regarding great denudations, but, as well, a multitude of details concerning river history and the evolution of individual mountain massifs. There are likewise involved correlative views of the physiographic development of the neighboring regions, both on the large scale and in details. Geographic description and nomenclature should be controlled by reference to the correct theory or theories of land-form origins. Finally, large conclusions concerning the origin of the force of mountain uplift must follow in the wake of certain of the hypotheses already announced to explain the phenomenon of accordance in summit levels. The attempt has even been made to connect the origin of fractures and of mineral veins with the specialized kind of crustal movement hypothecated by one explanation of this accordance.[1] There are thus abundant reasons for coming to a wise decision as to the best explanation of the fact.

THE VARIOUS EXPLANATIONS OF ACCORDANCE

The hypotheses dealing with this sympathetic attitude of alpine summits may be classified on the basis of the logical explanation of an organism. (*a*) How far is the feature in question due to *inheritance?* (*b*) How far is it due to *spontaneous development* in the present environment? A review of the hypotheses shows, everywhere and naturally, emphasis placed on erosion, but the writer believes that the possibilities of inheritance are only partially worked

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structures incidental to intense crumpling, metamorphism, and igneous intrusion as exemplified in the Swiss Alps.

[1] A. C. Spencer, *Transactions of the American Institute of Mining Engineers,* October, 1904, p. 35.

out, and, again, that the methods of spontaneous development are not yet brought into the proper balance for final discussion or decision on the question.

I. EXPLANATIONS BY INHERITANCE

The accordance of summit levels may well suggest the analogy of moderately or maturely dissected plains underlain by rocks of horizontal structure. Often with such plains there is little or no doubt of the original, simple form before erosion had produced the intaglio forms of dissection. The common agreement of altitudes among the hilltops of the sculptured plain is manifestly the effect of inheritance from the early, initial stage of the plain's history. Is there anything comparable in the derivation of existing alpine mountain ranges? Their almost infinite complexity of structure due to folding, blocking, thrusting, igneous intrusion, and metamorphism forbids that the analogy shall be anything more than an analogy; yet the question is raised whether, at some earlier stage in the history of each range, there may not have been produced a more or less perfect accordance of summit levels which would, through ordinary processes of erosion, furnish similar accordance in the later stages of the history, including the present stage. Three answers may be proposed to the question.

1. *The peneplain theory.*—The explanation which has, on the whole, won most attention from American students of the problem is that now familiar to physiographers as the peneplain theory. By this view the alpine range is supposed to have passed through the paroxysmal epoch of uplift by crumble, faulting, and thrusting; then through a period of denudation so prolonged that the once lofty range was thereby reduced to a gently rolling lowland, the surface of which stood near sea-level or the general base-level of the region. In every full published discussion the author favoring the peneplain theory has regarded it as probable or as certain that subordinate residual hills or mountains, monadnocks, rose above this peneplain.

A second chief premise necessary to the theory is that of a broad, massive warping of the peneplained surface; the major axis of upwarp being roughly coincident, or parallel, with the present topographic axis of the range. The existing details of relief are then regarded as due to inheritance, after mature erosion, from the initial peneplained surface with which the present physiographic cycle opened. The sculpture of the unwarped surface is by some attributed largely to streams definitely controlled in their direction of flow by the general slopes of the warped peneplain, i. e., consequent streams. In the Cascade Range of Washington, Messrs. Willis and Smith make the special supposition of transverse upwarps and downwarps complicating the initial form of the uplifted Pliocene peneplain from which the present range is supposed to have "descended." Mr. Spencer has deduced peneplanation and arch-warping for the Coast Range of British Columbia. He is therewith compelled to place in a different, antecedent, class a half-dozen of the chief rivers cutting clear across the range.[1] Revived subsequent streams—that is, those developed on weak rock-belts during peneplanation and incited to still deeper cutting on those belts by the upwarping—must form a third kind of corrasive agents. Following the upwarping, local and general glaciation will still further greatly complicate the scheme of drainage.

One may feel but little doubt that the peneplain theory is sound when applied to the more or less classic cases of the Appalachian Piedmont, the New Jersey, New England, and Acadian plateaus, the plateaus of the Rhine, of Bohemia, and of central France and Brittany. In each one of these instances the already well-discussed criteria of the uplifted and sculptured peneplain are apparently well satisfied. Each region shows excellent examples of the remnant, high-lying plateau flats truncating rocks of complex structures. Often the criterion of adjusted drainage is admirably fulfilled. Where glaciation has not disturbed the normal conditions, the plateau remnants of the former lowland still bear the deep residual soils expected on the theory. Finally, in none of these regions is the geological history of adjacent physiographic provinces discordant with the peneplain theory.

If any one of the criteria can be taken as more positive than the others, it is that of extensive plateau remnants of the peneplain surface. Yet it is clear that even those remnants will lose their flat-topped character with prolonged erosion. The perfectly mature

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[1] *Bulletin of the Geological Society of America*, Vol. XIV (1903), p. 125.

dissection of the former lowland will greatly weaken the proofs of approximate planation near base-level at the end of a former physiographic cycle. It is expected, however, that subequality of accordance of summit levels will long characterize the individual mountains produced by the intaglio cutting of the upwarped peneplain. Conversely, where such accordance of summit levels in structurally complex mountains is found, it is legitimate, if not necessary, to place ancient peneplanation as a possible stage in the topographic evolution.

This has been the principal criterion on which Messrs. Russell, Smith, and Willis have based wide-reaching conclusions regarding the development of the main Cascade Range of Washington. Mr. Willis has mapped a few, very small, flattish areas on summits which he considers as possible remnants of the peneplain.[1] Mr. Smith states that no remnant of it has been discovered in the large area of the Snoqualmie Quadrangle (U. S. Geological Survey map) which he has particularly studied.[2] Mr. Russell came to a similar conclusion regarding the high Cascades of northern Washington.[3] Geology and physiography owe much to these authorities for their systematic and masterly presentations of the theory which every worker in the general geology of the Cascades must entertain and carefully discuss. The problem is there, as in other similar ranges, peculiarly difficult because it is precisely in mountains of alpine height that the records of former peneplanation are most quickly rubbed out; it is there that positive criteria are reduced to a minimum. One must therefore especially welcome such constructive work as is represented in the memoirs recently published concerning a typical alpine range, the high Cascades.

The peneplain theory does certainly render the accordance of summit levels among alpine peaks intelligible. Yet that fact is far from proving the truth of the theory as applied to alpine ranges. This will be especially clear if it can be shown that there are, and have been, other agencies at work capable of producing the actual degree of accordance in the summit levels of such a range as the high Cascades. The writer believes that further constructive work along

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[1] *Professional Paper No. 19*, U. S. Geological Survey (1903), Plates 16 and 17.

[2] *Ibid.*, p. 34.

[3] *Twentieth Annual Report*, U. S. Geological Survey, Part II (1900), p. 141.

the lines of the peneplain theory is at present not so necessary as a critical inquiry into alternative hypotheses. For the same reason, a concrete criticism of the views on which have been based the attempts to establish the peneplain theory for special alpine ranges will here be left in abeyance.

The other possible explanations of accordance, including those already published as well as others which have occurred to the writer in the course of field-work, have one important feature in common—a feature which places all of them in opposition to the peneplain hypothesis. That hypothesis demands at least two cycles of erosion in the history of the mountain range; one cycle essentially completed at the time of penultimate extinction of relief, with a second cycle, the present one, advanced to the mature stage of dissection. Involved with this premise of multiple cycles is the conception that the present cycle has been initiated by a quite different kind of mountain-building from that which first gave the range its great altitude. Broad, relatively gentle warps, producing on the average an arch elongated in the axis of the existing range, form the kind of movement demanded in the uplift of the peneplained area, while intense plication, thrusting, and blocking gave the range its internal structures and its original relief. In short, the peneplain hypothesis stands in contrast with all the other hypotheses in placing peneplanation and subsequent warping among the necessary stages in the development of the existing mountains. Unequal in strength as these alternative hypotheses may be, they have the common characteristic of excluding a great denudation and a specialized kind of crustal movement from the list of complications in the history of the range. It is most important to observe that this common characteristic, coupled with the fact that the alternative explanations are not mutually exclusive, gives them cumulative force against the peneplain hypothesis, when applied to truly alpine mountains.

2. *Hypothesis of original rough accordance of summit levels, due to isostatic adjustment.*—Basal to all of the alternative hypotheses is the inquiry as to the original form of the range at the geological moment when paroxysmal folding of its rocks was practically completed. It is self-evident that the term "original" is here used arbitrarily, but the strain on language may be permitted in thus conven-

iently naming and emphasizing a principal epoch in the early history of the range.

At first sight one may be surprised to find this accordance of summit levels among high mountains of complex structure. Surprise should be tempered, however, by the consideration that the original relief was not even approximately determined by constructional profiles deducible from existing structures.

It is, for example, highly improbable that the "reconstruction" of a great alpine anticline through a study of its denuded roots can represent the original height of its crest above sea-level. Nor is it legitimate to conclude from the great shortening of the transverse axis of the range by the enormous tangential pressures that orogenic blocks of indefinite height could have been produced. Overthrusting, upthrusting, folding, mashing, and igneous intrusion have often occurred on such a scale, that were it not for other and inhibiting causes, differential elevations perhaps forty or fifty thousand or more feet in relative height might have resulted. No geologist believes that local blocks of such height have entered into the construction of any terrestrial range. Erosion during the absolutely slow, though relatively rapid, growth of the range has often been appealed to as sufficient to explain the lack of such heights in even the youngest alps of the world. But not sufficient emphasis has been placed on the quite different control of isostatic adjustment accompanying and following the paroxysmal uplift of orogenic blocks. Single steep slopes of possibly thirty thousand feet might, indeed, then exist if they were underlain by the strongest granite, which likewise formed the underpinning of the whole adjoining district, that granite being throughout at the temperatures of ordinary rock-crushing experiments. But such towering masses are highly improbable for weaker rocks which would crush down under the supposed conditions, and wholly impossible for mountain blocks overlying material as plastic as that which composes the original basement of an alpine range. The strength of the main mass of the range is diminished by the inevitable rise of subsurface temperatures with crumpling and mashing. It is the rule with alpine ranges that intrusions of hot magma on a huge scale either accompany or very soon follow the chief paroxysms of folding. In either case, and not only over the areas where denudation has exposed the intrusives, but also over much wider areas about the downwardly expanding bases of the batholiths, the heat of the intrusions still further increases the plasticity of the basement on which the mountains are growing. The weakness of the underpinning is further manifest in the case of such ranges as the Cascades or the Coast Range of British Columbia, so largely formed of granitic magma injected in a highly plastic, if not thoroughly fluid, state during or just after the last great period of plication in those ranges.

The conclusion seems unavoidable that the tendency of tangential force to erect orogenic blocks projecting much higher into the air than Mount Everest itself is operative only up to a certain critical point. Beyond that point the increasing weight of the growing block and the increasing plasticity of its basement call in another kind of movement due to the gravitative downcrushing of the block. As a whole, or in fragments separated from each other by normal faults, the block will assume a shape and position suitable to static equilibrium for the whole range. The range might conceivably find that equilibrium when the entire uplift has attained the form of an elongated arch accidented by already roughly accordant mountain summits. At any rate, subequality of height might characterize large areas.

This whole phase of gravitative adjustment forms a problem clearly indeterminate in the present state of geological physics. Critical laboratory experiments have yet to be devised, and careful, special field-work devoted to the problem, before it can attain even an approximate solution. So far as it goes, however, gravitative adjustment of the kind just described aids all the other processes tending toward summit-level accordance.

3. *Hypothesis of original rough accordance, due to differential erosion during the period of alpine plication.*—Co-operating with isostatic adjustment is the effect of the special erosive attack on each rising block from the moment it once begins to dominate its surroundings. On the average, the forces of weather and waste are most destructive on the summits of this time, as they shall be through all the subsequent history of the range as an alpine relief. Denudation is in some direct ratio to the height of uplift. Higher summits are thereby reduced, while lower ones are still growing under the stress of mountain-building. How far erosion thus checks the upward growth

of the rising massifs probably cannot be measured, but such differential destruction must develop still further the rough summit-level accordance already in part established by isostatic adjustment.

4. *Conclusion.*—The downcrushing of higher, heavier blocks with the simultaneous rise of their lower, lighter neighbors, coupled with the likewise simultaneous, specially rapid loss of substance on the higher summits, form a compound process leading toward a single, relatively simple result. In both the architecture and the sculpture of her alpine temple, Nature decrees that its new domes and minarets shall not be indefinitely varied in height. Such accordance as they have among themselves will be preserved and accentuated as her chisels fashion new details on the building. The accordance of the present time in any alpine range is in part inherited from what, in this paper, has been called the "original" form of the range. The original form meant a first approximation to the result; the later, spontaneous modification of that form means a second approximation to perfect accordance.

The composite explanation.— In passing to an analysis of erosion events following the epoch of folding, we are, therefore, illustrating the cumulative forces of all the hypotheses so far announced as alternative with, and as against, the peneplain hypothesis for truly alpine ranges. By the peneplain hypothesis, the accordance of summit-levels was most perfect in the initial stage of the physiographic cycle begun by the upwarping of the peneplain; by that hypothesis mature dissection of the range tends to destroy something of the initial accordance. The alternative, composite explanation, already in part outlined, involves the conclusion that the accordance tends to become more and more perfect as the stage of mature dissection of the newly folded range is reached. The question remains whether the accordance inherited from the forms original from the epoch of plication may be so much further developed by subsequent erosion in the physiographic cycle initiated by that plication, as to give the amount of accordance actually observed in the existing range. If the answer be affirmative, the second inquiry becomes imperative as to the relative merits of the peneplain and composite hypotheses when applied to individual ranges. For reasons given on a previous page, the second inquiry is not specially raised in the present paper.

II. THE SPONTANEOUS DEVELOPMENT OF SUMMIT-LEVEL ACCORDANCE

1. *Spontaneous development by isostatic adjustment.*—The last paroxysm of crumple and upthrust in the young alpine range has occurred. Henceforth its forms are to be determined chiefly by erosive processes—yet not altogether so. Several authors have suggested that the leveling influence of gravity is not only manifest in the piecemeal carriage of rock fragments out to the piedmonts, or finally to the sea; but that also the very accordance of summit levels is in large part related to gravitative adjustment on a large scale.[1] Where, for any cause or causes, denudation significantly lowers a localized area of the range faster than neighboring areas of the same altitude, the former area will tend to rise, the surrounding region to sink, so as to reproduce conditions of equilibrium in the range. This view entails belief once again in the principle of isostasy. It must be admitted that the ground has only been broken in the important field of inquiry as to crustal sensitiveness. The harvest of field and experimental observations has not yet been reaped in volume sufficient to enrich geological science with definite knowledge on the matter. But such facts as the apparent isostatic recoils of the earth's crust after the melting away of the Scandinavian, Labrador, and British Columbia Cordilleran ice-caps, and the notable increase of dips at the feet of the High Plateaus of Utah and Arizona, as described by Major Dutton[2], are among those already recorded in favor of a sympathetic entertaining of the isostatic doctrine. The appeal to the principle in the present case is all the more worthy because of the long continuance of the special plasticity belonging to the very slowly cooling basement of a recently folded alpine range.

2. *Metamorphism and igneous intrusion in relation to the degradation of mountains.*—It is a truism that the rocks of any alpine range vary enormously in composition and structure. It is quite as true that their resistance to weathering and wasting is far less variable. In hundreds of square miles together, the geologist may map gneisses, schists, granites, diorites, marbles, quartzites, or ancient lavas, several or all of these occurring in great masses, and yet he may not be able to ascertain by manifest field evidence that any one of the

[1] See discussion in Penck's *Morphologie der Erdoberfläche.*

[2] *Monograph II,* U. S. Geological Survey (1882), p. 47.

formations is more resistant to the weather than an adjacent formation. That experience is common in the alpine districts where accordance of summit levels has been described. The implication is that the real differences in power to resist attack are of a low order among the rocks of these districts. The writer has often been struck with this fact in the course of field-work in the Coast Range and Selkirks of British Columbia. There, as generally, the phenomenon must be attributed mainly to wholesale metamorphism. This relative homogeneity among the rocks must be regarded as playing an important part in the preservation of summit-level accordance. Whether inherited or not, accordance will be clearly favored by homogeneity.

Secondly, the original upper surface of the zone of intense metamorphism may be conceived as much less uneven than the outer surface of the original range. Mr. Van Hise has shown that pressure is the principal control in the metamorphism of the zone of rock-flow.[1] In the present case, pressure is applied by tangential force and by the weight of individual massifs. The former is in dominant control, as shown by the generally steep dips of planes of schistosity. The lines of force in the tangential pressure are, on the average, not far from horizontal. In the later stages of the period of plication the master-lines of that force pass beneath structural depressions in the range. During the same time constructional massifs will largely escape the maximum squeezing which affects their bases. The weight of each massif will, however, cause the metamorphism to extend upward locally in some degree. The upper surface of the metamorphic core of the massif will have a flatter and, probably, a more regular profile than the rugged land surface above. The composition of the two forces due to weight and tangential pressure should, then, tend to produce a relatively simple upper surface for the whole zone of metamorphism. The surface will be a flat arch as a whole, but locally bearing subordinate domes of low curvature. Along with these subordinate domes must be others of similar low curvature due to the thermal metamorphism of batholiths.

Many of the great intrusive bodies of alpine ranges had originally themselves a demonstrably dome-like form with broad, flattish tops.

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[1] *Monograph XLVII*, U. S. Geological Survey (1904), p. 43.

The foregoing statement of a difficult theme is brief, but it suffices to suggest the bearing of metamorphism and intrusion on the question of accordance. In what has been defined as its original state, an alpine range was composed of a hard, comparatively homogeneous core covered with a relatively thin veneer of already somewhat eroded, unmetamorphosed rock. The core is to be conceived as having an upper, limiting surface, with the form of a long, flat arch bearing subsidiary, low, broad, boss-like arches and domes. The erosion of the unmetamorphosed cover will go on apace. The erosion of the core, the main mass of the range, will progress much more slowly. Erosion may thus sweep away wide areas of the cover before the individual mountains between cañons sunk in the core have suffered significant loss of height by denudation. In such areas accordance of summit levels would henceforth be expected because of the original flattish tops of the core, and because of the comparative homogeneity of the core-rocks. For the same reasons, accordance among the summits of mountains cut out of a granite batholith would be expected. Where, however, the granite is distinctly harder than the surrounding metamorphics, there would not be simultaneous accordance with the summit levels of the metamorphic mountains, except for causes other than the two just described. As the composite explanation of accordance is further outlined, it will be seen that such other causes may operate effectively in some cases. Yet the common, special dominance of granite peaks in a truly alpine range agrees as well with the composite explanation as it does with their reference to the class of monadnocks on the peneplain theory.

3. *The influence of local glaciation on summit altitudes.*—Hitherto no detailed distinction has been necessary among the varied phases of erosion. All subaërial agencies of destruction combine their effects to establish so much of summit-level accordance as is due to erosion with consequent isostatic adjustment. Each of the agencies may take a part in the uncovering of the hard, metamorphic core of the range. Throughout the entire history of the range, however, special kinds and conditions of denudation independently do important shares of work in trimming the range to uniformity or accordance of summit levels. To ascertain the value of their work we must take the highland view. A few decades ago, when the power

of river corrasion was first adequately realized, the lowland view of earth sculpture became fruitful. It has led to the correct interpretation of land forms in every continent. Still later, the highland view that the alps of the world owe much of their form to conditions of erosion quite peculiar to high mountains, was first clearly taken by Penck, Dawson, Richter, and others. That their generalization came later than the brilliant statement of general erosion by Gilbert and Powell is natural, for man is a dweller in the lowlands; but science must know no such subjectivity. In the future the highland view must be sharpened and extended.

Local glaciers are characteristic of lofty, alpine mountains. High-lying cirque glaciers exist today by the hundreds in the Swiss Alps, by the thousands in the alps of British Columbia and Alaska. Pleistocene glaciers in vastly greater number and erosive power covered those same regions and, in fact, all the others where summit-level accordance in really alpine mountains has been described. Is there any connection between such glaciation and accordance?

The interesting problem of the origin of cirques or corries is not yet fully solved, but that they, by a vast majority, have been chiefly formed through glacial excavation is certain. In each glacier there are two loci of maximum erosion; one at the head of the glacier where the great *bergschrund* separates the ice from the solid rock of the head-wall; the other beneath the central zone of the glacier itself some distance upstream from the foot of the glacier. One result, noteworthy in the present connection, is to drive the head-wall of the growing cirque farther and farther into the mountain. In the nature of the case, it will be the higher peaks which are most vigorously attacked. From every side, it may be, comes the attack on the massif which, for any cause, specially projects above the general level of the range. Owing to the rapidity of the ice-erosion, that summit must tend to fall and reach something like accordance with its formerly lower, unglaciated or but lightly glaciated neighbors.

There seems to be no possible doubt that existing glaciers are thus working favorably with all the other methods of spontaneously producing summit-level accordance. How much more important has been the product of ancient glaciations in Europe and in America! Richter even makes local glaciation of the Pleistocene period responsible for most of the peaked and serrated topography of the Swiss mountains. He supposes that in pre-Pleistocene times the range had the comparatively smooth, flowing profiles of well-graded mountains; that the present ruggedness is mostly due to the recession of head-walls in cirque-making.[1] The view may be extreme, but it illustrates the importance which the distinguished European physiographer attaches to the work of local glaciers. Their gnawing action is just as manifest about the countless glacier-beds among the highest peaks and sierras of the Rockies, Selkirks, and Coast Range of British Columbia, of the Washington Cascades, of the mighty ranges of Alaska. In all these fields the highest peaks and ridges long suffered specially powerful attack, as they alone stood high enough to wear the fatal belts of *bergschrund.* During the ice period, they were nunataks and lost substance like nunataks; the loftiest peaks losing most, the lower ones with less linear extent of *bergschrund,* losing proportionately less. Peaks and ridges not penetrating the general surface of the Cordilleran glacier lost nothing by special *bergschrund* attack.[2]

It is certain that this differential erosion was long continued during the Pleistocene period in each of the ranges where accordance of summit levels has been discussed. There is every reason to suppose that like conditions and like results would characterize still earlier glaciations.

For the present purpose it is not necessary to inquire as to the deepening or other modification of main valleys in the range. Important as may be such valley changes to the future scenery of the range, they cannot have anything like the same control over summit altitudes as the direct trimming down of the summits by glacier heads. Moreover, head-wall recession among the higher summits continues throughout the whole epoch of glaciation; the excavation of the main valleys occurs only during maximum glaciation.

In summary, then, it may be said that partial explanation for

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[1] *Petermann's Mittheilungen, Ergänzungsheft* No. 132, 1900.

[2] Compare the views of W. D. Johnson and G. K. Gilbert, as announced in the *Journal of Geology*, December, 1904. The special glacial attack on the highest summit of the Big Horn Range (Cloud Peak) is excellently illustrated in the well-known paper by Matthes, *Twenty-first Annual Report*, U. S. Geological Survey, Part II, 1899–1900, Plate XXIII.

summit-level accordance is to be sought in a special, characteristic control of alpine climates. In general, the climate of high levels is a glacial climate. In general, glacial erosion is very great and the bulk of it is high-level erosion. In general, local glaciers and glacial erosion are most abundant and long-lived about the highest summits. One net result of glaciation is to cause the specially rapid wastage of those summits and to produce rough accordance among the peaks.

4. *The influence of the forest cap on summit altitudes.*—Climate not only breeds glaciers in the high levels of an alpine range; it normally determines a more or less well-defined tree-line. The treeless zone is always more extensive in area than the glacier-bearing zone, but the upper limit of trees is often not far from coincident with the lower limit of the zone of cirque glaciers. It is logical to find here a place for the theory that widespread accordance of summit levels in an alpine range is related to the differential rate of erosion above and below tree-line. The theory is so well known that it needs no special detailed statement in the present paper. Let it suffice to recall the principal reasons why denudation is faster above tree-line than below, and once more note the inevitable conclusion from that fact. Again we must take care to adopt the highland view of erosion. It cannot be too strongly emphasized that the conditions of rock destruction and transportation are vastly different from what they are at lower levels. It is only partially correct to discuss in terms of falling water the degradation of mountain slopes, whether tree-covered or not. Their degradation must chiefly be discussed in terms of falling rock-waste. In the lowlands stream corrasion has its maximum of destructive influence. Among the high mountains stream corrosion has a minimum of destructive influence. The analysis of high-mountain degradation deals, on the one hand, with the methods of rock-disintegration, and, on the other hand, with the methods of carrying the resulting waste out to the lowlands. The complete analysis waits on the discovery of quantitative data. We have here another instance of the need of sharpening and extending the highland view. Yet the qualitative data already recorded leave no doubt as to which zone is the more rapidly degraded.

a) Disintegration of rock.—A striking proof that Anglo-Saxons have only recently begun to take the highland view appears in the lack of a commonly used English equivalent for the German word *Felsenmeer*. Equally striking is the fact that very few physiographic textbooks even mention one of the most characteristic and widely exemplified features of alpine mountains. Frost-action is, of course, chiefly responsible for the wonderful chaos of broken rock above tree-line. The *Felsenmeer* is itself direct evidence of exceptionally rapid disintegration. At many points the blocks of the rock-chaos are in special danger of being swept away by avalanches, or of more slowly moving valleywards by the powerful thrusting action of freezing water. The development of the *Felsenmeer* means a vast increase of rock surface on which frost, changes of temperature, and all the other chief methods of weathering, and therewith destruction, can act. Below tree-line an all-mantling *Felsenmeer*, because of the forest blanket, is forbidden. Much of the broken rock below tree-line is exotic, having fallen from the treeless zone. The indigenous *Felsenmeer* below the tree-line is chiefly concentrated beneath cliffs, and is a vanishing quantity when compared with the immense rock-chaos above. Both as an evidence of incomparably more rapid frost attack above tree-line than below, and as a condition for more effective attack by agents other than frost, the *Felsenmeer* is significant.

b) *Removal of rock-waste.*—On the other hand, the streaming of weathered material down the slopes is, other things being equal, probably several times more rapid in the treeless zone than below it.

(1) The direct beat and *wash of the rain* have practically negligible effect on waste-removal below tree-line. The power of heavy rain washing the treeless zone, either in the derived form of rills or as a sheet flood, is manifest to anyone who has experienced a good shower above tree-line.

(2) During the last two field-seasons the writer has for the first time become conscious of the importance of *burrowing mammals* in preparing loose rock-waste for speedy transit to the valleys. In the western Cordillera field-mice, gophers, moles, marmots, bears, and other species are each year doing an immense geological work. There can be no exaggeration in saying that these burrowers annually turn over hundreds of thousands, if not millions, of tons of soil or disintegrated rock in either the Coast Range or the Selkirk Range of British Columbia. Such work is of relatively little importance

where mounds or fillings of snow tunnels are protected by trees overhead. It is very different above tree-line, where even the weak veneer of turf is broken in the burrowing, and where the millions of mounds or tunnel-casts are exposed to every agent of transportation.

(3) The transporting efficiency of *wind* in the treeless zone of lofty mountains has, on the whole, been more emphasized by European observers than by those of America. So far as this is the case, Europeans have come nearer to the highland view than we have in this country. The summer quiet of alpine summits of itself gives a most deceptive idea of the power of wind in the heights. During the other seasons winds of almost hurricane violence are far from uncommon, if we can generalize from the limited instrumental data so far issued from high-lying observatories. We may believe that dust, sand, and fine gravels are so rare above tree-line largely because of such winds. For obvious reasons, sand-blasting there plays no such rôle as it does in the sculpturing of rock-forms in lowland deserts; but transportation by the wind is another influence placing in strong contrast the conditions of erosion in the regions above and below tree-line.

(4) Erosion and transport through *avalanches* are enacted in both the treeless and the forested zone. In the lower zone the destruction wrought by a great avalanche may be great, but it is largely a ruin of tree-trunks. In the lower zone the avalanche paths are tolerably well fixed from year to year, sparing much the greatest part of the forested area. In the treeless zone, avalanches have generally less momentum, but they are more numerous, less localized, and therefore more likely to find and sweep down loose rock débris. Above tree-line their ruin is wholly rock-ruin. It seems safe to conclude that snow-slides are more powerful agents of degradation above tree-line than below.

(5) The general streaming and cascading of rock-waste under the direct pull of *gravity* are evidently immensely more rapid in the treeless zone than where the strong vegetation mat binds humus, soil, and bowlder to the bed-rock, though it be without perfect, ultimate success.

(6) The débris from the upper zone itself helps to protect the bed-rock of the lower zone. The very rapidity of general waste streaming above involves the slowing down of erosion below.

(7) The *chemical solution* of rock is, to be sure, probably more rapid beneath the forest-cap than it is above tree-line where the amount of vegetable acid is at a minimum. This cause may, however, be believed to do little toward counterbalancing the effect of the combined causes just enumerated. Erosion in alpine mountains takes place primarily by the removal of masses; in comparison, molecular transfer of rock material to the low grounds has but a very minor control.

Conclusion.—A review of the conditions of general degradation shows clearly its differential character above and below tree-line. Summits already reduced to the tree-line are bound henceforth to be stubborn against further erosion. Summits bearing a treeless zone are as clearly bound to continue wasting rapidly so as to tend to approach accordance of summit levels with their tree-covered neighbors. Since the glaciated zone of alpine mountains is, in general, well within the treeless zone, the special degradation due to local glaciers harmonizes with general erosion in the development of accordance.

5. *Accordance through river-spacing and gradation of slopes.*—A fifth method for the spontaneous development of summit-level accordance remains to be noted. The recent announcement and discussion of this explanation make it superfluous to present here more than the briefest analysis of the underlying ideas.[1]

Professor Shaler in America and Professor Richter in Europe have independently shown that, as mature dissection of a region under normal climatic conditions is reached, rivers of the same class tend to become nearly equally spaced. In perfect maturity the slopes of the interstream ridges are graded from top to bottom. This gradation of the slopes draining into two adjacent, nearly parallel streams flowing in the same direction, produces a comparatively even longitudinal profile of the intervening ridge. The even crest of the ridge must be more or less sympathetic with the profiles of the streams below, and, down stream, slowly attain a lower and lower

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[1] Cf. R. S. Tarr, *American Geologist*, Vol. XXI (1898), p. 351; N. S. Shaler, *Bulletin of the Geological Society of America*, Vol. X (1899), p. 263; W. S. T. Smith, *Bulletin of the Department of Geology*, University of Colorado, Vol. II (1899), p. 155; E. Richter, *Zeitschrift des deutschen und österreichischen Alpenvereins*, Vol. XXX (1899), p. 18; W. M. Davis, *American Geologist*, Vol. XXIII (1899), p. 207.

level. Local notches or cols may be gnawed in the ridge, but all the summits must be roughly accordant, though, of course, not uniform, in altitude. Other things being equal, the more mature the dissection, the more perfect the summit-level accordance; but the principle may be applied to alpine ranges. In those ranges the actual imperfect degree of accordance may often match the imperfectly matured state of dissection.

GENERAL CONCLUSION AND SUMMARY

The form of the preceding discussion has been analytical, but its main point has been to emphasize the synthetic nature of the process of mountain sculpture. Seven different conditions of erosion *work together* to produce accordance of summit levels in an ideal alpine range undergoing its first cycle of physiographic development. Isostatic adjustment and simultaneous, differential degradation of rising blocks tend to bring about rough accordance of summit levels in the range as "originally" formed. Later differential erosion and consequent further isostatic adjustment, the influence of metamorphism and intrusion, the sculpture due to high-level glaciation, the normal existence of a high-level tree-line, and, finally, the compound process of river-spacing and slope gradation—all these may combine their effects and render more perfect the accordance of levels inherited from the early, growing period of the range.

In an actual range, as distinguished from the ideal range, all seven of these conditions may not be present; the efficiency of those that are present make the special problem of that special range.

The composite explanation of accordance must always face the alternative explanation of the peneplain theory. The latter theory involves two physiographic cycles in the history of the range, and attributes summit-level accordance to inheritance from the initial, upwarped peneplain surface of the second, present cycle. Several of the chief conditions of erosion on which the composite explanation is based, tend, of course, to preserve the accordance of levels inherited from the peneplain.

The strength of each of the two explanations is so great that a decision as to which is true for a given alpine range may need nice discrimination. Nevertheless, the profound differences between the two theories regarding the geologic and physiographic history of the range makes the decision of primary importance. The existence of broad, little-dissected plateaus remnant from a greater plateau nearly or quite coextensive with the range having internal structures of alpine complexity, is a positive criterion favorable to the peneplain theory. From such remnant plateaus must be distinguished the elevated shelves due to high-level glacial erosion; to wind erosion; to the local control of internal structure; or to changes in conditions whereby the floors of former, high-lying basins of erosion, through deformation or through the migration of divides, become the summits. Peneplain remnants must further be distinguished from the common, often broad, ridge-summit formed by the meeting of two gentle slopes where the low angles of the slopes are incidental to general gradation of the mountain above tree-line. Analogous forms on a much smaller scale are never absent from the ridges in bad land topography where there is no suggestion of peneplanation.[1]

On the other hand, the remnant plateaus may not appear in the present topography of a range, and the accordance of summit altitudes may characterize peaks and serrate ridges only. Such accordance may give a comparatively even sky-line in the views from any dominating point, but the full force of the composite explanation of accordance as above outlined is directed against the reference of that even sky-line to the direct or inherited profile of an ancient, uplifted peneplain.

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[1] G. K. Gilbert, *Geology of the Henry Mountains* (Washington, 1877), p. 122.

THE OSTEOLOGY OF THE *DIADECTIDAE* AND THEIR RELATIONS TO THE *CHELYDOSAURIA*

E. C. CASE
State Normal School, Milwaukee, Wis.

Our present knowledge of the family *Diadectidae* has been obtained almost entirely from the writings of Cope. His work was done upon fragmentary material from the Permian beds of Texas—including, however, a few fine skulls—and was largely of a systematic character. Scattered through his many papers on this family are many brief notices and descriptions of anatomical characters, but nowhere has he given even an approximately complete description of the osteology. A summary of these brief notices would have no value beyond the historical. Suffice it to say that with his wonderful acumen he foresaw in his fragmentary material much that the more perfect material here described has made evident. For the bibliography and synonymy of the family the reader is referred to Hay's *Catalogue of the Fossil Vertebrata of North America* (Hay, 1902).

The material upon which the following description is based consists of several specimens collected by the author in the Permian beds of Texas, and now in the collection of the University of Chicago. The numbers given are the numbers of the University collection of fossil vertebrates.

The specimens consist of one nearly complete skeleton and several less perfect, as follows: (1) a skeleton lacking only the feet and free from distortion, No. 1075; (2) the anterior portion of a skull with the complete right half of the lower jaw and a portion of the left and a considerable portion of the vertebral column, No. 1076; (3) the sacrum and seven presacral vertebræ of a much larger specimen, No. 1077; (4) the major portion of a skull showing the palatal region nearly perfectly, No. 1078; (5) an imperfect skeleton showing the caudal region and some of the limb and foot bones, No. 62.

In 1896 Cope described (Cope, 1896) from the Permian of Texas two genera, which he called *Otocoelus* and *Conodectes*. These he placed in a new family of the *Cotylosauria*, the *Otocoelidae*, which he described as follows:

> Posterior border of the temporal roof excavated laterally by the meatus auditus externus. Teeth present in a single row, not transversely expanded. Ribs immediately overlaid by parallel transverse derm-ossifications which form a carapace.
>
> In the presence of the meatus auditorius this family differs entirely from the other members of the *Cotylosauria*. In the latter the vestibular space is inclosed by the lateral part of the temporal roof, and has no distal inferior bounding wall. The meatus results in the *Otocoelidae*, not merely from the excavation of the roof, but also from the excavation of the posterior border of the suspensorium. In *Conodectes* this excavation is not great, but in *Otocoelus* it is very considerable, the proximal extremity of the suspensorium having the anterior position seen in the *Loricata* and the *Testudinata*. It resembles the quadrate of the latter order in the decurvature of the proximal extremity into a descending hook, which partially bounds the meatus posteriorly.
>
> This meatal excavation constitutes an approximation in the *Cotylosauria* to other and later orders of the *Reptilia*, where it is nearly universal. It is interesting to observe that it precedes in time the division of the roof into longitudinal bars by perforation, in the series of which the *Otocoelidae* form a part. This fact renders it probable that it is from this family that the order of the *Testudinata* has descended. . . . . In this family the slight posterior concavity of the quadrate region of the *Diadectidae* is extended forward to a great distance, and the osseous tympanum is produced farther outwards.

Later, in 1898 (Cope, 1898), he erected this family into a distinct order, the *Chelydosauria*, defined as follows:

> These reptiles possessed a carapace of transverse osseous arches which extended across the back from side to side in close contact. The anterior part of the scapular arch below resembles the corresponding part of the plastron of a tortoise. The temporal roof is excavated posteriorly for the auricular meatus. The order is probably ancestral to the *Testudinata* and the *Pseudosuchia*.

In his synopsis of the orders of the *Reptilia* he describes the order as with the "scapular arch internal to the ribs; temporal region with complex roof and no longitudinal bars. A presternum; limbs ambulatory."

Cope regarded the *Otocoelidae* as the only family of the new order, but it will be seen from the following descriptions that the *Diadectidae* must be included therein. The order *Chelydosauria* is clearly distinct from the *Cotylosauria*, the points of ordinal difference being the exposure of the quadrate to the lateral surface of the skull, the meatus auditus externus forming a third pair of openings in the skull roof, and the peculiarities of the palate cited below. The presence of a more or less well-developed carapace is perhaps definitive, but, as it occurs in many Permo-triassic reptiles, and even in *Amphibia*, *Dissorophus*, it is not fundamental. Cope included in the *Diadectidae* (Cope, 1896[1]) *Diadectes*, *Empedias*, *Chilonyx*, *Bolbodon*, and *Phanerosaurus*, which he defined as *Cotylosauria* "with hyposphen-hypantrum vertebral articulation, and teeth with robust, molariform crowns transverse to the jaws" (Cope, 1898).

Of these, *Chilonyx* and *Phanerosaurus* must be excluded from the *Chelydosauria*, as the quadrate is covered on the lateral surface by the squamosal and prosquamosal bones, and there is no external meatus perforating the skull wall; *Bolbodon* is a very uncertain form, the condition of the specimen rendering an accurate judgment impossible.

DESCRIPTION OF SPECIMEN NO. 1075

The total length of the specimen as it lies is about 1.08^{m}. This is nearly the natural length, as only a few inches of the tail seem missing. The animal either died in the soft mud in which it is preserved, or was entombed therein immediately after death, as there is no trace of movement by currents or the attacks of predatory animals. The fine mud penetrated all parts of the skeleton, preserving the bones in their natural position almost perfectly. Unfortunately, the distal portion of all the limbs have been lost, so that only the proximal halves of the radius and ulna, tibia, and fibula have been preserved. As shown in the photograph (Fig. 1), the head is somewhat erect. This is not entirely the accident of fossilization, for, as pointed out by Boulenger, the Cotylosaurians had no neck to speak of, and the position of the head is partly the result of its close attachment to the body. The thoracic and pelvic girdles, because of their peculiar solidity, have been preserved undisturbed, with the exception that the scapula-coracoids of the two sides have been pressed together about 1^{cm}, giving a false appearance of overlapping. The vertebræ are in the normal position above the

FIG. 1.—Photographs of the skeleton of specimen No. 1075.

FIG. 2.—Outline of the skeleton of specimen No. 1075. *cl*=clavicle, *cleit*=cleithrum, *co*=coracoid, *intc*=interclavicle, *scp*=scapula. One-fifth natural size.

girdles, but in the post-dorsal and lumbar regions the column has sagged down of its own weight, causing a break and slight displacement, vertically, of the column. One peculiar effect of the sagging down of the vertebral column is that the ribs of the thoracic region have been bent upward and backward, reversing the natural curvature so that the plates covering them seem to be on the ventral surface. The upper edges of these ribs and the dorsal edge of the scapula stand well above the tops of the neural spines. The dermal plates, which are arranged shingle-wise, were evidently firmly attached together.

The humeri and femora of both sides are in position. The humeri are extended straight backward and the femora straight forward. This position, in harmony with the undisturbed condition of the rest of the skeleton, is important as indicating the natural position of the limbs and the prone position of the animal as it crawled upon its belly.

As described above, the skull has the lower jaws so fixed that it is impossible to clear the palate completely; but as it is entirely free from any distortion, the external form is perfectly shown. The surface of the skull, as in all of the *Diadectidae*, is very rugose, and the bones are closely anchylosed together, so that it is almost impossible to trace the sutures between the bones, such sutures as are given having been largely made out from the inferior surface of the skull in the less perfect specimens.

The skull is wide behind and narrows rapidly in the facial region, making the nose relatively thin, in this respect resembling the *Pariotichidae*. The skull proper is quite depressed, but seems much higher with the lower jaws in position, because of their great vertical extent. The upper surface of the skull is flat and of an elongate heart-shape. The parietal foramen lies near the posterior edge, and is not of such great size on the surface as to deserve the adjective "enormous" applied to it by Cope; but the edges of the foramen are beveled on the lower surface, so that the inner opening is two or three times the size of the outer. This is well shown in specimen No. 1078. There is no indication of grooves for the sensory organs.

Viewed from the side, the skull shows three openings; the external meatus, the orbits, and the nares. The quadrate region with its opening is similar in all important particulars to the same region in specimen No. 1078. The quadrate bone is a little longer, but, as it has been impossible to free the region from all matrix, minor details are uncertain. The orbits are oval, longer than high, and look directly outward. The lower edge projects rather more than the upper, and can be seen if the skull is viewed directly from above. The antero-posterior diameter of the orbit is 0.045^m; the vertical diameter, 0.032^m. The nares are nearly circular and located at the extremity of the skull. They are placed obliquely, so that they look outward and forward. The posterior and lower walls are continued funnel-wise, the opening being in the upper anterior corner of the nostril.

The quadrate region has the greatest vertical extent of any portion of the skull, making the postorbital edge of the skull, jugal, and quadrato-jugal descend abruptly as a flange, covering the posterior portion of the jaw. The whole length of the lower edge of the skull is sharply concave, reaching its greatest height just anterior to the orbit and then descending slightly to the anterior end. The anterior end of the nose overhangs the lower jaws considerably.

Viewed from the front or rear, it is seen that the skull is much narrower than the jaws; the sides of the postorbital portion slant outward as they descend, so that the wall of the skull is oblique. The supraoccipital region is depressed between two projections of the posterior angles of the skull formed by the squamosal, or possibly even by an epiotic, though this last-mentioned bone cannot be made out. Its possible presence is inferred as possible from the condition of the *Pariotichidae*, where Cope reports its presence.

There are two small openings, the post-temporal foramina, on the posterior face of the skull near the outer edge. These open directly upon the petrosal and the upper face of the pterygoid, so that their enlargement would produce exactly the condition of the *Chelonidae* among the turtles.

The total length of the skull from the anterior end of the nose to the posterior end of the slightly projecting lower jaws is nearly 0.2^m. The height across the skull and lower jaws is 0.125^m opposite the parietal foramen.

FIG. 3*a*

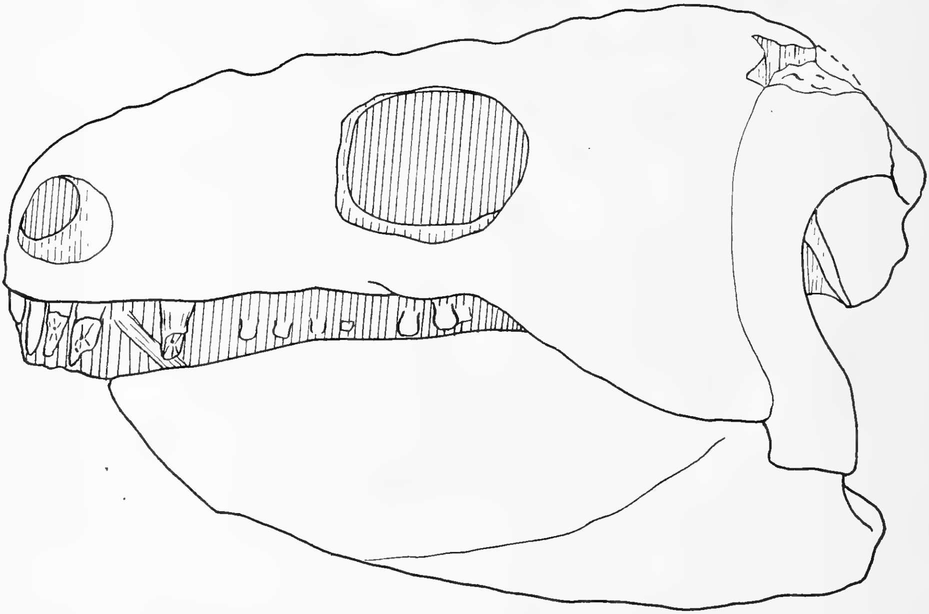

FIG. 3*b*

FIG. 3.—FIG. 3*a*, photograh of the skull of No. 1075; FIG. 3*b*, outline of the same skull.

In specimen No. 1078, from which the description of the palate is taken (with the exception of the vomer, which is taken from No. 1076), the skull is slightly crushed, the palate lying a little to the left of the normal position; but this has been so slight that the displacement does not amount to more than a centimeter, and the bones of the lower surface retain their connection with each other and the bones of the roof. The bones have been readily freed from a not very adherent matrix, so that the form and condition are beyond question (see photograph, Fig. 4), but the sutures are traced with difficulty. In specimen No. 1076 the skull was crushed badly, and the whole posterior portion is missing, but the lower jaws fortunately did not share in the crushing, and so show the form perfectly.[1]

FIG. 4.—Photograph of the palate of specimen No. 1078.

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[1] The matrix of specimen No. 1076 was a very hard calcareous material, which was so closely adherent to the bone that there was no line of parting where alteration due to weathering of the specimen usually marks the limits of bone and matrix. This made it almost impossible to clean the specimen with the chisel, so that recourse was had to the aid of acid, which readily attacked the matrix and the bone. As fast as a portion of the bone was freed from the matrix, it was coated with paraffin of a low melting-point, about 55° C., and the place was heated with the thin point of a blow-pipe flame until the paraffin sank into the bone, after which the attack with acid was resumed. It was found that the thin flame of the blow-pipe readily controlled the location of the paraffin, and that the heating was necessary, as simply coating the

Following is a description of the bones of the skull in detail.

The basioccipital.—The basi-occipital carries a widely oval, depressed condyle with a concave articular face. Laterally it passes into the exoccipital without appreciable sutures. It is impossible to make out the foramina.

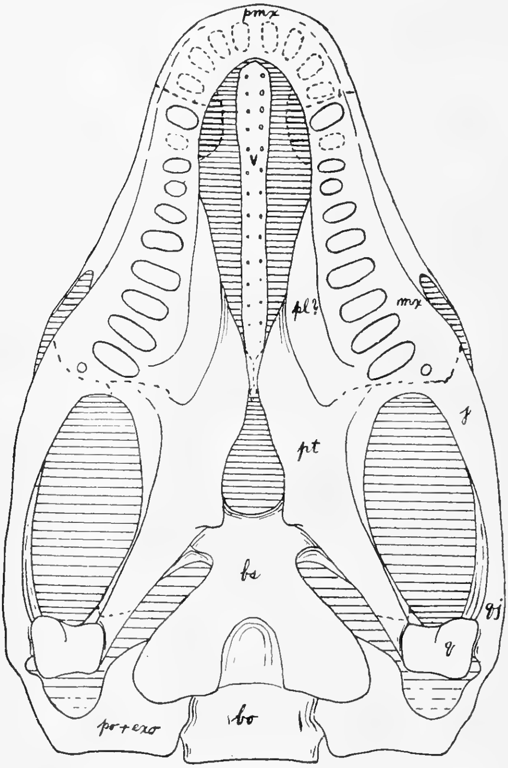

FIG. 5.—Restoration of the palatal surface of the skull from specimens Nos. 1076 and 1078.

The basisphenoid.—This bone has much the general form of the same bone in the *Pelycosauria* (Baur and Case, 1899; Case, 1905). It has the expanded posterior end where it unites with the basi-occipital, and a shallow concavity in the posterior portion of the mid-line of the lower face. The bone differs from the basisphenoid of the *Pelycosauria* in two particulars that are of great interest. (1) There is no anterior rostrum; the anterior end of the bone is rounded between the large basi-pterygoid processes, and there is no trace of any median process or of any rugosity. (2) The lower surface is not perforated by the twin foramina of the internal carotid arteries.

It is impossible to determine the limits of the bones of the brain

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surface permitted the acid to work under the paraffin and damage the bone. When the specimen was cleaned from the matrix, the paraffin was readily removed by boiling the bones in water. The action of such solvents as xylol was not satisfactory in removing the paraffin.

case. Consequently no separate description can be given of the exoccipital, paroccipital, opisthotic, or petrosal. Cope reported that the opisthotic and paroccipital were separate in Empedias and Chilonyx (Cope, 1896), but I can find no trace of a separation in the specimens here described.

The quadrate.—This bone both in form and relationships is best compared with those turtles which have the quadrate open posteriorly. The rugose bones of the skull roof terminate abruptly in the quadrate region, leaving an oval opening with its greatest axis vertical and open below. To the anterior and upper edge of this opening is attached the edge of the smooth quadrate, thus forming a conspicuous line of demarkation. The quadrate is approximately half funnel-shaped, pitching in on the upper, lower and anterior sides toward the center of the space. At this point the bone terminates by rounding in toward the center of the skull, leaving the posterior portion of the space open as the entrance of an opening to the interior of the skull. The upper part of the posterior edge of the quadrate is curved slightly downward, forming a hook. The lower portion of the quadrate is expanded into two articular faces which correspond to the articular faces of the

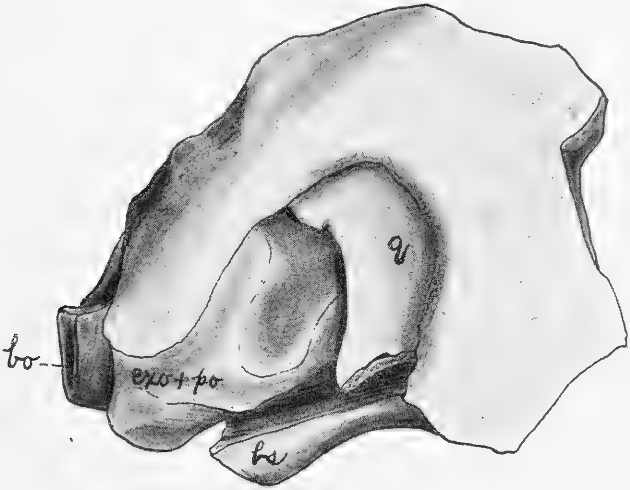

FIG. 6.—The quadrate region of specimen No. 1078. q = quadrate, bs = basisphenoid, bo = basioccipital, $exo + po$ = exoccipital and paroccipital.

lower jaw. Viewed from below, the quadrate is seen to be a thin shell which is sharply convex posteriorly, the convexity forming the posterior edge described above. (The form is best appreciated by direct comparison with that of the turtles.) The outer side of this convex bone is attached to the roof bones, as described above. The inner side is attached to the pterygoid. There is a very considerable cavity between the upper portion of the quadrate and the roof of the skull anterior to it. There was no trace of a stapes preserved in the cavity of the skull posterior to the quadrate.

Cope has described the condition of the auditory region and apparatus as follows (Cope, 1886):

> The brain case in the *Diadectidae* differs from that of the *Clepsydropidae* much as that of the *Varanidae* differ from those of other *Lacertilia;* that is, it is continued between the orbits, so as to inclose the olfactory lobes of the brain within osseous walls. These walls are thin, especially at the interorbital region, and in the specimen the anterior extremity is so far imperfect as to leave the form of the anterior fundus in doubt. . . . .
>
> The conformation of the cranial walls requires preliminary notice. In the first place, the vestibule of the ear can only have been separated from the brain by a membranous septum, as is the case in the *Protonopsis horrida* (Menopoma). In clearing out the matrix no trace of osseous lamina could be detected on either side, and the edges of the huge foramen thus produced are entire, and present no broken edges. Anterior to the vestibule, the proötic bone has a small extension, terminating in a vertical border. In front of this is the huge vertical foramen through which issues the trigeminus nerve, which is even larger than that found in the *Testudinata* and *Crocodilidae.* The anterior border of this foramen is formed by the probable alisphenoid, whose posterior edge is nearly parallel with the anterior border of the proötic, sloping forward as it descends. The basicranial axis is thin at their union on the middle line below, and, thickening forward, is excavated by a rather small conical fossa. Anterior to the fossa is a smaller impressed fossa, and on either side of it each lateral wall is excavated into a shallow fossa which descends toward it. The frontoparietal fontanelle is of extraordinary size. . . . .
>
> As already remarked, the internal wall of the vestibule is not bony, so that the cast of the brain cavity includes that of the vestibule also. On the external wall of the latter are the orifices of the semicircular canals. These are one double fossa at the superior anterior part of the wall, a second double one at the posterior superior part of the wall, and a single orifice at the inferior posterior part of the wall. The external part of the vestibule is produced upward and outward to the fenestra ovalis. The "double fossæ" above mentioned are the osseous

representatives of the membranous ampullæ at the junction of two pairs of semicircular canals.

On sawing open the periotic bones, which here form a continuous mass, the following is seen to be the direction of the semicircular canals: The superior canal is horizontal. The second canal from the posterior ampulla descends forward, and, after a course a little longer than that of the horizontal canal, turns posteriorly. The inferior canal from the anterior ampulla also descends, and, after a shorter course than the canal last mentioned, also turns backward and joins it, the two forming a single canal, which enters the vestibule by the single posterior foramen already described. The lumen of the longer perpendicular canal is much larger than that of the others. As its ampullar orifice is also the largest of all, I suppose this increased diameter to be partly normal; but it may be partly abnormal, as its walls are irregular and rough.

The fenestra ovalis is not preserved in this specimen, but can be seen in the crania of the species *Diadectus phaseolinus* and *Empedias molaris* above mentioned. The vestibule, or a diverticulum from it, is produced upward and backward, and terminates in a round os. This is clearly not a tympanic chamber, nor is it a rudimental cochlea. It does not appear to be homologous with the recessus labyrinthi, since that cavity is not perforated by the fenestra ovalis. It appears to be a promulgation outward of the vestibule and sacculus, which may be observed in a less degree in the genus *Edaphosaurus* (Cope), also from the Texas Permian formation. Here the adjacent bones are produced slightly outward, and the fenestra ovalis is closed by a large stapes similar in external form to the one I have described in the *Clepsydrops leptocephalus*. Its more intimate structure I have not yet examined.

The result of this examination into the structure of the auditory organs in the *Diadectidae* may be stated as follows: The semicircular canals have the structure common to all the Gnathostomatous *Chordata*. The internal wall of the vestibule remains unossified, as in many fishes and a few batrachians. There is no rudiment of the cochlea, but the vestibule is produced outward and upward to the fenestra ovalis, in a way unknown in any other family of the vertebrates.

The pterygoids.—These bones have the usual relations in the posterior part, but the anterior end is very different in its form and relations from that ordinarily found in the primitive reptiles. Near the middle point the pterygoids unite with the strong basi-pterygoid processes of the basisphenoid. There are strong anterior and posterior processes, but the external process which forms a buttress for the lower jaw, and is such a conspicuous feature of the skull of the *Pelycosauria* and the *Pariotichidae*, is totally absent. As this external process forms one of the chief points of attachment of the transverse bone, its absence in the skull is of considerable importance in considering the affinities. The middle portion of the pterygoid opposite the processes of the basisphenoid is flat and even somewhat concave on the lower surface. The anterior processes extend forward and outward as flat plates to articulate with the jugal and the maxillary. The processes of the two sides diverge rapidly, so that, if they met in the middle line at all, it was only for a very short distance. The outer portion of the anterior end unites directly with the maxillary on the level of the under surface of the skull, but the inner edge rises in the skull, and its anterior part lies on the upper surface of the strong alveolar shelf or buttress of the maxillary (see description of maxillary below.) Between the anterior end of this portion of the pterygoid and the maxillary there is, seemingly, a small bone separated from the two by indistinct sutures. This I take to be the greatly degenerated transverse. The suture between it and the maxillary is marked by a large foramen.

The posterior portion of the pterygoid is vertical and joins the quadrate in the usual manner. There are no traces of teeth on the pterygoid.

The palatines.—These are very degenerate. The portion described by Cope as the palatines is evidently the anterior part of the pterygoids and the palatines he described as "maxillary ridges." They appear as ridges which originate near the middle of the maxillary bones and curve backward with them, growing gradually wider as they recede, till they terminate sharply near the posterior end of the maxillaries. At the same time the ridge curves downward and away from the maxillaries as a thin process which terminates in a sharp, rather rugose edge, much like the edge of the maxillary of a turtle after the horny sheath has been removed. This ridge is separated from the maxillary by an indistinct suture, so that it is evidently the palatine; but it occupies a most anomalous position in that it does not meet its fellow of the opposite side in the middle line, and is not articulated with the pterygoid except at the posterior end; neither does it touch the vomer. Cope mentioned teeth on what he regarded as the palatines, but I can find teeth on neither palatine nor pterygoid in two well-prepared specimens.

The transverse.—This has been described above with the pterygoid.

The vomer.—This is a single bone of considerable vertical extent which is attached anteriorly to the inner side of the premaxillaries, and posteriorly either ended freely or was touched by the anterior median portion of the pterygoids which met, or nearly met, in the middle line. Its lower surface is marked by a double ridge of sparsely set, small, conical teeth. It is impossible to trace the attachment of the upper edge of the vomer. Anterior to the parietal foramen there are, in the two skulls, the remnants of a descending median plate, but in neither can this be traced into contact with the vomer. It seems probable either that the vomer was attached to this plate by a bony connection which has been destroyed, or that there was a cartilaginous attachment between them. There is no trace of any prevomers. It is possible that in this weak palate we have the condition premised by those (Bland-Sutton, 1884; Broom, 1902) who have contended that the true vomer is the parasphenoid developed into secondary importance to supply a weakened palate.

The premaxillaries.—It is impossible in the specimens to make out the limits of these bones. Cope describes them as having short and strong spines, which ascend in the median line as far as the posterior edge of the external nares. In none is the number of teeth certain, but it does not exceed four or five. They are chisel-shaped incisors, evidently adapted to the cutting of pretty solid food.

The maxillaries.—The vertical portion of the maxillaries is very thin, but the alveolar surface is disproportionately widened to accommodate the alveoli for the great teeth. This alveolar edge, while quite wide, is not of great vertical thickness, and stands out abruptly from the side wall of the skull (formed by the vertical portion of the maxillary), as a sort of shelf upon the upper surface of which terminates the anterior end of the pterygoids and the transverse, as described above. There are eleven teeth in the portion which I take to be the maxillary. The posterior one is very small and peg-like, but the next to the last is nearly, if not quite, the largest of the series. The surfaces of the teeth are worn on the inner edge only, as described by Cope.

The palate in general.—It will be seen from the above that the palate is very aberrant and in no wise resembles the palate of the *Cotylosauria.* The bones are so closely united that it is difficult to make out the sutures distinctly in all cases. Among the peculiarities of the palate are the following: There are no buttresses for the lower jaw on the outer portion of the pterygoids. The pterygoids end anteriorly on the upper surface of the maxillary, with a very degenerate transverse separating them only partly. The pterygoids touch the vomer only at the extreme posterior end, if at all. Because the palatines do not extend inward to meet in the middle line, there is a great median vacuity which is divided by the vomer. Into this vacuity the anterior nares open directly (Figs. 4 and 5).

The lower surface of the skull roof is marked by two descending processes which originate just posterior to the pineal foramen and extend forward well anterior to it. The lower ends of the processes are not preserved, but they are in the position of the descending plates of the parietal bones found in the turtles. Cope describes them as alisphenoids and mentions their extending forward to carry the brain case between the orbits. The upper ends of the plates are fused with the lower surface of the parietals, so that they cannot be reckoned as epi-pterygoids. Immediately in front of these two processes there is a wide process on the lower surface of the skull in the median line, so that it in some measure closes the anterior end of the space between the paired processes. This median process is continued forward and downward as a thin plate which lies immediately above the vomer, but in no specimen of the collection can be shown to connect with it. Possibly the two were united by cartilage. I take this median plate to be the forward and upward continuation of the basi-cranial axis, the ethmoid.

The lower jaw.—Except for the teeth, the lower jaw is peculiarly testudinate in appearance. The anterior portion has a relatively great height, due largely to the dentary; but there is a very inconspicuous coronoid process. The bones, like those of the upper portion of the skull, are so closely united that the sutures are almost unrecognizable.

The inner surface is marked by an enormous opening into the Meckelian groove. This opening is separated from one equally large on the superior surface of the posterior portion of the bone by a narrow bridge, presumably formed by the splenial. The cavity of the Meckelian groove is large, so that the jaw is practically a shell with the upper portion thickened to receive the alveoli of the great teeth. The teeth are set in shallow alveoli, which do not reach to the outer side of the bone, but are separated from it by a deep groove, the outer edge of which is formed by a narrow elevated edge of the dentary. In the anterior end of the jaw the teeth reach the outer surface. The anterior portion of the jaw descends slightly to the symphasis.

FIG. 7.—Photograph of the inner surface of the right half of the lower jaw of specimen No. 1076.

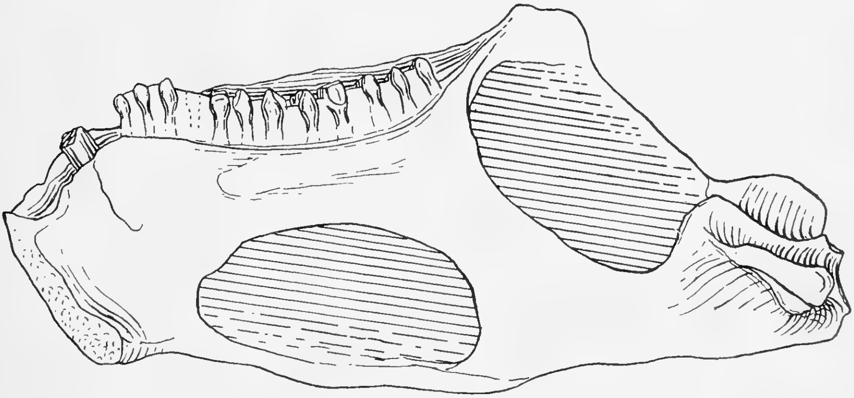

FIG. 8.—Outline of jaw shown in Fig. 7. One-third natural size.

The posterior portion of the jaw descends rapidly from the coronoid; the articular surface is not above the middle half of the jaw. The articulation consists of two deep cotyli elongated in the anterior direction and deeply concave from side to side. The shape is best shown in Figs. 8 and 9. The outer of the two cotyli is the larger, and is nearly twice as wide as the inner. It is impossible to distinguish the bones of this region as separate elements.

The outer face of the jaw is rugose, and near the anterior end of specimen No. 1076 it is marked by a depression evidently for the attachment of powerful muscles. This depression at first seems due to crushing, but there is no evidence of breaking, and the same thing occurs on both jaws. There is no such depression in the jaws of specimen No. 1075. The symphasis of the jaws was sutural, narrow, and nearly vertical.

There are eleven of the wide molariform teeth, and one empty alveolus in the posterior portion of the jaw. Anterior to these there is a single large incisor tooth, and the empty alveoli for four more, so that, if there was a small peg-like tooth at the posterior end corresponding to the small tooth at the end of the maxillary series, there were in all seventeen or eighteen teeth. The whole series of teeth is slightly concave from before backward and convex toward the middle line. The teeth are worn on the outer half only, to correspond with the wear of the inner side of the maxillary teeth. The posterior teeth are the wider, and after the posterior eight they rapidly narrow toward the front.

The shoulder girdle (the description of the shoulder and pelvic girdles is taken from specimen No. 1075).—The shoulder girdle consists of the interclavicle, clavicles, scapulæ, coracoids, precoracoids, and cleithra. The scapula, coracoids, and precoracoids are closely united. This, with the condition of the bones, makes it impossible to trace the exact form of the separate elements. The form of the three united bones is very similar to the scapula-coracoid figured by Broili as belonging to *Naosaurus* (Broili, 1904, Figs. 5, 5*a*, Plate XIII). This determination of the bones is erroneous, as it is very far from the condition of the *Pelycosauria* and closely approaches that of the *Diadectidae* here figured. The scapula is rather elongate and narrow vertically. Its posterior end terminates in a rather sharp point. The edge of the articular cotylus is very prominent, and the face looks backward rather than outward. In the *Pelycosauria* there is a foramen which penetrates the shaft of the scapula on the outer side just posterior to the articular face, and passes forward and inward to open on the inner face of the bone in the bottom of a pit which also receives the opening of the coracoid foramen. In this specimen the foramen opens on the lower edge of the shaft and is almost within the articular space. Its position on the inner face cannot be given.

The line between the coracoid and precoracoid cannot be distinguished. The two bones extend forward and inward as flat plates which terminate in a straight anterior-posterior line medially. The two plates of the opposite side normally joined in a symphasis, but the two sides of the shoulder girdle have been pressed together, causing the two plates to overlap each other to the extent of about 1^{cm}. In addition to reaching inward to the middle line, the coracoid is extended so far backward that its posterior edge is nearly on a line with the posterior end of the interclavicle. There is a prominent articular face on the coracoid, opposed to the face on the scapula and arranged to permit the same sort of an oblique articulation with the head of the humerus as occurs in the *Pelycosauria*. Between the two articular faces originates a deep elongate pit which runs about 2^{cm} towards the precoracoid. It occupies much the same position as the cavity between the scapula and precoracoid figured in *Pareiasaurus* by Seeley and called by Furbringer the *Incisura (Fenestra?) coraco-scapularis*, but it does not open through the bone. I cannot imagine the meaning of this pit, unless it is a scar formed on the bottom of the humeral cotylus by the attachment of a very strong ligament, such as sometimes occurs in the acetabulum. The coracoid foramen cannot be made out. In the *Pelycosauria* it opens at the base of the scapular portion of the humeral face, but I cannot find it there in this specimen. However, it was undoubtedly present.

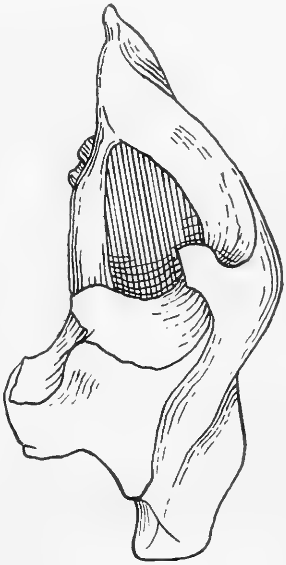

Fig. 9.—Rear view of jaw shown in Figs. 7 and 8. Natural size.

The inward and posterior extension of the coracoids and precoracoids, and their union in the median line, made a strong ventral covering to the thoracic region not unlike that of *Procolophon.*

The cleithrum.—The posterior portion of the upper edge of the scapula is bordered by a short bone which is wider posteriorly and narrows to a point anteriorly. It is anchylosed to the scapula, but posteriorly the division is marked by a deep groove. The form is best seen in Fig. 2. Its anterior edge touches, but does not articulate with, the scapula. This bone is evidently the cleithrum. It has much the appearance of the same bone in *Pareiasaurus* and the scapula figured by Broili, mentioned above, and is in about the same stage of degeneration.

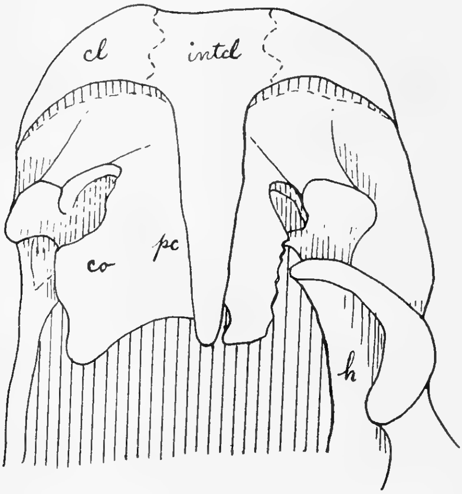

FIG. 10.—Ventral view of the shoulder girdle of No. 1075. *cl* = clavicle, *intcl* = interclavicle, *co* = coracoid, *pc* = precoracoid, *h* = humerus. One-half natural size.

The clavicles.—The clavicles do not meet in the middle line, but are separated by the interclavicle, with which they are closely articulated by strong sutural processes. Cope speaks of the symphasis of the clavicles behind the interclavicle, but this is an impossibility in the *Diadectidae*, as will be seen from the description and figures of the interclavicle. Viewed from above, the clavicles plus interclavicle have the form of a narrow horseshoe, the anterior end of the clavicles being wide and narrowing gradually to a point at about the posterior one-fourth of the scapula. The upper surface of the clavicles is quite flat. Viewed from the side, the anterior portion of the clavicles is broad, but rapidly narrows to an edge which disappears behind the cleithrum.

The interclavicle.—This bone is somewhat T-shaped. Its form is best seen in Fig. 10. The middle of the anterior end is slightly concave and rounded. Laterally the wing-like sides unite by strong interlocking sutures with clavicles. The posterior process is continued backward, gradually narrowing to a point. Fig. 11 is a photograph of the interclavicle of a larger specimen (No. 1079), but shows the character of the surface and the connections with the clavicles.

FIG. 11.—Ventral surface of an interclavicle of a larger specimen than No. 1075—No. 1079.

The vertebræ. — Specimen No. 1077 consists of the two sacral vertebræ and seven presacrals. They are much larger than any of the specimens in which the skull is preserved. The whole series is characterized by the great width of the neural arch compared with the antero-posterior diameter. The neural spines are short and stout; the centrum is simple and deeply biconcave; there are no intercentra preserved. The anterior one of the seven presacrals is free from the others and very perfect, so that I have selected it as characteristic of a mid- or posterior dorsal. The anterior and posterior faces of the centrum are round and deeply concave, and it is perforated by the notochordal foramen. The lower edge of the centrum is slightly concave from before backward, and is without any median keel. The neural arch is anchylosed to the centrum, and there is no trace of the suture. As shown in Figs. 12–14, the anterior and posterior zygapophyses are far above the neural canal. The articular faces are almost flat, but are inclined slightly toward the median line, so that the anterior ones look inward as well as upward, and the posterior ones outward as well as downward. The posterior face is considerably higher than the anterior. Both faces are marked by faint rugose ridges concentric around the inner end. Between the two faces and on a level with the posterior the transverse process for the rib originates and extends forward and downward until the lower end is just above the upper third of the anterior face of the centrum and directly below the anterior zygapophysis. On the anterior face of the vertebræ the inner ends of the articular faces of the zygapophyses are continued inward and downward as strong processes which bear on their inner ends the faces of the hyposphene inclined sharply inward and downward. These faces are shorter than the zygapophysial faces, but are fully as deep and as well developed. They form a striking feature of the vertebræ. Between the inner ends of the zygapophysial faces is a deep nearly round pit with a rugose bottom. It is directly above the neural canal, from which it is separated on the face of the vertebræ by a wide V-shaped partition. The posterior face of the inner ends of the zygapophyses are continued downward and inward as strong ridges which separate a deep triangular pit above, in the median line, from the hypantrum faces below. This triangular pit corresponds to the rounded pit on the anterior face, and the two evidently afforded attachment to a very stout ligament which bound adjacent vertebræ together. (Compare Cope's idea of the external form and habits given below.) The upper end of the neural spine is divided antero-posteriorly by a shallow, V-shaped channel. The anterior and posterior edges of the spine are drawn out into sharp edges, giving the whole a diamond-shaped section.

FIG. 12.—Anterior view of the seventh presacral vertebra of specimen No. 1077, showing hyposphene and pit above the neural canal.

This vertebra is undistorted, so that the following measurements are characteristic:

Total height from the lower edge of the anterior face to the apex of the spine	0.143^{m}
Width across the anterior zygapophyses	0.111
Width across the transverse processes	0.122
Antero-posterior diameter across the zygapophyses	0.066
Antero-posterior diameter of the centrum, approximate	0.036

The six presacral vertebræ following the one described above do not differ from it in many particulars. The centra become slightly shorter in the posterior ones, the first presacral is the shortest, and the dorsal spines become irregularly larger and heavier. The main difference is in the size and position of the transverse processes. These become progressively shorter, and with less well-defined articular faces for the ribs, as they approach the sacrum. The shortening is accomplished at the upper end only. The lower edge of the process, except in the last two, remains opposite the upper fourth of the centrum, but the upper end gradually drops from a

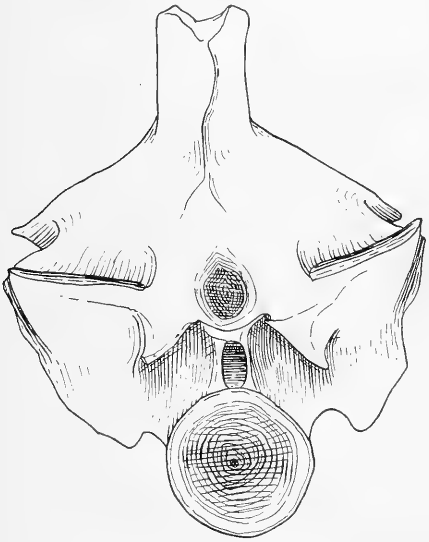

FIG. 13.—Outline of vertebræ shown in Fig. 12. One-half natural size.

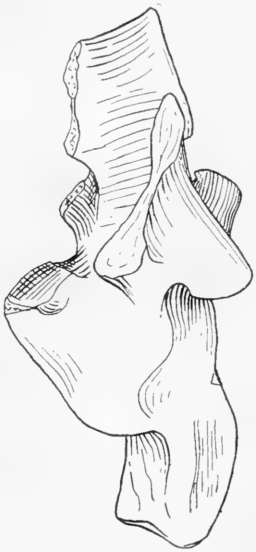

FIG. 14.—Lateral view of vertebra shown in Figs. 12 and 13. One-half natural size.

point opposite a line connecting the zygapophysial faces to a point opposite the neural canal. The articular faces of all except the last two retain the same slant forward and downward as described

Fig. 15.—Photograph of the sacrum and six presacral vertebræ of specimen No. 1077.

in the seventh presacral. The last two vertebræ have the transverse processes much smaller than the preceding ones, and the upper end is much farther to the rear; the articular face is more nearly horizontal. The articular faces for the ribs are very poorly developed, in strong contrast with the condition of the more anterior vertebræ; these two may be recognized as lumbars.

The two sacrals present a strong contrast to the presacrals. They are closely anchylosed together, so that not only are the centra joined, but the zygapophysial articulations have disappeared and the processes pass into one another without suture. Both vertebræ present well-developed articular zygapophysial faces to the adjacent lumbar and caudal vertebræ. The transverse process of the first sacral is very wide, originating from the bases of the zygapophysial processes and maintaining a width equal to the anterior-posterior diameter of the centrum. The articular face for the rib is completely horizontal, but the rib is anchylosed to the process, so the face is traceable by a suture line only. The process and rib extend almost straight downward and articulate with the anterior end of the ilium (shown by specimen No. 1075). The transverse process of the second sacral is very much narrower and more rounded than the first, but extends downward, and is anchylosed with a sacral rib as in the first. The neural spine of the first sacral is larger than the

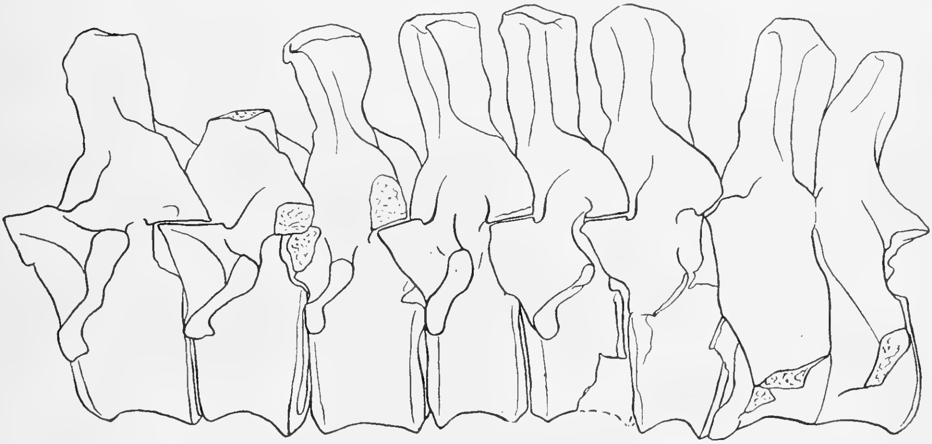

FIG. 16.—Outline of vertebræ shown in Fig. 15. One-half natural size.

lumbar spines and is inclined sharply to the rear, leaving a considerable space between it and the last lumbar. The second sacral has a smaller and more slender spine than the first, but there is the same inclination to the rear. The neural arch, seen from above, is much narrower, and the sides are not rounded out into the almost hemispherical form characteristic of the presacrals. In fact, the sides of the neural arch are almost concave. The centra are abruptly longer than the last lumbar, and the bases of the centra are closely united. There is no intercentrum. Attached to the anterior edge of the first sacral is an intercentrum which underlies the space between the last lumbar and the first sacral. This is the only intercentrum preserved in the specimen. The total length of the sacrum and six presacrals is 0.33^{m}. The average height of the vertebræ is 0.165^{m}.

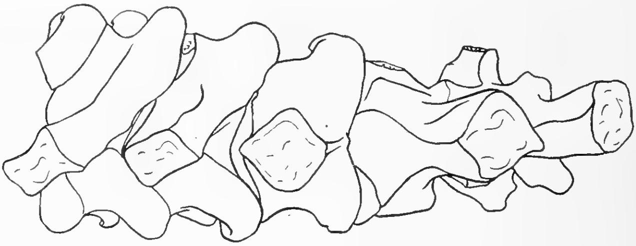

FIG. 17.—Superior view of the posterior five vertebræ shown in Fig. 16.

The vertebræ of specimen No. 1076 consists of five anterior dorsals in series, and, after a break, six more in series connected with the two sacrals, making thirteen in all. The vertebræ are smaller, but present no points of generic difference from specimen No. 1077 and are less well preserved. The five anterior vertebræ are all of the same type, and the description given of the vertebræ in No. 1077 is strictly applicable. In the middle of the series the heads of two or three ribs are preserved, and show that there was no division into a capitulum and tuberculum, nor any approach to such a division. There are no intercentra preserved. In the posterior series the transverse processes of the vertebræ show the same series of changes as described in No. 1077, and the sacrals confirm the observations made on that specimen.

In specimen No. 1075 the entire vertebral column is preserved, with the exception of a few terminal caudals. The vertebræ cannot be freed from the hard matrix sufficiently to warrant a complete description, but enough can be seen to show that they conform very closely to the descriptions given above of the other specimens, and that from anterior dorsals to lumbars there is very little change in form. The anterior cervicals are preserved, but the matrix at this point is exceptionally hard and is fissile, so that it has been impossible to make out this important region. A short cervical rib has been uncovered on one side. Although the anterior caudals of this specimen have not been made out, another specimen in the collection, No. 62, shows the caudal region. This shows that the tail was short, and that the posterior caudals were supplied with strong chevrons pointed sharply backward (Case, 1903; Fig. 10).

Intercentra are preserved in all parts of the column exposed, i. e., from the cervical to the lumbar. They are thin plates, only slightly curved, so that they extend only a short way up on the sides of the centra. They are broad antero-posteriorly. The intercentra simply underlay the point of contact of two centra and were not closely attached.

The ribs.—There were evidently ribs on all the vertebræ. The anterior cervicals are covered with matrix, but on one side a rib of about 2^{cm} has been exposed which was attached to either the second or the third cervical. On the third or fourth vertebra the ribs have reached a considerable length, and by the fourth or fifth the ribs have reached the greatest length of the body. As far back as the ninth vertebra the ribs have suffered the distortion described above, so that they are bent sharply backward and upward. In the posterior portion of the column the ribs curve sharply to the rear and gradually shorten, so that on the posterior dorsals and the lumbars they are quite short and slender. The dorsal plates overlie the ribs of the anterior vertebræ only. But four plates can be counted in series, but there were probably one or two anterior to them. In the description of specimen No. 62, mentioned above, the author described for the first time the occurrence of the plates in the *Diadectidae.* In that specimen they occurred as a fragment, but show the presence of at least five. In the anterior plates the ribs seem to be short and fused to the under surface of the plates as in the turtles (this point is somewhat uncertain), but in the posterior plates the ribs are separate. The anterior plate is the broader and larger; the following ones diminish rapidly in size, and do not reach nearly to the end of the rib. It is evident that the plates did not cover the back, but lay on the sides of the body, with a wide interspace over the neural spines. In this as in other respects the carapace is much less perfect than in the *Otocoelidae.* Cope describes the shoulder girdle of the *Otocoelidae* as lying within the ribs. This does not occur in the *Diadectidae.* The plates lie between the scapula and the ribs. So peculiar is their position that at first glimpse they have a strong suggestion of beginning plastral elements.

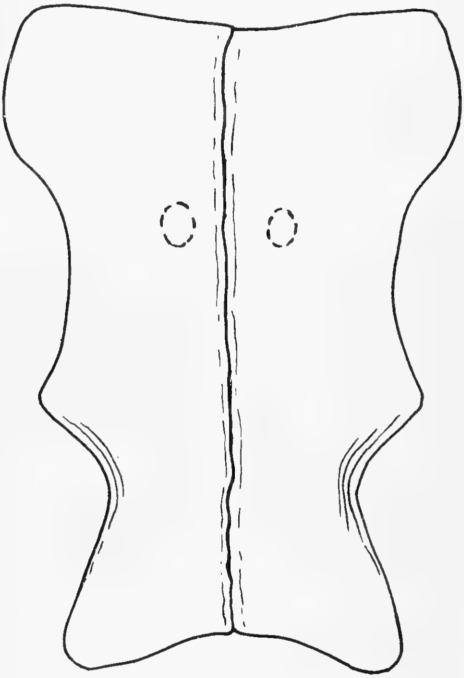

Fig. 18.—Outline of the lower surface of the pelvis of specimen No. 1075. One-half natural size.

The pelvis.—The pelvis shows the same adaptation to the depressed form of body as the shoulder girdle. The pubis and ischium are flat and plate-like, and the lower surface of the pelvis formed by the four bones is horizontal. There is no trace of the pubo-ischiadic suture, and the bones of the two sides meet in a straight symphysis, which is marked by an elevated ridge. The ilium stands vertically at a right angle to the other bones. (See Figs. 2 and 18.)

The ilium.—The crest of the ilium is nearly straight on the upper edge, the anterior end is rounded, and the posterior end is continued backward into a straight point. The lower portion forms the upper part of the acetabulum. The anterior edge of the lower parts slants forward and downward to join the pubis.

The pubis.—This is wide anteriorly and narrows slightly anterior to the acetabulum. The pubic foramen is near the middle of the bone. The anterior edge is nearly straight, but is slightly inclined backward toward the middle line, so the edge is somewhat notched.

The ischium.—This is narrower than the pubis and is sharply contracted posterior to the acetabulum, which has on this bone a prominent rim. The posterior edge of the pelvis formed by the two ischia is even more deeply notched than the anterior.

FIG. 19

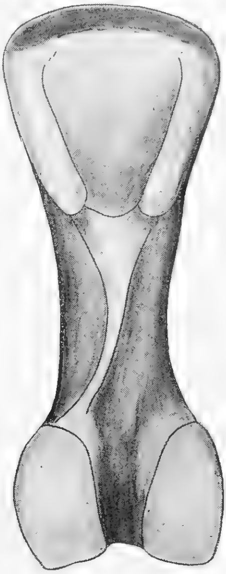

FIG. 20

FIG. 19.—Anterior view of humerus of specimen No. 1075. One-half natural size.

FIG. 20.—Anterior, lower view of femur of specimen No. 1075. One-half natural size.

The humerus.—This is a relatively short and wide bone, but of the same general type as occurs in all of the *Cotylosauria*. There is a very strong radial process reaching to near the middle of the shaft, and a large entepicondylar foramen near the middle of the lower end. The process for the head of the radius is broken away, but the entepicondylar process is exceptionally wide and large. The total length of the bone is 0.157^m. The width of the lower end is 0.102^m.

The femur.—The femur is of a very simple type. There is no distinct head, and there is the usual concavity on the anterior face near the proximal end. There is a low but distinct ridge connecting the upper and lower ends on the anterior (inferior) face which crosses the bone somewhat obliquely. The distal condyles are almost entirely on the anterior face. The length of the bone is 0.150^m.

Only the proximal ends of the bones of the forelegs remain, but these, with the described bones of specimen No. 62, show that they were proportionately short and stout. In the description of specimen No. 62 figures were given showing that the phalanges were short, and that the foot must have been short and strong, with stout nails or claws, perhaps fitted for digging. Unfortunately, no attempt can be made to give the phalangeal formula.

Form and habits.—Cope makes the following suggestions regarding the *Diadectidae:*

> There is some reason to believe that the Diadectes relied exclusively upon the pineal eye for the sense of sight. The species of the family were subterranean in their habits, since their humeri indicate great fossorial powers, resembling those of the existing monotremes and even the moles. The vertebræ are locked together with hyposphen beside the usual articulations, and the arches of the neural canal form an uninterrupted roof from the skull to the tail, of extraordinary thickness and strength. That the species are not aquatic is rendered probable by the fact that the orbits do not look upward. Their superior borders are, on the contrary, prominent and straight. Add to this fact the apparent absence of optic foramina, and the probability that the *Diadectidae* were blind and subterranean in their habits becomes still stronger.

There seems little doubt that the points made by Cope are in the main correct. The animals were undoubtedly flat of body and strong of limb in regard to their digging powers. It may be doubted, however, if there is sufficient evidence to warrant the suggestion that they were blind. If they resembled the turtles as much as seems probable, it is very possible that the optic nerves escaped from the brain case in the same way without any special foramen.

It will be seen from the above description that the family *Diadectidae* must be removed from the *Cotylosauria* and placed in the order *Chelydosauria*. It also supports in a most striking manner the statement made by Cope that the last order was ancestral to the turtles. It is not assumed that the *Diadectidae* are the direct ancestors of the turtles, nor can this statement be made in regard to any of the *Chelydosauria;* for in none is there any beginning of the development of a plastron, and only an incipient carapace, which cannot be regarded as determinative, as it also occurs in an amphibian *Dissorophus*, of the same beds. The only features of the body skeleton prophetic of the turtles are the beginning of the carapace and the number of presacral vertebræ, which is eighteen—a number which also occurs in many of the *Cotylosauria.* It is in the skull that the testudinate affinities appear. For convenience of discussion, the seven most important points are listed below:

1. The form and relations of the quadrate.
2. The degenerate palate and the disappearing transverse bone.
3. The absence of teeth on the pterygoids and palatines.
4. The absence of a parasphenoid process on the basisphenoid bone.
5. The absence of prevomers and the presence of an anteriorly placed single vomer (parasphenoid).
6. The method of entrance of the internal carotid arteries into the skull.
7. The presence of paired descending plates from the skull roof anterior to the brain cavity.

These will be discussed in order.

1. The form and relations of the quadrate. In the order *Cotylosauria* there are, as in the *Stegocephalia*, but five openings in the skull roof—the nostrils, the orbits, and the pineal foramen. The quadrate region is covered by dermal bones, so that the quadrate bone is seen only from behind or below to any extent. In the *Chelydosauria*, as described above, the quadrate appears on the side of the skull, and forms a portion of the side wall, surrounding an opening, the meatus auditus externus; the meati of the two sides forming a third pair of openings to the interior of the skull. As pointed out in the description, the quadrate bears exactly the relations to the bones of the roof and lower portion of the skull that the same bone bears in the turtles, and there is a suggestion of an overhanging hook on the posterior edge, indicating the beginning

of a closure of the bone to form a complete tympanic ring. But we know that there are many turtles in which the tympanic is open behind. Baur gives the following list: *Amphichelydia*, *Dermatemydidae*, *Staurotypidae*, *Kinosternidae*, *Toxochelydae*, *Platysternidae*, *Emydidae*, and *Adelochelys*.

2. The degenerate palate and the disappearing transverse. It is evident that the palate is very different from that of the *Cotylosauria* and from any of the more primitive orders of reptiles, as *Proterosauria*, *Proganosauria*, *Rhyncocephalia*, etc. There is no anterior rostrum (presphenoid auct.) on the basisphenoid; there are no paired prevomers; the palatines and transverse are degenerate; there is no descending buttress on the external process of the pterygoids for the lower jaw. The condition of the anterior rostrum of the basisphenoid and the prevomers is discussed below. It is apparent that the palate is in process of change toward a new type. It may well be that the *Diadectidae* show an extremely degenerate example of this change, and that the more successful line showed no such violent differences from the parent form at any stage. The ridge-like form of the palatines on the edge of the maxillaries speak of their extension toward the middle line to meet a median element extending far posteriorly—an element which already exists, but from which they are separated by the long antero-posterior vacuities of the palate. The firm attachment of the pterygoids to the maxillaries is indicative of the final disappearance of the transverse, one of the most characteristic features of the Chelonian palate.

3. The absence of teeth on the pterygoids and palatines. In all other forms of the *Cotylosauria* there are teeth on the pterygoids or palatines, or both. Two specimens show that they are absent in the *Diadectidae*.

4. The absence of a parasphenoid process on the basisphenoid bone. If we accept without argument or review the position taken by Broom, that the true vomer is the parasphenoid in a new position and with a new function, and that the paired elements of the reptilian skull usually called vomers, are really distinct elements, then the identification of the parasphenoid in the skull becomes of extreme morphological importance. It has been shown by Howse and Swinnerton (Howse and Swinnerton, 1901) and Siebenrock (Sieben-

rock, 1897) that in *Sphenodon* the rostrum of the basisphenoid is the parasphenoid; the basisphenoid with its anterior rostrum develops from three centers—two posterior, in the cartilage of the skull axis, and one anterior, in the lining membrane of the floor of the pituitary space. The same observation has been reported and confirmed in the development of the Lacertilian skull. It is evident, then, that the rostrum of the basisphenoid is the remnant of the parasphenoid in the reptiles. (It is common to refer to this rostrum as the presphenoid—a distinct error, as the presphenoid is a continuation of the cartilaginous basicranial axis, and not a membrane bone.)

There is no such rostrum developed in the turtles. I am aware that Parker reported (Parker and Bettany, 1877, p. 214) that the basisphenoid of the turtle is developed from three centers, as in the *Lacertilia*, but this is denied by Siebenrock (Siebenrock, 1897), who also cites Rathke (Rathke, 1848), as follows:

> Dass sich das Basisphenoideum bei den Schildkröten nur in einfacher Zahl bildet denn selbst bei denn reifern Embryonen, konnte Rathke nicht das geringste Zeichen anfinden, dass es ursprünglich aus einem hinteren und vordern Stücke bestanden hatte.

Siebenrock further explains the apparent rostrum of the turtles by the elongation and approximation of the trabeculae inferiores (Siebenrock, 1897, p. 18).

In an examination of the *Reptilia* I find the following condition: The parasphenoid is absent as a rostrum of the basisphenoid in the *Chelydosauria*, *Testudinata*, *Cotylosauria partim* (*Telerpeton*, *Pareiasaurius* (?), *Procolophon*). It is present in the *Ichthyopterygia*, *Sauropterygia*, *Squamata*, *Theropodous Dinosaurs* (*Diplodocus*), *Cotylosauria partim* (*Pariotichidae*, *Labidosaurus*).

It now becomes necessary to discuss this point in connection with the fifth point:

5. The absence of the prevomers and the presence of an anteriorly placed single vomer. In the forms where there is a rostrum on the basisphenoid there are always paired prevomers, but where this rostrum is not developed there is a single, anteriorly placed vomer and no prevomers.

Broom has shown (Broom, 1904) that the median vomer of the turtles is probably the parasphenoid. The condition of the vomer of the *Diadectidae* indicates that it may well be the parasphenoid detached from the basisphenoid and placed in an interior position, retaining its connection with the basisphenoid by extension of the cartilaginous basicranial axis, if at all. Perhaps the median ossified plate described as descending from the anterior part of the skull roof is an ossification of the ethmoid complex, and aids in the support of the vomer. The list given above shows that the parasphenoid rostrum of the basisphenoid is not a constant feature even in well-defined *Cotylosaurians.*

6. The method of entrance of the internal carotid arteries into the brain cavity. In the *Rhynchocephalia* and *Squamata* the carotid arteries divide beneath the skull floor, and the internal carotids pass through the basisphenoid from below, leaving a pair of foramina which are very constant and noticeable features. In many of the turtles the carotids pass into the skull through a foramen posterior to the quadrate, and then divide into an internal and external carotid. The internal carotids enter the basisphenoid through the side of the bone, and then pass out of the top, leaving no foramina on the lower surface. This character is not constant for all turtles. In some the internal carotids enter the pterygoid, or the foramen is in the suture between the basisphenoid and pterygoid.

I find foramina on the lower surface of the basisphenoid in the *Rhynchocephalia*, *Squamata*, and probably *Dinosauria*. In the *Testudinata* (*partim*), *Chelydosauria*, *Crocodilia*, there are no foramina on the lower side of the basisphenoid.

7. The presence of paired descending plates from the skull roof anterior to the brain cavity. As no trace of an epi-pterygoid was found, the paired plates descending from the lower surface of the parietals is strongly prophetic of the plates in the turtles. They have the same position and, apparently, the same relation to the pterygoids below and the foramen for the fifth nerve.

Opposed to the Testudinate affinities is the absence of any plastral elements, even abdominal ribs, and proscapular process of the shoulder girdle.

In just the characters in which the *Chelydosauria* (*Otocoelidae*, *Diadectidae*) approach the turtles they are distinct from the *Cotylosauria* (*Pareiasauridae* and *Pariotichidae*), and so it seems very probable that we have in the *Diadectidae* forms very closely related to the ancestral stem of the turtles which tell us much regarding the development of the *Testudinata* directly from the *Cotylosauria.*

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SOME INSTANCES OF MODERATE GLACIAL EROSION[1]

RALPH S. TARR
Cornell University

Instances of marked glacial erosion have in recent years been reported from many sections, but very little has been written regarding evidences of moderate glacial erosion. In several widely separated localities I have found definite proof of moderate ice-erosion, which, in view of the growing tendency to assign to ice great erosive power, seems worthy of statement at the present time. These instances will be considered one by one.

SOUTHERN CENTRAL NEW YORK

South of the Finger Lakes is a plateau upland which was completely overridden by ice of the Wisconsin stage. Across this upland extends a series of moraines marking a prolonged halt of the receding ice. South of the recessional morainic belt there are numerous evidences of moderate glacial erosion, and no proof that the topography was perceptibly modified by ice-erosion, although during the time that the ice-front stood at the terminal moraine, about 50 miles farther south in Pennsylvania, the highest hills were completely covered.

The most important evidence of moderate glacial erosion in this plateau region is supplied by the presence, in numerous localities, of residually decayed materials in place, not only on lee slopes, but on hilltops and on the stoss sides of hills. The decayed material varies from discolored and disintegrated shale fragments beneath sandstone caps to fine-grained residual clay resulting from the decay of the shale (Fig. 1). In such cases the sandstone cap layers are cracked and broken, and the decayed shale is in some instances three feet below

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[1] This paper was presented before the first meeting of the Association of American Geographers at Philadelphia. The facts relating to New York were discovered while working for the U. S. Geological Survey, and are published by permission of the director.

the surface. That this clay is not the result of postglacial decay is proved by the fact that in some places the striæ on the sandstone caps are not yet destroyed by weathering.

It is only occasionally that cuts fresh enough to reveal the actual condition are found, but it is evident in the field that unremoved products of rock decay are widespread. This is proved by the presence in the fields of abundant slabs of sandstone, many of which are profoundly decayed, with a deep rim of oxidized rock, and with fossils completely weathered out. Very often plowing has encountered weathered sandstone caps under the thin upland soil, and, by upturning the slabs, has transformed the fields to such stony areas that the sandstone fragments cover fully 50 per cent. of the area. The till of this region is made up largely of local sandstone fragments, mixed with residually decayed clay and a relatively small proportion of foreign stones and rock flour, making a very peculiar soil. The

FIG. 1.—Decayed shale between sandstone layers, one mile east of Berkshire, N. Y., on Harford (U. S. Geological Survey) Topographic Sheet. The shale shows spheroidal weathering and between the nodules is residual clay.

Soils Bureau of the U. S. Agricultural Department recognized this peculiarity, and in mapping the soils of the Elmira Sheet correlated the upland till with a type of residual soil under the name of Hagerstown shale loam.

This residually decayed material is not confined to a small area, but has been found in the mapping of glacial deposits on eight topographic sheets, and it is certain that throughout this area there has been such slight glacial erosion that in many places, even where conditions seem favorable, the residually decayed products were not removed by the Wisconsin ice-sheet. Whether this is preglacial or interglacial decay is not certain; but so far no facts have been discovered in this region to prove an earlier ice-advance.

It is true that this is a region in which the length of ice-occupation was relatively brief, and in which the hilly topography was opposed to vigorous ice-action. But even under these conditions it is a significant fact that ice could have moved over it and have advanced 50 miles beyond it, building a traceable terminal moraine, and yet leave so much decayed rock even in exposed places, like hilltops and stoss slopes.

THE CAYUGA VALLEY

At Portland quarry, about 6 miles north of Ithaca on the east side of Cayuga Lake, the excavations for the removal of the Tully limestone have revealed a condition of profound decay. By this decay the upper layer of limestone has been separated into rounded blocks, with a reddish residual clay occupying the spaces between them, both along the vertical joint planes and along the nearly horizontal stratification plane between the two upper layers. The decay extends from 2 to 3 feet below the surface, and the residual clay is several inches thick. Delicate glacial striæ are still perfectly preserved on the surface of limestone blocks between and beneath which this residual clay occurs.

The depth and extent of this decay, together with the evidence of slight postglacial decay furnished by the glacial striæ, demonstrate that this residual clay was formed before the advance of the Wisconsin ice-sheet, and that in this place the erosion by the last ice-sheet was insufficient to remove the products of earlier decay. The site of this quarry, near the junction of Salmon Creek and Cayuga Lake on a nearly level bench below the edge of the steepened slope of Cayuga valley, is a point where, if anywhere in the valley, glacial erosion should have been extensive.

Farther north, between Union Springs and Cayuga, marked decay was revealed in the gypsum beds of one of the quarries; but this has now been removed. It was situated on a level surface near the northern end of the Cayuga trough, at a point where glacial erosion should have been pronounced, and in a soft stratum which ice-erosion would easily wear away.

At frequent points near the heads of Cayuga and Seneca valleys, notably near Ithaca and Watkins below the edge of the steepened slope, there are pronounced cliffs, often several score yards in length and from 5 to 15 feet in height, with sharp edges and angles whose formation by ice-erosion is inconceivable. Their length and height, as well as the absence of rounded edges, indicate origin by weathering and not by ice-erosion; and that they were not produced after the ice disappeared is proved in a number of cases by the presence of till and moraine banked up against them and partly burying them.

A system of hanging valleys tributary to both the Cayuga and Seneca troughs ends at about the 900-foot contour, below which the valley slope is decidedly steepened. Down this steepened slope extend old gorges antedating the last ice-advance, and partly buried beneath deposits of the Wisconsin stage. So far as can be seen, the gorge walls are not markedly worn by ice-erosion. It has been proposed as a theory that the steepened slope and great depth of the Cayuga and Seneca valleys are the result of glacial erosion; but that such profound erosion, amounting to at least 845 feet in the Cayuga and 1,500 feet in the Seneca valley, could have been performed without erasing these earlier gorges, or at least so modifying them as to give evidence of such erosion, seems inconceivable.

The evidence in the Cayuga valley is believed to demonstrate that the work of erosion by the Wisconsin ice-sheet above present lake-level was very slight. What occurred below lake-level or during possible earlier ice-advances is not clear; but if this evidence eliminates erosion in the visible part of the valley by the only known ice-advance in this region, as it seems to do, it throws doubt upon the whole hypothesis of ice-erosion for this valley, notwithstanding the remarkably straight, smooth sides, the steepened slope, and the hanging valleys whose characteristics suggest ice-erosion origin.

CAPE ANN, MASSACHUSETTS

This cape, extending into the sea north of Boston, has upon it an interesting morainic deposit in which there are large numbers of bowlders (Fig. 2), in some cases with bands of bowlders piled one on the other, making bear-den moraines (Fig. 6). It is no overestimate to state that there are tens of thousands of bowlders on the Cape, and that fully 90 per cent. of these are of local origin, especially granite of which the Cape is chiefly made. So far no satisfactory explanation of this marked accumulation of local bowlders has been proposed.

Fig. 2.—Bowlders in the Cape Ann (Mass.) moraine, showing the ordinary condition of the moraine surface.

Years ago I did work on the geology of Cape Ann as an assistant to Professor Shaler, and the result of his studies was published by the U. S. Geological Survey.[1] Numerous visits since then, together with the fact that quarrying operations have opened up scores of new exposures, have furnished new facts which show conclusively that ice-erosion on Cape Ann was very ineffective, and that the large numbers of bowlders are probably directly due to this fact. Indeed, they evidently represent the slightly moved bowlders of decay prepared for removal before the last ice-advance. The evidence of moderate ice-erosion is of several kinds, as follows.

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[1] *Ninth Annual Report*, U. S. Geological Survey (1887–88), pp. 529–611.

Larger valleys.—In the first place, the major valleys all antedate the ice-advance, for they extend at all angles to the direction of ice-motion, and have all the characteristics of subaërially formed valleys.

Angular cliffs.—A second evidence is furnished by angular cliffs, especially on lee slopes. These vary in elevation from an inch or two to a score of feet or more, being due either to the influence of joints or of dikes. They are seen in all parts of the Cape, the smaller instances being revealed where quarrying operations have recently stripped rock-surfaces bare.

Some of the smaller cliffs may be the result of plucking, but the larger ones are certainly not of this origin. The smaller cliffs are often associated with incompletely developed *roches moutonnées* surfaces, which conform closely in outline to the concentric joints of the granite (Fig. 3). Viewed from the stoss side, these surfaces are typical *roches moutonnées,* but from the lee side they appear angular, with small cliffs extending from one *roches moutonnées* down to the next lower joint plane.

FIG. 3.—To show the relation of *roches moutonnées* surfaces and minor cliffs to the concentric jointing (dotted lines) of the Cape Ann granite.

Dikes.—In a number of places there are small valleys where dikes cross the granite, and these occur at all elevations, even above the level at which the sea formerly stood. They extend at all angles to the direction of ice-motion, and, being occupied by drift, are not of postglacial origin. Every evidence proves these valleys to be due to greater decay of the dike than of the inclosing granite; and that the ice should not have eroded the granite down to the level of this dike decay is proof of its slight erosive power at this point.

At the Rockport granite quarry one of these decayed dike valleys extends up to the edge of the quarry, and, while the residually decayed surface material is gone, there is evidence of some decay in the dike even to the bottom of the quarry. This decay consists of the development of abundant joints in the dike and a slight disintegration along them. A similar case occurs where a large porphyritic diabase dike crosses a quarry at Pigeon Cove; but here residual clay remains along the joints, by which the dike is separated into a series of rounded bowlders.

"*Sap.*"—In all the quarries at Cape Ann the granite is stained yellow along both the vertical and horizontal joint planes. This stain, which in some cases extends three inches into the granite, is known by the quarrymen as "sap." It is due to a partial disintegration of the iron-bearing minerals and consequent staining of the granite. The depth to which this stain extends in the quarries, being found even at the very bottom of the largest, and the extent to which it enters the rock, are altogether too great for postglacial decay.

Joint planes.—Almost uniformly over the Cape it is the case that joint planes are much more numerous in the upper than in the lower portions of the quarries.[1] They are in some places so close together that small quarries have been opened and, after being worked for a while, have been abandoned because the "grout" (small irregular blocks stained with "sap" and useless even for making paving blocks), which must be handled and disposed of, is too abundant. These joint planes have evidently been developed by weathering, and by weathering of longer duration than postglacial times would permit. Glacial erosion has not been sufficient to remove this upper zone of jointed granite, although the joints produce masses favorable for plucking.

Interglacial (?) beds.[2]—At Stage Fort, just outside of Gloucester, there is a bed of fossil-bearing sands, clays, and gravels, overlain by till and grooved by glacial erosion. The layers are crumpled by the ice-shove. Although in the lee of a range of hills, it would hardly be expected that such a deposit would escape vigorous erosion.

Decayed granite.—In Lanesville, on the stoss slope of the Cape, and in a situation where there is no topographic reason for protection, there occurs in the Edwin Canney quarry a striking instance of decay in the granite (Figs. 4 and 5).[3] This decay, which extends

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[1] See Plates LXVI and LXVII in *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

[2] Tarr, *Bulletin of the Museum of Comparative Zoölogy*, Vol. XLII (1903), p. 189.

[3] See also Plate LI, *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

along both the vertical and horizontal joint planes, has produced a gravel of disintegration to a depth of five feet and with a width, in one or two places, of eighteen inches. By it the granite has been separated into rounded, bowlder-like blocks incased in disintegrated granite gravel exactly like those revealed in quarries in Maryland where the granite is covered by a residual soil.

FIG. 4.—Disintegration of granite along joint planes at Lanesville, Cape Ann, Mass. Gravel underlies these bowlders, which are in place.

Nowhere on the Cape is so good an instance of decay found as this; but in dozens of places decayed gravel occurs along the joint planes, in one or two instances to a depth of five feet. These localities are found in all parts of the Cape, and on both stoss and lee slopes. In a number of places granite masses that are thus partly incased in gravel are scratched and polished on the surface, showing how slight has been postglacial decay, and proving that the disintegration farther down cannot be postglacial.

That these masses should have resisted ice-erosion is remarkable; and that this erosion has not extended below the level of the disintegrated granite is clear proof of its general weakness on Cape Ann.

The till.—One of the most striking features of the till of Cape Ann, aside from its bowldery nature, is its sandy and gravelly condition. In some cuts the till very closely resembles the disintegrated gravel above described, and everywhere it seems to contain a large percentage of this decayed material. From the field evidence I am convinced that the till of Cape Ann is in large part made up of gravel disintegrated before the last ice-advance and pushed forward a short distance to its present position.

The bowlders and bear-den moraines.—It has been stated above that the bowlders of Cape Ann are prevailingly local, probably as much as 90 per cent. being of rocks at present in place on the Cape. Many of these are angular (Fig. 2), with joint-plane faces, as if broken from a ledge and carried a short distance without attrition. On the other hand, many, although carried only a short distance, are well rounded.

Both of these conditions are readily explained on the theory that they represent the dislodged products of decay prior to the ice-advance. Fragments surrounded by disintegrated gravel were rounded; those broken from the markedly jointed sections had angular faces. No other explanation that has occurred to me will account for this vast number of local bowlders; and the fact that some unremoved masses are left (Fig. 4) points clearly to this explanation as the true one.

The bear-den moraines (Fig. 6), representing bands of excessive bowlder accumulations, occur at various levels, so that they can scarcely be assigned to marine action, on the assumption that when they were accumulated the sea stood at the ice-front. Opposed to this theory also is the further fact that some of the occurrences are on protected valley slopes where sea-action could not have been very effective. So far as observed, they are all situated on lee slopes, which suggests that they were combed over the edges of the hills by ice-push, and perhaps added to accumulations which, being in the lee, the ice was incapable of removing. The only alternative explanation that appears is that they owe their origin to the action of water run-

FIG. 5.— Disintegrated granite along joint plane at Lanesville, Cape Ann, Mass., showing a portion of Fig. 4.

FIG. 6.— Bear-den moraine, on lee (southeast) slope of a granite hill, Cape Ann, Mass.

ning out from the ice-front, and, by removing the smaller fragments, concentrating the larger ones. Between these two theories I have been unable to find facts to decide.

Decayed bowlders.—Many of the bowlders have been broken open along joint planes since they were deposited by the ice. Although this is the result of postglacial weathering, it is due to the presence of joints partly developed before removal from the ledge. Other bowlders have disintegrated to gravel hills (Fig. 7) since they were brought to their present position, and every gradation from slight disintegration to instances where only a mass of gravel remains to mark the site of a former bowlder, may be found by the score. This disintegration is surely postglacial; but, taken in connection with other facts indicating preglacial decay, it seems certain that such decay must have been made possible by the fact that, before removal from the parent ledge, the rock was already weakened by decay. Nowhere on the Cape is there such difference in the granite in place as to permit marked decay on one surface and slight decay on another, as is true among the bowlders. On the contrary, wherever the thin till-cover has been stripped from the bed-rock, its surface is found to be polished or scratched, proving that postglacial weathering has done little work.

FIG. 7.—A granite bowlder in process of disintegration on Cape Ann, Mass. Other bowlders are represented only by heaps of gravel.

Conclusion.—That glacial erosion failed to remove the products of preglacial decay on Cape Ann is evident from the facts stated above; and that the marked accumulation of bowlders on the Cape is due to this lack of erosive power is advanced as a theory toward which all facts point, while no facts at present known oppose it. Whether there are reasons why the ice was locally thus ineffective, or whether it is a common condition along the New England coast, I cannot say. The Cape is a moderate salient against which ice-currents may have divided, leaving this region only slightly affected by its erosive action. Facts from a wider area must be obtained to settle the question whether this condition is local or general along the New England coast.

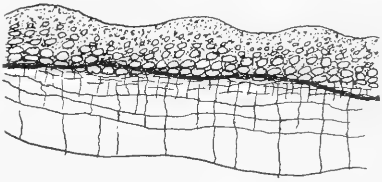

FIG. 8.—To illustrate the probable changes at Cape Ann. A jointed granite with joint planes increasing in number toward the surface, changing to a condition of bowlders with gravel between, and capped by residual soil, has, by ice erosion, been lowered to the level of the heavy line.

TURNAVIK ISLAND, LABRADOR

This island, which is approximately in latitude 55° N., is one of a number of islands in an indentation on the Labrador coast. It rises from 300 to 400 feet above the water and is a barren mass of rock, mainly porphyritic gneiss, so far as examined. Its surface is strongly glaciated, with numerous very perfect *roches moutonnées* forms, and many perfectly preserved striæ and deep grooves, but with very little till and few foreign bowlders.

Crossing the gneiss are a number of diabase dikes, one of which is 60 feet wide, and where these dikes occur their sites are quite uniformly indicated by chasms. The large 60-foot dike, whose site is marked by a long, deep valley (Fig. 9), extends at right angles to the direction of ice-motion, so that the valley cannot be explained by ice-erosion. That the chasm has not been formed since the ice left is proved by its rounded, ice-worn edges, and by the presence of fresh striæ on its walls. The valley is evidently the result of earlier decay; but that the ice removed the entirely disintegrated products of this decay is proved by the fact that fresh diabase was collected in the bottom of the valley.

This dike chasm, produced before the last ice advance, was not entirely erased by glacial erosion, proving that at this point the ice did not accomplish much work. It would be interesting to know how widespread this weakness of ice-erosion was along the Labrador coast, and whether this particular instance is due to some local retardation of the ice; but facts are not available for answer of these questions.

FIG. 9.—Dike valley, formed before last ice advance, on Turnavik Island, Labrador.

These observations, in widely scattered localities, do not prove anything beyond the regions in question. It is a well-known fact that the erosive power of ice varies with the conditions, and it is possible that close by some of these localities of moderate ice-erosion there may have been profound changes caused by the ice. Nevertheless, such pronounced cases of moderate ice-erosion, in such widely different situations, including surroundings apparently favorable to erosion, prove that under some conditions the erosive power of the continental glacier was very limited. More facts are necessary before the exact efficiency of the ice as a sculpturing agent can be determined, or the reasons why it erodes little in one place and apparently a great deal in another. All that is claimed for this paper is that it is a small contribution toward the accumulation of facts necessary for these determinations.

REVIEWS

SUMMARIES OF RECENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE

C. K. LEITH
State University, Madison, Wis.

EDWARD B. MATHEWS. "The Structure of the Piedmont Plateau as Shown in Maryland." *American Journal of Science,* 4th Ser., Vol. XVII (1904), pp. 141–59.

Mathews discusses the structure of the Piedmont Plateau. The Baltimore gneiss (William's biotite gneiss in part) is correlated with the Fordham gneiss of New York, the Arrowmink arkosic gneiss of Philadelphia, the Carolina gneiss (in part) of the Washington area, all of which are referred to the pre-Cambrian. He concludes:

1. The older rocks of the Piedmont consist of both sedimentary and igneous types, which since their formation have been more or less metamorphosed.

2. The metamorphosed sediments include banded micaceous and hornblende gneisses of pre-Cambrian age; a more or less intermittent, thin-bedded, generally tourmaline-bearing quartzite of Cambrian age; an intermittent dolomitic marble or magnesian limestone of Cambro-Ordovician age; and a series of mica-schists and the gneisses of Ordovician age. Above these occur a somewhat intermittent, poorly developed quartzitic conglomerate and the Peach Bottom slates.

3. The igneous rocks consist of an immense gabbro sheet, intruded by numerous large bodies of granite and meta-rhyolite, and accompanied by numerous more basic serpentinized bodies. These various masses represent stages in a single extended period of igneous activity.

4. The time when this activity took place was later than early Silurian and earlier than the late Carboniferous; probably in the early part of this interval.

5. The chief structural features of the region are the metamorphism and constant schistosity, and the broader folding of the different rocks.

6. The metamorphism of the rocks, especially of the banded gneisses, probably commenced prior to the intrusion of the gabbro and granite, and was accentuated by them in the eastern portion of the Plateau.

7. The folding of the region is of the Appalachian type, the rocks occurring in several long, more or less parallel, folds, with few faults and but occasional overturned folds.

8. The eastern and western areas are probably of the same age; differences in metamorphism being due to the large bodies of deep-seated intrusives on the east and the smaller bodies of surface volcanics on the west.

9. The sequence found in Maryland may be recognized from Washington to Trenton and in the region north of New York.

A. A. JULIEN. "Genesis of the Amphibole Schists and Serpentines of Manhattan Island, New York." *Bulletin of the Geological Society of America*, Vol. XIV (1903), pp. 421–94.

Julien discusses the genesis of the amphibole schists and serpentines of Manhattan Island, New York (including the Manhattan and Fordham series), and concludes that they are derived from the alteration of basic igneous rocks. This appears established by the correspondence of the hornblende rock in chemical composition to basic igneous rocks and to hornblende schists of that derivation, by identity of its hornblende constituent with that found in volcanic rocks, by the discovery of many apophyses, isolated or in groups, and other structural features, and by the survival of products of contact alteration. The absence of pyroxene and of dike-like intersection of the associated gneisses may be well explained by the extent of shearing and metamorphism.

T. L. WATSON. "Granites of North Carolina." *Journal of Geology*, Vol. XII (1904), pp. 373–407.

Watson maps and petrographically describes the granites of North Carolina.

WILLIAM H. HOBBS. "The Geological Structure of the Southwestern New England Region." *American Journal of Science*, Vol. XV (1903), pp. 437–49.

"Lineaments of the Atlantic Border Region." *Bulletin of the Geological Society of America*, Vol. XV (1904), pp. 483–506.

Hobbs concludes that the crystalline rocks of southwestern New England have been deformed by a system of joints and faults of post-Newark age superimposed upon older structures which appear to be largely due to folding. He concludes further, that the crystalline and later rocks of the Atlantic coast in general show lineaments suggesting regular sets of faults in a nearly meridional series and in two other series which make nearly equal angles with this direction. Other lineaments which more closely approach the equatorial direction vary more from one another, and are both numerically less important and less strikingly brought out.

CHARLES R. VAN HISE. "A Treatise on Metamorphism." *Monograph No. 47*, U. S. Geological Survey, 1904. Pp. 1,286.

Van Hise discusses principles of metamorphism applicable to the study of pre-Cambrian and other metamorphic rocks, and cites many illustrative pre-Cambrian rocks and localities.

W. S. BAYLEY. "The Menominee Iron-Bearing District of Michigan." *Monograph No. 46*, U. S. Geological Survey, 1904. Pp. 513.

CHARLES R. VAN HISE AND W. S. BAYLEY. "The Menominee Special Folio." *Geologic Atlas of the United States*, Folio No. 62, U. S. Geological Survey, 1900.

Journal of Geology, Vol. IX (1901), pp. 451–54.

Bayley and Van Hise describe and map the geology of the Menominee iron-bearing district of Michigan. The essential facts are covered in a preliminary report summarized in a former number of this *Journal*. An additional feature of interest is the discovery of minute granules in the Menominee iron formation similar to the greenalite granules from which the Mesabi ores are largely derived.

Comment.—The age of the Quinnesec schists cannot be regarded as finally settled.

They have been assigned to the Archean because of lithological characteristics, but the contact between them and the Lower Huronian sediments to the north is covered by Upper Huronian and glacial deposits. Greenstones to the west on the Brulé River, similar to the Quinnesec schists, are closely infolded, and perhaps interbedded with slates which have been mapped as Upper Huronian. In view of these facts, it is quite possible that the Quinnesec schists are as late as Upper Huronian, thus corresponding to the Clarksburg volcanics of the Marquette district.

On the basis of the triple division of the Huronian series which has been adopted since the discovery of an unconformity in the previously called Lower Huronian series of the Marquette district, the Upper and Lower Huronian series are represented in the Menominee district, and not the Middle Huronian, unless we except certain pebbles taken to represent the Negaunee formation. It is still possible that the iron formation mapped as Upper Huronian may in reality be Middle Huronian, as suggested by partly hypothetical structural connection with formations mapped as Middle Huronian to the north, but in this case there should be found an unconformity between the iron formation and the slates above, and none has yet been found, although the field has been most carefully examined.

S. WEIDMAN. "The Baraboo Iron-Bearing District of Wisconsin." *Bulletin XIII*, Wisconsin Geological and Natural History Survey, 1904. Pp. 190, with map.

Weidman describes and maps the Baraboo quartzite region of south-central Wisconsin.

A pre-Cambrian quartzite formation, having an estimated thickness of 3,000–5,000 feet, forms an east-and-west synclinorium about 20 miles long, and ranging in width from 2 miles on the east to 10 or 12 miles on the west, resting on a basement of igneous rock consisting of granite, rhyolite, and diorite, in isolated and widely separated areas both north and south of the quartzite synclinorium. The largest area is one of rhyolite near the lower narrows of the Baraboo. The upturned north and south edges of the quartzite form respectively the North and South Ranges of the Baraboo Bluffs, standing 700–800 feet above the surrounding country and above the intervening valley. In the valley are pre-Cambrian formations younger than, and conformable with, the quartzite. These are the Seeley slate, having an estimated thickness of 500–800 feet, and above this the Freedom formation, mainly dolomite, having a thickness estimated to be at least 800 feet, bearing iron-ore deposits in its lower horizon.

Flat-lying Paleozoic sediments, unconformably overlying the pre-Cambrian rocks, occupy the surrounding area and partly fill the valley. The Paleozoic rocks range from Upper Cambrian, Potsdam, in the valley bottom to the Lower Silurian, Trenton, on the upper portions of the quartzite ranges. The Potsdam sandstone has a thickness ranging from a few feet to a maximum of about 570 feet in the valley. Glacial drift is abundant over the quartzite ranges and in the valley in the eastern half of the district, but occurs only in the valleys in the western half.

The iron ore is mainly a Bessemer hematite with soft and earthy, hard and black, and banded siliceous phases. A very small amount of hydrated hematite or limonite is also present. The rocks immediately associated with the ore and into which the ore grades are dolomite, cherty ferruginous dolomite, ferruginous chert, ferruginous slate, and ferruginous dolomite slate—in fact, all possible graduations and mixtures of the minerals dolomite, hematite, quartz, and such argillaceous minerals as kaolin and chlorite. In the ferruginous rocks associated with the iron ore the iron occurs as hematite and also in the form of carbonate, isomorphous with carbonate of calcium, magnesium, and manganese in the form of ferro-dolomite and manganic-ferro-dolomite, and as silicates combined with various proportions of alumina, lime, magnesia, and manganese, as chlorite and mica, and also very probably to a small extent as iron phosphate.

It is believed that the iron ore of the Baraboo district was originally a deposit of ferric hydrate, or limonite, formed in comparatively stagnant, shallow water, under conditions similar to those existing where bog or lake ores are being formed today, and that through subsequent changes, long after the iron was deposited as limonite, while the formation was deeply buried below the surface and subjected to heat and pressure, the original limonite became to a large extent dehydrated and changed to hematite.

Comment.—The theory of the origin of the ores here proposed differs from that worked out for the Lake Superior region. It is believed that insufficient data are yet at hand to warrant a positive statement concerning the origin of the ores, and that until such data are at hand the theory worked out for the Lake Superior region in general, with which the Baraboo district has many points in common, should be assumed to apply to the Baraboo district. A detailed analysis and criticism of Dr. Weidman's argument is published by the reviewer in Vol. XXXV of the *Transactions of the American Institute of Mining Engineers.*

Drilling in the east-central portion of the valley has recently seemed to show the presence of an Upper Huronian quartzite series unconformably overlying the series described by Weidman, but this is yet to be confirmed.

JAMES M. BELL. "Economic Resources of Moose River Basin." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 135–97.

Bell describes the Laurentian and Huronian rocks of the Moose River basin. The former include acid igneous rocks, and the latter, greenstones, green schists, and certain sediments, with doubtful relations to each other and to the Laurentian.

GEORGE F. KAY. "The Abitibi Region." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 104–34.

Kay describes the rocks seen on a trip from Mattagami to Nighthawk and the area west of Lake Abitibi. No attempt is made to describe their stratigraphy and structure.

A. P. COLEMAN. "The Classification of the Archean." *Proceedings and Transactions of the Royal Society of Canada*, Vol. VIII (2d Ser., 1902), Sec. IV, pp. 135–48.

Coleman discusses the classification of the Archean (pre-Cambrian of the U. S. Geological Survey), and proposes the following:

Middle and Lower Cambrian ? or Algonkian ?	Keweenawan (Unconformity) Animikie

EPARCHEAN INTERVAL

- Archean
  - Laurentian = Fundamental gneiss, etc.
  - (Eruptive unconformity)
  - Huronian
    - Upper Huronian or Huronian proper
    - (Unconformity)
    - Lower Huronian or Keewatin
      - Schistose pyroclastics and eruptives
      - Coutchiching

(Upper Huronian to Coutchiching) = Grenvile and Hastings series

A. B. Willmott. "The Contact of the Archean and Post-Archean in the Region of the Great Lakes." *Journal of Geology*, Vol. XII (1904), pp. 40–42.

Willmott finds a step-like regularity in the contact of the Archean (pre-Cambrian of the U. S. Geological Survey) and the post-Archean rocks in the region of the Great Lakes, and believes it to be explained by a dislocation in the Archean before the deposition of the post-Archean sediments.

A. P. Coleman. "The Northern Nickel Range." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 192–224. With geological map.

Coleman describes and maps the northern nickel range of the Sudbury district of Ontario. It constitutes the northern upturned edge of a synclinal of eruptive rocks resting on Laurentian granites and gneisses, and including within it a little-disturbed basin of Cambrian or Upper Huronian sediments and tuffs. The contact with the rocks both above and below are eruptive. The eruptive grades from acid in its inner margin to basic in its outer or lower margin. The nickel is concentrated or upper in its basic edge.

A. P. Low. "Report on an Exploration of the East Coast of Hudson Bay." *Annual Report of the Geological Survey of Canada*, Vol. XIII (New Ser., 1900), Part D. With geological map.

Low describes and maps the geology of the east coast of Hudson Bay. With the exception of the rocks which form the chains of islands along shore between Portland promontory and Cape Jones, and also a narrow margin on part of the coast in the same region, they have all been cut by granite which has not only intimately penetrated them, but by its heat and pressure has so changed them to crystalline schists and gneisses that only in a few places can any trace of an original sedimentary origin be found. The unaltered sedimentary rocks with their associated sheets of trap and diabase bear a remarkably close resemblance not only to the so-called Cambrian rocks of other parts of the Labrador peninsula, but also to the iron-bearing rocks of the southern shores of Lake Superior and the Animikie and Nipigon rocks to the north of Lake Superior. In all likelihood they are of pre-Cambrian age and, in the opinion of the writer, are the oldest known sedimentary rocks of Canada. Notwithstanding this opinion, they will continue to be classed as Cambrian in order to correspond with the areas of similar rocks of Labrador which have already been so classed. The series comprises from the base up: Coarse arkose, banded arkose, sandstone and graywacke, chert, impregnated with oxide of iron and red jasper, cherty carbonate, carbonaceous shales, sandstone. Included in this series are sheets or laccolites of dark-green trap. This rock also flowed out to the surface. The basement rock from which this series is derived has not been recognized in the region under discussion.

J. E. Todd. "The Newly Discovered Rock at Sioux Falls, South Dakota." *American Geologist*, Vol. XXXIII (1904), pp. 35–39.

Todd reports the presence of gabbro within one-half mile of the Sioux quartzite of South Dakota. He believes it to be intrusive into the quartzite, although no contacts are found.

E. R. Buckley and H. A. Buehler. "Quarrying Industry of Missouri." *Missouri Bureau of Geology and Mines*, Vol. II (2d Ser., 1904). With geological map.

Buckley and Buehler map and describe the pre-Cambrian granites of southeastern Missouri in connection with a report on the building-stones of the state.

J. D. Irving. "Economic Resources of the Northern Black Hills." Part I, "General Geology" by T. A. Jaggar, Jr., *Professional Paper No. 26*, U. S. Geological Survey, 1904, pp. 13–41. With geological map.

Jaggar describes the general geology of the Black Hills and gives particular attention to the dynamics of the later intrusions of the northern part of the uplift. The southern portion was occupied by massive ancient pegmatite granites, themselves pre-Cambrian intrusives in Algonkian strata. Probably they acted as a rigid cementing and hardening agent to prevent fracturing in the southern schists; the northern, less indurated phyllites cracked and faulted more readily to permit the younger intrusives to rise from the depths. The northern exposed schist areas contain many hundred dikes and some stocks; these must have induced movements of horizontal extension in the schist, and such movements are attested by bedding-plane faults at the base of the Cambrian. The dikes have a common trend and dip parallel with schistosity. The dip gave them tendency to spread in the Cambrian in one direction more readily than in another.

Two illustrative sections are given. North of the Homestake mine on Deadwood Creek, near Central, Algonkian rocks appear as follows from west to east: graphitic schist, mica-schist, heavy ferruginous black schist with quartzite bands cut by irregular white quartz bodies which form a distinct zone, ferruginous schist, mica-schist, all dipping toward the east; mica-schist with thin sandstone stringers, dipping to the west. This sudden change of dip just opposite the De Smit and Homestake ore bodies is significant, and suggests that perhaps the great ore body may fill a synclinal saddle pitching to the southeast.

A section from north-northwest to south-southeast along the ridge northeast of the Clover Leaf mine is: garnetiferous mica-schist, graphitic schist, ferruginous quartzite, amphibolite, mica-schist, white quartz, mica-schist, amphibolite, quartzite, and amphibolite.

Joseph A. Taff. "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma." *Professional Paper No. 31*, U. S. Geological Survey, 1904. With geological map. See also *Geologic Atlas of the United States*, Folio No. 98, U. S. Geological Survey, 1903.

Taff describes and maps the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. In the Arbuckle Mountains, unconformably below middle-Cambrian sediments, are granite, granite-porphyry, and aporhyolite containing basic dikes. The granite (Tishimingo) occurs in the eastern part of the mountains in a rudely triangular area twenty miles in length and ten miles wide in its widest part, near the western end. The porphyry and aporhyolite areas occur in the Arbuckle Mountains proper in the western end of the uplift.

In the Wichita Mountains pre-Cambrian granite, granite-porphyry, and gabbro cut by diabase form a considerable part of the mountains. Granite is the principal mountain-making rock in the Wichita region. Its area is greater than that of all the other igneous rocks combined, and is about equal to that of the others and the older Paleozoic sediments. It makes all of the high land of the Wichita, Quana, Devil's Canyon, and Headquarters Mountains, and a large part of the Raggedy group.

The gabbro is exposed for the most part in the valleys or on the plains which surround the mountains. The granite porphyry comprises practically all of the Carlton Mountains, the igneous mass lying between the limestone hills in the vicinity of Blue Canyon, north of Mount Scott, and some hills near the northwest end of the limestone areas east of Rainy Mountain Mission.

ERNEST HOWE. "An Occurrence of Greenstone Schists in the San Juan Mountains, Colorado." *Journal of Geology*, Vol. XII (1904), pp. 501–9.

Howe describes green schists in the pre-Cambrian of the Needle Mountains in San Juan and La Plata Counties of southwestern Colorado. They comprise massive and schistose, granular and porphyritic meta-gabbro, and areas of mashed granitic intrusives and other schistose rocks, presumably altered quartzites. No evidence of surface origin is noted in the igneous rocks. The greenstones antedate the Algonkian sediments to the north, as shown by the pebbles contained in the Algonkian conglomerate, and have an older aspect than the other rocks of the neighboring areas. They are therefore assigned to the early Algonkian. Attention is called to their similarity to the greenstones of the Menominee and Marquette districts of Michigan and to rocks near Salida, Colo.

ARTHUR C. SPENCER. "The Copper Deposits of the Encampment District, Wyoming." *Professional Paper No. 25*, U. S. Geological Survey, 1904.

Spencer discusses the geology of the Encampment district of Wyoming. Pre-Cambrian rocks form the main mass of the Sierra Madre Mountains with Mesozoic beds dipping away from them. They comprise sedimentary and igneous rocks. The sedimentary rocks are from the base up: hornblende schists, derived from surface volcanic rocks, interbedded with thin but persistent beds of sandy shale and impure limestone, limestone, quartzite, slate, and conglomerate. In the Encampment area the quartzite and slate formation is more in evidence than any other of the bedded rocks, but all occur in a limited area having the form of a narrow triangle, with its apex on the Encampment River about 5 miles south of Encampment, and its base, about 7 miles wide, in the foothills on the west side of the range. The belt of quartzites and associated strata is exposed for about 20 miles, but on the west their extent is not known, since they are overlapped by younger formations. The rocks within the sedimentary belt strike in general nearly east and west, and they seem at first sight to have an enormous thickness, since they dip almost invariably toward the south. An examination shows the sediments to be in an east-and-west synclinorium with axial planes of both major and minor folds dipping to the south. Strike faults and transverse faults are common.

A complex of igneous rocks comprising granite, quartz diorite, and gabbro, occur both to the north and south of the synclinorium, and the gabbro occurs also within the synclinorium. The relations of the granite and quartz-diorite to the sediments are not definitely known, but their distribution is such as to suggest that they are intrusive into the hornblende schists at the base of the sedimentary series, and that with the hornblende schists they form the basement upon which the sedimentary rocks were deposited. The gabbro is intrusive into the sediments.

Comment.—The description indicates that the basal rock of this region, the hornblende schist, is similar in essential features to the schistose volcanic rocks with associated sediments making up the Keewatin series, the lowest in the Lake Superior region.

WALDEMAR LINDGREN. "A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho." *Professional Paper No. 27,* U. S. Geological Survey, 1904. With geological map.

Lindgren makes a geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho. Practically the entire area of the Bitterroot and Clearwater Mountains is occupied by granite with some gneiss. West of the Clearwater River, and only imperfectly exposed below the lava, is an extensive sedimentary area adjoining this granite; smaller sedimentary areas are exposed on Lolo Fork and on the head of the South Fork of Bitterroot River. In no place have well-defined fossils been found, but there is some foundation for the belief that the two last-named areas on the east side are very old, possibly pre-Cambrian, while the western area probably includes Triassic, Carboniferous, and possibly still older sediments. The granite constitutes a great bathylith whose age is not certain, but probably of post-Triassic age. The gneisses include older gneisses of the Clearwater Mountains, probably of pre-Cambrian age, and later gneisses resulting from the deformation of the granite occurring principally on the eastern side of the Bitterroot Mountains. On the accompanying map all are colored together as pre-Tertiary.

F. L. RANSOME. "The Geology and Ore Deposits of the Bisbee Quadrangle" *Professional Paper No. 21,* U. S. Geological Survey, 1904. "Geology of the Globe Copper District, Arizona." *Professional Paper No. 12,* U. S. Geological Survey, 1903. "Description of the Globe Quadrangle." *Geologic Atlas of the United States,* Folio No. 111, 1904. "Description of the Bisbee Quadrangle." *Geologic Atlas of the United States,* Folio No. 112, 1904.

Ransome describes in the Pinal Mountains of the Globe district of Arizona mica-schists with occasional bands of amphibole-schists which he calls the Pinal schists. These are intruded by quartz, mica-diorite, and granite. The schists and intrusives are unconformably below a non-fossiliferous series supposedly of pre-Cambrian age. The schists are believed to represent metamorphosed arkoses or grits. They are probably to be correlated with the Vishnu series of the Grand Canyon, provisionally called Algonkian by Walcott. In the absence of other criteria the Pinal schists are referred to the pre-Cambrian.

In the Mule Mountains of the Bisbee district, 90 miles to the south, are similar schists, also called Pinal schists.[1] Evidence of sedimentary origin is less satisfactory then in the Globe district and pre-Cambrian granitic intrusives are absent. Here also they are referred to the pre-Cambrian.

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[1] The Pinal schists probably correspond to the Arizonian schists of Blake, *Engineering and Mining Journal,* Vol. XXXV (1883), pp. 238, 239.

A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho. By WALDEMAR LINDGREN. (Professional Paper No. 27, U. S. Geological Survey, 1904.) Pp. 122, XV plates, and 8 figures.

The area embraced in Mr. Lindgren's reconnaissance contains about 12,000 square miles, of which 6,000 are included in the Bitterroot Forest Reserve. It lies between the 113th and 117th meridians and between the parallels of 45° and 47°. Roughly speaking, one-fifth of the area is in western Montana, and the remainder extends across Idaho to the Washington boundary. The whole area lies in the watershed of the Columbia River. The Snake River is the largest stream which has its source in the region.

From east to west the characteristic topographic features are, in order, the following: (1) the Bitterroot Valley, (2) the Bitterroot Range, attaining an elevation of some 11,000 feet, and merging westward into (3) the great, dissected, high plateau of the Clearwater Mountains, and still farther westward (4) the Columbia River lava plateau, to which the Clearwater plateau descends rather abruptly. In this great plateau such streams as the Salmon, Clearwater, and Snake are deeply incised.

The geology is fairly simple, according to Mr. Lindgren's statement. The main Bitterroot Range is a quartz-monzonite mass, the northward continuation of the central Idaho bathylith. This is an intrusive mass of probably post-Carboniferous age.

The eastern slope of the range is a fault plane that dips about 18° to the east. The rocks of the fault zone are both gneissic and schistose. In addition to these igneous and metamorphic rocks, there are areas of sedimentaries, quartzites, and slates, supposed to be of Cambrian or pre-Cambrian age. Into this series the granite is found to have quite extensively intruded. Other areas of sedimentaries, supposed extensions of the Seven Devils' series, are presumably Mesozoic. The granite of the Clearwater Mountains is intrusive into these in many places. These sedimentaries are confined, as a rule, to the flanks of the central granite mass, which is the prevailing rock in both the Bitterroot and Clearwater Mountains.

The Columbia River plateau is formed of essentially horizontal lava flows, in which are intercalated shallow water deposits which contain Miocene plant remains. In the discussion of the lava flows, Mr. Lindgren mentions some interesting facts that go to show the existence of differential uplifts and subsidence in the plateau region.

Glaciation, whose effects are to be seen down to about 4,000 feet in some places, is also given some considerable mention. This must have been one of the most extensively glaciated regions in the whole Cordilleran system

From an economic standpoint this district has not yet proved a dangerous rival of its sister regions farther north in the Cœur d'Alène Mountains. The valuable minerals are chiefly confined to the western slope of the Clearwater Mountains. Gold, in fissure veins and gravels, is the most important mineral. Some few prospects of copper, silver, and silver-lead ores have been worked. Elk City is the chief center of the mining industry of the region.

Some fair coal of a lignitic character, and of probably Tertiary age, has been discovered, but may not prove profitable on account of the thinness of the beds. This lignite is found in two rather remarkable associations. In one case the lignite is interbedded with rhyolitic flows, and in the other in a series of sediments intercalated in the Columbia River basaltic flows.

It is evident that this region, because of its great extent and rugged character could merely be skimmed over in a reconnaissance, and, doubtless, much of interest yet awaits the scientist and practical miner.

W. D. S.

"A New Marine Reptile from The Trias of California," *University of California Publications*, Vol. III, (1904), pp. 419–21.

Among the recent discoveries in vertebrate paleontology, none is of greater interest than that by Dr. Merriam of a new order of marine reptiles to which he has given the name Thalattosauria, from the typical genus *Thalattosaurus* Merriam, from the Upper Trias of California. This new order presents many of the peculiar aquatic adaptations of other well-known, marine saurians, though differing markedly in structure. The skull is elongate; the vomers (prevomers) and pterygoids are covered with flat, button-like teeth, primitive characters lost in all other marine reptiles, save the pterygoid teeth of the mosasaurs; the dorsal ribs are single-headed; and the bones of the limbs are short, though the pelvis is robust, indicating, either incomplete aquatic adaptation, or a short non-propelling tail. The order is related, the author thinks, more to the early rhynchocephaloid reptiles than to the ichthyosaurs. Further information concerning these strange reptiles will be awaited with interest.

S. W. W.

"Neue Zeuglodonten aus dem unteren Mitteleocen vom Mokattam bei Cairo," *Geologisch-Paläontologische Abhandlungen*, Vol. VI (1904), p. 199.

A startling suggestion as to the origin of the Zeuglodon "whales" is that given by Professor Fraas in a recent paper on the Zeuglodonts from the Eocene of Africa: "Systematisch betrachtet trenne ich die Archaeoceti vollständig von den Cetaceen und schliesse sie als Untergruppe an die Creodontier an, während die übrigen Walthiere nach wie vor eine selbständige Gruppe bilden, die so lange beliebig in der Systematik eingeschaltet werden kann, bis wir deren Stammesgeschichte kennen;" and his conclusion that these animals belong among the early carnivora seems well substantiated by him.

S. W. W.

"*Teleorrhinus browni*—a New Teleosaur in the Fort Benton," *Bulletin of the American Museum of Natural History*, Vol. XX (1904), p. 239.

Another discovery of much interest is that of a true teleosaur crocodile from the Benton Cretaceous, by Professor Osborn. That the teleosaurs should occur in America is perhaps not so remarkable as their occurrence in the Upper Cretaceous, all the forms hitherto known being from the Jurassic and Wealden of Europe. The specimen upon which Professor Osborn bases his new genus *Teleorrhinus* has a skull one meter in length, and typical teleosaurian vetebræ, the latest biconcave crocodile vertebræ known.

S. W. W.

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JOURNAL OF GEOLOGY

APRIL–MAY, 1905

THE ZUNI SALT LAKE[1]

N. H. DARTON
U. S. Geological Survey

Forty-two miles south-by-east from the Pueblo of Zuñi there is a small salt lake, affording a local supply of salt for the Indians and others. It occupies a portion of the bottom of a remarkable steep-sided, circular depression about a mile in diameter, near the center of which rise two fresh volcanic cinder cones. The depression appears not to be a volcanic crater, but has walls of Cretaceous sandstone capped by a lava sheet and deposits of volcanic ejecta. One of the cinder cones rising near the center of the depression has a deep crater containing a pool of salt water at the lake-level.

This salt lake has been known to the Zuñi Indians for a very long period, and for a half-century or more to Mexicans and a few travelers. The first account of its geologic relations was a brief note by E. E. Howell, of the Wheeler Survey,[2] who visited the locality in 1873. This observer noted the sandstone walls capped in part by lava flows, and the cinder cone with deep crater, but offered no suggestion as to their origin. Professor C. L. Herrick visited the salt lake in December, 1899, and afforded some further descriptive details.[3]

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[1] Read to the Geological Society of America, December 28, 1904, and published by permission of the director of the U. S. Geological Survey.

[2] George M. Wheeler, "U. S. Geographical Surveys West of 100th Meridian," *Reports*, Vol. III, pp. 538, 539.

[3] *American Geologist*, Vol. XXV.

He suggested that the depression might be due to the solution of the salt in underlying strata, causing the depressed area to subside.

The lake is shallow, and its waters are saturated with common salt, containing 26 per cent. in December, 1899, according to Professor C. L. Herrick. As the natural evaporation progresses, salt is constantly deposited, and doubtless a large amount has accumulated. On the north shore of the lake there is a small settlement of Mexicans, who gather the salt for shipment, and many persons make special trips to the lake, often from long distances, to collect a load of the salt. The quality is excellent and the supply large. Only the crudest methods are employed for gathering the freshly deposited salt in the shallow waters near the north shore of the lake.

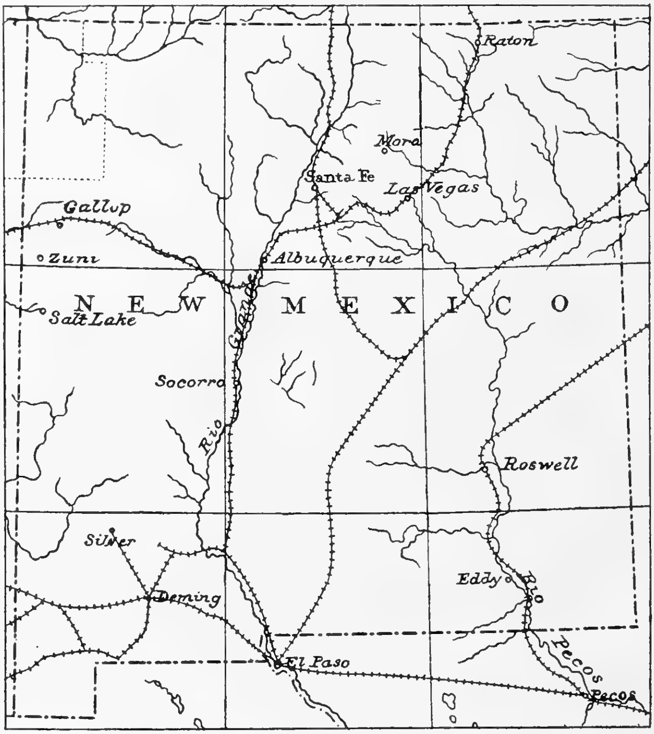

FIG. 1.—Map of New Mexico, showing the location of the salt lake south of Zuñi.

The Indians have utilized this source of salt for many centuries and regard the lake with great veneration.

There is a large amount of salt in the lake and springs. An average of about three tons a day is produced by very crude methods; it is valued at from $2 to $2.50 a ton. This industry sustains the small settlement of Mexicans.

The origin of the salt is believed to be in springs which rise under the water near the south end of the lake. If the water from these is not saturated with salt, the percentage increases by the great evaporation in this arid region. Undoubtedly it is derived from the underlying Red Beds, which have the relations shown in the cross-sections. These Red Beds outcrop at no great distance, and yield salt springs at some points. A small amount of fresh water flows into the lake, partly from a small spring on the east shore, which flows constantly, and partly from scanty rains falling directly into the depression, or running into it from a small drainage area lying mainly on the high slopes south. Although no deep borings have been made, the depression appears to contain a salt deposit of considerable thickness, mixed with small amounts of mud washed from the surrounding slopes, and dust carried by the wind. Apparently the lake occupied the entire floor of the depression at one time, but, by evaporation and the deposition of mud, it has greatly diminished in size; doubtless the lake has been crowded over to the north side of the depression because the greater amount of detritus is deposited on the south side.

In the map and cross-sections of Fig. 2 are shown the principal features of the salt lake depression, and the photographs reproduced in Figs. 3–5 show the lake from three points of view.

The depression is in a plain sloping gently northward on the south side of the Carrizo Valley. A short distance to the south rises a line of cliffs of Cretaceous sandstones, in part capped by lava, while there is a corresponding ridge several miles north on the opposite side of the valley. The floor of the valley is Cretaceous sandstone, overlain in places by lava flows, one of which forms part of the upper wall of the northern, eastern, and southeastern sides of the depression. All about the margin of the depression there is a widespread mantle of fragmental material, mostly volcanic, which thickens toward

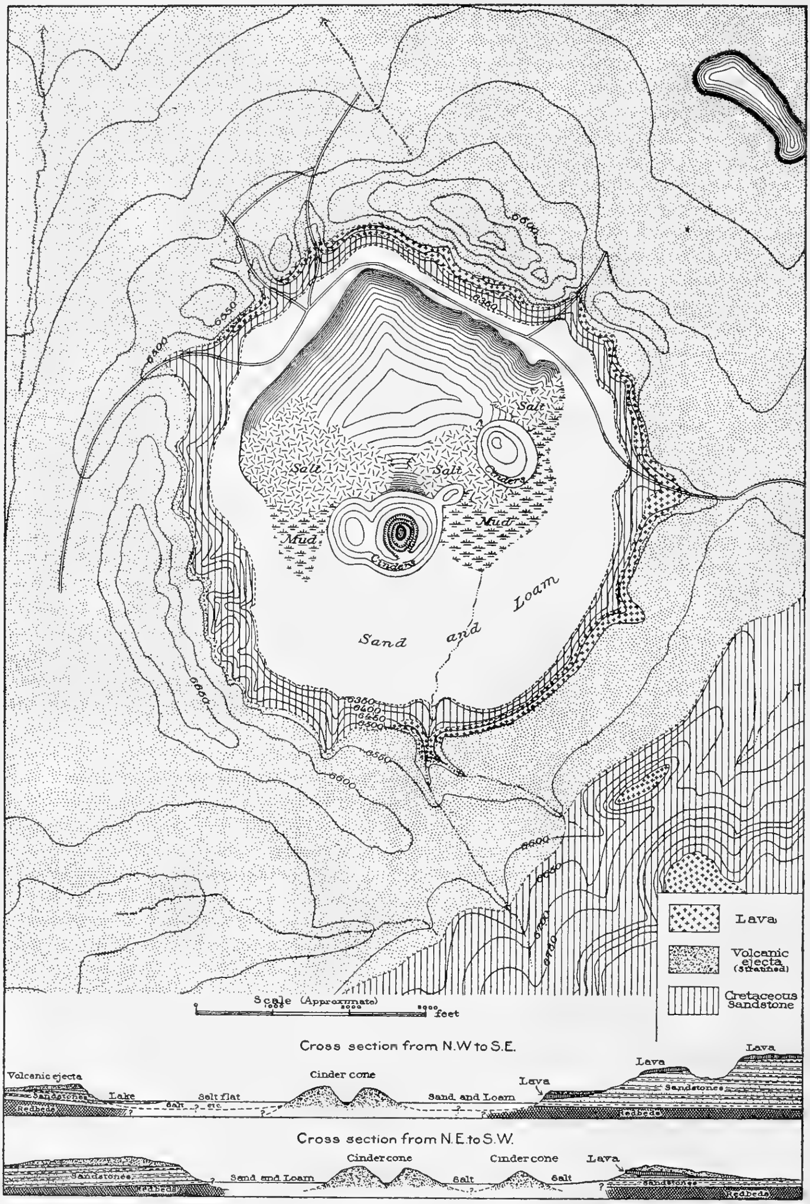

FIG. 2.—Sketch map and sections of Zuñi salt lake, New Mexico, by N. H. Darton. Contour interval 50 feet.

the rim. It attains a thickness of over 100 feet on the north and southwest portions of the rim, where it rises in a ridge of considerable prominence. The material is mostly stratified, fine-grained, and in part cross-bedded. It consists mainly of scoria, but includes fragments of various kinds of sedimentary rocks, including Carboniferous (Aubrey) limestones with characteristic fossils.[1]

The view from the rim of the depression is impressive. The ground sinks for 150 feet or more in a circular area a mile in diameter, with flat bottom in part occupied by the lake and in part by the glistening salt and mud flats. The two volcanic cones in the center of the basin are prominent features, rising steeply to an elevation of nearly 150 feet above the lake. The larger cone has a deep crater in its summit, which contains a circular pool, about 150 feet in diameter, at the lake level. The water of this pool is very salt, but several per cent. less so than that in the main lake. The cone is nearly circular, except on its western side, where it merges into the remains of a slightly older volcanic mass. The second cone is a short distance northeast, rising steeply out of the mud flat at the southeastern margin of the lake. It has no crater, is smaller, and appears to be somewhat older than the other cone. Both cones consist of scoria and other volcanic ejecta, and they are similar to the cones in the numerous lava fields of New Mexico. Walls of Cretaceous sandstone encircle the depression, which to the north, east, and southeast are capped by a sheet of lava from 30 to 50 feet thick. To the west and southwest the sandstone wall rises in cliffs and rocky slopes about 150 feet above the bottom of the depression, and is capped by rolling hills composed of beds of fragmental volcanic materials, while to the north, east, and south it rises from 60 to 70 feet to the base of the lava sheet. The lava sheet which caps the sandstone walls on the southeast, north, and east sides of the depression is an ordinary sheet of "malpais" or black lava, which appears to be older than the cinder cone with the crater in it.

[1] These fossils were determined by Dr. George H. Girty as follows:

Lophophyllum sp.
Productus ivesi.
Productus mexicanus ?
Productus sp.
Bakewellia ? sp.
Laeviadentalium cana.
Phillipsia sp.
Chonetes n. sp.
Productus occidentalis.
Seminula mexicana.
Schizodus sp.
Euomphalus sp.

FIG. 3.—Looking north across Zuñi salt lake, showing large cinder cone with crater. Ridge of scoria in middle-ground, sandstone plateau in distance.

The origin and history of the depression are an interesting problem. From the continuity of its sandstone walls, it clearly is not a portion of an old valley dammed by a lava stream, and it presents none of the ordinary features of a crater. In some respects it is comparable to "Coon Butte," a great depression west of Winslow in eastern Arizona, which, Mr. Gilbert has shown, is due to explosion, but although there is a ring of ejected rocks around the margin of the Zuñi depression, the relative bulk is small and the materials are waterlaid. The most reasonable hypothesis appears to be that the depression is due to the sinking of its bottom, and the fact that there are salt springs and the area is underlain by salt-bearing beds are significant in this connection. It seems possible that a salt bed has been dissolved, possibly by hot water issuing from a volcanic vent, and the depressed area has dropped or faulted several hundred feet. Several instances are known of the development of deep crater-like depressions due to underground solution of salt and gypsum beds, and sinking of overlying strata, notably at the "Salt Lake" near Meade, Kansas, and the "Devil's Hole" near the River Virgin in southwestern Utah. At the Zuñi salt lake, however, volcanic phenomena appear to be connected with the development of the depression, especially the presence of cinder cones in the center and the mantle of stratified ejecta encircling its rim. Probably the lava sheet capping the east rim is older than the depression, and perhaps did not come from the same orifice as the cinder cones. In the plateau region of New Mexico such cones are usually built following an outflow of lava and mark the last stage of the eruption. The cones in the depression appear to be very fresh and recent, and while they may be connected with a lava flow under the floor of the depression, there is no evidence on this point. The following hypothesis as to the origin and history of the Zuñi salt lake depression lacks positive evidence along several lines, but it is the most plausible one suggested.

FIG. 4.—Looking southwest across Zuñi salt lake. Large cinder cone to the right, small cinder cone to the left, rising out of salt fields. South rim of depression in middle-ground, plateau of Cretaceous sandstone in distance.

Originally the area was a plain sloping gently to the Carrizo Creek and on this plain a sheet of lava was ejected, possibly from a vent marked later by the cinder cones in the depression. Following the lava flow there was a great ejection of hot water from a central vent, which dissolved a thick mass of salt, and brought to the surface and spread in all directions a large amount of fine scoria and rock frag-

FIG. 5.—Looking into the crater in the larger cinder cone; showing pool of salt water which is at lake level.

ments, including the fossiliferous limestone. By this means a great, low mound of irregularly stratified material was built, extending from the edge of the depression. Consequent upon this eruption, a circular depressed area, a mile in diameter, subsided into the space made by the solution of salt and in smaller measure by the ejection of various rocks.

A much less probable hypothesis is that not only the lava sheet was extruded, but the sheet of volcanic ejecta was deposited and the cones built up *prior* to the subsidence. If this was the case, there is under the floor of the depression a sheet of lava overlain by a thick mass of volcanic ejecta, faulted down from the level of the lava and ejecta deposits on the rim. After the subsidence a new eruption gave rise to the cinder cones, at least to the one with the crater, for the other cone northeast may represent the stock of an earlier eruption. Water has continued to rise in the bottom of the depression, now only in small volume, but carrying much salt. Probably the lake occupied the entire bottom of the depression at one time, but evaporation and sediments especially those deposited by the torrential water courses on the south side, have evidently diminished the water area.

THE TERTIARY HISTORY OF THE TENNESSEE RIVER

DOUGLAS WILSON JOHNSON
Massachusetts Institute of Technology, Boston

CONTENTS

The following paper was presented as a thesis in a graduate course in physiography at Harvard University in June, 1904, on the basis of a study of previous essays concerning the Tennessee River, a review of the general problem of river-capture, and an examination of the district about Chattanooga during a two-weeks' excursion in April, 1904. The writer is under obligations to Dr. C. Willard Hayes, Mr. Marius R. Campbell, and others, for numerous courtesies extended in connection with both field and office work.

INTRODUCTION

The Tennessee River, after flowing southward through a broadly open, longitudinal valley for some distance in the eastern part of the state of Tennessee, to a point near the city of Chattanooga, turns abruptly westward through a deep, narrow, winding gorge, which is cut in the high, flat-topped mountain known as Walden Ridge; and then bends southward again in a longitudinal valley similar to the one it occupied before entering the gorge. Both of the longitudinal valleys are opened on anticlines of easily eroded limestone, while the transverse gorge cuts across a shallow syncline of resistant sandstone underlain by limestone. The turn of the river from the broad longitudinal valley abruptly westward through a high mountain barrier presents a problem that has interested physiographers for some time.

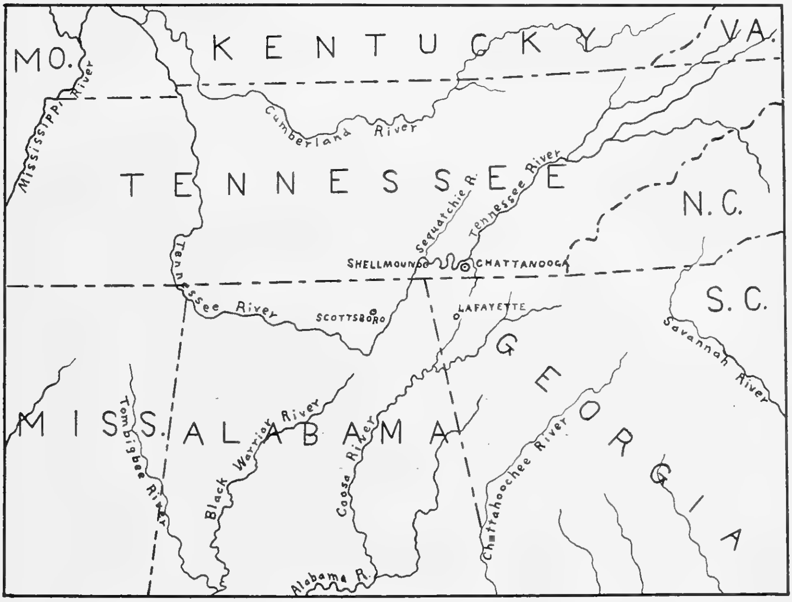

FIG. 1.—Location map.

Two hypotheses have been advanced in explanation of this problem. According to one, the river acquired this course across the mountain some time before the close of the Cretaceous period of baseleveling, probably near the close of that period, when the present flat top of the mountain was continuous with the rest of the Cretaceous peneplain; after later uplift the river continued to flow in that course throughout the Tertiary and Recent cycles, cutting its narrow transverse gorge below the level of the Cretaceous peneplain at the same time that the broad longitudinal valleys in softer rock were being excavated. According to the other hypothesis, throughout the Tertiary cycle the river flowed on southward in the longitudinal valley east of the mountain, and so, by way of the Coosa and Alabama Rivers, into the Gulf of Mexico, continuing in this course until the present broad valleys both north and south from Chattanooga were completed (Fig. 2); then, at the close of the Tertiary cycle, by a process of stream capture, the Tennessee was tapped at a point near Chattanooga by a branch of a stream occupying the valley west of the mountain, and so diverted from the former course to its present course through the gorge (Fig. 3). In recent years this latter theory has been most strongly supported. Certain new evidence, now available, appears to afford good reasons for adopting the first of these theories. It seems desirable, therefore, to review the previous considerations of this problem, weighing carefully the evidence both for and against each theory.

LITERATURE

In 1894 there appeared a paper by C. Willard Hayes and Marius R. Campbell on *The Geomorphology of the Southern Appalachians.* Their essay gives a somewhat detailed account of the physiographic history of the region treated, and devotes a number of pages to the Tennessee drainage problem. The results of their studies led them to believe in the post-Tertiary diversion of the Tennessee from a former southward course; hence they support the second of the above hypotheses with a variety of evidence. This evidence is discussed in detail below.

In a later paper, on *The Physiography of the Chattanooga District,* Dr. C. Willard Hayes discusses the physiographic development of the region more fully than in the former paper by himself and Mr. Campbell. Dr. Hayes traces the past history of stream-adjustments throughout the region in great detail, offering a new interpretation regarding one or two points in the Tennessee problem, but supporting the main conclusion reached in the earlier report.

In 1900 Mr. Charles T. Simpson published a paper on *The Evidence of the Unionidæ Regarding the Former Courses of the Tennessee and Other Southern Rivers.* Working along entirely different lines, Mr. Simpson independently came to the same conclusion as that reached by Messrs. Hayes and Campbell, supporting the second of the two hypotheses already referred to, on biological evidence alone. This came as a most striking confirmation of the work of Hayes and Campbell, and the paper created much interest. The biological evidence is given in greater detail in Mr. Simpson's monograph on *The Naiades, or Pearly Fresh-Water Mussels*. The nature of this argument is considered below.

In 1901 Mr. Charles C. Adams accepted the theory of capture as set forth by Messrs. Hayes and Campbell, explaining upon the basis of this theory certain faunal peculiarities of the region in question. Mr. Adams' paper, entitled *Baseleveling and its Faunal Significance, with Illustrations from the Southeastern United States*, accounts for the differences existing in members of the same group of shells as found in the Tennessee and Alabama systems as being due to a separation of the group into parts by the diversion of the upper Tennessee at Chattanooga, and subsequent evolution of these two groups along somewhat different lines.

A recent number of the *Journal of Geology* contains an article by Mr. C. H. White on "The Appalachian River *versus* a Tertiary Trans-Appalachian River in Eastern Tennessee." Mr. White reviews the evidence presented by Hayes and Campbell, believes that it is not sufficient to prove the diversion of the Tennessee from a former southward course, and concludes in favor of the first of the hypotheses given above—that the river has occupied its present course across the mountain since the Cretaceous cycle. The biological evidence furnished by the Unionidæ is not considered by Mr. White, nor does he present direct evidence in support of his conclusions.

Professors T. C. Chamberlin and R. D. Salisbury, in their recent textbook on *Geology* (Vol. I, pp. 164-68), devote several pages to a presentation of the Tennessee problem as an example of river capture due in part to crustal warping.

THE PROBLEM STATED

Hayes and Campbell have shown that near the close of the Cretaceous period the region about Chattanooga had been reduced to a nearly featureless peneplain over which the streams wandered with sluggish courses. The completion of this peneplain marked the close of the first physiographic cycle of which we have satisfactory evidence in the district. With the elevation of the region above sea-level at the beginning of the Tertiary, the second cycle commenced, during which the streams, flowing over weak rocks, were able to excavate broad valleys nearly to their headwaters, developing in these valleys a second plain of denudation, the Tertiary peneplain, while hard rock regions remained unreduced, preserving the Cretaceous peneplain over broad areas. This Tertiary cycle was followed by depressions and elevations, the final result of which has been to leave the Tertiary peneplain well elevated and to allow the streams to cut their valleys some distance below its level. The elevations and depressions were accompanied by distinct warping, and the warping is correlated with certain drainage modifications (1894).

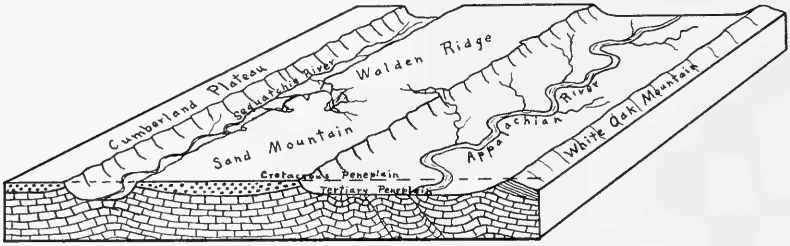

FIG. 2.—Supposed former course of Tennessee (as Appalachian).

Dr. Hayes, in his report on the physiography of the Chattanooga district, gives specific names to the different peneplains, the Cretaceous peneplain being known as the Cumberland, the Tertiary as the Highland Rim, and a still later level, near the present beds of the streams, as the Coosa peneplain. We are not here concerned with the more exact ages ascribed to the several peneplains, nor with the last formed of the three, the Coosa. And since we are dealing with a particular problem, which is more fully discussed in the earlier paper by Hayes and Campbell, we will, for sake of convenience, employ the more general terms used in that essay.

In the accompanying figures (Figs. 2 and 3) the flat top of Walden Ridge, continued southward as Sand Mountain, represents a remnant of the old Cretaceous peneplain. In the broad valleys on either side of this mountain was developed the Tertiary peneplain, remnants of which are still distinctly visible in places, although post-Tertiary erosion has destroyed much of its surface. Fig. 2 shows the supposed former course of the Tennessee as given by those who support the theory of capture. According to this theory, a great river, called the Appalachian by Hayes and Campbell, flowed southward past Chattanooga, across what is now the low divide near Lafayette, on south through this valley to the Coosa River, and thence by way of the Alabama River to the Gulf. In the Sequatchie valley, west of Walden Ridge, a parallel, southward-flowing, subsequent stream, the Sequatchie River, is believed to have occupied a level 100 feet lower than its neighbor to the east, thus having some advantage over the latter. It is conceived that near the close of the Tertiary period a branch of the Sequatchie worked headward through the ridge, finally tapping the Appalachian River at a point near the present site of Chattanooga, and diverted its waters westward down through the gorge to the lower level of the Sequatchie valley, thus giving birth to the present Tennessee River. The broad valley southward from Chattanooga, being thus deserted by the upper Appalachian River, was left to the occupancy of the shrunken lower portion of that beheaded stream, and a small tributary of the new Tennessee River (Chicamauga Creek and its branches) succeeded in pushing the low divide which was first established at the point of capture southward along this valley nearly to Lafayette.

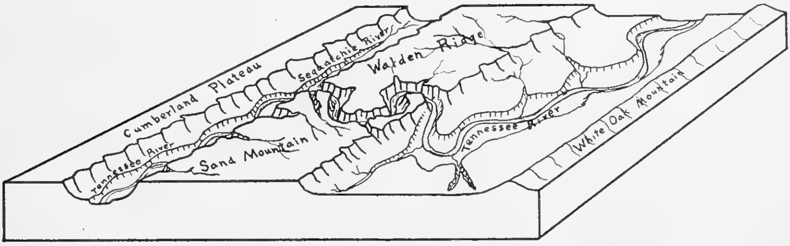

FIG. 3.—Present course of Tennessee River.

Opposed to this theory, which has as its essential feature a grand example of river-capture, is the conception that since the close of the Cretaceous period, at least, the drainage relations in this region have been essentially as they now are; that the present valleys were carved by the streams which now occupy them; and that, so far as the time element is concerned, all of these valleys are of practically the same age, no recent capture having taken place.

Previously to the appearance of Mr. White's paper, above referred to, and before I was aware that he was interested in the Tennessee problem, I became convinced that the evidence presented by Messrs. Hayes and Campbell, and by Mr. Simpson, while very suggestive, was not conclusive. Being at the time interested in the study of river-capture in general, I was in hopes that an examination of the Chattanooga district with this particular drainage problem in mind might result in securing certain evidence which would throw additional light on the question. Accordingly, in April, 1904, the region was visited, and a brief study made of the winding gorge; the river above and below the point of supposed capture; the divide between the Tennessee and Coosa drainage south of Chattanooga, and the small streams flowing north and south from this divide; the Sequatchie River in the valley west of the mountain, a branch of which is supposed to have effected the capture; and the valley southwest of Scottsboro, Ala., which has been contrasted with the gorge of the Tennessee. Certain facts were noted which seemed to indicate that the Tennessee River has occupied its present course since the Cretaceous period of baseleveling, instead of having been diverted westward by a comparatively recent capture; and which seemed to explain satisfactorily the peculiar features of the gorge on the basis of this hypothesis. Since this evidence would lead to a conclusion so radically different from that reached by former students of the problem, it is desirable carefully to consider both lines of evidence—that in favor of the theory of capture, as well as that in favor of the alternative theory.

EVIDENCE IN FAVOR OF THE THEORY OF CAPTURE

Hayes and Campbell base their conclusions, that the southward-flowing Appalachian River was captured near the site of Chattanooga by a branch of the Sequatchie River, upon the three following lines of evidence: (1) the character of the divide between the Tennessee and Coosa-Alabama drainage basins; (2) a comparison of the amount of material eroded from the Appalachian valley with that of the sediment deposited at the mouth of the Coosa-Alabama River; (3) the character of the gorge of the Tennessee below Chattanooga.

Evidence from the Coosa-Tennessee divide.—Regarding the character of the divide between the Tennessee and Coosa-Alabama basins, Hayes and Campbell point out the fact that the divide is low and indistinct, and that it occurs as a less prominent feature in the well-defined, broad, open valley which is continuous to the northeast with the valley of the present Tennessee above Chattanooga, and to the southwest with the valley of the present Coosa and Alabama Rivers. The well-marked character of this broad valley, which continues directly across the dividing line between the two river basins, is thought to indicate the former presence of a large northeast-southwest stream, the Appalachian River. This being true, the present position of the large stream must have resulted from river-capture, and a diverting stream must have led the upper Appalachian westward through the new-made gorge.

It does not seem to me that the baseleveled character of the divide alone necessitates the conclusion that a large stream once flowed across it. In order to make such a conclusion necessary, we should have to assume that every such broad valley developed across a low divide must have been carved by a large stream—an assumption which does not seem to be warranted. The region is one of parallel bands of alternating hard and soft rocks. (This parallelism of structure would prevent the development of dendritic drainage, the absence of which is noted by Hayes and Campbell.) The soft bands are rapidly eroded, while the hard bands remain as intervening ridges. Thus the region is characterized by broad, northeast-southwest valleys, many of which are occupied by very insignificant streams between whose headwaters are inconspicuous divides. Nor does there seem to be any need of assuming the former presence of larger streams, since the softness of the rocks and their easy solubility sufficiently account for the phenomena observed. Indeed, there are cases in which it seems practically certain that no drainage readjustments have taken place in recent geological time. Hayes and Campbell recognized this fact, and, after stating the argument and their conclusion, added another paragraph in which they said that, while they formerly regarded the argument as conclusive, further study of other similar divides had led them to modify this opinion. They cited the divides between the Potomac and James, and between the James and Roanoke basins, as cases similar to the one in question, but where there was no reason, so far as known, for supposing that a large stream ever existed. Evidently, then, this one of the arguments is only of negative value; it is permissive, but in no wise conclusive. That in this particular case the divide really presents features which make it difficult to conceive how a large stream could ever have flowed across it, is pointed out in subsequent pages.

Evidence from the volume of material eroded and deposited.—The second line of evidence developed by Hayes and Campbell is as follows: If we can ascertain the quantity of sediments carried out by the Alabama River system during Tertiary times, and can also ascertain the quantity of material eroded from the basins of the Coosa-Alabama system and the upper Tennessee system during Tertiary times, we can then compare the two results and find out whether the amount of sediments deposited is balanced by the amount of material eroded from the Coosa-Alabama basin alone, or whether it is only balanced when we add to it the material eroded from the upper Tennessee basin also. Lines are drawn midway between the Alabama and the Chattahoochee on the east, and between the Alabama and Tombigbee on the west, and all the Tertiary sediments between the two lines regarded as the material carried out by the Alabama system in Tertiary times. The amount is estimated at 2,340 cubic miles. Turning now to the amount of material eroded from the basin of the present Alabama system during Tertiary times, a careful estimate places the amount at 622 cubic miles. It is evident from these figures that some other area must have contributed to the formation of the vast amount of sediments laid down opposite the old mouth of the Alabama. If we add to the material eroded from the basin of the present Alabama system the material eroded from the basin of the upper Tennessee system, it is found that the total material eroded from both basins, during Tertiary times, is about 2,500 cubic miles. This agrees closely enough with the 2,340 cubic miles of Tertiary sediments found opposite the old mouth of the Alabama River. It follows from this that the Upper Tennessee basin must formerly have drained out through the Coosa-Alabama system by a river occupying the old valley across the divide south of Chattanooga, that stream having since been diverted westward through Walden Ridge by a branch of the Sequatchie River.

If all of the sediment laid down in the sea opposite a given river is brought there by that river alone, then this evidence would indeed seem conclusive in favor of the theory of capture. It is believed, however, that such an assumption would be contrary to what we know regarding the behavior of river-brought sediment under marine control. It would imply an absence of all appreciable transportation and distribution under the action of oceanic and littoral currents, the well-recognized drift to leeward produced by storm-waves, and the small but long-continued action of the tides. That these agencies have a very important influence seems well established by a large number of concrete observations. According to LeConte, the sediment brought down by the Amazon is carried seaward by a strong tide, taken up by the ocean currents, swept to a distance of 300 miles or more, and much of it deposited on the coast of Guiana (p. 40). It is estimated that the Nile carries out past its delta 36,600,000 cubic meters of silt every year. Yet this enormous amount of sediment apparently does not add to the seaward extent of the delta, because of a powerful marine current that sweeps past the coast and transports the sediment far eastward, where it is finally thrown down along the coast of El Arich desert. Over a portion of Blake plateau, southeast of Georgia, between depths of 100 and 600 fathoms, the bottom seems to be swept clean of mud, ooze, and almost so of living species. Agassiz attributed this to current action. And, again, LeConte tells us that the sediments brought into the Gulf of Mexico by the Gulf rivers are swept along by current action, and in part deposited on Florida Point, and the Bahama Banks (p. 40), while Mr. White (p. 36) refers to the fact that "after the formation of the Nita Crevasse in 1890, fine mud from the Mississippi was deposited in Mississippi Sound even up to the mouth of Mobile Bay, driving out the fish and killing the oysters" (E. A. Smith *et al.*, p. 30). Account must also be taken of the numerous well-recognized cases of transportation due to the set or drift given by storm-made waves and currents. Dana records the drifting of large quantities of coal and brick from wrecked vessels many miles from where they were dropped (p. 224). An anchor with ten fathoms of chain attached was carried one and a half miles in three weeks (p. 225). The effect of such storm-made waves and currents on small gravel, sand, and the finer sediments must be profound. Coarse gravel on Moray Firth is drifted eastward for over fifteen miles (Geikie, p. 418); the ground-swell off Land's End washes cobbles weighing as much as one pound into lobster pots at a depth of thirty fathoms (Douglas, quoted by Geikie, p. 419). Much of the material forming the great barrier beaches along the Atlantic coast is believed to have been brought from considerable distances. As a result of the strong southward drift along the coast of the southeastern United States, according to Professor Bache, the siliceous sands are carried the whole length of the limestone coast of Florida (LeConte, p. 36). Dana tells us that the large amount of sediments brought to the sea by all of the rivers of the Atlantic coast is *widely* distributed (p. 224). It is believed, then, that however closely the estimates of material eroded from a river basin and of material found opposite the mouth of that river agree, or how widely they may disagree, no conclusions as to the former extent of those river basins can be rightly based on such estimates, in the face of the strong probability, amounting almost to a certainty, that an unknown amount of sediments carried out to sea by that river have been transported by marine action beyond the area in front of the river, while an unknown amount of sediments brought out by other rivers has been carried into that area.

There are still other considerations which seem to place difficulties in the way of accepting this line of argument. As Mr. White has pointed out, a large proportion of the sediments in question is of limestone, containing quantities of corals and other fossils (E. A. Smith, *et al.*, pp. 226–31). It is not believed that the Alabama River can properly be held responsible for those deposits which are transported in solution and in a very finely divided state, and which may originally have come, in part at least, from far-distant rivers. Mr. White notes still another objection to this argument in the following words:

> The thickest and most important of the beds attributed to the Appalachian River, the Lignitic (900 feet), is composed of cross-bedded sands and clays, and

> would seem, at first sight, more than all others, to have been deposited by this river; but a study of the whole area shows that this formation increases in thickness and coarseness toward the west, in western Alabama and in Mississippi; while east of the Alabama River it is very calcareous and inconspicuous, showing that these sandy sediments were brought down from the west instead of from the north (p. 36).

In view of the considerations stated above, it is not believed that any argument in favor of the supposed capture of the Appalachian River by a branch of the Sequatchie can be properly based on a comparison of the sediments opposite the mouth of the Alabama River with the amount of material eroded during Tertiary times from the basin of the Alabama or other rivers. So far as such evidence goes, there seems to be no reason for supposing that the Coosa-Alabama River was ever any larger than it is now.

Evidence from the character of the gorge below Chattanooga.—The third line of evidence developed by Hayes and Campbell in favor of the diversion of a southward-flowing Appalachian River by a branch of the Sequatchie River to the west, is based on the youthful character of the transverse gorge west of Chattanooga. They recognize the fact that the course of the river through a ridge capped by hard sandstone several hundred feet in thickness would necessitate, on the basis of either theory, a valley of younger expression at this point than east or west of it where the river follows weak rocks. Their argument is that the *degree* of youthfulness is too great to be accounted for on any other theory than that of a comparatively recent diversion of the river to that course by a process of stream-capture. This is a point which does not readily admit of demonstrable proof, and the best evidence is to be secured from a comparison with other valleys of known age and formed under similar conditions. Hayes and Campbell, therefore, compare the gorge of the Tennessee through Walden Ridge with a valley southwest of Scottsboro, Alabama, in the following words:

> While a direct comparison cannot be made between the Walden gorge and the upper Tennessee valley on account of difference in conditions, such a comparison can be made between the gorge and a valley in northern Alabama, extending from Scottsboro southwestward to the mouth of Flint River. . . . . It is nowhere less than six miles broad, and its floor is very regular, forming a portion of the Tertiary peneplain. The age of this valley is easily determined; it is carved in the Cretaceous peneplain; therefore it is more recent than the Cretaceous;

it is continuous with the Tertiary peneplain, and hence was complete at the close of the Tertiary baseleveling period; and at the close of that period it was deserted by the stream which carved it. The conditions under which this valley was cut are practically the same as those now prevailing in the gorge through Walden plateau. In both cases the rocks are nearly horizontal, heavy sandstones capping the plateau, with easily erodible Carboniferous limestones beneath. Such conditions are highly favorable for rapid corrasion of a river channel. The sandstone cap is undermined, and its débris rolls down and forms a talus on the lower slopes. The rate at which the cliffs recede depends largely on the rate at which the sandstone talus is removed from the slopes and the limestone is exposed to erosion. No conditions could be more favorable for this rapid removal of the protecting débris than those now present in the Walden gorge, where the base of the slope is washed by a stream competent to remove all talus from the cliffs above, the coarsest as well as the finest. Certainly the conditions in the gorge are fully as favorable as they were in the valley west of Scottsboro when that was being cut, and the stream which flowed in that valley was probably smaller than the present Tennessee; therefore, if under the same conditions a smaller stream than the present Tennessee could cut so broad a valley as it did in northern Alabama during the Tertiary cycle, the conclusion seems inevitable that the present gorge through Walden plateau has been occupied a very much shorter time, and hence the Appalachian drainage was not diverted to its present westward course till after a part or the whole of the Tertiary cycle (pp. 113, 114).

While a comparison of the Tennessee gorge with some valley of known age may be expected to give us our best light on this particular phase of the question, two very serious criticisms must be urged against the comparison given above. In the first place, sufficient account is not taken of the details of geological structure in the two regions compared, although these details are features of prime importance in the present connection. In the second place, the comparison is one between the *Tertiary* valley southwest of Scottsboro and the *present* gorge of the Tennessee. The references are always to "the present gorge through Walden plateau," the conditions "now prevailing in the gorge," etc. A proper comparison can only be made between the Scottsboro Tertiary valley and the gorge of the Tennessee *as it also appeared at the close of the Tertiary period.*

When the geological formations in the region of the Scottsboro valley and in that of the Tennessee gorge are compared, it is found that the conditions under which the two valleys were carved were far from being the same. It is true that in each case we have soluble limestone capped by hard sandstone, but the sandstone cap in the two cases is of very different thickness. An examination of the Sewanee, Stevenson, and Gadsden folios of the United States Geological Survey shows that the sandstone covering thins out toward the Scottsboro region, this thinning being due in part to an original westward thinning of the beds, but more especially to the beveling of the successive formations by the Cretaceous peneplain, represented by the plateau tops. The Walden sandstone disappears entirely over much of the Sewanee area, northeast of the Scottsboro sheet, so that the underlying Lookout sandstone alone is represented on many of the plateau remnants; and while in the Stevenson and Gadsden regions the Walden sandstone covers a greater area, it is markedly thin, even on Sand Mountain, where the underlying Lookout sandstone comes to the surface over considerable areas, probably in part the result of a shallow synclinal fold. Over that part of the Stevenson region immediately northeast of Scottsboro, the Walden sandstone is wholly absent, and only a thin layer of the Lookout sandstone caps the plateau remnants. So, while we have no folio of the Scottsboro region itself, the conditions over the adjoining districts are such as to lead us to expect a much thinner cap of the sandstone over the lime about Scottsboro than in the vicinity of the Tennessee gorge. An examination in the field proves this to be the case. Just what the difference in thickness of the sandstone cap is in the two cases is difficult to determine with accuracy, owing to the fact that the limestone readily weathers out from under the overlying sandstone, allowing fragments of the latter to drop down and mantle the mountain slopes, thus concealing the limestone and making it harder to ascertain its true thickness. The tendency is to underestimate the thickness of the limestone, and correspondingly to overestimate that of the sandstone. But even if we assume the maximum possible thickness of sandstone over the Scottsboro region, and the minimum thickness over the region of the Tennessee gorge, there is still shown to be a markedly greater thickness at the latter place than at the former.

Ten miles southwest of Scottsboro the valley has its normal development, and the adjacent plateau remnants are well shown. Here, as elsewhere, the valley is seen to be cut largely in limestone, which shows conspicuously on the mountain slopes. Limestone float is abundant all along the foot of such slopes, and comparatively little sandstone is seen. Two sections in this vicinity showed the practically continuous limestone ledges up to within 190 feet of the top of the plateau or mountain. For reasons stated in the preceding paragraph, it is highly probable that the limestone continues still higher, no sandstone ledges being seen until nearer the top, and sandstone débris mantling the slopes for some distance. But even if we ascribe the entire thickness of 190 feet to the sandstone, the contrast with conditions at the Tennessee gorge is very marked. North of Scottsboro it appears that the sandstone cap was somewhat thicker, suggesting a progressive thinning toward the western end of the valley, although the possibility that the limestone goes higher up the slope than is apparent makes a definite statement impossible. Such a westward thinning would be in accord with the indications on the geologic folios of adjacent areas, however.

Turning now to the conditions at the winding gorge through Walden plateau, we find plenty of evidence that the gorge is cut largely in sandstone. Instead of conspicuous limestone ledges well up the mountain slopes, we find the slopes mantled with coarse sandstone débris, generally down to the level of the river. Only near the eastern and western mouths of the gorge was the limestone shown at all prominently, and this is where the gentle rise of the sides of the synclinal trough would naturally bring the limestone to a higher level; while in the Scottsboro valley the limestone is everywhere prominently shown well up toward the plateau summit. Limestone is shown at various other points throughout the gorge, but always, so far as seen, in limited exposures well down at the foot of the slope. Limestone float was little in evidence, usually only close to the small ledges referred to, sandstone débris being everywhere abundant. Although the limestone was undoubtedly greatly masked by the sandstone débris, exposures of the limestone on the spurs of the mountain, and the careful examination of float and ledges along the courses of side streams emptying into the gorge, indicated that in the main portion of the gorge the limestone-sandstone contact could not be far above the level of the river. In the half-dozen best sections seen, the limestone exposures or limestone débris always stopped short at elevations of between 100 and 200 feet above the river. The limitation of the limestone to the bottom of the gorge is also indicated by the presence of sandstone in ledges apparently in place well out on spurs projecting forward from the main base of the mountain. These spurs occupy a position which does not seem to admit of their sandstone being interpreted as débris that had been let down from above by the undermining of the limestone.

The geological map accompanying the Chattanooga folio represents a larger portion of the gorge as being in limestone. Thus the thickness of the limestone exposed in the gorge is shown as over 600 feet in places, and as less than 300 in others. Throughout a large part of the central portion of the gorge the 1,000-foot contour line is taken as the upper limit of the limestone, and the indicated thickness of between 300 and 400 feet of limestone may be taken as a fair average figure as given by this line of evidence. This leaves, as the map shows, a cap of between 600 and 700 feet of sandstone.

It appears, then, that if we take the more conservative estimates of the thickness of sandstone in the Walden gorge, the sandstone cap at that locality is still over three times as thick as the similar cap in the Scottsboro valley. If a thickness of sandstone be taken nearer that indicated by the sections given in a preceding paragraph, the contrast is still more marked. Such a difference in geological structure must result in a marked difference in form between the two valleys. The Scottsboro stream, having the thin cap of hard rock to cut through must have reached the underlying soft rock, and so have had ample opportunity to widen its valley under favorable conditions, while the stream through Walden gorge, having the thick cap of hard rock to contend with, still continued for a long time to carve a narrow gorge in the resistant beds. The great degree of contrast to be expected in this particular case will be more apparent after a consideration of the next point.

A second serious objection to the comparison between the valley southwest of Scottsboro and Walden gorge is found in the fact that it is throughout a comparison between the former as it was at the end of Tertiary times, and the latter as it is at present. As Hayes and Campbell have shown, the Scottsboro valley was completed at the end of the Tertiary period, and the valley floor forms a part of the

Tertiary peneplain. It has not been materially modified since, and therefore it is truly a Tertiary valley. On the other hand, while the Tennessee gorge had a certain form at the close of the Tertiary period, post-Tertiary cutting has lowered the gorge 250 feet, almost obliterating all traces of the old Tertiary valley floor at the higher level. Manifestly, then, the two valleys as they are at the present cannot be properly compared. The comparison becomes of value only if we conceive the post-Tertiary cutting in the gorge to be replaced, filling up the bottom of the gorge to the level of the Tertiary peneplain. We may then compare the two valleys as they were at the close of the long period of Tertiary baseleveling. Such a comparison shows a more marked contrast in geological conditions in the two valleys than that already indicated.

Hayes and Campbell have shown that the Tennessee River at Chattanooga has cut down its channel 250 feet below the level of the Tertiary peneplain, while the distribution of the Tertiary gravels, to be considered later, indicates that the gradient of the river through the gorge was then much the same as now. Hence filling up the gorge to that old level, and thus restoring the Tertiary peneplain, means a reduction of 250 feet in the extent to which the river had cut into the limestone then as compared with now. And since the vertical extent of limestone now shown in the gorge is between 300 and 400 feet, according to the larger estimates, this means that at the close of the Tertiary baseleveling period the Tennessee had cut into the limestone underlying the massive sandstone cap only between 50 and 150 feet; while if we accept the smaller estimates for the thickness of the limestone exposed at present throughout the main portion of the gorge, which seems to the writer to be nearer the actual conditions, we find that at the close of the Tertiary the river was in places still flowing wholly in sandstone, not having yet reached the underlying limestone. At this same time the stream southwest of Scottsboro had cut through the thin sandstone cap of that region and over 400 feet into the underlying limestone. The following figures illustrate graphically the different conditions obtaining in the two areas at the close of the Tertiary baseleveling period.

These diagrams are based on the more conservative figures given above. It is believed that the actual conditions at the close of the

Tertiary period would be more accurately represented by making the sandstone cap over the limestone of the Scottsboro valley (Fig. 4) thinner than it is shown, and the sandstone of the gorge (Fig. 5) enough thicker to show the gorge entirely in sandstone.

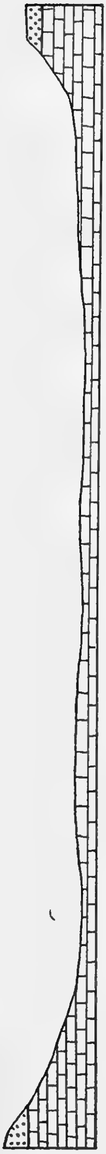

Fig. 4.—Section of Scottsboro valley showing relations of sandstone cap and underlying limestone at close of Tertiary cycle (same as at present).

(Horizontal scale, 1 inch = 1 mile. Vertical scale, 1 inch = 2,000 feet.)

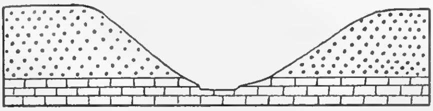

Fig. 5.—Section of Tennessee gorge showing relations of sandstone cap and underlying limestone at close of Tertiary cycle.

(Scale, same as in Figure 4.)

But even on the basis of the more conservative representation, the contrast in conditions under which the two valleys were carved is such as to explain satisfactorily the difference in form which has been noted. Indeed, it is difficult to conceive how the gorge of the Tennessee could be otherwise than narrow and steep-sided as compared with the Scottsboro valley, since it was carved almost wholly, or possibly entirely, in hard sandstone throughout the long period of Tertiary baseleveling, and only during the comparatively very short post-Tertiary trenching have favorable valley-widening conditions existed; whereas the Scottsboro valley was carved largely in easily erodible limestone, favorable conditions certainly existing a vastly longer period in this case. It appears, then, that the gorge of the Tennessee might be more properly compared with other gorges cut through sandstone ridges since the Cretaceous period, such as those of the Delaware and Susquehanna Rivers through the Pennsylvania ridges; for while the present conditions at Walden gorge and the latter localities are different, they were much the same until comparatively recent times, barring the greater width of the Walden ridge, and a possible difference in hardness of the sandstone.

The degree of similarity between these gorges (Fig. 6) is what we should expect when the conditions under which they were carved were for so long a time so much alike; and inferences drawn from such a comparison seem more reliable than those from a comparison with a valley where the conditions were for so long a time so radically different. No comparison between the gorge through Walden Ridge, and the broad longitudinal valleys east and west of the ridge, can be made, since the latter were carved entirely on broad bands of soft rocks.

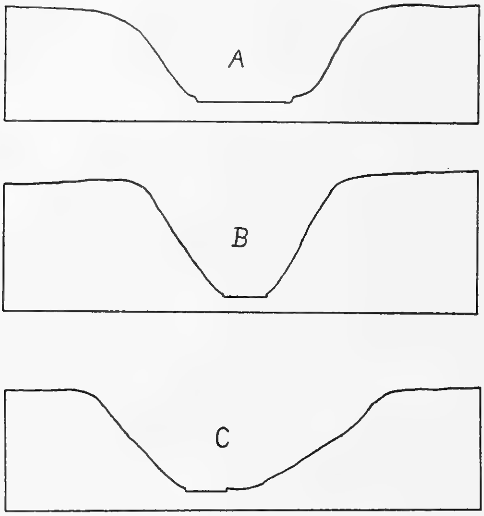

FIG. 6.—Profiles of (A) Susquehanna Watergap above Harrisburg through Second Mountain, (B) Delaware Watergap, and (C) Tennessee gorge.

(Horizontal scale, 1 inch = 1 mile; vertical scale, 1 inch = 2,000 feet.)

It is believed, then, that when the geological conditions at the Walden gorge and the Scottsboro valley are carefully considered, and the comparison between the two made on the same time basis, the difference in form between the two will afford no evidence in favor of the recent diversion of the Tennessee River to a westward course. It is further believed that these considerations fully explain the present narrowness of the gorge on the basis of the alternative theory, the youthful features being just what we must expect under the conditions that have controlled erosion at this point since Cretaceous time.

Evidence from the distribution of the Unionidæ.—Six years after the publication of the paper by Hayes and Campbell giving the above lines of evidence, and the conclusions to which they led, Mr. Simpson reached the same conclusions from a study of the fresh-water mussels of the region. The facts that Mr. Simpson brought forth are as follows: *Pleurobema*, a genus of Unio, has its metropolis in the Tennessee River. It is not found throughout the other portions of the Mississippi basin. But it is found abundantly in the Coosa and Alabama Rivers. Also certain other forms of Unio common to the Mississippi-Tennessee basin are found in the Coosa-Alabama basin. From these facts Mr. Simpson concludes that at some time the upper Tennessee River must have flowed southward into the Coosa-Alabama River, since, to quote his words, "these forms cannot travel overland from river to river, but must have water communication in order to pass from one stream to another."

Mr. Simpson's argument in favor of the theory of capture is based on the assumption that the fresh-water mussels must have direct water communication (evidently meaning direct fresh-water communication) in order to pass from one stream to another. It appears that the recorded observations of many naturalists, and the facts of Unionidæ distribution, are both contrary to this assumption. In the first place, there are so many authentic cases where birds, insects, etc., have been taken with fresh-water shells attached to them, that students of the subject are compelled to believe in this method of dispersion of these forms from place to place. Darwin proved that young mollusks just hatching will attach themselves to the feet of a duck, and remain alive in this position out of water from twelve to twenty hours (p. 174). Mr. Arthur F. Gray, of Danversport, Mass., had in his possession the foot of a waterfowl to which was attached a bivalve shell. Canon Tristran shot a bird in the Sahara which had attached to it the eggs of some mollusk. Some shells attach themselves to plants which are carried away by birds (Darwin, p. 174). Insects are frequently taken with shells attached. There are at least five recorded cases of the capture of the water scorpion, *Nepa*, a large flying-bug, with small shells attached. The great water beetle, *Dytiscus*, is known similarly to aid in the dispersion of fresh-water Mollusca. The same is true of *Dineutes*. Mr. Albert P. Morse, of Wellesley, has kindly shown me specimens of these last two forms having attached shells. *Notonecta* has likewise been proved to carry these forms from place to place. Some of these insects are powerful flyers. Darwin records the capture of one of them out at sea, 45 miles from the nearest land (p. 174). Beddard, Kew, and other students of zoögeography regard birds and insects as undoubtedly important agents in the dispersion of fresh-water shells. Woodworth catalogues a number of agencies recorded as aiding in this dispersion, in addition to those mentioned above (pp. 214–17). It appears, then, that other means besides river-capture for the passing of fresh-water shells from one stream to another are not lacking. That these means are efficient is proved by the distribution of these shells. Ponds are sometimes made by excavating a place where no water stands ordinarily, lining the excavation with concrete and allowing the rain to fill it. These ponds, for a time devoid of life, gradually become populated with mollusks and other shells, proving, as Beddard says, the capacity for active or passive migration on the part of the Mollusca. Careful and successive observations have proved in some instances the actual time in which a given pond may become populated. R. Ellsworth Call records the presence of a western species of Unio in a small isolated eastern lake, which was located down between high hills, fed by a mountain brook, and absolutely foreign to any stream through which the species might have been introduced.

But the most conclusive objection to Mr. Simpson's argument in favor of the theory of capture is found in the actual distribution of the very shells upon which he bases his argument. Mr. Simpson finds the genus *Pleurobema* in both the Tennessee and Coosa-Alabama basins. He says that in no case are the species in the two basins identical, but only similar. The basis of the argument, then, is similarity of forms; but if mere similarity of form proves former river connection, certainly identity of form should prove it with double force. Accordingly, we should not expect to find the same species of *Pleurobema* in any two rivers of this section whose location is such as to render practically impossible a former connection with each other, either directly or by way of intervening streams. An examination of Mr. Simpson's later monograph on the pearly fresh-water mussels (pp. 745–65) is of value in this connection. As will be seen, he records *Pleurobema similans* Lea, from Black Warrior and Cahawba Rivers, Alabama; and Pine Barren Creek, Escambia County, Florida. So far as can be judged from available maps, previous fresh-water connection between the former and the latter is extremely improbable. *Pleurobema strodeana* Wright is recorded from Escambia

River, Florida, and Flint River, Georgia. Any former connection in this case seems improbable. *Pleurobema harperi* Wright is recorded from Altamaha and Flint Rivers, Georgia; and Suwanee River, Florida. Here, again, connection between either of the former and the later seems out of the question. Other cases might be added—indefinitely, if we continue with other genera than *Pleurobema.* If we find it impossible to hold river-capture responsible for the distribution of identical species in all these cases, then mere similarity of forms in the Tennessee and Coosa-Alabama basins cannot be regarded as a valid argument in favor of river-capture near Chattanooga.

If we carry this line of argument to its logical conclusion, the objections to it become even more apparent. Mr. Simpson records one group of Unios as occurring everywhere in the streams draining into the Atlantic from Labrador to Georgia (1900, p. 134). If the occurrence of the *Pleurobema* in the Tennessee and Coosa-Alabama Rivers proves river-capture in that case, then the distribution just referred to must prove a great succession of river-captures from Labrador to Georgia. Nor is this all. The same species is in one instance found in Europe, northern Asia, Japan, northern North America, and Iceland (p. 677). According to the argument advanced, this means an inconceivable series of river-captures. Such violent hypotheses compel the conclusion that some other means than river-capture is commonly operative in effecting the distribution of fresh-water shells.

Certain features of Unionidæ distribution have led some to believe that their dispersal may take place by migration along the seacoast from one river system to another, as well as by the means already considered. Mr. Simpson evidently regards this as a possibility in the case of another instance of supposed river-capture (1900, p. 135), but does not consider it in connection with the more important problem of the Tennessee, unless certain statements near the first of his article are meant to imply such a consideration indirectly. He states that none of the *Pleurobema* are found in the lower 300 miles of the Mississippi River, in the Pearl or Pascagoula Rivers, or any of the small rivers in Mississippi or Louisiana flowing into the Gulf (p. 134). If it is meant to imply by this that no migration down the Tennessee to the Gulf, thence along the coast and up the Alabama and other streams, could have taken place, because the intervening streams should, at the same time, have become populated by such a process, two answers may properly be made: (1) Such absence in the intervening streams is no more remarkable than that shown repeatedly in the distribution of the species of *Pleurobema* in the southern rivers, and of other forms elsewhere. (2) The migration along the coast may have taken place near the close of the Tertiary, at which time the rivers and portions of rivers referred to were not in existence. In this connection it is suggestive to note that, although Hayes and Campbell consider that the lower portion of the Tennessee River was diverted northward to the Ohio in recent time, not a trace of the Tennessee shells has been found to mark the supposed former southwestward course of the river through Mississippi.

The evidence recorded by Mr. Adams is much the same as that introduced by Mr. Simpson, except that Mr. Adams emphasizes more especially the *differences* existing between members of the same group found in the two river systems, and seeks to explain the differences by the proposed capture, whereas Mr. Simpson seeks to prove the capture by the similarity of these forms. It is believed that all of the phenomena noted are easily explicable independently of the theory of capture, and in this connection it is well to note that the presence of a longitudinal open valley across the low divide between the two basins is peculiarly favorable for the operation of some of the means of dispersal referred to above. The northward and southward migrations of birds along certain valleys are known, and where a low divide in a prominent valley alone separates the waters of two river systems it is to be expected that more or less mingling of forms will very likely take place.

In closing our consideration of this line of evidence, it is of interest to recall Mr. Simpson's statements regarding the dispersal of these shells, which appear in his paper on the *Distribution of North American Unionidæ,* published seven years prior to his Tennessee paper. In a footnote (p. 354) he observes:

> In many cases the Unionidæ seem to have had no difficulty in migrating across the country from river to river; an example of this being the Mississippi Valley species which now inhabit all the rivers of Texas, and some of those of eastern Mexico; while, on the other hand, species of South America extend up

> into Central America. The embryos, in some cases, may be carried by aquatic birds in the manner elsewhere mentioned in this paper; in others, they probably migrate across overflowed regions near the sea, in time of floods.

Farther on (p. 358), in accounting for the presence of *Unio luteolus* in both the Missouri and Columbia Rivers, Mr. Simpson says:

> I have traced it up the Missouri River to near its source, and when it is taken into consideration that the Marias, a tributary of this stream, heads within a few miles of Flathead Lake on Clarke's River, a branch of the Columbia, and that the embryos of Unios are provided with hooks by which they can attach themselves to the feet or feathers of aquatic birds, it is very easy to see how this species might have been carried from the waters of one drainage system to those of another.

Mr. Simpson does not consider the possibility of such means of dispersal when discussing the Tennessee problem, the whole force of his argument in that case lying in the statement: "These forms [the Unios] cannot travel overland from river to river, but must have water communication in order to pass from one stream to another."

It is believed, then, that the well-authenticated means of dispersal of Mollusca, and more especially the facts of Unionidæ distribution, are such as to render the argument in favor of the theory of capture, based on the evidence of the Unionidæ, invalid; for while it is believed that such a capture as has been proposed would result in the dispersal of the *Pleurobema* and other forms throughout the two basins, it is equally believed that other means of dispersal will account for all of the phenomena noted, some of which are inexplicable on the theory of capture alone.

SUMMARY OF EVIDENCE IN FAVOR OF THE THEORY OF CAPTURE

To review our consideration of the four lines of evidence in favor of the theory of a recent diversion of the Tennessee to its westward course through the gorge in Walden Ridge:

It has been shown that divides similar to that between the Tennessee and Coosa-Alabama basins exist in other regions at points where no large stream is ever supposed to have held its course. A consideration of the behavior of river-brought sediments under marine control, and of the character of the Tertiary sediments in Alabama, is believed to show the impossibility of properly basing any argument in favor of the capture on the comparison of sediments now exposed with amount of material eroded. A study of Walden gorge and the Scottsboro valley shows the invalidity of any argument in favor of the theory of capture based on a comparison of the two valleys, and satisfactorily explains the narrowness of the gorge on the basis of an alternative theory. The supposed evidence of the Unionidæ in favor of the theory of capture is seen to be based upon assumptions which do not seem to be warranted by due consideration of the various means of molluscan dispersal or by the facts of Unionidæ distribution. It is therefore believed that the arguments brought forward in support of the theory of capture are far from conclusive, and that the history of the Tennessee is still open to consideration. Certain lines of evidence, some of which have hitherto been unconsidered, appeal to the writer as weighing strongly against the theory of capture, and as strongly indicating the continued presence of the Tennessee River in its present path across Walden Ridge since Cretaceous time.

EVIDENCE IN FAVOR OF THE ALTERNATIVE THEORY

The evidence against the proposed theory of capture, and in favor of the long continuance of the Tennessee in its present course through Walden Ridge, is derived from a consideration of (1) the winding character of the gorge; (2) the character of stream-dissection on the ridge both north and south of the gorge; (3) the character of the divide between the Tennessee and Coosa-Alabama basins, south of Chattanooga; (4) the lack of sufficient inequality of levels between the valleys east and west of Walden Ridge; (5) the absence of the Tertiary river gravels from the supposed former southward course of the river.

Before considering these lines of evidence which appear to bear directly on the present problem, it is desirable to note one line of evidence which might be available in certain cases, and to make clear my reasons for not applying it in the present instance. When a mature stream has developed a broad, open valley, the floor of that valley will have a gentle slope downstream, represented by the line *AD* in Fig. 7. Now, if capture of this stream takes place at a point *B*, the portion of the stream *AB* will intrench itself, developing a profile *A′B′*. From the point of capture, *B*, the divide will be pushed in the direction of D to some point C, by what is termed the "inverted stream," whose profile is $B'C'$. It is possible that the profile $C'D'$ may remain practically coincident with CD. In the interstream areas remnants of the old valley floor between A and C not yet destroyed by erosion will show surfaces which coincide with the prolongation of the line CD toward A.

On the other hand, if C represents a divide which has been long maintained, no large stream having flowed from A to D, then the profiles will be as represented in Fig. 8: streams flowing from A and C toward B to meet and find an exit from the valley developing the profiles AB and BC, while the stream flowing from C toward D developed the profile CD. Now, if the streams intrench themselves, remnants of the old valley floor in the interstream areas between A and C will show surfaces which do not coincide with the prolongation of the line CD. It may thus be possible, by a study of the interstream spaces, to determine whether the present profile of the streams, $A'B'C'D'$, which is much the same in either case, is developed as a result of capture (Fig. 7), or merely represents the intrenching of streams which have long maintained their present general relations (Fig. 8).

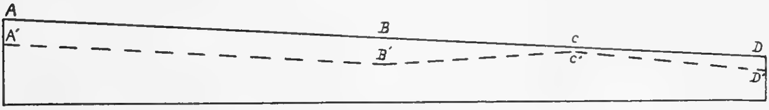

FIG. 7

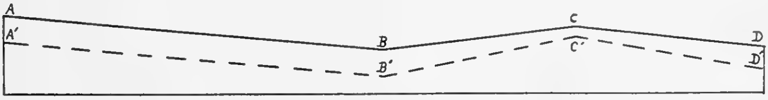

FIG. 8

The limited application of this test is evident. It would not apply to young streams with narrow valleys. It is equally obvious that if the streams had reduced their valleys nearly to baselevel, so that all slopes were very slight, and recent erosion had greatly dissected the former valley floors, the detection of the desired evidence might be impossible. In the case of the Tennessee drainage the streams had reduced their valley floors nearly to baselevel at the close of the

Tertiary cycle, and erosion subsequently to the uplift at the close of that cycle has been extensive. Sufficient time was not available for the work in the field necessary to prove whether or not this test was applicable, but it is not believed that satisfactory evidence of this nature is obtainable.

The winding character of the gorge.—In order to account for the winding character of the Tennessee gorge, those who support the theory of capture have been led to suppose a most complicated hypothetical series of drainage rearrangements. This series involves: the successive transference of divides from place to place along the headwaters of three or four separate streams, by a roundabout course some ten miles longer than that offered by the path of the stream supposed to be first encountered by the diverting stream; the removal of the massive sandstone cap throughout the courses of every one of those streams even to their headwater areas preparatory to the capture; and the definite localization of the axis of a broad, gentle uplift which is supposed to have determined the location of an assumed divide between the supposed contending streams. There are two difficulties in the way of accepting this explanation: It is impossible to accept the assumption that the several streams were able to breach the massive sandstone cap even to the divides between the streams, whereas much larger and more powerful neighboring streams, with all the advantage of post-Tertiary cutting, have scarcely begun to accomplish that work in their lower courses. This will appear more fully in a later paragraph. The proposed process of capture involves so much that is purely hypothetical that one is led to seek a less complicated explanation.

The winding character of the gorge is, on the other hand, what we should naturally expect if the meanders of the river are inherited from a former baseleveling period when the river meandered broadly over the site of the present ridge. Meanders which were developed when the river flowed with sluggish course over the Cretaceous peneplain would necessarily intrench themselves with some modification when the uplift occurred; and whatever the form of these meanders, no special and complicated explanation would then be necessary in order to account for each portion of the various curves. This more simple explanation finds confirmation in the succeeding lines of evidence.

Character of stream-dissection on Walden Ridge and Sand Mountain.—The streams occupying the open longitudinal valleys on either side of the ridge belong to that type known as subsequent streams, since they must have gained their present positions by a process of adjustment to weak structures from some former position more directly consequent upon the initial folding of the region. The branches of the subsequent streams which head up the ridge belong to the group of streams termed obsequent, since they have grown headward against the dip of the beds which they cut. It is one of the characteristics of obsequent streams that they are not located, so far as is known, by any specific structural factors, but develop at more or less regular intervals, as is required by the removal of rainfall. Over an area where practically uniform conditions prevail the development of such streams will be roughly uniform. We should not expect one stream of this class to dissect an area deeply, while similar adjacent streams had barely begun their work.

An examination of the Chattanooga and Stevenson topographic sheets shows that the dissection on Walden Ridge and Sand Mountain, north and south of the Tennessee gorge, has progressed at a fairly uniform rate. It also appears that the dissection is of no great extent, the integrity of the plateau remnant being quite well preserved in either direction. Only at the gorge is the flat-topped mountain cut wholly in two. Now, the theory of capture necessitates the assumption that one of the obsequent streams grew headward entirely through the mountain and cut down to the level of the main stream in the broad valley to the east, during the same time that its neighbors were able to make but a small beginning on the dissection of that mountain—an assumption which it seems difficult to accept. If one of the obsequent streams was able to cut its ways entirely through the ridge, then we should expect to find the ridge more or less nearly breached at various other points. This is distinctly not the case. The marked contrast between the amount of dissection at the gorge and elsewhere points to an entirely different origin for the gorge from that of breaching by an obsequent stream.

According to the suggested procedure of the supposed capture, the branch from the Sequatchie River to the west was aided in the breaching of the ridge by several small obsequents working back into the ridge from the valley to the east. Such a process seems to add to the difficulties of the case rather than to decrease them; the disposal of the rainfall of a given area on the ridge by several streams instead of by one must mean less powerful streams and decreased cutting in each individual case. That such streams should have been able completely to breach the thick sandstone cap of the ridge, even at their headwater areas, by the close of the Tertiary period, whereas their larger neighbors, with the additional advantage resulting from 250 feet of post-Tertiary incision of the main streams, have only begun that process in their lower courses, seems wholly incredible. (In this connection it must be borne in mind that such streams as flow short distances down steep slopes directly into the present Tennessee are not comparable with streams heading in the ridge, but flowing some distance out across the open valley to join the main stream, or its tributary, the Sequatchie. Thus, in the immediate vicinity of the gorge, where the streams enter the main Tennessee while it is still fairly within the limits of the Walden syncline, dissection of the ridge is very marked, as at points west of Brown's Ferry, east of Kelley's Ferry, and along Running Creek just south of the gorge. This local dissection, consequent in part upon the 250 feet of post-Tertiary trenching of the main Tennessee, is wholly in accord with the hypothesis that the Tennessee has held its present course since Cretaceous times.)

In order to account for the diversion of the upper Appalachian independently of this process, which involves such great dissection by obsequent streams, it has been suggested that the diversion may have been accomplished by what has been termed "cavern capture." This process involves a leakage from the Appalachian valley east of the ridge into the Sequatchie valley to the west, whereby a system of caverns was developed in the limestone below the massive sandstone cap of Walden Ridge, resulting in a diversion of the Appalachian River through this underground channel into the Sequatchie River, with the subsequent falling in of the cavern roof. There are several objections to this theory. It is difficult to conceive that the Sequatchie valley could have been lower than the valley of a great river to the east, as is pointed out more fully in a later paragraph, so as to admit of such a leakage as this theory involves. The process would entail a cavern or series of caverns twenty-five or thirty miles in length, having a beautiful meandering course, developed under a massive cap of hard rock which came down nearly or quite to the level of the valley floors. As Dr. Hayes has pointed out to me, such underground channels would in this case run counter to the trend of geological structures in the region, whereas it is generally true that caverns are developed parallel with such structures. The impossibility of accepting this theory is further evident from the consideration of points to follow. We are therefore forced to the conclusion that the present breach through Walden Ridge was made by the Tennessee itself, it having maintained its present course from a former baseleveling period.

Character of the divide south of Chattanooga.—The Tertiary peneplain on the present divide between the Coosa-Alabama and Tennessee basins, south of Chattanooga, is less than 1,000 feet above sea-level. Those elevations rising to or above the 1,000-foot contour are to be regarded as monadnocks which projected above the peneplain at the close of the Tertiary baseleveling period. Care was taken to verify this statement in the field, in order not only to guard against errors arising from incorrect maps, but particularly to eliminate the effect of possible warping of the peneplain so much as to bring it up to the 1,000-foot level. It was thus found that for a number of miles north and south of the divide those elevations contoured as 1,000 feet or over, as well as a number of elevations not so represented on the map, rose distinctly above the peneplain level, and that the above statement as to the altitude of the peneplain is correct.

Now, if we take the Ringgold topographic sheet and color the areas remaining unreduced at the close of the Tertiary cycle, it brings out very clearly one serious objection to the proposed theory of capture. It will be seen that numerous remnants, some of them over 200 feet in height and of considerable areal extent, were left unreduced on the present divide between the Tennessee and Coosa basins. The supposed former southward course of the Appalachian across this divide must have led between these remnants, because the capture is represented as taking place at the close of the Tertiary. In order to accept the theory of capture, then, we must conceive that a great river, flowing over soft, valley-making rocks, still found itself at the close of the long period of Tertiary baseleveling, confined for a number of miles in one part of its course (the present divide) by soft rock monadnocks of considerable magnitude to a valley less than two miles in width. This, however, is inconsistent with the accepted theories of valley development. It is thus seen that the features of this present divide are not such as would characterize a region of soft rocks occupied for a long time by the middle course of a great river. On the contrary, the frequent occurrence and large size of the unreduced remnants contrast strongly with the portions of the present Tennessee valley in the same rocks north and south of the gorge, but compare favorably with other divides between the headwaters of small streams, as, for example, that between East Chicamauga and east Armuchee Creeks, on the opposite side of Taylor Ridge, where no large stream is supposed to have ever held its course. When seen in the field, this objection to the supposed former southward course of the Tennessee across this divide is brought out even more strikingly than on the maps; and one is forced to conclude that the river has held its present course for a much greater period of time than since the Tertiary, and that no great Appalachian River could have flowed southward across this divide.

It is possible that an appreciation of this difficulty led Dr. Hayes to place the date of the diversion later than was done in the earlier paper by himself and Mr. Campbell. In the original essay the statement was made: "That the Appalachian drainage was diverted to its present course before this uplift is quite certain, for no channels are cut in the Tertiary peneplain across the Coosa-Tennessee divide" (1894, p. 115). In the later paper Dr. Hayes says:

> The large axial stream in the Appalachian valley continued to flow southward across the present divide for a short time after the uplift, but it was able to cut its channel less than 100 feet in the peneplain before it was diverted to a westward course (1899, p. 55).

It will be seen that this latter interpretation, which regards the present level of the divide as a channel cut below the peneplain instead of a part of the peneplain itself, would mean a reduction of something less than 100 feet in the heights of the monadnocks referred to, and a decrease in their areal extent. But while this provides for a somewhat wider valley for the supposed Appalachian River, it does not fully satisfy the objection urged, and does involve two other serious difficulties. If we accept a theory of a channel across this divide at the point north of Lafayette, we must account for the fact that small branch streams all over this area have been able to develop low, flat divides of remarkably uniform altitude, and having the same elevation as the channel in question. And, since in nearby areas elevations of 1,000 feet are represented by Dr. Hayes as monadnocks rising above the peneplain, we must either accept the idea of the narrow valley north of Lafayette referred to in the preceding paragraph, or else assume a very restricted local warping of more than 100 feet in four miles. It is also true that no direct evidence of the existence of any channel across the divide has been presented. For these and other reasons that will appear, I am forced to agree with the earlier statement that "no channels are cut in the Tertiary peneplain across the Coosa-Tennessee divide."

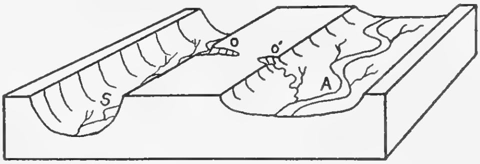

Fig. 9

Insufficient inequality of levels between the two valleys.—In order that one stream, *S* (Fig. 9), may divert another stream, *A*, from its course, it is essential that the stream *S* occupy a level so much lower than its neighbor *A* that even the uppermost headwater portions of the branch *O* which effects the capture shall eventually be able to work at a lower level than that of the stream to be captured. That a small branch of the Sequatchie River, a stream which is itself comparatively small, could work back through a high mountain barrier along a course over 40 miles in length, and still have its headwaters low enough to capture the large Appalachian River, demands that the Sequatchie valley west of the ridge should have been much lower than the Appalachian valley to the east. Several conditions indicate that such a marked inequality of level did not exist between the two valleys at the close of the Tertiary cycle.

On theoretical grounds alone we should be led seriously to question the possibility of such an advantage of position developing under the conditions preceding the supposed capture. It is difficult to conceive that a small stream like the Sequatchie, having its very beginning less than 70 miles to the northward, and flowing over 300 miles to the sea without receiving the waters of any large stream, could have reduced its upper course to a lower level than the middle course of a neighboring great Appalachian river. It is true that the smaller stream would have had some advantage of more direct outlet to the sea, as the region of the gorge is something over 300 miles from the mouth of the Sequatchie and about 400 miles from the mouth of the Appalachian, as represented on Hayes and Campbell's map of the Tertiary peneplain. It is also possible that there is some difference in the character of the rocks over which the streams were flowing, which was to the advantage of the smaller stream, although both were developed largely on soft rocks. But, after making all due allowance for these advantages, it is still impossible to admit that, whereas the great Appalachian River still had a fall of 3 inches per mile throughout its middle and lower courses, the comparatively small Sequatchie had reduced its gradient almost to zero even in its upper portion, as has been represented.

The fact that the Tertiary peneplain is somewhat lower in the Sequatchie valley than in the valley east of the ridge, while presenting grave difficulties in the way of a satisfactory explanation on the basis of the theory of capture, is wholly in accord with the alternative theory. We should expect the peneplain to be higher on the eastern side of the ridge, for two reasons: it is there farther upstream; and, what is probably of greater importance at this point, the stream in flowing from east to west passes through a mountain barrier which sheds abundant waste into its waters and obstructs its passage with coarse débris, compelling the maintenance of a steeper gradient throughout 25 miles or more; and when it is remembered that nearly or quite to the close of the Tertiary period the mountain served as a sandstone barrier in the path of the stream, it is seen that the base-leveling process must necessarily have gone on at a higher level in the valley in soft rocks east of the ridge. The observed difference in elevation is not greater than we should expect under the conditions referred to, and is not believed to be sufficiently great to account for the proposed capture, even were it possible for this difference to have been developed under the conditions imposed by the theory of capture.

Hayes and Campbell report the occurrence of the Tertiary river gravels on remnants of the Tertiary peneplain about Chattanooga, 250 feet above the present river, and in the Sequatchie valley, 150 feet above the river. If this difference of 100 feet in the relative elevation of the gravels were correct, it might be advanced as evidence in favor of the theory of capture; for on the basis of the alternative theory we should expect to find the gravels about as high above the river on one side of the ridge as on the other. On the contrary, if these gravels should be found 250 feet above the river in the Sequatchie valley, that in itself would be practically conclusive against the proposed capture, as it would show the former presence of the river at an elevation incompatible with the theory advanced.

North of Shellmound, in the Sequatchie valley, is a series of hills which rise well above the present valley floor. The contour lines show the summits of these hills to be something over 200 feet above the river. The Tertiary gravels, of material that could have been brought from far to the northeast by the Tennessee River alone, are abundantly developed on these hills, completely cloaking the summit in one case. Barometric readings showed that the gravels occur up to 265 feet above the level of the river itself, or about 230 feet above the river floodplain.

Absence of Tertiary gravels south of Chattanooga.—The Tertiary river gravels are abundantly represented about Chattanooga and in that portion of the longitudinal valley to the northward of the city. These gravels occur capping remnants of the Tertiary peneplain and widely distributed over lower levels. Their presence in the valley west of the ridge and southward from the gorge has been also noted. Therefore, if the river flowed southward into the Coosa-Alabama system until the close of the Tertiary cycle, we should find ample evidence of that fact in the distribution along this former southward course of the gravels which are so abundant along the present course of the river. These gravels cannot be confused with any that might be derived from sandstones or conglomerates locally represented, but, as has been pointed out by Hayes and Campbell, must have been brought from far to the eastward. And since these gravels are so well preserved on the small remnants of the Tertiary peneplain situated near the present river and subjected to extreme erosion, they should show doubly well on the beautifully preserved portions of the peneplain near the present divide south of Chattanooga where post-Tertiary erosion has been at a minimum. On the other hand, if the Tennessee River took its present westward course before the close of the Cretaceous period, and has maintained that course throughout all Tertiary and more recent time, we should not expect to find any such development of the gravels in the valley southward from Chattanooga. Indeed, even if in earlier Cretaceous times the river may have held some course carrying it farther southward in this region (as is possible, perhaps even probable, on the basis of either theory), the most that we could expect to find in the way of gravels would be occasional scattered pebbles having no relation to the Tertiary peneplain, since the erosion of Tertiary time must have swept away all but occasional traces of what may have existed in a former period.

North and south of the divide the valley was examined for a distance of forty miles to ascertain the character of the stream dissection and to discover traces of the Tertiary gravels. About 100 miles of road were traversed, peneplain remnants being visited and beds of streams examined. In all this district not more than a few dozen pebbles were noted, aside from the angular fragments of chert, etc., evidently of local origin. These gravels occurred at scattered intervals, usually only a few at a place, and in or near the beds of streams draining high land areas. A longer and more detailed search would, of course, show other scattered traces of these gravels, but their extreme scarcity cannot be doubted. This remarkable lack of the gravel seems irreconcilable with the theory of capture, but is just what we should expect on the basis of the alternative theory.

On the divide between the Tennessee and Coosa-Alabama basins the Tertiary peneplain developed in this broad valley east of the ridge is very well preserved. As has been pointed out before, this peneplain is not well developed across the entire breadth of the valley, but where it has been so developed it remains very little dissected by subsequent erosion. The conditions are here especially favorable for the preservation of the gravels represented elsewhere so abundantly on mere scattered remnants of the peneplain. But not a trace of the gravels could be found over this area, nor on any surface elsewhere south of Chattanooga which could be referred to the Tertiary peneplain. It thus appears that the true Tertiary gravels are wholly absent in the valley southward from Chattanooga —a fact which forces us to the conclusion that this valley was not occupied by the stream which left such abundant evidence of its presence on the Tertiary peneplain elsewhere.

SUMMARY AND CONCLUSIONS

There are many features in the physiography of the Chattanooga district which are of great interest and importance, to which it was impossible to give special attention in the time at the writer's disposal. A detailed discussion of these features will be found in the reports by Dr. Hayes and Mr. Campbell. It may be said in general, however, that it appears that all of these features may be interpreted in accordance with the theory that the Tennessee River has held its present course since near the close of the Cretaceous period. The warping of the peneplains, which was supposed to determine the point of the proposed capture, may doubtless be present; and while it is not believed that such a broad, gentle arching as marks that region could sharply limit a series of divides to a given line representing the axis of the uplift, the presence of such warping is perfectly admissible on the basis of the conditions which are believed to have existed. That the drainage on Walden Ridge north of the gorge is to the eastward, while the drainage south of the gorge is to the westward, seems wholly in accord with what we should expect when the master-stream of the region is east of the ridge in the one case, and west of the ridge in the other. Those streams flowing into the master-stream by the most direct route would have a marked advantage over their neighbors flowing in a longer, more roundabout course, and would in consequence gain control of a large part of the area drained, pushing the divide to the western part of the ridge north of the gorge, and to the eastern part of the ridge south of the gorge. That the drainage in Cretaceous times may have been very different in places from what it is now, and that parts of this drainage may have persisted far enough into the beginning of the Tertiary cycle to leave traces of its existence on portions of Walden Ridge, is conceivable on the basis of either theory.

In summing up the evidence which has been presented in favor of the theory of a recent westward diversion of the Tennessee from a former southward course, it has been pointed out that while the facts noted in that connection admit of a rational interpretation on the basis of the theory of capture, they are to be explained just as readily and satisfactorily entirely independent of that theory.

On the other hand, there are certain grave objections to the proposed theory of capture, and certain lines of evidence which seem to prove that the Tennessee River has held its present course throughout Tertiary and more recent times. The winding character of the gorge, on the basis of the theory of capture, necessitates a process of diversion so involved and complicated that one is led to seek a more simple explanation for the phenomenon. The conception of meanders inherited from a former baseleveling period offers such an explanation. The character of stream-dissection on the ridge both north and south of the gorge is seen to bear strong evidence against the theory of capture, but is wholly in accord with the alternative theory. The complete breaching of the massive sandstone cap in several places by small streams at a time when larger and more powerful streams had scarcely begun that work, appears incredible. The divide south of Chattanooga is seen to present features distinctly different from what we should expect had a large stream flowed across it until the close of the Tertiary baseleveling period, but well in accord with the features observed on other divides developed by small streams working under similar geological conditions. In order to accept the theory of capture, we must admit that the headwater portion of a comparatively small stream, having, apparently, no marked advantage in regard to its length or the rocks over which it flowed, was able to reduce its valley to a considerably lower level than the middle portion of a great river near by—a thing which does not seem possible. The supposed former difference in relative elevation of the river-brought gravels above the Tennessee in the two valleys—advanced in favor of the capture—is seen not to exist. The altitude of these gravels noted in the Sequatchie valley strongly negatives the possibility of the proposed capture. The absence of the gravels from the peneplain southward from Chattanooga and the presence of nothing more than occasional scattered pebbles whose distribution indicates their Cretaceous age, completes the evidence that the Tennessee River has persisted in its present course through Walden Ridge for a long period of time, probably since the close of the Cretaceous period at least.

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ADDITIONAL NOTE ON HELICINA OCCULTA

B. SHIMEK
Iowa City, Iowa

Since the publication of the paper on *Helicina occulta*[1] the writer visited the type locality at New Harmony, Ind., from which Say obtained his fossil specimens of this species. Not only did the more or less plant-covered bluff from which Say probably obtained his specimens yield a number of shells, but more numerous specimens were obtained from several large exposures along the roads leading south from New Harmony which have been excavated since Say's time. The species is not as common, however, as in many of the more westerly localities.

Two loesses also occur here, the lower being the characteristic post-Kansan loess, and the upper, a light yellow loess, probably post-Illinoian. Few shells of *Helicina occulta* were found in the upper loess, and they average about 6.5 $^{\mathrm{mm}}$ in diameter.

The species is more common in the post-Kansan loess, and the shells from this loess are of special interest because of their large size. In the paper cited (pp. 177–79) the diameter of the largest fossil shells known from the loess is given as 7.25 $^{\mathrm{mm}}$, while that of the largest known recent specimens from the loess-covered region is 7.50 $^{\mathrm{mm}}$.[2] Several of the shells from the post-Kansan loess of New Harmony measure 7.50 $^{\mathrm{mm}}$, and the average is more than 7 $^{\mathrm{mm}}$. Thus the range of variation in the size of the recent shells within the loess-covered territory is fully equaled by that of the fossils, and differences in size cannot, therefore, be accounted for by general climatic conditions. The distribution of the smallest forms of this

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[1] *Proceedings of the Davenport Academy of Science*, Vol. IX, pp. 173–80.

[2] The largest authentically reported recent specimens were collected by Walker and Pilsbry on Mount Mitchell, North Carolina, and are reported in the *Proceedings of the Academy of Natural Sciences*, Philadelphia, in May, 1902, on p. 421, as follows: "A few large specimens, diameter 7¼ to 8 $^{\mathrm{mm}}$, were found under the dead leaves around the roots of the basswoods and buckeyes." This locality, however, is far outside the loess-covered region.

species, as well as the example of other terrestrial shells such as *Succinea obliqua*, *Polygyra multilineata*, etc., would suggest rather that local variations in the minimum amount of moisture are responsible for the differences in size, the smallest shells occurring in the driest or most exposed places. The average diameter of both recent and fossil forms becomes a little less as we go westward into drier regions, and "depauperation," so far as it exists not only in this, but in other species which occur in the loess, points decidedly toward a dry rather than a cold climate.

Perhaps further emphasis should be placed upon the distribution of both the recent and fossil forms of this species. Reference to the first paper on *Helicina occulta*[1] shows that the northernmost points at which recent specimens of that species were collected are Winona and Stockton, Minn., and De Pere, Wis.; the westernmost point is Eldora, Iowa; the most southerly point is South Pittsburg, near the southern line of Tennessee; while eastward the species extends beyond the mountain to Virginia. The southern limits of distribution lie beyond the border-line of the southernmost drift-sheet, the Kansan, and the eastern limits extend beyond the southeastern border-line of the Wisconsin drift. Northward the species extends locally over the Iowan, and a portion of the Wisconsin drift areas (in Minnesota (?) and Wisconsin), and also over a part of the driftless area in Iowa.

The fossils are more restricted in both their northerly and southerly distribution, but extend farther west, being known from the southwestern part of Howard County, Nebraska.[2] The known northern limit extends from Cuming County, Neb., to Woodbury and Johnson Counties, Iowa, Moline, Ill., and Sullivan County, Ind.[3] The southern limit, so far as is now known definitely, is at Kansas City, Booneville, and St. Louis, Mo.; Gallatin County, Ill.;[4] and Posey County, Ind. Owen also mentions *Helicina*, without specific name,

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[1] *Loc. cit.*, pp. 174, 175.

[2] See *American Geologist*, Vol. VII (1891), p. 40.

[3] Reported from the last locality by Collett, *Second Report of the Geological Survey of Indiana* (1871), p. 227.

[4] Reported by Cox, *Geological Survey of Illinois*, Vol. VI (1875), p. 210; *Economic Geology of Illinois*, Vol. III (1882), p. 561.

as occurring in Hickman County, Ky.[1] This is probably *H. orbiculata*, as Dana reports this species from Hickman, Ky., on the authority of Wetherby,[2] though Hickman County is so near the southern limit of fossil *H. occulta* that it may have been the latter species. However, neither conclusion would affect the discussion herein presented.

Since these two species have been frequently confused, the error leading to erroneous references to distribution which would mislead those who are not familiar with the facts in the case, some additional notes on this point are here offered.

Binney's and Aughey's errors have been noted in the previous paper.[3] In 1868 Tryon repeated Binney's error,[4] stating that *H. occulta* is found "fossil and bleached in the post-Tertiary of the western states, Indiana, Ohio, Mississippi, etc." All the authentic records of *Helicina* from Mississippi are those of *H. orbiculata.* Dr. A. Binney reported that species from the loess of Natchez in 1846.[5] In 1854 Wailes reported "*Helix helicina*" from Mississippi, this evidently being intended for *H. orbiculata.* The writer found it very common in the loess of Natchez in 1898,[6] but did not find *H. occulta.* It is safe to say that all specimens of fossil *Helicina* reported from south of Kentucky are *H. orbiculata*, fossils of that species being known only from the loess bluffs along the Mississippi River from Mississippi to Kentucky. Recent specimens of the species may be found from southern Florida to Texas, and northward to Tennessee, and Jasper County, Mo., the latter being the most northerly locality known.[7]

Other errors have resulted from this confusion of species. Thus, in 1875, Cox stated[8] that *Helicina occulta* Say, "has not, I believe, been found living north of Arkansas." The statement applied, at the time, only to *H. orbiculata.* Dr. Snyder's report of *H. orbiculata*[9]

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[1] D. D. Owen, *Geological Survey of Kentucky* (1856), p. 18.

[2] *Manual of Geology*, 4th ed. (1895), p. 966.

[3] *Loc. cit.*, p. 176.

[4] *American Journal of Conchology*, Vol. IV, p. 12.

[5] *Proceedings of the Boston Society of Natural History*, Vol. II, p. 130.

[6] See *American Geologist*, Vol. XXX, pp. 279–98.

[7] See *Nautilus*, Vol. VIII (1894), p. 18.

[8] *Geological Survey of Illinois*, Vol. VI (1875), p. 210.

[9] In Leverett, *The Illinois Glacial Lobe*, Monograph No. XXXVIII, U. S. Geological Survey (1899), p. 171.

from Virginia, Ill., is also manifestly an error. The same probably applies to Dr. A. Binney's report of the same species from Ohio.[1]

Neither recent nor fossil *H. orbiculata* extends northward to the border of the Kansan drift, both reaching almost the same latitude, that of the southwestern part of Kentucky. It is, therefore, decidedly a southern species, which has never been found in any condition in colder regions, and it is an abundant fossil in the southern loess. Indeed, the genus *Helicina* is almost wholly tropical, and before the habits and distribution of modern *H. occulta* were understood, the presence of a representative of this genus in the loess was looked upon as evidence that the climate was once *warmer* than at present. In this connection it may be of interest to read Dr. A. Binney's observations on this point, made more than half a century ago in connection with a discussion of the fossils of the Wabash River loess.[2] As the work in which it appears is not easily accessible, the material portion is quoted in full:

> As the genus *Helicina* belongs mostly to inter-tropical regions, and has rarely been met with in a recent state in so high a latitude as that occupied by these fossils, a good deal of importance has been attached to its occurrence here as indicating such a change of climate as has been alluded to. But this supposition creates more difficulties than it obviates, for the numerous species of other genera found in company with the species in question, and which live at this time in the same district in which the fossils are situated, must, according to this view, have also been adapted to a warmer climate than the present, though they do not now exist in southern latitudes, and therefore a very considerable change in their habits must have *since* taken place. Notwithstanding the facility with which the terrestrial mollusks accommodate themselves to the physical influences which act upon them, such a change is not consistent with what we know of their history, and hence the most reasonable conclusion is that the climate in which they lived, from the days when the multitudes which now compose the mass of the fossil beds were in the enjoyment of life upon the surface of the earth, to the present time, has remained essentially the same.

Dr. Binney did not in his day, of course, take into account the intervals between the several loesses, during which it is more than probable that the climate was severe. With this modification his statement concerning the climate is still further borne out by the species under discussion, for it is now known that the habits of *H. occulta* are essen-

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[1] *Terrestrial Air-breathing Mollusca of the United States* (1851), Vol. II, p. 353.

[2] *Ibid.*, Gould's ed., Vol. I (1851), pp. 182, 183.

tially the same as those of a number of terrestrial species now inhabiting the same area, and also often associated with this species in the loess. The present writer, long before he had access to Dr. Binney's work, repeatedly called attention[1] to the fact that the climate during the deposition of loess, as indicated by the fossils, was similar to that which prevails in the same region at the present time, and *H. occulta*, in common with a number of other species of terrestrial mollusks, offers strong testimony to this effect. The species does not extend far to the north, either in recent or fossil form, nor was it pushed far south by the ice-sheets following the Kansan. We have direct evidence of its existence only since the Kansan, but even if it occurred previous to the advance of Kansan ice, as it probably did, it still had plenty of room southward in which to persist. From this territory it again spread northward, but was checked by each of the ice-sheets following the Kansan. How far north the species extended during the several intervals preceding the final advance of the Wisconsin ice cannot be determined, as each advancing ice-sheet destroyed all the evidence of their presence, if any existed. That its advance[2] to the more northerly localities in which it lives today was comparatively recent, however, is supported by the fact that it has nowhere been found fossil in these northern localities. Thus, while recent specimens are not uncommon in Winneshiek and Howard Counties, Iowa, the loess of these counties has as yet yielded no fossils of this species.

Helicina occulta is not arctic, nor is it associated in the loess with species which are distinctively arctic. The fact that its range was not greatly extended during the oscillations of the successive glacial advances, and that it remained practically unchanged through all the interglacial loess-forming intervals, indicates a greater lack of

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[1] First in the *Proceedings of the Iowa Academy of Sciences* for 1895, Vol. III, p. 85, and subsequently in several papers.

[2] The question might here be raised as to the manner in which such advance could be made. While the writer does not contemplate here the discussion of this subject, he desires to suggest that, among possible agencies, violent storms may be included. The *American Journal of Conchology*, Vol. V (1870), p. 118, contains the statement that "John Ford exhibited specimens of *Gemma gemma* Totten, remarkable for having fallen during a storm which occurred at Chester, Pa., on the afternoon of June 6, 1869." *Gemma gemma* is a small marine bivalve.

plasticity and adaptability than that which is displayed by almost any other terrestrial species. It therefore, supports, better than any other single species, the conclusion that in time past the conditions under which this and other loess species existed were essentially like those under which this species lives today—especially those which pertain to climate and vegetation—and that, therefore, during the deposition of the fossiliferous loess the climate was not glacial.

THE GLACIAL FEATURES OF THE ST. CROIX DALLES REGION[1]

ROLLIN T. CHAMBERLIN
The University of Chicago

Lying partly in Wisconsin, partly in Minnesota, this region has claimed the attention of the surveys of both states and is covered in their reports by general descriptions, in common with the adjacent regions. Because of their clearness and grasp of the salient points, the accounts to be found in Vol. III of the *Geology of Wisconsin* relative to the main movements of the Superior glacier in the northwest section of that state, form an excellent introduction to a detailed study of the St. Croix Dalles quadrangle. The Kewatin glacier, whose drift barely crosses the river into Wisconsin, has fallen to the Minnesota geologists to investigate. The differentiation of the glacial deposits of the last epoch into the red and gray drift, whose upper, oxidized portion is spoken of as the yellow till, appears in the works of Winchell[2] and Upham[3]. More recently a part of the Dalles quadrangle has been subjected to a closer, detailed investigation by Dr. Berkey,[4] who describes, among other aspects of the Pleistocene, the two drifts, the erosion of the St. Croix channel, and the river terraces. In that article the view of the Minnesota geologists, that the ice-sheet of the red drift advanced across the region from the northeast, is entertained.

The topography of northern Wisconsin, in so far as it was molded

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[1] My first acquaintance with this region was made as a member of the field class of Dr. W. W. Atwood in July, 1904, at which time the views of Dr. Berkey, and the Minnesota geologists, relative to the formation of the red drift by a movement from the east, and of the gray drift by a movement from the west, and related interpretations, were assumed to be correct, and made the basis of our working hypotheses. At the close of the work, however, some of the interpretations were unsatisfactory. After spending an additional month in further study under a wider range of alternate hypotheses, I have reached the conclusions set forth in this paper.

[2] N. H. Winchell, *Geology of Minnesota*, Vol. I, p. 126.

[3] Warren Upham, *ibid.*, Vol. II, pp. 399–425.

[4] C. P. Berkey, *American Geologist*, Vol. XX (1897), pp. 345–83.

during the last glacial epoch, was due to the work of glaciers from the Labrador ice-cap. But over a large part of Minnesota the surface drift dates from an invasion of the Kewatin ice-sheet from the northwest. The Labrador ice arrived first, covering much of Minnesota; subsequently its deposits were buried by the advance from the northwest. The eastern limit of the Kewatin invasion was reached near the St. Croix River, in the vicinity of the Dalles.

The St. Croix Dalles quadrangle comprises those portions of Polk County, Wis., and Chisago County, Minn., which border on the St. Croix River between latitude 45° 15′ and 45° 30′, and longitude 92° 30′ to 92° 45′. The river, with some windings, flows generally south through the western half of the quadrangle. On opposite banks are the centrally located towns of Taylor's Falls and St. Croix Falls, while seven miles downstream is Osceola, Wis. The region as a whole is covered with a thick mantle of drift, which effectually hides the rock formations, except where uncovered by the river, or where an occasional boss of Keweenawan trap protrudes with a *roche moutonnéed* surface.

There are not only two separate drift-sheets represented as surface formations in different parts of the quadrangle, with the likelihood of an older till below, but the two dissimilar drifts both belong to the Late Wisconsin. The Dalles region is peculiar in having the eastern half of the quadrangle glaciated by the Labrador ice-sheet, and the surface of the western part covered by till from the Kewatin sheet. The glacier from the former source was the first to appear as a vigorous sheet, spreading heavy deposits of drift over the entire area. First to come, it was the first to go. It had retired quite beyond this region before the weaker development from the Kewatin gathering ground, spread to the St. Croix River. This ice crossed into Wisconsin less than a mile at St. Croix Falls, though about four miles in the vicinity of Osceola; but it quickly withdrew, leaving in most places only a thin covering of Kewatin drift. To get an idea of the work and relative importance of the two ice-sheets, conceive of the glacier of the red drift, or the Superior (Labrador) glacier, as a vigorous, long-enduring sheet, which produced most of the present topography, and of the glacier of the gray drift, or the Kewatin glacier, as a thin, transient advance of ice, which left as its record only a gray veneering of the red hills.

THE WORK OF THE SUPERIOR GLACIER

Whatever older drift there may be in this region has been so deeply buried under the thick Late Wisconsin deposits that no certain evidence of it was seen. The oldest glacial deposit thus far found is the red drift of the Lake Superior glacier. The first characteristic of this drift to catch the eye is its unusually red color, due to the presence of much ferric oxide. The unaltered till is very red; the stratified deposits from which the water has removed part of the coloring matter, less so. Often the surface layer has been partially leached of its ferruginous compounds, which have concentrated below, leaving the soil a brownish color. Another distinguishing characteristic of this till is that it is prevailingly sandy, and only locally clayey, signifying that the path of the ice advance was over an extensive sandstone and crystalline rock area, and that little limestone or shale was encountered. Of like import is the fact that, while there is the lithological heterogeneity characterizing glacial deposits, the pebbles are confined to a group of rocks chiefly of igneous origin, such as diabase, basalt, serpentine, various porphyries, granite and crystalline schists, together with sandstone. Limestone pebbles are conspicuous by their absence. The basalts predominating, the till may be described as a reddish sandy formation containing chiefly dark-colored igneous pebbles and bowlders. The source of this material is the Lake Superior region, the reddish sands coming from the Lake Superior Potsdam and Keweenawan sandstones, which are similarly tinted. Some of the red coloring-matter was also probably derived from decomposed ferruginous igneous rocks.

The movements and path of this ice-sheet are known from previous investigations to be these: The great ice advance from the Labrador snow-fields in the last Wisconsin epoch separated, west of the Soo, into two principal parts—one developing into the Michigan and Green Bay glaciers, which deepened the pre-existent valleys they entered, and partly formed and partly molded the troughs for the bodies of water which now bear these names; the other, similarly fashioning the Lake Superior basin, pushed on to the southwest, and formed the Superior and Chippewa glaciers. The Superior glacier, emerging from the Duluth finger of the Superior basin, deployed over much of Minnesota, and, spreading on its left flank in a southeasterly direction across the St. Croix, advanced some distance into Wisconsin.

Topography.—In this region the topography, with the exception of postglacial erosion by the river and a few minor streams, is largely the work of the ice of the red drift. In the western part the covering of gray till, and the leveling action of the ice which made it, have modified the original red surface somewhat, though not enough to disguise it effectively; in the eastern portion it remains unaltered, so far as later ice advances are concerned. The most prominent features of this topography are three roughly parallel, or concentric

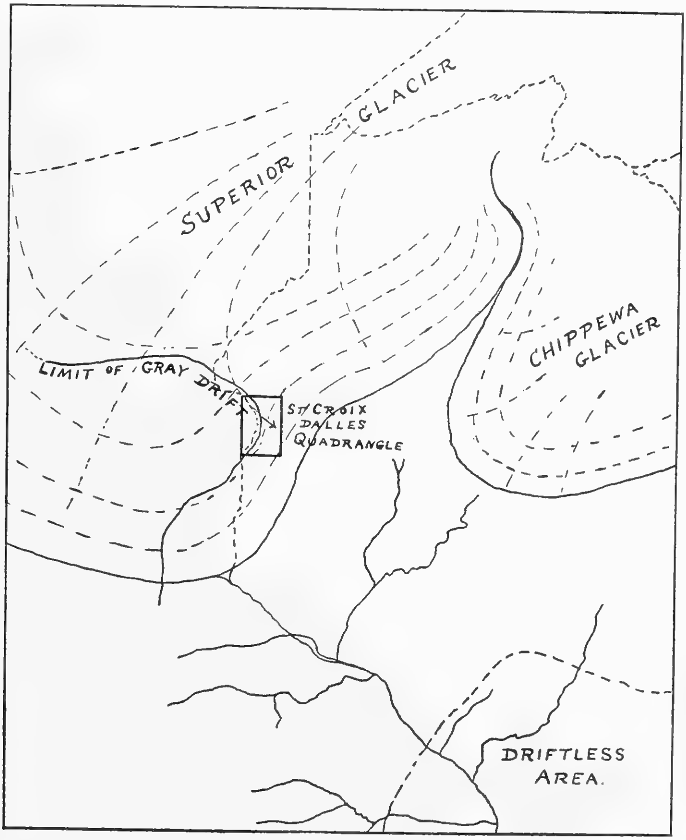

FIG. 1.—Sketch map, showing the general relations of the area of the St. Croix Dalles quadrangle. Data from maps of Wisconsin and Minnesota State Reports.

terminal morainic ridges which, running northeast and southwest across the quadrangle, mark successive halts in the glacier's retreat. These may be termed in the order of their ages, the Alden, St. Croix, and Franconia recessional moraines. (See map.) Splendid outwash and pitted-plain topography, especially east of the St. Croix ridge, together with some ground moraine, appear between these morainic belts.

The Alden moraine.—To the oldest of the three terminal moraines which come within this quadrangle, as I interpret them, I have given the name Alden, from the township on the Dalles map in which it occurs. Only a small portion of the big moraine is included in the Dalles sheet, whose southeast corner it crosses. In this neighborhood the axis of the belt apparently runs nearly northeast and southwest, but a short distance beyond the edge of the sheet it must quickly turn nearly due north (as the St. Croix terminal does), for the Alden moraine is found as a wide belt of alternating hummock and kettle, about two miles off the map, northeast of Deer Lake. Just how far east of this belt the outermost terminal moraine of the Superior glacier lies, I am unable to say, though it cannot be a great distance.

While the ice-front oscillated back and forth across this Alden belt, a rough ground-moraine topography was being formed under the body of the glacier to the west. Later, when the ice-edge was at the St. Croix recessional, much of this rough country was covered by outwash. This is particularly true of the northern portion, where only the higher hills of ground moraine have escaped the covering of stratified deposits. But from Sand Lake south, for reasons which will be brought out later, not only the hills, but the great hollows as well, remain. Some of the land appears rather rough for ordinary ground moraine, but it must be borne in mind that this area lies between two adjacent terminal moraines, and that all of the intermediate ground might be broadly included in a comprehensive terminal belt. That the high-hill and lake-basin topography was the type to be seen in the northeast portion of the quadrangle before the outward streamlets began their work, seems probable.

The St. Croix moraine.[1]—After a period of melting faster than the glacier advanced, according to my views, equilibrium was again

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[1] Name given by Dr. Berkey, *American Geologist,* Vol. XX (1897), p. 360.

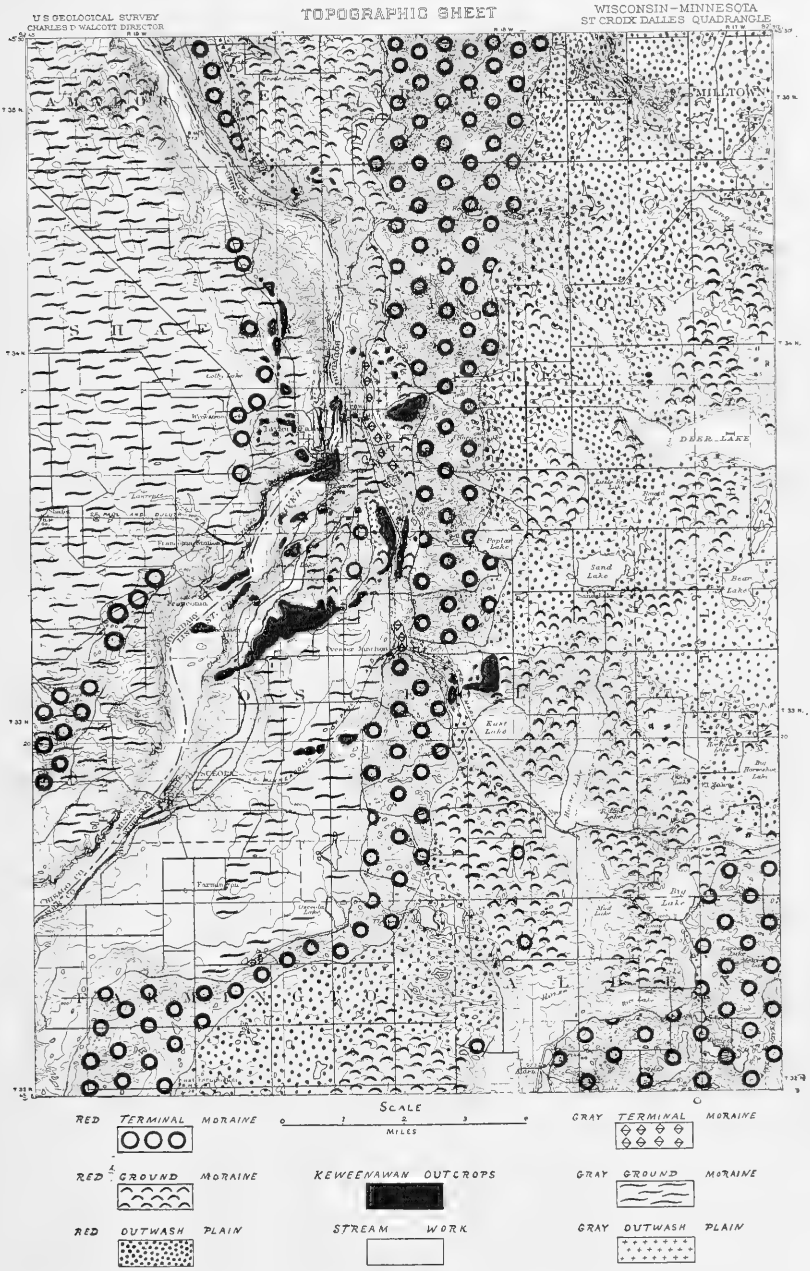

FIG. 2.—The geology of the St. Croix Dalles quadrangle. The Cambrian, which outcrops at points in the bluff of the St. Croix River, is not shown.

roughly established with the ice-front six or seven miles farther west, where the St. Croix moraine was piled up. This belt appears on the quadrangle about midway of the north margin, from which point it runs nearly straight south for ten miles to Dresser Junction, where it is cut in two by a gap. Beyond the gap it continues south for four miles, and then, as a much narrower strip, turns southwest, becoming wider in the extreme southwest part of the quadrangle. (See map.) In width, the belt varies from three miles in the northern portion, to about half a mile in the Township of Farmington. Like the older moraine, its concave side faces west-northwest. It is exceedingly rough and choppy, abounding in hummocks and kettles, knobby ridges, and blind valley depressions, the whole heavily overgrown with small trees and underbrush. The noticeably different aspect of the ridge when approached from the east and from the west is worthy of mention. On its eastern side the moraine merges into a smooth plain dipping gently away from it. There is no steep descent, nor are the moraine hills very much higher than the plain. On the west side, however, a steep declivity along the entire edge of the belt gives it an abrupt, ridge-like appearance. The hills in many places rise 200 feet above the lowland to the west. The significance of this marked difference will be readily understood in connection with the formation of the moraine and its outwash plain toward the east.

The St. Croix outwash plain.—Most of the region between the St. Croix and Alden moraines, with the exception of some hills of ground moraine which stand up above it, and an area near East and Horse Lakes which was never covered by outwash, belongs to the St. Croix outwash plain. With an altitude steadily diminishing to the east and southeast, the plain fades out in the neighborhood of the Alden terminal. East of Long Lake it reaches, and has even buried, some of the lower slopes of this ridge, over six miles from the ice-front at the St. Croix stage. But in general, east of the edge of the map, the outwash development is weak, and the underlying ground-moraine topography becomes more and more pronounced. The smoothness of this gravel plain, its rise near the crest of the moraine, its gentle slope to the eastward, and its mergence into drainage tracts in that direction, furnish the grounds for my interpretation of it as an outwash sheet formed when the glacier stood hard against the western side of the St. Croix moraine.

The surface of the plain is everywhere covered with a fine grayish-brown loam, free from stones, which hides the stratified material. The stratified deposits beneath are of variable thickness, from several scores of feet, as shown by some of the wells, down to two or three feet in road-cuts. While exposures are generally uncommon in the outwash plain and good sections rare, a few of them reveal typical red till underlying the sands and gravels. It is in these that the difference in coloring of the stratified and non-stratified red drift is so noticeable. Along some of the roads in this wide belt, red till appears in some places without any stratified material in sight. These patches are found to be above the level of the surrounding outwash plain on slight eminences which escaped the depositing streamlets. Such isolated hills of considerable size occur northeast of Poplar Lake, and both north and south of Deer Lake. A feature which quickly catches the eye is that on the ground-moraine areas large bowlders are numerous, whereas they are nowhere to be seen on the outwash plain.

One of the pronounced features of the outwash is the pitted-plain development. The pits are of varying dimensions, from depressions in which there are small frog-ponds, up to deep hollows exceeding a mile in length. Many of them contain lakes but many, even of the large ones, do not. The several hundred which are large enough to be represented on the map are pretty evenly distributed throughout the plain, but it is reserved for Eureka Township, in the northeast corner of the quadrangle, to display the most striking pitted-plain spectacle. In this locality there is a splendid series of pits, some of them of great size and as much as 100 feet deep. Their steep sides drop rapidly from the plain in which they are sunk, and the bottoms, instead of being flat, or basin-like, are very hummocky.

The region southeast of the Dresser Junction gap is characterized by a topography not usually seen in the midst of an outwash plain. The question arises: Why do great depressions like the basins of East, Horse, Round, and other similar lakes, exist with ground moraine hills between, when even the hilltops are lower than the level of the outwash plain to the north? Horse Lake is but tw miles from the St. Croix moraine, and as low as 960 feet, but its basin has escaped filling by outwash material. Less than a mile northeast of the extremity of the lake flat, the outwash plain ends at the 1,140-foot contour. East Lake is still nearer the moraine, but on the east side of the lake, one mile from the terminal, no stratified drift is found, from the 1,100-foot hilltops to below 1,000 feet, where the hill has been modified by the lake when at a higher level than now.

The reason for this considerable area of ground moraine, almost unaffected by the St. Croix outwash, though at a low level, is found in the established drainage lines. Previous to the outwash deposits, a well-developed drainage channel existed from the Dresser Junction neighborhood, past East and Horse Lakes, following what is now the Horse Creek valley, to the Apple River. When the glacier front stood at the St. Croix moraine, the streams from the melting of the near-by ice quickly collected in this course, producing sufficient volume and velocity to prevent extensive aggradation of the channel. Gathered into one course, the rivulets from the immediate neighborhood did not spread out over the country to the east, whose hills and marshes remained unaltered. However, several miles farther east, in the vicinity of the two Horsehoe Lakes, streamlets from the north, which avoided the Horse Creek drainage system, have been able to spread much farther south, where they have partially filled in the low, marshy areas four and five miles from the moraine.

The Dresser Junction gap.—When the ice stood some distance west of the St. Croix moraine, possibly while at the Franconia recessional, perhaps not so far, the high St. Croix morainic ridge blocked the drainage from the melting ice. As a result, the water ponded between the moraine and the ice-sheet until it rose to the lowest point in the barrier ridge, which happened to be at Dresser Junction, whether by chance, or because of the influence of a pre-Wisconsin channel at this point. Upon reaching the proper height, the overflow cut the barrier down rapidly; for, having dropped most of its load in the ponded portion, the water was relatively clear. The Horse Creek channel was still further eroded and the gap lowered nearly to this level. In later times, when the gray ice advanced to Dresser Junction, its outwash went through the gap. The extensive flat east of Osceola appears to have had its beginning with the ponded waters and outwash from the west.

The Franconia recessional.—The most westerly, and youngest, of the red terminal moraines in the Dalles region, I have termed the Franconia, from the fact that it was first detected on the uplands back of Franconia. It is the most difficult of the three to trace, because most of it has since been rubbed over by the gray ice, which covered what was left with a thin sheet of gray till. As mapped, the chain consists of seven separate links, disconnected by the later ice invasion, but all in a slightly curved strip, whose missing boundaries could easily be drawn. With the exception of the most northerly patch, this moraine lies west of the river in Minnestoa. (See map.) The curved belt is concentric with the two other moraines across the river. In this buried recessional all degrees of terminal topography are displayed, from that which can scarcely be identified, to a strong kettle moraine. Opposite Osceola its great depressions and hummocks have been well preserved; between Taylor's Falls and Franconia station it has been almost entirely obliterated. The veneering of gray drift varies in thickness; on the northernmost strip of this moraine, east of the river, practically no gray till was found, though the presence of limestone pebbles, and also striæ beyond it, proves that this ice once visited that section. Along the railroad tracks, between Taylor's Falls and Franconia, some of the steep banks expose from 20 to 30 feet of gray till, but this is unusual and excessive. The average thickness is perhaps best represented in the strip back of Franconia village, or near Wyckstrom Lake where, in a number of cuts, from 2 to 3 feet of gray drift rests upon the red.

While a strong terminal moraine belt can survive the effects of a subsequent ice advance, and still be recognized by its topography, an outwash plain is much less easily distinguishable under these unfavorable conditions. But by its stratified material it is readily identified. In the road-cuts near Franconia, and from this point south, in the excellent sections revealed by the gullies which are working from the river back into the Minnesota uplands, a thick deposit of stratified sands and gravels is found everywhere to separate the red and gray till-sheets. The lines of contact are sharp. Lithologically, these gravels are the same as the coarse material of the unaltered red drift, from whose ice-sheet they are unquestionably the outwash. Occurring beneath the gray drift nearly everywhere between the Franconia moraine and the river, they belong to the glacio-fluvial work at the Franconia stage. No limestone pebbles are found *in situ* within these deposits, though much limestone frequently has rattled down, as talus, from the gray drift above, and the gravel has often been cemented into a Pleistocene conglomerate by the calcareous waters from the later till-sheet.

In July, 1904, beds of humus material and clay containing pelecypod and gastropod shells, apparently of land types, were reported to have been found between the red till and the stratified drift above, in one of the gullies south of Franconia. In August these beds could not be found. Evidences of slumping were everywhere, induced by the unusually heavy rains of July; possibly the reported interglacial beds had been buried; perhaps they themselves were earlier slumps partially covered with gravel talus. Elsewhere in the same gully, and in the various tributaries where good exposures of the till and outwash gravels could be examined, the contact was clearly marked without any indication of a soil line. The same conditions obtain in the numerous cuts and sections in the strip between the moraine and the river. Vegetable matter and fossiliferous clay, in place, between the red till and red overwash, would mean that, after the unstratified drift was deposited, the ice retreated west far enough and for a time long enough to permit the growth of vegetation and the immigration of mollusks, and that it again advanced, producing the Franconia moraine and the overwash gravels.

West of the Franconia terminal is a gently rolling ground-moraine topography for several miles beyond the boundaries of the quadrangle. Still farther in this direction, a region of many lakes and some moraine belts was seen from the train; but, since the gray drift becomes thicker toward the west, it was not apparent how much of the topography is to be assigned to the red ice. The main fact is that the red glacier retreated toward Lake Superior before the gray ice invaded the region. How far the red had receded by the time the gray appeared, and where the two ice-sheets met, if they ever did come together, are questions which cannot be answered from a knowledge of the St. Croix region alone. Upham[1] reports a soil line between

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[1] *Geology of Minnesota*, Vol. II, p. 414.

the modified drift (red outwash) and the gray above, as found in several places in Chisago County. This would indicate a considerable interval between the two ice-sheets.

The story of the rocks.—The hard ledges of Keweenawan trap-rock in the Dalles region exhibit good stoss sides, which furnish strong evidence of the direction of ice movement. East of the river, and especially east of the gray terminal moraine, the planed sides are almost invariably the west or northwest slopes of the ledges, the few exceptions being clearly local accidents. These may be called the red stoss sides; they occur also on the west side of the river, but here the complication of the Kewatin ice is added. Knobs and tails produced from the resisting amygdules in the diabase agree with the story of the stoss sides. Striæ have not been well preserved on these rocks, which in general have weathered sufficiently to destroy the scratches. By looking over a large number of ledges, however, plenty of records can be obtained. The location, direction, and significance of these can best be understood from the striæ map. While there is considerable variation, owing to the fact that they were made at no great distance from the fluctuating edge of the ice, they tell a consistent tale. The striæ are in three sets.

1. The earliest set of scratches discovered affect only a few outcrops above the bend in the river, four and a half miles due north of Taylor's Falls. In a gully whose stream has cut deeply into the drift and laid bare the Keweenawan, striæ reading S. 11° E.[1] and S. 13° E. were found, accompanied by a more marked set running S. 40° E. Half a mile northeast, the hillside ledges bear striæ S. 8° E., S. 11° E., and S. 15° E. As shown on the map, these were probably made when the ice covered the entire quadrangle and was making its terminal moraine at a considerable distance away. The set of striæ next to be described, S. 40° E., are better represented on these rocks, but those of the latest, or third, group are absent; suggesting that the ledges became covered by drift and were protected during the St. Croix terminal stage. This protection may explain the presence of the old striæ which are not found in less favored places. The weak ice of the gray drift, however, has left a still later set of marks

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[1] The directions of striæ are all corrected for magnetic variation.

on the hillside ledges, though those in the ravine which were buried, escaped.

2. The second set of striæ formed by the red ice trend about S. 40° E., with some S. 45° E., and even S. 49° E. These striæ are interpreted as the work of the ice-sheet which had its front at the Alden moraine. This set is the most persistent in the region, suggesting vigorous ice-work at this time.

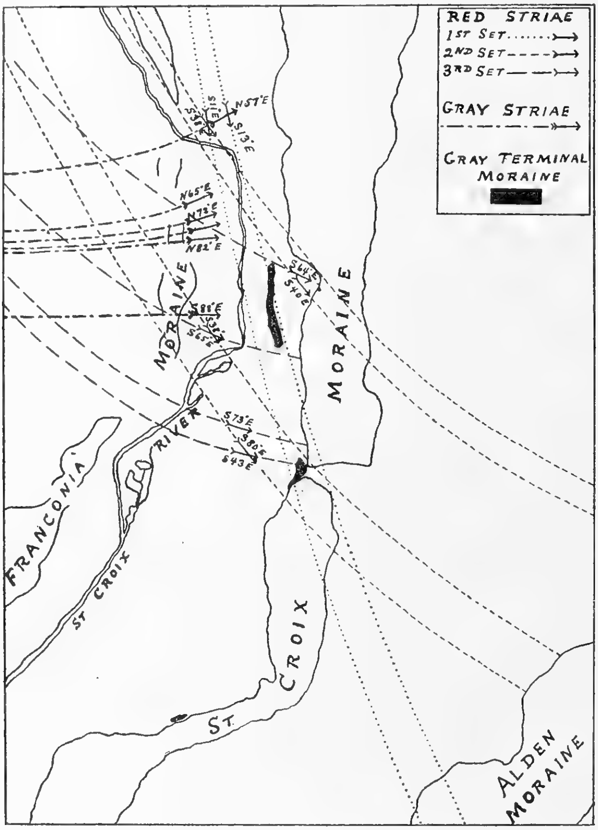

FIG. 3.—Map showing the glacial striæ of the St. Croix Dalles quadrangle

3. The third, and most recent, group of striæ vary from S. 63° E. to S. 80° E., and are thought to have been engraved while the St. Croix moraine was being formed. A comparison of the three sets shows that the first possessed most nearly the direction of main move-

ment; the second, formed as the lateral edge of the ice-lobe came nearer to the rocks in question, deviate about 28° more to the east; while the last, produced near the edge of the ice, trend 30° more to the east. A progressive turning toward the border of the lobe is thus shown. This is in accordance with the law of ice-flow in broad, flat lobes. The general direction of movement of the Lake Superior lobe was southwesterly, but on this, the left flank, its advance was southeasterly toward the ice-edge. The dotted lines on the striæ map are attempts to show this.

Bowlder trains are not of great service as indications of the direction of ice advance in this region, as they are poorly developed. In the lee of only one prominent outcrop—a mile and a half east of Dresser Junction—are the fragments of diabase conspicuous. There bowlders occur in great numbers on the east side of the rock hill.

WORK OF THE KEWATIN GLACIER

Some time after the Superior glacier had withdrawn, the Kewatin sheet, coming down the Red River valley, advanced from the west to the middle of the Dalles quadrangle, spreading its drift over the previous red deposits. This younger drift is strikingly different from the older in several particulars. Its color is a grayish buff, somewhat like that of the drift of southern Wisconsin, though lacking the brownish ferruginous tints. Frequently the surface layer which has been leached exhibits a more yellowish or brownish shade than the unaltered till, due to the oxidation of the iron compounds. While the red drift is sandy, the gray is clayey; the former, as previously noted, contains neither limestone nor shale, both of which abound in the latter. Since much of the western drift is the product of limestone ground up, it follows that it is highly calcareous, except in the upper foot or two where leaching has occurred. The red drift is non-calcareous. Part of the limestone, and most of the dark gray shale which is so characteristic, were probably derived from the Cretaceous strata of western Minnesota and the Red River valley. However, a few Trenton fossils found in the glacial pebbles prove that the Cretaceous series was not the source of at least a part of the limestone in the gray drift.

Gray drift covers all the territory in the quadrangle west of the river, with the exception of some small patches of red drift over which the western ice crept, but either did not leave any débris, or so little that it has since been removed. In Wisconsin it occurs largely in patches, partly because little or no drift was left in some localities, and partly because of stream erosion. East of Osceola this glacier actually reached the St. Croix moraine; from the north of the map to within three miles of St. Croix Falls no gray drift was found on the east side of the river, though striæ interpreted as belonging to the gray ice, and a few limestone pebbles, indicate that the Kewatin glacier visited these parts. As this region was covered only by the extreme edge of the Minnesota glacier, which seems to have been thin, and not to have remained here long, it did not effect a great change in the topography. Some of the hills of red drift were worn down, and many of the depressions filled, but the covering of gray drift is too scanty to mask entirely the old red topography.

The gray terminal moraine.—While the red terminal moraines in this region are all of the recessional type, though large and prominent, the gray moraine is a limiting terminal marking the extreme extension of the sheet, but it is the weakest and most obscure of all. So far as my knowledge goes, the gray terminal first appears at the north within the quadrangle about half a mile east of the river, and a mile north of St. Croix Falls, where it is very indistinct. North of this, on account of the scarcity of gray drift, it has not been recognized. From this point it runs slightly east of south for two miles, becoming a more pronounced ridge; but it cannot be traced beyond the great pit near the railroad tracks, one mile southeast of St. Croix Falls station. From the pit the boundary of the gray till-sheet swings sharply to the west, and then southwest along the slopes of a high veneered rock hill, until it is lost amid Keweenawan ledges, two and a half miles south of Taylor's Falls. Farther south, however, at Dresser Junction, there is a hummocky ridge, though scarcely more than half a mile long, piled up across the front of the great gap in the St. Croix moraine. This is the best-developed portion of the gray moraine. Considering the position of this strip, and the direction of the ridge running from St. Croix Falls south to the great pit, it appears a plausible view that the ice-front at its maximum point stood along a line connecting these morainic strips, approximately where the railroad is today. However, no gray drift was found on the upper part of the hill to the west, which must have been overridden by the ice according to this view, nor has any direct evidence appeared in support of this idea. A further study will be necessary to establish this portion of the border line. South of Dresser Junction the terminal moraine was discovered only in a single isolated spot, three miles southeast of Osceola, where, as is strikingly shown in a road-cut, the ice punched against the red St. Croix terminal, leaving the red and gray till in a dovetail contact. That the limit of the gray ice south of Dresser Junction was the western edge of the St. Croix ridge seems probable.

From so transient an ice advance an outwash plain would not necessarily be expected. In but one place, the Dresser Junction gap, where drainage was concentrated, is gray outwash material seen in any quantity. In the gap not far from the Kewatin moraine at least 10 feet of limestone gravel rests upon the older stratified deposits of the Superior glacier.

The Minnesota upland, except in the belt of the buried Franconia moraine, and at a few points where hills of red drift protrude, in the northwest corner of the quadrangle, is surfaced by a gently rolling ground moraine with abundant marshes and undrained areas. The thickness of this drift sheet is variable; on the hillside, a quarter of a mile west of the picnic grounds in Taylor's Falls, the older red drift appears at the surface in an isolated spot; at the picnic grounds, and also in some of the cuts along the railroad to Franconia station, between 25 and 30 feet of gray till are exposed. As previously stated, 2 or 3 feet is about the mean depth of gray material on the Franconia moraine. The thick sections of gray drift which so greatly exceed the average all occur near the river, suggesting a pre-Kewatin valley or depression favorable to greater accumulation of débris. West of this strip of heavy gray drift along the river—between Taylor's Falls and Franconia—the buried red terminal moraine has been nearly obliterated.

Work upon the rocks.—Instead of the northwest sides of the Keweenawan ledges being planed, as is the case east of the gray terminal, the outcrops west of the river are rounded and polished on the west or southwest slopes. In many cases the work of the red ice is still visible, but the southwest stoss sides, fashioned later, are the more pronounced. These, with the steep drop-off faces on the east and northeast sides, give the general direction of movement, but for more exact data recourse must be had to the striæ. On the hill west of Taylor's Falls the prevailing striæ read in the neighborhood of S. 88° E., showing that the ice moved nearly due east here. In Senator Deedon's yard, a mile and three-quarters to the north, they trend N. 82° E. Farther north, on the opposite side of the road, the following were recorded in order about a quarter of a mile apart: N. 73° E., N. 72° E., and N. 65° E. Across the river, two miles farther north-northeast, scratches were found reading N. 57° E. These varied, but progressively changing, directions put together on the map, show very prettily how the ice of the gray drift spread out near its outer border until, in places it advanced nearly due northeast. On some of the less exposed portions of the *roches* striæ of the Superior ice are still to be seen.

POSTGLACIAL PHENOMENA

Since the Kewatin ice-sheet retreated, the region has undergone some interesting changes, due to erosive action, chiefly that of the St. Croix River. As to what may have been its preglacial course, this region offers little in the nature of a clue. There may have been a preglacial channel past Dresser Junction, and along Horse Creek valley to the Apple River, which lower down empties into the present St. Croix. While the cut between the diabase hills, one and a half miles north of Dresser Junction, was very likely a sluice-way for waters from the melting red ice farther north, to the ponded area, it does not appear to be low enough to form part of a river course before the area just north of it was built up by the thick deposits of drift.

During the early stages of the river's postglacial history, when great floods of water descended the St. Croix from Lake Duluth, much of the flat land east and south of Osceola was temporarily covered, and the already nearly flat area appears to have been still further leveled by sedimentation. Later the river retired to a more definite course which soon deepened. Since the first well-marked course was formed, the stream between Taylor's Falls and Osceola where the most Keweenawan trap-rock was encountered, has migrated westward down the slopes of hard diabase, and cut away the less resistant sandstone and shale. The slopes on the Wisconsin side, opposite

Franconia station for instance, are comparatively gentle, but the Minnesota bank is a steep cliff of Cambrian sedimentaries. A well-developed channel, nearly parallel to the present course and about one mile east of it, can be followed from the bend in the river at the interstate park in Taylor's Falls to Osceola, where it joins the St. Croix today just below Eagle Point. It is not difficult to find the points at which this course was abandoned in the migratory process —first two miles north-northeast of Osceola at a barrier of Keweenawan, next two and a half miles farther upstream at a similar obstacle, again at Thaxter Lake, and lastly at the elbow near Taylor's Falls, where, finding a deep rock fissure, running northeast and southwest, more in line with the new course of the stream below, the opportunity was taken to readjust itself. Some readjustment is evident also above the Dalles in the immediate vicinity of the town of Taylor's Falls.

Terraces.—Objections based chiefly upon the depth of the gorge at the Dalles, and an assumed slowness of erosion through the compact igneous rock, have been raised against considering the canyon to be the work of the St. Croix since the glacial epoch. By Dr. Berkey it has been referred to postglacial erosion. That this is so is evident from a number of considerations. While the river occupied the earlier channel just described, which was long after the ice withdrew, it was cutting the rock barrier of the Dalles at 850 feet, more than 150 feet above the stream-level at this point today. The portion of the Dalles below the bend is still younger. But perhaps the most conclusive and neatest bit of evidence is that furnished by the terraces.

Well-defined alluvial terraces line both banks of the St. Croix above the Dalles, though there are none corresponding to them below the bend in the river, and most of them gradually disappear a few miles upstream. On the Wisconsin side the best benches are at 725 feet, 780 feet, and 810 feet levels; while in Minnesota the most prominent are at 750 feet and 920 feet. There are some correspondencies between the two banks, but, in general, where there are extensive flats on one side, the stream has swept away those opposite. The 750 and 920-foot terraces have small tallying benches across in Wisconsin; but, the 725 and 810-foot flats are not to be found in Taylor's

Falls. Other terraces occur at 880 feet in Taylor's Falls, and 875 feet at its highest point in St. Croix Falls.

The significant feature of these terraces is that none of them is continued below the Dalles. The highest, and that at 880 feet, end against the Keweenawan barrier near the Taylor's Falls schoolhouse; the 750-foot flat, upon which most of the town is built, terminates with the trap-rock in the interstate park; the 875 and 810-foot flats disappear less abruptly on the wooded river banks not far from the diabase ledges; the lowest bench is stopped at the rocks close to the toll bridge. The hard trap-rock at the Dalles acted as a barrier, while the stream above formed a flood-plain. As soon as the falls which developed from the more rapid cutting below the barrier, cut a stope through the barrier and reached the drift above, a trench was quickly cut in the alluvial plain, producing a terrace. At a later time, when the stream-level to the south had lowered sufficiently, falls again developed and produced another terrace; and so on. The pronounced 780-foot terrace, instead of extending upstream from the Dalles, starts with the narrows at the present falls, nearly a mile farther north, where another, but much lower, barrier checked the stream's progress. Falls were therefore here at the time of the formation of that terrace, and with the same reasoning it is safe to predict that the next terrace to appear will be just above the present falls.

The highest of the terraces, at 920 feet, represents approximately the original level of the drift at this point, showing that soon after drainage adopted this course, the igneous rock was encountered, and the stoping process begun; the younger benches, lower upon the slopes of the trench, mark the stages or repetitions of this method of rock erosion with alternate filling and cutting upstream. These postglacial terraces, intimately associated with, and dependent upon, the receding falls, indicate that the cutting of the deep, but short, gorge in the Keweenawan has all been accomplished by the St. Croix since the retreat of the last ice-sheet.

A FOSSIL STARFISH FROM THE CRETACEOUS OF WYOMING

STUART WELLER
The University of Chicago

A specimen of a fossil starfish has recently been presented to the Walker Museum of the University of Chicago, by Mr. N. H. Brown, of Lander, Wyo. The specimen is preserved in a fine-grained, light yellow sandstone from near the summit of the Upper Cretaceous which may be referred to the Fox Hills formation. Though all the characters desirable for the classification of the specimen are not perfectly preserved, yet there is justification in the description of such a specimen because of the extreme rarity of such fossils in the Cretaceous faunas of America, and because it is probably the best specimen of a Cretaceous fossil starfish yet found in America; at least no specimen so nearly complete has been mentioned in the literature.

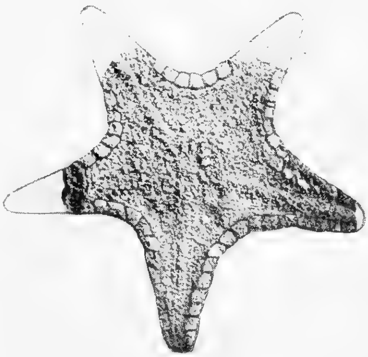

FIG. 1.

The specimen is apparently exposed from its dorsal side, but, apart from the large marginal plates, all the plates of this surface have been destroyed. The impressions of the ambulacral furrows of the ventral surface are exposed by the weathering away of the dorsal surface, and appear as rounded, slightly elevated ridges extending from the arm tips to the center of the disk; but the characters of the ambulacra are not sufficiently well preserved to be accurately determined.

The presence of highly developed marginal plates upon the specimen mark it at once as a member of the order *Phanerozonia*, and it may be placed, without serious question, in the family *Pentagonasteridae.* The reference of the specimen to its proper genus is less satisfactory, but it seems to agree more closely with *Pentagonaster* than with any other, although the interradial arcs are somewhat deeper than is usual in that genus. In the recent species *P. arcuatus* Sladen,[1] however, these arcs are nearly as deep as in the fossil specimen, the proportion between the minor and major radii being 1 to 1.93, while in the fossil specimen it is 1 to 2.08.

The specimen also more or less closely resembles, in the characters which are preserved, some of the recent species of *Gnathaster*, a genus also belonging to the family *Pentagonasteridae*, in which the interradial arcs are often much deeper than in *Pentagonaster*, in *G. elongatus* Sladen,[2] the proportion of the minor to the major radii being 1 to 3.5. This genus, however, is usually characterized by the presence of an odd interradial marginal plate—a character not clearly shown in the fossil specimen. In one of the interrays such a plate seems to be present, but in the others not. For the present, therefore, the specimen may be referred to the genus *Pentagonaster*.

Pentagonaster browni *n. sp.*

(Fig. 1)

Description: Stellato-pentagonal in outline, major radius 24^{mm}, minor radius 11.5^{mm}. Disk large, apparently flat. Interradial arcs broadly rounded, the rays elongate for the genus, rounded at their extremities. Marginal plates large, about sixteen occupying each interradial arc from tip to tip of adjacent rays, the character of their ornamentation not preserved.

Horizon and locality: Fox Hills sandstone, S. E. ¼, Sec. 16, T. 32, R. 99, near Lander, Wyo.

Type specimen: Paleontological Collection, Walker Museum, No. 10725.

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[1] *Challenger Reports*, Zoölogy, XXX, p. 277, Plate 52, Figs. 1, 2.

[2] *Ibid.*, p. 288, Plate 48, Figs. 1, 2.

THE SO-CALLED ALKALI SPOTS OF THE YOUNGER DRIFT-SHEETS

O. W. WILLCOX
Fort Hancock, N. J.

The surface of cultivated fields on the younger sheets of glacial drift in Iowa, Wisconsin, Illinois, and Indiana is frequently marked by patches of a white efflorescence which is distinctly hostile to many cultivated plants, particularly corn. These patches have received the name of "alkali spots" from the farmers of the region, to whom they are a source of perplexity and loss.

Genetically, these "alkali spots" are invariably connected with the small sloughs or lakelets which characterize the extreme topographic youth of drift-sheets. As is well known, the surface of the Wisconsin drift is pitted with countless thousands of these small bodies of water; the Iowan drift bears them in notably smaller proportion, a circumstance in harmony with the more advanced development of the natural drainage of this drift-sheet. In their undrained condition these basins are a hindrance to agricultural operations, although in general the water may readily be removed by drainage; this is being done on an enormous scale in the states mentioned. In a very large number of cases, however, the farmer, after doing away with the standing water, finds the reclaimed land affected by the harmful efflorescence mentioned above.

Analysis shows the efflorescence to consist of small amounts of sodium chloride and much larger amounts of the carbonates and sulphates of magnesium and calcium; magnesium sulphate is a leading constituent. Sodium carbonate is absent; the efflorescence lacks therefore the character of a true alkali, and the soil infested with it is not an alkali soil, as this term is understood in the semi-arid West. The hostility of the soil of the "alkali spots" to corn is due to the presence of excessive amounts of magnesium salts in the soil moisture.

The *raison d'être* of the efflorescence is not far to seek. It will be borne in mind that many of the innumerable sloughs of the younger drift-sheets occupy the lowest points of depressions without outlet. These depressions constitute isolated basins having an area varying from two or three up to as many hundreds of acres in extent. The floor of these basins consists of the finely pulverized rock-flour characteristic of the ground moraine. Owing to its fineness, the material of the till is in the most favorable condition to be attacked by the agencies of weathering. The alkaline-earth carbonates are attacked and rendered soluble by the carbon dioxide of the air; the sulphur in the pyritiferous minerals of the till is oxidized and converted into sulphuric acid, which ultimately appears in the form of its calcium and magnesium salts. Doubtless a certain proportion of the material dissolved out of the till enters the general underground circulation, but a large part simply collects in the water which has found its way to the lowest part of the basin and has there been concentrated by evaporation. Since the final retreat of the ice, this process of concentration has in many cases brought the percentage of dissolved matter up to a figure quite beyond that which is usual for surface water. This is especially true of small ponds which receive the drainage of large areas; but even those located in small basins frequently contain appreciable amounts of salts, as is apparent from the white residue left on their floors when they dry up in summer. Many of the lakelets of the drift are, on a small scale, embryo salt lakes, in which magnesium sulphate instead of sodium chloride is the principal dissolved substance.

The earth in their vicinity is consequently saturated with water carrying a notable amount of saline matter, chiefly soluble salts of magnesium. When the farmer tiles out the basin, the excess of water is drawn off through the drains. Much of the dissolved magnesium is thus removed, but not all, for no drain will at once remove all of the water; even the percolation of the rain water of several successive seasons is frequently insufficient to wash out all of the deleterious salts.[1] Although these

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[1] This will be understood by every student of chemistry who has had occasion to wash a dense precipitate to free it from a soluble salt. The obstinate retention of certain salts freely soluble in water by a finely divided solid is not always purely mechanical. The phenomena of adsorption (*ad*sorption is different from *ab*sorption), of which chemists have only recently begun to take account, come largely into play.

salts are slow to find their way out of the soil through the drains, capillary flow during dry weather readily brings them to the surface, where evaporation raises the percentage of magnesium in the soil moisture in the zone of root-growth beyond the point of toleration by the plants; continued evaporation of the surface moisture produces the efflorescence.

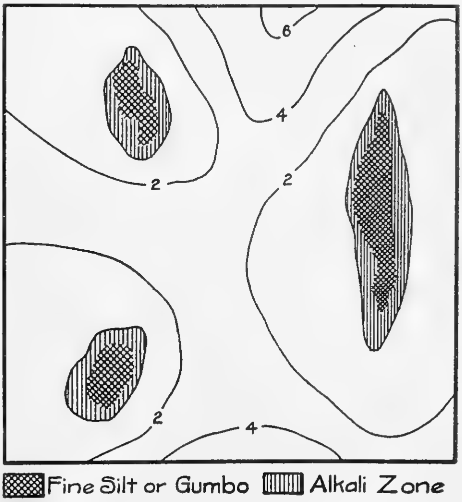

FIG. 1.—Group of small annular "alkali spots" on the Story County Poor Farm, Iowa. (Horizontal scale: 1 inch = 200 feet.)

If the floor of the slough was originally somewhat peaty, and therefore porous, the efflorescence is fairly evenly distributed over the area formerly occupied by the water; but if, as is more usually the case, the slough has been silted up with fine material, the efflorescence appears in a zone corresponding to its former margin. It is the occurrence of this annular area of barren ground in an otherwise productive field which mystifies the farmer and the agricultural writers.

The occurence of this annular zone of poisonous soil is accounted for on the following considerations: The surface water which finds its way into the slough carries with it both fine and coarse material; the particles of the grade of sand are deposited first, while the silt is distributed farther from the border. The soil and subsoil of the margin are consequently more open-textured than the soil of the interior; hence there is a predominant flow of capillary moisture toward the porous margin, where evaporation renders conspicuous both the efflorescence, and the poisonous condition of which it is the sign.

The essential features of typical "alkali spots" are shown in the accompanying figures.

Adsorption is undoubtedly a considerable factor in geological chemistry, and should receive greater attention from soil investigators.

It is a matter worthy of remark that the immediate surface of the Iowan drift-sheet seems to be much poorer in soluble sulphates than is the case with the Wisconsin. The Iowan has its "alkali spots," to be sure, but their occurrence is due to the preservation of favoring topographic conditions. Where natural drainage has long been established, as in the vicinity of the master-streams, the proportion of soluble sulphates in soils of the Iowan drift is quite normal. It appears to be otherwise with the Wisconsin drift, even in the broken area adjacent to the streams which flow across the tip of the Des Moines lobe south of the Gary moraine; in this region is to be found that part of the Wisconsin drift which, in Iowa at least, has been longest exposed to weathering, since it was the first to be left bare by the retreating ice. Close examination of hillside surfaces in this area after several days of fine weather often reveals the presence of an efflorescence similar in appearance to that found in the "alkali spots;" the presence of soluble sulphates is easily shown by scraping about twenty grams of earth from the surface, extracting with pure water and adding a solution of barium chloride, whereupon a copious precipitate of barium sulphate will be obtained. This appears to be a point of difference between the surfaces of the two drift-sheets.

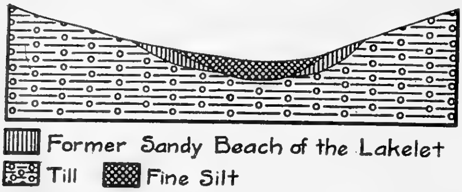

FIG. 2.—Section through an "alkali spot."

It will be recalled that in estimating time ratios within the glacial epoch much weight has been laid upon the obvious differences in the present condition of the upper zones of the various drift-sheets. The absence of lime, the decay of the felspars, the complete oxidation of the iron content so unmistakably patent in the ferretto of the Kansan clearly stamp this till as of greater age than that made by later ice-sheets. No such obvious differences set off the later tills one from the other. The difference between the surface zones of the Iowan and Wisconsin tills in regard to lime content is not particularly noticeable, and the same may be said of the degree of oxidation of the iron in these tills; the granite bowlders of the Wisconsin are not noticeably fresher in appearance than those of the Iowan. The chemical criteria heretofore in use are apparently not sufficiently delicate to differentiate such recent glacial deposits.

The writer's personal observations are perhaps much too limited to warrant the assertion that a criterion of the required delicacy has been obtained, but there will be no harm in expressing the opinion that more extended observations will probably confirm the preliminary indications. There are abundant reasons for assuming *a priori* that in the earliest stage of the after history of a drift-sheet it will be characterized by a noticeable amount of sulphates and that these will begin to disappear long before any appreciable diminution of calcium carbonate or decomposition of ferro-magnesium minerals have occurred—granted, of course, that the drift contains pyritiferous minerals, which in fact is always the case. Pyrite is peculiarly susceptible to the action of moist oxygen and its conversion into ferrous sulphate and free sulphuric acid follows its exposure to the dissolved oxygen of the ground water. Considering the relatively small amounts of pyrite and sulphates in the drift as compared with calcium carbonate, the great excess of atmospheric oxygen over atmospheric carbon dioxide, and the great solubility of the sulphates as compared with the solubility of calcium bicarbonate, it is quite natural to expect that the surface of the till will be desulphurized much sooner than it will be decarbonated.

PERIDOTITE DIKES NEAR ITHACA, N. Y.

GEORGE C. MATSON
Chicago

The country rock at Ithaca consists of Upper Devonian shales and sandstones. The rocks are traversed by two series of well-marked joint planes. One series extends nearly north and south; the other series, east and west. Both series are at right angles to the bedding planes. In general, the joints are more abundant in the shales than in the sandstones.

Many dikes have been discovered in the north-south joint planes, but none have been found in the east-west joint planes. This fact may be accounted for in two ways. The streams, which usually flow either east or west, cross many more north-south than east-west joint planes. Therefore the dikes in the former are more likely to be exposed than those in the latter. However, as the dikes were probably intruded while the rocks were being folded, it seems more probable that the east-west joint planes, which are roughly parallel to the folds, were kept closed by compression during the period of intrusion.

Location and size of the dikes.—The existence of a few dikes near Ithaca has long been known. Professor J. F. Kemp[1] speaks of the three dikes in Cascadilla Creek near the bridge at the entrance to the Cornell campus, and he also mentions the one in Six-Mile Creek above Green Tree Falls. The dike just above the upper bridge across Cascadilla Creek measures about 3 feet. It outcrops on the south side of the gorge; on the opposite side the gorge wall is covered with débris. The other two dikes are each about 2 inches wide. They show on the south wall of the gorge between the upper and lower bridges.

In his *Geology of the Third District of New York*, Vanuxem[2]

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[1] J. F. Kemp, "Peridotite Dikes in the Portage Sandstones Near Ithaca, N. Y.," *American Journal of Science*, 3d Ser., Vol. XLII (1891), pp. 410–12.

[2] Vanuxem, *Geology of the Third District of New York* (1842), p. 169.

speaks of four dikes in a gorge near Ludlowville. This gorge is the first one south of the road running east from the village. Two of the dikes referred to by Vanuxem are located near an outcrop of the Tully limestone; the other two are farther upstream, above a high fall over the Genesee shale. The two dikes near the outcrop of Tully limestone, together with a third located near the base of the fall mentioned above, are each about an inch wide.

Above the high fall, instead of two dikes there are four, all showing on the south wall of the gorge. Three of these have been faulted; the fourth does not reach up to the fault plane. The amount of the displacement is about 2 feet. The largest dike is 7 inches wide in its widest part; the others are all small, varying from 1 to 2 inches. There is much branching, and it is doubtful whether more than one of them reaches the top of the gorge wall. Farther upstream is another fall. Above this fall are several small dikes. These are all less than 2 inches wide and appear only on the south side of the stream.

In the gorge just south of the one above mentioned there are five dikes, ranging from ½ inch to 5 inches in width. These dikes may be merely outcrops of some of those which appear in the other gorge; but unfortunately the intervening space is covered with glacial drift, so that the continuity cannot be established.

Just below Taghanic Falls, five small dikes, all less than 4 inches wide, appear on the south wall of the gorge. At least one of them reaches the top of the cliff. A thrust along a bedding plane has displaced these dikes about 20 inches. There is much branching, which often includes fragments of shale thicker than the dikes themselves. On the north wall of the gorge only three dikes were found. Farther upstream, about 100 yards above where the wagon-road crosses, there is a dike about 2 inches wide.

In Glenwood Creek, above the railroad, a dike 7½ feet wide outcrops in the bed of the stream. About 3 feet of the center of this dike weathers like ordinary peridotite; the remainder takes on a schistose appearance when weathered. This peculiar weathering is due to the presence of many vertical cracks along which disintegration progresses rapidly.

Besides the dike in Six-Mile Creek which was mentioned by

J. F. Kemp,[1] there are four others. Two are just below the old pumping-station, and two are about one-quarter of a mile farther upstream. The two near the pumping-station measure 4 and 9 inches respectively; the two above the pumping-station, 3 and 8 inches.

In a quarry at the south end of Hazen Street in the city of Ithaca there are three dikes, ranging from 2 to 6 inches in width. The possibility of these dikes being connected with those near the pumping-station in Six-Mile Creek, and also with some of those in Cascadilla Creek, should not be overlooked. However, direct proof is wanting, and only the fact that they are all in a line nearly parallel with the direction of the joint planes can be cited as supporting the hypothesis that they are connected.

The rocks penetrated by the dikes at Ludlowville, Taghanic, and Glenwood are Genesee shales and Portage shales and sandstones. The dikes in the immediate vicinity of Ithaca penetrate rocks belonging to the Ithaca Group.

Megascopic appearance of the rocks.—The rock is porphyritic, with a dense black aphanitic groundmass, containing phenocrysts of reddish-brown mica and black fibrous masses having the structure of serpentine. The mica is usually in small glistening scales, with an occasional crystal which has a diameter of one-half inch or more. In some cases crystals of olivine may be seen. With a hand-lens, grains of a black metallic mineral (magnetite) are occasionally found. The phenocrysts of serpentine often cover the surface of the weathered rock as black protuberances, sometimes as much as one inch in diameter. These resemble pebbles, but are soft, and when broken, show their fibrous structure.

As the dikes weather they lose their dark color and become a light greenish-gray. On the surface are many mica scales which have faded to a light brown. Further weathering produces a yellow incoherent clay, containing many scales of light brown mica.

Microscopic description of the rock.—Two well-defined phases of the rock are noticeable: (1) porphyritic, (2) non-porphyritic. The porphyritic peridotite contains abundant phenocrysts of olivine, with a subordinate amount of biotite. The olivine phenocrysts are usually

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[1] *Loc. cit.*

altered to serpentine and a carbonate. None of the phenocrysts contain inclusions of magnetite, ilmenite, or perofskite, except such fine grains of magnetite as commonly result from the alteration of the olivine. The groundmass consists chiefly of serpentine with some mica, and small amounts of magnetite, ilmenite, and a carbonate. Much of the mica of the groundmass has lost its original color, and become either green or light brown. Flow structure is very common. The porphyritic phase of the peridotite is confined to the small dikes and to the borders of the large ones.

The non-porphyritic peridotite was originally composed of olivine and biotite, with subordinate amounts of diopside, magnetite, ilmenite, perofskite, picotite, and apatite. Much of the olivine has been changed to serpentine with the formation of magnetite, opal, and a carbonate. The pyroxene is partly altered to calcite and serpentine. The ilmenite and titaniferous magnetite have been partly removed by solution, leaving a white, cloudy substance, leucoxene. The perofskite has partly changed to calcite and rutile. The relations of the minerals indicate that apatite, ilmenite, magnetite, perofskite, and picotite all belong to an early stage of crystallization; following these came the diopside; and still later the mica and olivine. The mica and olivine were in part pyrogenic, as indicated by their mutual interference during growth.

Mineral composition of the rock.—The following tables give approximately the proportions of the different minerals present, as determined by microscopie measurement;

	I	II
Serpentine	55.881	45.927
Biotite	18.285	29.343
Olivine	0.000	10.178
Ilmenite and magnetite	4.257	6.130
Perofskite and picotite	5.563	6.845
Apatite	tr	0.521
Calcite	15.932	0.873
Diopside	0.000	0.000
	99.918	99.817

The section for No. I was taken from near the center of the Glenwood dike, while the one for No. II was taken from near the margin of the same dike. In both cases the rock is considerably altered.

Neither section shows more than one or two crystals of pyroxene, and careful study does not indicate that any large amount was ever present. For purposes of comparison, the calcite and serpentine may be considered as olivine, for it is apparent, from the form of the grains, that they occupy the position of the original olivine grains. The sum of the serpentine calcite and olivine is, for No. I, 71.713 per cent.; for No. II, 56.978 per cent. If these represent the percentages of olivine in the original rock, the evidence of magmatic differentiation is striking. A similar result is obtained by a comparison of the percentages of biotite in the two sections. The comparison of the magnetite and ilmenite is not a safe means of judging, because No. I shows more weathering than No. II, and much of its magnetite has been removed by solution.

The composition of the other dikes shows considerable range, but all may be classified under the head of mica-peridotite—a name proposed by J. S. Diller[1] for a peridotite of similar composition occurring in Crittenden County, Ky.

Contact phenomena.—Along the contact the shaly sandstone and shales are slightly hardened. Near the Cascadilla and Glenwood dikes the rocks are traversed by an unusually large number of joints. There are many irregular cracks in the sedimentary rocks near the contact of most of the dikes. These cracks are filled with calcite. No new minerals occur in the shales, though near the contact they are abundantly impregnated with calcite and are stained with limonite. The contact is irregular, and frequently the lava has extended in long, thin tongues into the bedding planes. This shows the great fluidity of the magma. The same thing is shown in the small dikes at Taghanic where they cut the Genesee shale. There they frequently pinch and swell very rapidly, and often branch from one joint plane to another where two joints intersect. Frequently branches of a dike pass on both sides of a fragment of shale which is thicker than the combined width of the two branches of the dike. The great fluidity of the lava in such cases does not necessarily mean an excessively high temperature, as basic lavas liquefy at comparatively low temperatures. The meager contact effect is explained by thinness of dikes and their low fusion point.

[1] *American Journal of Science*, 3d Ser., Vol. XLIV (1890), pp. 286–89.

The olivine.—Not a single complete grain of olivine was seen in any of the slides, and in several slides it was difficult to find more than a few small fragments of the mineral imbedded in a network of serpentine. The olivine was colorless and contained numerous fine, dust-like inclusions of a dark color, and occasionally grains of a carbonate. Usually the shape of the masses of serpentine indicated that the olivine was in rounded or irregular grains; but occasional sections were found which had sharp crystallographic outlines. Mica scales were found within the serpentine derived from olivine, and some of the grains of serpentine were surrounded by mica. The contact between the two minerals was usually irregular, even when the same grains showed sharp crystallographic outlines elsewhere. This indicates that the two minerals were in part pyrogenic. The olivine enveloped grains of magnetite, perofskite, apatite, and picotite, indicating that these minerals belonged to an earlier stage of crystallization. During the alteration of olivine to serpentine much magnetite was formed. This magnetite occurs in small grains, sometimes so abundant as to make the serpentine appear black. Many of the irregular patches originally occupied by olivine were filled, either wholly or in part, by carbonate. This was doubtless partly dolomite, resulting from the removal of a part of the magnesia and silica, the carbonation of the remaining magnesia, and the infiltration of calcium carbonate. Probably in some cases the magnesia was largely removed, for when the rock was treated with weak HCl it effervesced vigorously for several minutes, indicating the presence of much calcite.

Serpentine.—Serpentine is the most abundant mineral in the rock. It occurs, as pseudomorphs after olivine or pyroxene, in rounded or irregular masses averaging 0.064^{mm} in diameter. It is frequently found inclosing fragments of the unaltered olivine. Two kinds occur: (1) a yellowish fibrous variety, (2) a green fibrous variety. The yellow serpentine has its fibers arranged nearly parallel, and hence its double refraction is considerable. The extinction is parallel. In converging light a biaxial interference figure appears. The axial plane lies at right angles to the fibers, and the black hyperbolas barely remain in the field when a No. 9 objective is used. A faint pleochroism is sometimes noticeable, ranging from green parallel to the fibers, to brown at right angles to them. The elongation of the fibers is parallel to **c**. Occasionally the yellow serpentine appears granular rather than fibrous. Closely related to the yellow serpentine in optical properties is the nearly clear variety found in the cracks where the original olivine granules were apparently fractured by shearing. The fibers always have the same optical orientation, and stand at right angles to walls of the cracks.

The green serpentine is frequently traversed by fibers, giving a bright interference color. Radiating from these fibers are others which show little double refraction; inclosed by these are light green patches which have low interference colors.

The serpentine contains an abundance of magnetite and a carbonate. The light green patches are almost free from magnetite, except for a small amount of very fine dust. As alteration progresses, the fibers become cleared of magnetite, which is evidently removed by solution, and is taken first from the large cracks where the alteration began. During alteration the amount of serpentine gradually diminishes, and the amount of carbonate increases. In some cases a clear isotropic substance is enveloped by serpentine. This substance, which has a low index of refraction, is probably opal, as the formation of opal and magnetite is a frequent accompaniment of the change of iron-bearing olivine to serpentine. The presence of the carbonate is doubtless due, in part, to infiltration of calcite, in part, to the carbonation of magnesia with the freeing of silica.

Mica.—The mica occurs in light brown crystals averaging 0.04^{mm} in diameter. The mica has a weaker absorption than ordinary biotite, and probably has the composition of phlogopite. Plates cut at right angles to the cleavage frequently show a rim with a reddish-brown color. The same color often shows along the cleavage planes. This colored rim is probably the result of alteration with oxidation of the ferrous iron. As alteration proceeds, this coloring-matter is removed, and the mica becomes lighter colored than it was originally. Frequently three zones of color can be recognized in the same crystal: an inner yellowish-brown zone, surrounded by a zone of reddish-brown color, and this in turn surrounded by a zone which is almost colorless. These zones are optically continuous; but all differ in pleochroism and double refraction. The pleochroism of the light-brown mica ranges from pale green to yellowish-brown; that of the highly colored border, from green to reddish-brown; and that of the clear margin, from colorless to light brown. The double refraction is high, but as the mica begins to alter, the interference colors appear ragged and are less intense. The extinction angles are usually small. The interference figures range from distinctly uniaxial to biaxial with a very small axial angle. Between the scales of altered mica there are frequently lenticular masses of a carbonate. The mica often alters to chlorite. This alteration was most commonly met with in the porphyritic variety of the rock. In several cases slender needles occur at the contact of an altered mica crystal and serpentine. These needles extend radially from the mica into the serpentine, and are too small to give much indication of their optical properties, except the fact that they are strongly double-refracting, with nearly parallel extinction. They are probably an amphibole.

The mica contained inclusions of magnetite, perofskite, apatite, and picotite, showing that these minerals belonged to an earlier stage of crystallization. There were a few inclusions of serpentine, having a structure which indicated that the original mineral was olivine. Sections in the basal plane showed many fine, dust-like particles of a brown or black color.

There were many large crystals which showed crystal outlines either wholly or in part. The contact between these and the olivine indicated that both were growing at the same time. The mica sometimes extends into irregular embayments in the pyroxene.

Besides the micas described above, there are irregular jagged or shredlike plates of a much smaller size. These surround the alteration products of the olivine, and they may be secondary micas.

Pyroxene.—The pyroxene is a clear, non-pleochroic mineral, containing inclusions of magnetite and perofskite. It is thus seen to belong to a later stage of crystallization than the magnetite and perofskite.

The extinction angles range from 35° to 40°, and the axis of least elasticity which lies in the acute angle β makes an angle of 36–37° with the prismatic cleavage. In converging light the mineral is seen to be biaxial, with a small axial angle. Rectangular cleavage blocks show the emergence of an optic axis. This fact, taken with the relation of the axis of least elasticity to the prismatic cleavage, indicates that the mineral is the variety of pyroxene called diopside. A trace of a pinacoidal parting shows on sections normal to the prismatic cleavage. The alteration gives rise to a carbonate which often surrounds the crystals and extends along the cleavage cracks. Some of the grains of serpentine with fibers at right angles to each other are doubtless the result of alteration of pyroxene.

Magnetite and ilmenite.—Magnetite is scattered throughout the rock, sometimes in the form of minute grains in the serpentine, and at other times in octahedrons or irregular grains which are as much as 0.03^{mm} in diameter. Cross-sections are quadratic, trigonal, or irregular. The grains in the serpentine are usually very small and result from the alteration of olivine, or, less commonly, pyroxene. As alteration progresses, these fine grains are removed by solution. In the alteration of some of the irregular grains and crystals a white, semi-translucent substance, leucoxene, is produced, indicating the presence of titanium in the form of titaniferous magnetite or ilmenite. Almost all the original crystals appeared to be titaniferous; the only pure magnetite being that resulting from the alteration of olivine and other ferro-magnesian minerals.

Apatite.—Apatite occurs in irregular grains or in slender prisms, which sometimes show a basal parting. It occasionally occurs as inclusions in the olivine or biotite; at other times the grains or crystals are scattered about between the crystals of mica. The apatite is a clear, colorless, non-pleochroic mineral, with a high index of refraction and a low double refraction. Basal sections show a uniaxial interference figure. No alteration takes place, but the surface of the crystals is often pitted.

Perofskite and picotite.—The perofskite occurs in yellowish-brown crystals and grains. The cross-sections are varied, being diamond-shaped, trigonal, hexagonal, or irregular. Many of the irregularities are due to aggregations of crystals. Some skeleton crystals and some incipient forms of growth occur. The index of refraction is high, and the sections are usually entirely isotropic between crossed nicols. The sections are often traversed by irregular cracks, sometimes showing slight alteration. In one case a grain of perofskite which had been included in apatite was partly altered to a carbonate (calcite), containing minute fibers of a clear, non-pleochroic mineral, with high double refraction and nearly parallel extinction. This was probably rutile. Similar alteration was frequently seen elsewhere, and associated with the rutile was leucoxene. Scattered through the sections is a light-yellow mineral, with a slightly lower index of refraction than perofskite. This is probably picotite. It is entirely isotropic between crossed nicols.

Chlorite.—Chlorite is only important along the contact of the dike with the shales, though it also occurs at the contact of mica and serpentine. Doubtless the chlorite is the result of the action of aluminous solutions on the ferro-magnesian mineral olivine.

At right angles to the polarizer the fibers of chlorite are almost colorless, having only a slight yellowish tinge. Parallel to the polarizer the fibers have a bright green color. Basal sections usually have a greenish color. They show a biaxial interference figure with a small axial angle; and the sign is positive. The extinction angles are very small. The fibers are often bent and broken, though few show any crushing of pressure. The variety is probably prochlorite.

Age of the dikes.—The age of the peridotite dikes is a difficult question to solve. That they are younger than the Upper Devonian rocks through which they have been intruded is perfectly evident. During the field investigations certain facts were discovered which may help to fix their age more definitely. The sedimentary rocks have been folded into anticlines and synclines. The age of these folds has been discussed by Mr. E. M. Kindle:

> It appears certain that the comparatively insignificant structural features which have been described are of the same age and origin as the great open folds of the northern Alleghenies. In the quadrangle cornering with the Watkins Glen quadrangle on the southwest are folds whose arches, if restored, would rise 2,500 feet above their troughs. Less than twenty miles to the south of the Watkins Glen quadrangle another great fold shows a crest of similar or greater elevation. From theoretical considerations it would appear improbable that the effects of the epirogenic forces which have developed structures of such magnitude should terminate abruptly at the northern edge of the highly folded belt. Instead of abrupt change from highly folded to monoclinal or nearly horizontal structure, we find the mountain flexures subsiding gradually into the low, gentle swells which have been described. This may be illustrated by a comparison of the maximum dips exhibited by the anticlinal folds encountered between South Mountain in Bradford County, Pennsylvania, and the southern end of Lake Seneca. Eighteen

miles south of the Watkins Glen quadrangle runs the axis of the Towanda anticline between two synclinal mountain ridges—Mount Pisgah and South Mountain. Dips of 70° or more have been observed on the south side of this anticline, but the average dip for the belt of maximum inclination is approximately 40°. The dips of the north limb of this fold are very much lower than the south dips. The writer, although familiar with the region, has not observed any dips which will exceed 20°, and the dips in the zone of maximum inclination will probably not average more than 15°. It is noteworthy that the great excess of the south dip over the north dip of this fold is a characteristic common to nearly all folds of the Watkins Glen quadrangle.[1]

Accompanying the folding were movements along the bedding planes; some minor thrust faults were formed. These two forms of displacement pass into each other. Willis discusses the conditions under which displacements along bedding planes take place, in his article on "The Mechanics of Appalachian Structure:"

> The transmission of pressure through a folding stratified mass may be stated as follows: So long as the stratification is parallel to the original direction of pressure, the force is transmitted as a whole and tends to reduce the volume of the mass; when the strata are inclined to the direction of pressure, the thrust is resolved into two components, the one parallel to the bedding, the other perpendicular to it; the former produces movement when it overcomes the friction on the bedding planes, the viscosity of the strata and any opposing force, as the load; the latter becomes active when it causes some part of resisting mass to move.[2]

It was doubtless the thrust parallel to the bedding planes which produced the displacements under discussion. Where the cohesion between the strata was less than the strength of the rock, the movement took place along the bedding planes; where the cohesion was greater than the strength of the rock, a fracturing of the beds resulted, and movement took place along the fracture plane. Since these displacements have a bearing on the history of the dikes, a few of them will be discussed here. On the south limb of the Watkins anticline, in Six-Mile Creek, is a small thrust fault which passes into a displacement along the bedding planes. In Shurger's Glen there is a similar fault connected with the anticline which crosses Lake Cayuga near Shurger's Point. In this case the fault passes into displacements along several adjacent bedding planes. On the north

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[1] "A Series of Gentle Folds on the Border of the Appalachian System," *Journal of Geology*, Vol. XII, No. 4 (1904), p. 287.

[2] Willis, *Thirteenth Annual Report*, U. S. Geological Survey, Part 2 (1891–92), p. 246.

limb of this same anticline there has been a movement along a bedding plane. This movement has faulted four dikes on the south wall of Taghanic Gorge and three dikes in a gorge east of Ludlowville. The amount of displacement of the ends of the dikes is only about 2 feet, and the movement is largely confined to a single bedding plane. The dikes are nearly at right angles to the axis of the fold, and hence eighteen inches can hardly be taken as the measure of the amount of movement. Probably the movement was nearly parallel to the dikes, and, if so, the amount of actual displacement might be several times the distance between the severed parts of the dikes. Slickensides are not noticeable, but the bedding plane is occupied by a thin layer of pulverized shale. At first the possibility of the dikes having passed for a short distance along this bedding plane was considered. This theory was discarded, because all the dikes showed the same displacement; and the clay between the strata did not contain any of the mica scales which are so prominent in the clays derived from the disintegration of the dikes.

The sequence of the earth movements in this region appears to have been as follows: folding with the development of joint planes; the intrusion of the dikes and their consolidation; renewed folding, accompanied by minor thrust-faulting and movements along bedding planes. The relation of the folds of this region to those of the Appalachian Mountains makes it clear that the periods of folding must have been the same. It follows, then, that the dikes are probably younger than the earliest period of folding and older than the latest. This would fix the date of the intrusion near the close of the Paleozoic.

GLACIATION OF SAN FRANCISCO MOUNTAIN, ARIZONA[1]

WALLACE W. ATWOOD
The University of Chicago

During the summer of 1904 the slopes of San Francisco Mountain were examined with some care, and to the northeast of the main peaks records of ancient glaciation were found. The latitude of San Francisco Mountain is approximately 35° 21′, and the records of glaciation found here may possibly be those of the southernmost ice which existed in this country during the Pleistocene period.

San Francisco Mountain is in the north-central portion of Arizona, about ten miles north of the village of Flagstaff. It is of volcanic origin, having been built by numerous outpourings of lava and by explosions of fragmental material. The ancient crater of this mountain is bordered on the north, west, and south by a series of peaks (see Fig. 1) which are remnants of the once higher rim of the crater. These peaks rise to elevations of from 12,250 feet to 12,794 feet above sea-level, and nearly 7,000 feet above the general level of the plateau on which the mountain stands. To the east the rim of the crater is wanting, and the one stream which drains the central portion of the mountain flows through this opening or gap, and then, turning to the north, descends quickly to the alluvial deposits about the base of the mountain.

The general topographic relations, shown in Fig. 1, indicate that there is today a well-protected catchment area for rain and snow. The high walls on the south and southwest of the basin give the most favorable conditions, in this latitude for the preservation of snows. The floor of the crater varies in elevation from 10,000 to 11,000 feet, and is bordered by the bold, and at places, precipitous, slopes of the lofty peaks which surround it. The dimensions of the catchment basin are best seen in Fig. 1. The total possible area of

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[1] The work reported in this article was done in company with a party of students from the University of Chicago, and the author is indebted to the members of the party for assistance in collecting data.

snow accumulation was about one and a half square miles, and the possible depth of snow and ice was somewhere near 2,000 feet.

Ascending the mountain from the east, the first morainic deposits appear at an elevation of about 9,250 feet and at a distance of about two miles from the head of the basin. At this point morainic ridges jut out into the valley from either side, but fail to cross the stream course and unite. This connection was probably complete at one time, but the material of the terminal moraine has been largely washed away.

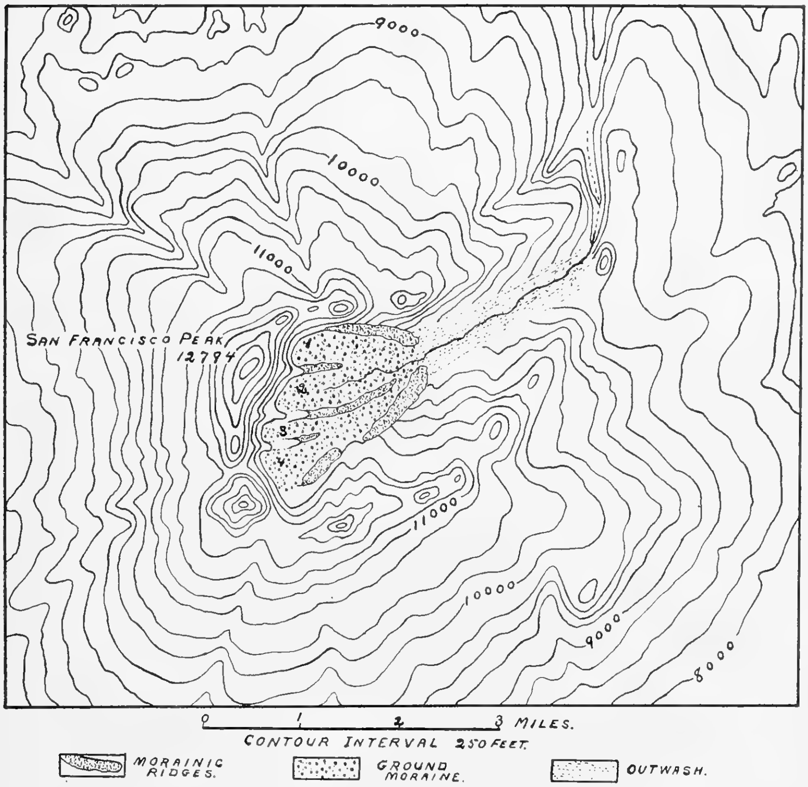

FIG. 1.—Topographic sketch of top of San Francisco Mountain, Arizona.

Down-stream from the position of the terminal moraine there is a heavy alluvial deposit, made by torrential waters issuing from the end of the glacier. This outwash or valley train extends at least one and a half miles down-stream, and perhaps much farther, but farther out it would be difficult to distinguish it from the preglacial and postglacial alluvial deposits.

Up-stream from the position of the terminal moraine, the drift ridges, already mentioned, swing to appropriate positions for lateral moraines and continue to the lower margin of the basin, as shown in Fig. 1. The crests of these moraines are commonly but 40–50 feet above the valley bottom, but they increase in elevation to the eastward, until at their down-stream termini they are at least 100 feet high. The valley between the lateral moraines contains a drift-filling which at places is more than 50 feet deep, and which may perhaps be classed as ground moraine. In addition to the lateral and ground moraines, there are medial moraines projecting downstream from the rock spurs which subdivide the basin.

The topography and topographic relations of these deposits of loose material are such that it would be extremely difficult, if indeed possible, to account for their formation under any other hypothesis than that of glaciation, but an examination of the material in these deposits furnishes conclusive corroborative evidence of glaciation. The material is entirely volcanic, but nevertheless has the characteristic physical and lithological heterogeneity of glacial drift. Bowlders up to 10 feet in diameter are found in the moraines, and in the exposed sections there is every gradation down to the very fine material in which the stones are imbedded. In all the exposures seen the drift was unstratified. Many of the larger stones and bowlders are subangular in form, with smooth and polished surfaces. In a region of undoubted glaciation, such forms and surfaces would have been accepted as positive evidence of ice-action, but in this region more conclusive evidence was looked for, and in the fresher exposures, especially in the débris from a 30-foot excavation in the bottom of the valley, beautifully striated stones were found.

The basin is not cirque-like in form, and probably it was not greatly modified by the ice. It is subdivided at its head by projecting rock spurs into four minor upper basins (1, 2, 3, 4, Fig. 1). Basins 1 and 2 have floors which are broader than would be expected if developed by stream-erosion alone. On the floor of the basin numbered 1, a surface of bed-rock is exposed which has been polished and grooved. The stoss sides of all minor prominences on this rock are characteristically worn. On the floor of the basin numbered 2, there are irregular hillocks or mounds which were formed by the ice, and among them were formerly small ponds or marshes. The minor basins numbered 3 and 4 show little modification due to ice, but it may be that the extensive talus slopes obscure the former flat bottoms of these basins. No proof of more than one epoch of glaciation was found.

Since the melting of the ice, the amount of erosion accomplished has not been great. Much of the talus material about the rim of the crater is presumably of postglacial age, but the washing away of the terminal moraine along the main stream is the most conspicuous task that has been done. The surface-weathering of the glacial material is so slight as to be insignificant.

In comparison with the records of ice-action in higher latitudes in this country, the records on San Francisco Mountain are meager. They indicate appropriately weaker glaciation in this lower latitude.

A CORRECTION

CHARLES R. VAN HISE
University of Wisconsin

In Monograph 47 of the United States Geological Survey, *A Treatise on Metamorphism,* a serious mistake is made in reference to the redistribution of sodium. It is stated on p. 997 that the deficiency of soda in the sediments as compared with the original rocks is 2.4985 per cent., and that this deficiency amounts to 70.38 per cent. of the whole. In estimating the deficiency in metric tons for the soda, the computor, instead of using the amount of soda in the original rocks as the base, took the weight of the entire mass of sediments, and thus the deficiency of soda is given as 475,065,000,000,000,000 metric tons, whereas it should be 16,864,875,000,000,000 metric tons. The total amount of soda in the ocean, 19,101,000,000,000,000 metric tons, instead of being but a small fraction of the total deficiency for the sediments, is 13.2 per cent. in excess of the deficiency.

This error requires the modification of a number of statements made on p. 998. It is there stated that the result obtained suggests that the soda of the salt deposits of the land is probably greater in amount than in the salt of the sea, whereas the true result indicates that the soda of the salt deposits of the land is unimportant as compared with that in the sea. Also a criticism in reference to calculating the age of the earth from the amount of salt in the sea is without force.

No adequate excuse for the error in calculation can be offered; it can only be said that it occurred. In the *Treatise on Metamorphism* there are the results of thousands of numerical calculations. In the one cited a blunder was overlooked. We hope that for the most part the calculations will be found substantially correct.

REVIEWS

Report on the Origin, Geological Relations and Composition of the Nickel and Copper Deposits of the Sudbury Mining District, Ontario, Canada. By A. E. BARLOW. (Annual Report of the Canadian Geological Survey, Vol. XIV. Part H, 1904.) With geological maps.

Dr. Barlow publishes in this report the results of his careful and exhaustive study on the Sudbury nickel district of Ontario. He makes the succession as follows:

1. *Lower Huronian.*—No rocks of this age are at present known in the nickel-bearing area, but this period is represented, in part, by the banded siliceous magnetites and associated rocks of the townships of Hutton and Wissner.

2. *Upper Huronian.*—(A) Diorites, hornblende-porphyrites, and green schists; (B) conglomerates, graywackes, and quartzites; (C) norite and diorite (Worthington mine belt, and areas southeast of Evans mine and east of Sudbury).

3. *Laurentian.*—Granite and diorite-gneiss near Wahnapitae station.

4. *Upper Huronian* (?).—Tuffs, felspathic sandstones, and slates classified provisionally on previous geological maps as of Cambrian age.

5. *Post-Huronian.*—(A) Granites; (B) nickel-bearing eruptive of the main belt (quartz-hypersthene-gabbro or norite, diorite, with their peculiar differentiation product, micropegmatite). (C) dykes of olivine diabase.

On the accompanying maps the rocks are separated lithologically and are all bracketed under the general heading "Archean." All of these terms are used in the sense commonly given them by the Canadian Geological Survey. The district is closely related with the Lake Superior region on the west, and there the U. S. Geological Survey uses different terms for what are believed to be equivalent series. Barlow's Lower Huronian may be correlated with the Archean of the U. S. Geological Survey; Upper Huronian, with the U. S. Geological Survey Lower Huronian; Laurentian, with the granites mapped as intrusive into the Huronian of the U. S. Geological Survey; Upper Huronian (?) with the Upper Huronian of the U. S. Geological Survey.

The nickel and copper are confined to the norite and its altered varieties. Closely associated with this is a rock of granitic composition of prevailing gneissoid texture, which cannot be sharply separated from the basic eruptive, although the change is usually sharp enough to allow of a boundary being drawn between them. The norite ranges, as shown by Coleman, are probably the exposed portions of one continuous laccolite, with occasional minor irregularities or offsets, which has been folded into a platter-shaped trough, holding in its depressed interior nearly flat-lying Huronian (?) sediments constituting the uppermost series of the district. The relations of these sedimentary rocks to the norite are in doubt, but later work seems to indicate a close relationship, both in origin and age, with the main masses of norite.

The nickel is mainly in the form as a nickel iron sulphite, pentlandite, associated with pyrrhotite and chalcopyrite. That the ore has been segregated more or less directly from magma is believed to be shown by the following facts:

The deposits, without exception, all occur at the margin of the gabbro or norite, the rock itself in immediate association with the ore being finer in texture, and relatively much more basic in composition, than portions further removed from the contact.

The sulphides are always much more sharply defined against the walls of the intrusion than on the inner side towards the main mass of the gabbro.

These deposits are always found in such intimate association with the norite or hypersthene gabbro.

Pyrrhotite, chalcopyrite, and pyrites are all ordinary constituent minerals of the normal norite, and are, at times, comparatively abundant even in exposures situated some distance from the contact.

The sulphides are, undoubtedly, of primary origin, and are among the earliest of the minerals to crystallize out from the original magma, sometimes even antedating the iron ore, in which they are occasionally completely inclosed.

The transitional type between the normal norite and the richer forms of the pyrrhotite-norite furnishes unmistakable evidence that in these cases, at least, the sulphides were formed during the cooling and crystallization of the norite magma, and that they were very little affected by any secondary action.

Secondary quartz, calcite, and dolomite are occasionally present, in appreciable amounts, but the prevailing scarcity of these minerals at most of the deposits has always been a subject of remark.

The deposits are singularly uniform in chemical and mineralogical composition, and their monotonous character, in this respect, has been frequently commented upon.

Brecciation, which is so frequently characteristic of these deposits, is an almost constant feature of eruptive contacts, resulting from the detaching of material from the containing walls.

This conclusion is in accord also with evidence drawn from analogy with chemical and metallurgical principles.

Dr. Barlow concludes further that there can be little doubt of the abundant presence of heated solutions and vapors, which were capable of dissolving out, and, under certain conditions, redepositing these sulphides. Such agencies certainly began their work before the whole magma had cooled, bearing their heavy burdens of sulphide material, most of which was obtained from the magma in the immediate vicinity,to occupy the various cavities and fissures as fast as these were formed. The whole of this action was practically completed before the intrusion of the later dikes of the olivine-diabase, which are now regarded by Dr. Barlow as the end product of the vulcanism to which the norite masses owe their intrusion. In certain of the deposits the various hydrochemical agencies accompanying dynamic action have been more active than in others, as at the Victoria mine, and some of the Copper Cliff mines, but in others—as, for instance, the Creighton mine—magmatic differentiation has been the main and almost sole principle determining and favoring the development of this, the largest and richest sulphide nickel mine in the world.

The evidence summarized by Dr. Barlow seems to show beyond reasonable doubt that the norite is the original source of these sulphides. However, he describes evidence of redistribution by aqueous and gaseous solutions accompanying later stages of the norite eruption, and it is difficult to see how this evidence will enable one to draw any line between, or determine relative emphasis to be placed on, redistribution by such agencies and redistribution by meteoric waters heated by contact with the cooling norite or by meteoric waters acting subsequent to its cooling. Difference in emphasis on these factors now constitutes the main outstanding difference of opinion as to the origin of the ores.

The report is accompanied by a brief description of the geology of well-known nickel deposits of the world, and a summary of the metallurgical principles applicable to the extraction of nickel, making it useful as a nickel handbook. All interested in the geology of ore deposits will appreciate Dr. Barlow's adequate and satisfactory treatment of his subject.

Reference should be made to two other reports on the district which have appeared in the last two years—one by Mr. Charles W. Dickson, in

Vol. XXXIII of the *Transactions of the American Institute*, 1903, and another by Professor A. P. Coleman, in the *Annual Report of the Bureau of Mines of Ontario*, 1903. Dr. Barlow is in essential accord with Professor Coleman, though differing in details and emphasis on certain points. He differs from Mr. Dickson in putting emphasis on the magmatic segregation of the ore rather than on the secondary concentration. Dickson concludes that the preliminary concentration accompanying the intrusion of the norite was comparatively slight; that appeal must be made to a more distant source of the metals, probably minutely disseminated in the rocks through which the depositing solutions passed; and that, in general, the whole weight of the evidence points to the secondary formation of the Sudbury ore-bodies as replacements along crushed and faulted zones, with only minor indications of open cavities.

C. K. L.

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THE

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THE TWIN LAKES GLACIATED AREA, COLORADO[1]

LEWIS G. WESTGATE

OUTLINE

PRECLACIAL TOPOGRAPHY OF THE UPPER ARKANSAS.
GLACIAL FEATURES OF THE TWIN LAKES REGION.
  I. Morainic System of Lake Glacier.
  II. Pleistocene History of the Upper Arkansas.
  III. Glacial Erosion.
POSTGLACIAL CHANGES.
MOUNTAIN FORM.

The Upper Arkansas occupies a broad north-and-south valley between the Park Range on the east and the Sawatch Range on the west. Twin Lakes are on the lower course of Lake Creek, which heads in the Sawatch and flows east to the Arkansas. The lakes are held back by two small recessional moraines deposited by the glacier

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[1] The writer, on returning from the Harvard excursion to the Great Basin in 1904, spent several weeks in the valley of Lake Creek. Together with Professor W. M. Davis, he had stopped here for a few days earlier in the summer, and he wishes to express his indebtedness to Professor Davis for pointing out the district to his attention as deserving study for its glacial features, and for suggestions in the field and later.

The only early detailed report on the region is found in the *Annual Reports* of the Hayden Survey for 1869, 1873, and 1874. A paper by Capps and Leffingwell, which was published in the *Journal of Geology* for November–December, 1904, discusses the glacial geology of the upper Arkansas valley, and with the conclusions of these writers the author is in substantial agreement, in so far as the two papers deal with the same area. Professor Davis, in *Appalachia*, November, 1904, uses the valley of Lake Creek to illustrate glacial erosion.

which formerly occupied the valley of Lake Creek. This paper describes the topographic features of the basin of Lake Creek and of the neighboring part of the Arkansas valley, and treats of the preglacial topography of the region, the topographic effects produced by Pleistocene glaciation, and postglacial changes.

PREGLACIAL TOPOGRAPHY OF THE UPPER ARKANSAS

All of the larger tributary valleys of the Arkansas on the west, and some of those about Leadville on the east, were occupied by valley glaciers during Pleistocene time, while the other tributary valleys and the main valley were free of ice. It is thus possible to compare the glaciated and non-glaciated areas, and to determine what features are due to stream-erosion in preglacial time, and to contrast that topography with that which has been changed by glacial action.

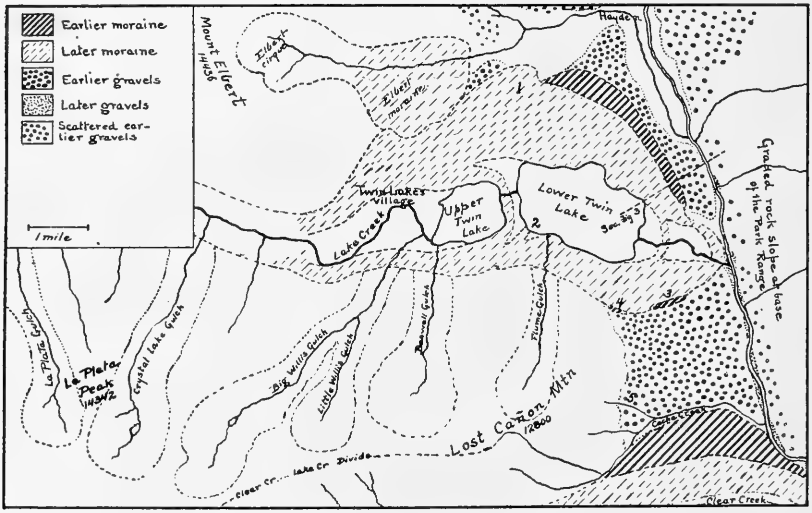

Fig. 1.—Map of the Twin Lakes area.

Fig. 2 will make clear the main elements of preglacial form along the Arkansas. The river flows in a narrow interglacial valley cut 300 to 400 feet into the granite. From the edge of this inner valley on the east a terrace (*BC*), from one-half to a mile in width, rises at an angle of 5° to the foothills of the Park Range. This terrace is cut in granite, and while now somewhat dissected, is evidently a part of the graded rock-floor of the preglacial Arkansas. The west wall of the narrow valley is granite, but the plain (*AD*) stretching west from its upper edge is glacial wash, and not cut on the rock. The rock-plain which one naturally looks for to match that on the east is buried under this wash and is shown at only one point along the base of the range, just south of the south Lake Creek moraine, where placer mining has removed the thin cover of gravel over a considerable area, and shows a graded slope of weathered granite inclining to the east, and at the same level as the back of the corresponding rock-slope east of the Arkansas. Placer digging west of Granite, and occasional shafts, show that the gravel is upwards of 50 to 75 feet in thickness; it may be much more. This gravel filling is probably not thick enough to carry the bottom of the broad preglacial valley, which ran west of the present river, down to the present level of the Arkansas. The dotted line in the section restores approximately the surface of the preglacial valley.

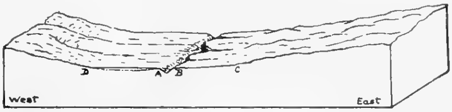

FIG. 2.—Section across the Arkansas River north of Granite.

Horizontal and vertical scale, 1 inch =4 miles (nearly).

At its back edge the graded rock-slope passes into the foothills of the Park and Sawatch ranges. The hillsides comprising these ranges are not steep, rarely over 20°, and have graded slopes, without prominent outcropping ledges, and this type of hill form is kept all the way to the summits. These rise some 3,000 to 5,000 feet above the valley, and are rounded and massive. Sharpened summits occur only in the glaciated areas. The Sawatch Range above Granite, Lost Canyon Mountain, and Mount Elbert all show this massive form, which may be taken as the typical preglacial form.

GLACIAL FEATURES OF THE TWIN LAKES REGION

That part of the Lake Glacier (name shortened from Lake Creek Glacier) which lay in the broad valley of the Arkansas was characterized by morainic deposition; that part above Twin Lakes village, and which lay in the narrow valley in the Sawatch, by glacial erosion.

I. MORAINIC SYSTEM OF LAKE GLACIER

1. *Two periods of glaciation.*—The moraines of the Lake Glacier form a rough semi-circle on the west side of the Arkansas, reaching almost to the present Arkansas River.[1] Within this area moraines of two distinct dates are found, separated by a time interval of sufficient length to constitute two separate glacial periods. Their distribution is shown on the accompanying map (Fig. 1). The later drift forms a continuous moraine about the lakes. The earlier drift occurs outside the later drift for four miles north of Lake Creek, and at one or two isolated points south. The evidence for the different age of the two moraines lies (A) in the relations which they hold to the gravels of the Arkansas valley, (B) in the difference in weathering in the two moraines and gravel-plains, and (C) in differences of topographic expression and amount of stream-dissection of the two moraines and their correlated gravels.

A. Relation of moraines to gravels. Two series of gravels occur along the Arkansas. One is a succession of terrace fragments, lying within the interglacial gorge of the Arkansas and rising some 30 to 40 feet above the river. At Lake Creek this terrace rises somewhat steeply to the front of the later moraine, and the relations of the two show clearly that the gravel is a wash-plain formed by the glacial waters contemporaneously with the accumulation of the moraine. The later moraine is therefore of later date than the cutting of the rock-gorge of the Arkansas.

A second series of gravels occurs up to 400 feet above the river-level, back from the upper edge of the rock-gorge, and on both sides of the river. East of the river they form in places a thin veneer over the graded rock-plain of the preglacial Arkansas; in large part, however, they are represented only by scattered bowlders.[2] West of the river they form extensive terraces. That the deposits were originally continuous is shown by their occurrence at the same levels on both

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[1] There is no evidence that the Upper Arkansas was ever occupied by a north-and-south master-glacier, as suggested by Hayden, *Annual Report* for 1873, p. 48.

[2] Referred to by Capps and Leffingwell (*Journal of Geology*, Vol. XII, p. 702) as possibly indicating a third period of glaciation earlier than the two to be mentioned later. They seem to be associated, however, with the upper terrace gravels, though floating ice may have had some share in bringing them to their present condition, as they are sometimes 2 to 3 feet in diameter.

sides of the river, and by the fact that the gravel east of the river contains material recognizable as derived from the valley of Lake Creek, and not found east of the Arkansas. Through this sheet of gravel the Arkansas cut its valley, and then 300 to 400 feet into the rock. These higher gravels are therefore older than the rock-valley. But it is with this older series of gravels that the outer moraine is to be correlated. Fig. 3 shows the relations that hold along the whole stretch of the old moraine north of the river. *A* is the later moraine; *B*, the earlier moraine; *C*, the upper gravel-terrace. On the rock-terrace at *D*, scattered bowlders or thin gravel veneer mark the former eastward extension of the terrace. *E* is the gorge gravel of younger date. *C* is the wash-plain to the outer moraine *B*, just as the gorge gravels are to the later moraine. These relations of the moraines to the gravels show that the periods of ice-advance indicated by the two moraines are separated from each other by a time interval sufficient for the Arkansas to cut its gorge 300 to 400 feet below the floor of its broad, graded, preglacial valley. When one compares the work done in this period with that done by the river in postglacial time, in which it has not been able completely to clean out of its valley the gravels of the later glacial period, one can get an idea of the relatively long time separating the two periods.

FIG. 3.—Profile from lower Twin Lake northeast to the Arkansas. Symbols as in Fig. 1.
Horizontal scale, 1 inch=2,000 feet; vertical scale, 1 inch=5,000 feet. The section is located on the map.

B. Differences in weathering of the two moraines and their associated wash-plains. The great difference in age of the two glacial advances is further shown by the difference in the amount of weathering of their deposits. The later moraine, as seen in cuttings, is everywhere fresh and unweathered. The large stretch of older moraine north of Lake Creek does not show sections which will enable one to make a comparison with the later drift. The western of the two occurrences south of Lake Creek, however, shows a long section where the moraine is crossed by an irrigating flume. The moraine here is thoroughly disintegrated, bowlders crumbling to pieces beneath the blow of a hammer, while the same rock on the inside of the younger moraine is quite fresh. It may be noted, though, in this connection, that in one or two exceptional cases the younger moraine contains frequent decomposed bowlders.

It is, however, when we come to examine the gravels associated with the two moraines that the difference in amount of weathering is most apparent, and numerous placer openings and trial shafts in the gravels have made this comparison easy. Sections in the gravels in the gorge show that the bowlders are, with very few exceptions, perfectly sound. Numerous sections in the upper gravels show a large proportion of the bowlders to be thoroughly rotten. One of the most easily recognized rocks of the region is a coarse porphyritic granite. In the gorge gravels, bowlders of this rock are fresh. In the upper terraces they can often be picked apart with the knife-blade, and frequently have been cut across in digging the shaft, it being easier to cut across than to dig out blocks lying in the wall of the shaft. This very general and thorough weathering of the upper gravels, compared with the freshness of the gorge gravels, indicates that the former are several times older than the latter, and that interglacial was longer than postglacial time.

C. Differences in topographic expression and in amount of stream-dissection of the two moraines and their associated gravels. In a later place this consideration will be presented more fully. It is enough here to say that the younger moraine is the steeper and more rugged of the two. The differing amount of dissection is especially well brought out in the two gravels. Of course, the gorge gravels have been in large part cleaned out by the Arkansas in postglacial time, since along the main river conditions have favored erosion. More striking is the great amount of destruction of the upper gravels at points where erosion has not been favored. They have been completely cleared away by Lake Creek at its mouth, and by the small stream entering the Arkansas at Hayden. Between these two points no permanent streams enter the Arkansas from the west, but several dry valleys head in the old moraine, cross the wash-plain and enter the main river. Near the river they are in granite and narrow, farther back they are in gravel and widely open. These widely open valleys in the old gravels contrast well with valleys cut by much larger streams in the younger drift—as, for example, the valley of Lake Creek where it crosses the moraine—and point to the gravels being much older. There is reason to believe that the streams entering the Arkansas from the west between Lake Creek and Clear Creek have, by widening their valleys until they joined, succeeded in reducing the whole level of the upper gravel deposits some distance below its original height. The dry valleys which cross the gravel terrace north of Lake Creek head, as has been mentioned, in the older moraine. Their continuation from the river with essentially unchanged dimensions and expression, back across the gravel terrace into the older moraine, but not into the younger moraine, shows the connection of the older moraine and the higher gravels. The younger moraine is not eroded by any drainage originating on the moraine itself.

The relation of the moraine to the gravels shows that the valley of Lake Creek was at two distinct periods in Pleistocene time occupied by a glacier, and that these two periods were separated by time enough for the cutting of the rock-gorge of the Arkansas. And the much greater weathering and erosion of the older deposits indicate that interglacial time was much longer than postglacial time, in this region.

2. *The earlier moraine.*—The character of the older drift is well shown outside the younger moraine north of Lake Creek. Here, toward the south, it forms a low terrace several hundred feet wide rising some 30 to 50 feet above the wash-plain which fronts it. From a distance it looks almost like a second terrace rising above the general level of the upper terrace, but its surface is rolling and uneven. It is usually separated from the younger moraine by a shallow valley. Its surafce, while rolling, is less uneven and rocky than that of the younger drift; scattered erratics up to 6 or 8 feet in length are common over its surface, but these do not reach the size of those on the other moraine. Northwest, this terrace widens to about a mile, forming a gentle slope away from the later moraine to the wash-plain nearer the river. This older drift has not been traced beyond the Twin Lakes–Hayden road.

The older drift is mapped at two places south of Lake Creek. The western of these two occurrences (Fig. 1, 4) is not large enough to be of topographic importance. The other (Fig. 1, 3) is a low ridge nearer the river, apparently connected with a fragment of the upper terrace gravels, and less rugged than the younger drift just north of it. It is not in as marked contrast with the younger drift as the belt of older moraine north of Lake Creek, and there might be some doubt as to its identification. No sections occur, so that one kind of evidence as to its age is lacking.

3. *The later moraine.*—The later moraine forms a loop about the lower end of Lake Creek, with its higher parts, near the Sawatch Range, rising some 1,000 feet above Lake Creek. Its surface has already been described as more rugged than that of the older moraine, yet it shows typical kettle topography at but one place, where the Hayden road crosses the north lateral (Fig. 1, 1). The outer slope is the steeper of the two. An interesting feature of the inner slope of the north moraine is a series of ridgings which remain parallel to the main crest of the moraine for some two miles as it drops to the east, and which seem to represent later stages of accumulation during the beginning of the retreat of the glacier.

At several points there are sags in the moraine crest, and here the moraine is pushed forward as if tongues of ice had pushed out a short distance beyond the general front of the glacier. The best illustration of this is at the lower end of Lake Creek, where the main morainic ridge is breached, and a small moraine pushes out through the breach nearly to the Arkansas River. The contrast is especially noticeable on the north, where the two make a sharp angle with each other. A second illustration occurs on the north lateral, where it is crossed by the Hayden road, and again on the south lateral between the two areas of older drift.

Moraines of recession occur along the course of Lake Creek. The first of these is just below the lower lake—a belt of low morainic knolls which swings around and unites with the inner side of the main moraine. This moraine of recession can be traced to its union with the main moraine, but it cannot be separated from the main moraine thereafter. A second low recessional moraine swings in a semi-circle across the valley at Interlaken, separating the two Twin Lakes from each other. This has its wash-plain, and merges with the larger moraine, though it can be followed back as a distinct ridge for a greater distance than the moraine below the lower lake. A third morainic ridge (Fig. 1, 2), a part of a recessional moraine, is developed on the south side, just down-stream from the one just mentioned at Interlaken. It runs below the level of the lower lake, and is not found on the north side of the lakes. Masses of morainic drift occur within the rock-gorge, but irregularly distributed, rather than in the crescentic shape characteristic of recessional moraines. In all cases these moraines are small, forming a belt of rolling drift 20 to 30 feet high and not exceeding several hundred feet in width.

Above Twin Lakes village, in the rock-gorge of Lake Creek, the drift occurs irregularly and is not aggregated into moraines. Erosion and not deposition was here the rule. From the base of the mountains to the Arkansas the drift occurs in simple morainic embankments. There is an intermediate area, on both north and south sides, where an intermediate relation holds. On the south side of Lake Creek the south lateral rests against the lower slope of Lost Canyon Mountain, its crest dropping slowly to the east and interrupted only where cut by streams flowing into Lake Creek. At these places a typical moraine section is shown, as the moraine was built across the mouths of the lateral valleys which were occupied by streams in their lower course and entered the main valley well below the level of the glacier surface. Opposite the intervening divides the moraine crest is continuous with the crest opposite the valleys where it has not been cut away. Sections on the inner face of the moraine opposite the divides, however, frequently show rock in place; and while this inner slope is drift-covered, it appears that the drift forms but a veneer over the truncated spurs of the rock divides between adjacent lateral valleys, so that the apparently simple moraine along the base of Lost Canyon Mountain is really a cut-and-fill affair, moraine-veneered truncated spurs opposite the divides, and typical moraine embankments opposite the lateral valleys. This double character holds for four miles along the south side of the valley, and for a short distance along the north side back of Twin Lakes village.

4. *The Clear Creek morainic system.*—This paper is concerned with the Lake Creek region, yet it is permissible to note that the history which has been outlined above for the glacier occupying the valley of Lake Creek was duplicated in every essential feature by the

glacier occupying the valley of Clear Creek, four miles to the south. Here are two series of moraines. An inner one of late date is represented by two great lateral embankments rising 1,000 feet above the valley bottom of Clear Creek and extending to the Arkansas. These laterals do not unite toward the valley, but the lower moraines of the same age between them are connected with gravels which follow down the gorge of the Arkansas at levels not far above the river. Outside the younger moraines there are, both north and south, extensive areas of older moraine, better developed even than about Lake Creek, and associated with higher gravels which lie above and outside of the Arkansas gorge, and indeed are continuous with the higher gravels about Lake Creek. The same differences in expression, in weathering, and in dissection by streams hold here between the earlier and later moraines and gravels as in the valley of Lake Creek, and make less probable any serious mistake in the interpretation which has been given to the features of that basin.

II. PLEISTOCENE HISTORY OF THE UPPER ARKANSAS

1. *The terraces of the earlier glacial period.*— One of the most striking geological features of the Arkansas Valley is the great development of the high-level gravels. From Granite, for a distance of 10 miles to the north, they occur nearly continuously on the west side of the river. Opposite Hayden, on the east side of the river, the graded rock-plain which has been noted as occurring to the south, becomes covered by an extensive alluvial fan similar in physical composition to the gravel terraces west of the river, with its lower edge forming a terrace of the same altitude as the terrace on the west, but rising steadily from this height back toward the gulches which head in the Park Range back of Leadville. The earlier glacial period was a time of ice-erosion. The streams leading down from the glaciers were overloaded, aggrading was the rule, and extensive wash-plains were formed. In the Arkansas valley aggrading went on until the stream was flowing many feet, in some cases many scores of feet, above its earlier level. Wash-plains extended continuously along the main valley, and vast alluvial fans extended down from the glaciated mountain valleys on either side. About Leadville these fans are largely intact today; but on the west they do not seem to

have been so extensively developed, and are now found in distinct, but not conspicuous, remnants on the shoulders of Mount Massive between the glaciated valleys.

Emmons[1] and Hayden[2] have suggested that the gravels are lake deposits of an interglacial period. They do not seem to be interglacial deposits, as they are closely related to the earlier moraines; and interglacial time was an epoch of valley-cutting and not of valley-filling. But are the gravels lake deposits? To the writer there is nothing to suggest that they are not stream-built gravel-plains. The material is mainly coarse, bowlders up to one and two feet in diameter being very abundant. It is slightly or not at all stratified. Where coarse gravel and fine gravel alternate there is a rude stratification, but in the coarse gravel stratification is wanting. If the material had been deposited in a body of standing water, a marked development of foreset beds (delta structure) should be found throughout the gravels; but any such structure is lacking. At one point only was any considerable amount of fine material noted, just north of Cache Creek (Fig. 1, 5), at the base of Lost Canyon Mountain. Here there is a considerable body of fine gravel, and some clay, in the plain. This is explained by the protected position, between the points of discharge of Lake Creek and Clear Creek. It is probable that the more rapid building up of the plain both to the north and south may have left depressions which might be filled with finer material or even clay, but such deposits of fine material are very local.

Not only the character of the gravels, but the disposition of the surface, indicates stream-work. Emmons notes that south of Leadville the gravels occur on the spurs back from the river at an elevation 1,000 feet greater than along the river, and infers the elevation of the Park Range over the valley by that amount. But a similar rise of the gravels occurs west of the Arkansas, though the gravels do not reach the altitudes they do near Leadville. Gravel fragments occur on the foothills of Mount Elbert several hundred feet above the level of the terrace along the river. These gravel terraces rising

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[1] Emmons, *Geology and Mining Industry of Leadville*, Second Annual Report, U. S. Geological Survey, pp. 220, 229.

[2] *Annual Report* for 1873, p. 53, and for 1874, p. 52.

toward the mountains have every appearance of alluvial fans. To the writer, who came into the region after several weeks in the Utah portion of the Great Basin, where the long slope of alluvial wash at the base of the mountain ranges is a striking feature, their topographic resemblance to alluvial fans was very strong.

The question may be raised as to the possibility of damming by the glaciers entering the Arkansas valley. The moraine of the earlier Lake glacier does not appear to have reached the present Arkansas by a half-mile, and cannot have dammed up the stream. Further the height of the gravels above and below Lake Creek is essentially the same. At Clear Creek the conditions are different. Here the old moraine lies along the western edge of the gorge, and the height of the gravels to the north seems to be determined by the rock-level at the top of the gorge outside of the moraine. The Arkansas was pushed to its present position on the east side of the valley by the advancing moraine of the Clear Creek glacier, and the height of the gravels up-stream determined by the position of that moraine. This does not necessarily mean, however, that a lake was formed to the north; the character of the gravels is against that interpretation. The probable explanation is that in earlier glacial time the advance of the Clear Creek glacier and moraine went on contemporaneously with aggradation by the Arkansas, until at the maximum the Arkansas was flowing on its flood-plain about the nose of the Clear Creek moraine, pushed to that position by the gradual advance of the glacier. Farther north also the Arkansas hugs the east side of its valley. This, however, is not due to pushing by glaciers, but probably to a greater supply of detritus coming in from the glaciated valley of Lake Creek, building a wash-plain with slope to the west, and constantly tending to push the main stream to the east.

2. *The work of interglacial time.*—Glacial periods are times of valley-clogging; interglacial periods, of valley-cutting. The first glacial period with its moraines and gravels was succeeded by an interglacial period in which the Arkansas and its tributaries were engaged in valley-cutting. To this period is assigned the excavation of the rock-gorge of the Arkansas. From a point two miles north of Lake Creek, south to beyond Granite, the Arkansas was flowing on the east side of its own gravel deposits and well to the east of its

earlier course. Here it quickly sunk its channel through the gravels into the underlying granite, and its interglacial valley is in consequence narrow and gorge-like. North of its rock-valley, toward Leadville, the Arkansas does not flow in rock, and its interglacial valley is much wider, averaging three-quarters of a mile, though not less deep than to the south. This difference in valley-width is, of course, due to the difference in hardness of the materials in which the valley has been opened. There is probably a double reason for the failure of the river to lay bare rock to the north. North of Lake Creek glaciers occurred on both sides of the valley, there was not the unsymmetrical development of wash that farther south forced the river to hug the east side of the valley, and it therefore kept more nearly its preglacial course. Further, the preglacial Arkansas was flowing in a graded rock valley which probably had a gentle gradient, while the interglacial gravels were laid down by rapid streams handling coarse material and building that same material into steeper slopes. Later erosion would naturally reach rock more generally along the lower course of the river where the gravels were less thick.

As the Arkansas cut its valley during interglacial time, the side streams were lowering theirs. Those from the east were flowing over a rock-graded plain thinly veneered with river gravel, and as they cut down, they dissected the plain and largely removed the gravel, so that now it occurs only in scattered bowlders over the divides between the tributary streams. The slope of these tributaries from the east steepens toward the main stream; they have not quite been able to keep up with the main stream in downward cutting. The small stream which enters the Arkansas through drift from the west at Hayden has swept away the whole terrace for a half-mile in width along its lower course, and at Lake Creek the terrace has been quite cleared away west of the river. No permanent streams enter the Arkansas between these two, but wet-weather streams originating on the old moraine and terrace have cut out wide, shallow valleys, whose depth is determined by the ledge of hard rock which the streams have found at the edge of the river. North of Lake Creek this action has cut out several broad, transverse valleys, but has not destroyed the original surface of the higher terrace. Between Lake Creek and Clear Creek there are different conditions. Here several streams come down the face of Lost Canyon Mountain, cross the plain, and enter the Arkansas. Only one of these, Cache Creek, is a permanent stream, but the others carry much more water than the channels which head in the moraine to the north of Lake Creek. The effect of their combined action is that the original surface has been cut into series of eastward-sloping terraces, whose level is determined by the distance the streams have cut into the rocky edge of the Arkansas gorge—levels which are lowest toward the south, where Cache Creek cuts deepest toward the river. These valleys have widened till they met, and in this manner the original constructional level of the terrace has been replaced by a terrace of stream-erosion. The only points where the original surface is kept are on the salients at the base of Lost Canyon Mountain, where the gravels have been protected from erosion by their position on the divide between the small valleys crossing the plain. Here the gravels rise to the level of the gravel fragments east of the river and north of Lake Creek. At one point nearer the river a remnant of the higher level is kept. A small hill just south of Lake Creek on the west side of the Arkansas rises 50 feet above the general level of the plain in its neighborhood. The part above the surrounding terrace-level is rock with a covering of gravel. This is a remnant, not of the original terrace, for it is covered with quartzite gravel derived from north of the Lake Creek region, but of an intermediate terrace which stood above the present terrace-level; and it is a witness to the general degradation of this part of the old plain. The Arkansas here cut across a shoulder of granite coming from the east, and this granite nucleus has preserved the gravel over it from removal.

The cutting of interglacial time was marked by the development of terraces (*F* in Fig. 3) at intermediate levels. The benches so produced are not conspicuous features of the topography, and are determined by the levels at which the streams came upon rock barriers as they cut through the gravels to the underlying rock. One such terrace is cut in the high gravels along the east side of the Arkansas opposite Hayden, and is determined by the highest rock-level in the gorge to the south. At this level in the gorge a narrow terrace is worked out in the rock. The gravel on these intermediate terraces is largely composed of quartzite bowlders of medium size, while the bowlders of the upper terrace are largely granitic in composition and contain only an insignificant amount of quartzite. Quartzite is abundant in the Park Range about Leadville, but is not found on either side of the valley about Lake and Clear Creeks. This difference in rock composition of the terrace gravels indicates that the upper gravels about Lake Creek were almost wholly composed of material swept in from the adjacent valleys, while during interglacial time the Arkansas was sweeping that material away and bringing large amounts of material down from the upper parts of the valley. Incidentally it means that in early interglacial time continuous gravel trains, above the level of the rock in the gorge, extended up towards the head of the valley.

3. *Second glacial and postglacial.*—The later glacial period marked a new advance of the ice, the accumulation of the younger moraines, and the development of a valley train in the rock-gorge of the Arkansas, but was not marked by any change in the course of the river. The later gravels occur in scattered terrace fragments north to Granite Gulch. North of that point they are not distinct. Postglacial time has been marked by the resumption of clearing by the stream, and the removal in large part of the terrace made during the later glacial advance.

III. GLACIAL EROSION

1. *Valley form.*—The cross-profile of a maturely glaciated mountain valley will be typically as shown in Fig. 4; a broad U-shaped valley below, surmounted by gentler, but still steep, slopes (*AB*) made by undercutting, which, in a region not too thoroughly glaciated, will pass above into the gentle slopes (*AC*) of preglacial origin. The most striking feature of a view along such a valley will be its broad U-trough. This form is well shown both in the main valley of Lake Creek and in those of its tributary valleys which were occupied by ice. The best illustration is afforded by the middle and upper part of Willis Gulch. No hanging valleys above, and no rock-sills or buttresses below, mar the simplicity of its general form. It is a remarkably regular example of the type. The middle part of several

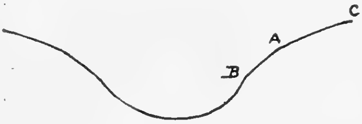

FIG. 4.—Cross-profile of a glaciated valley.

other tributaries which were occupied by valley glaciers show the same general features. See in this connection Fig. 10.

The main valley above Twin Lakes shows the same broad U-cross-section, but in the matter of broad detail there are serious interruptions to the regular profile, in rocky barriers across the stream-floor, and in some cases in buttresses standing out prominently from the valley side. The longitudinal profile of the valley is not even. For a distance the stream may be swinging from side to side in an alluvial valley floor, and then may for a fraction of a mile be flowing with more rapid fall in a rock-gorge between the low, rolling, glaciated hills of one of the valley-sills. Four such sills occur in the main valley within a distance of six miles above the mouth of the rock-gorge. The largest is the one at the mouth of the rock-gorge. It consists of a series of rounded rock-bosses rising to the higher walls of the valley on either side, but is most conspicuous on the north, where it forms a long rocky barrier, reaching nearly to the upper limit of glaciation. The difference in level of the stream between where it enters this rocky portion of its valley above, and where it leaves it below, is 600 feet; and it is here flowing for a mile in a narrow postglacial gorge. Other sills occur at several points upstream, but are not as conspicuous as the one at the mouth of the rock-valley.

Rock-bosses standing out from the valley wall also occur. The two on either side of Monitor Gulch are the best—Monitor Rock[1] on the west side, and another nearly as high on the east. Monitor Rock rises nearly 1,500 feet above the valley floor, nearly to the upper limit of valley glaciation, and stands out conspicuously into the valley.

An even U-trough is the ideal toward which the glacier tends to shape its bottom; but rock-sills and buttresses show that in the process of valley-cutting the glacial bottom may be fashioned quite irregularly, on account of differences either in rock-resistance or in glacial erosion at different points. Monitor Rock may be due to difference in rock hardness, as it is composed in part of a finer grained, denser, and probably more resistant facies of the porphyritic granite which is the common rock of the valley. But it is not pos-

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[1] Described by Hayden, *Annual Report* for 1873, p. 54.

sible to make any general statement as to the greater hardness of the rock barriers, because much the same kind of rock is found all along the valley. In the present case these irregularities occur well below the limit of hanging valleys, and so in that part of the valley excavated by the glacier; they are not due to subaërial erosion, though the prominence of projecting buttresses may have been so increased.

The separation of the different elements of the valley side indicated in Fig. 4 is difficult, on account of weathering and of the indefiniteness of the upper limit of glaciation. The upper preglacial slope is easily recognized in the rounded summits of the divides between the tributaries to Lake Creek. It is a graded slope of about 10°, is usually grassed over, and is shown where the divides between the tributaries have not been sharpened by glacial erosion. But it is not easy to distinguish the cliff of glacial abrasion from the oversteepened cliff above the former glacial bed. The glaciated valley surfaces have been largely destroyed by subsequent weathering, and where the height of the glacier was changing, it may easily have been that the passage from a well-glaciated wall below to a non-glaciated wall above was originally gradual and indefinite. In the lateral valleys weathering has practically destroyed all the glacially smoothed surface of the valley walls, and the upper limit of glacial erosion can be made out only approximately. In the main valley the upper limit can be more definitely fixed, and while even here there is doubt about its exact location, a lower portion of the valley wall can be recognized, showing under favoring conditions well-developed glaciated surfaces, while an upper, steep, rocky portion

FIG. 5.—Monitor Rock, Lake Creek Gorge, looking down the gorge.

seems to have been above the ice-level, and to have been formed by undercutting, or sapping, of that part of the valley side above the glacier surface. The ridges between some of the more vigorous lateral valleys, as between Crystal Lake and Willis gulches, seems to show this intermediate slope due to glacial sapping. The preglacial slope has been destroyed by valley-cutting, but the steep slope of the upper glaciated valley gives place to a gentler, but still steep, slope, which is best explained by glacial sapping. The same element in the valley slope is shown in the upper angle of the truncated spur in the main valley shown in Fig. 9.

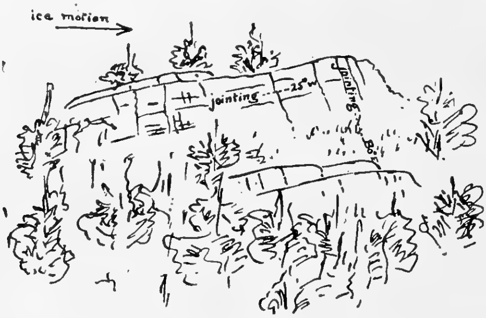

FIG. 6.—Glaciated and jointed ledge.

2. *Glaciated surfaces.*—Glacially smoothed surfaces are common in the main valley, especially so on the rock-barriers and rock-bosses which were peculiarly exposed to glacial erosion. In the matter of abundance of glaciated surfaces there is a great difference between the main valley and its tributaries. The larger lateral valleys, such as Willis Gulch and Crystal Lake Gulch, have suffered an almost complete destruction of their glacial surfaces. At one point on the wall of Willis, glacial smoothing was recognized, and in Crystal Lake Gulch a small area on the west wall, and a certain amount of smoothing on the hummocky surface of the cirque floors, are all. Some of the other gulches show even less remnants of glacial surfaces than do these two. Glacial striæ are found only on the more perfectly preserved surfaces in the granite of the main valley.

A matter of importance is the proportional amount of erosion due to glacial abrasion or glacial plucking. In almost all cases rock-ledges and rock-bosses show a great difference between the stoss and lee ends. The former are apt to be well-rounded; the latter, almost invariably steep and coarse-hackly. The jointed structure of the granite in the main valley is such as to favor plucking. The accompanying figure (Fig. 6) of a glaciated ledge on the north side of the valley brings this out. Three prominent series of joints intersect the granite. The direction of ice-movement is toward the east. One series of joints has a dip of 70° E., and so runs almost at right angles to the direction of ice-movement, and gives easy conditions for plucking. Two other series of joints dip respectively steeply to the south and more gently to the north, while the blocks into which they divide the rocks pitch to the west. The result on the form of the ledge is shown in the figure in which the glaciated surface rises to the east, evidently determined by the jointing. When a ledge cut out from a rock jointed in this manner is seen end on, it usually shows a composite profile and not a simple glaciated curve, the profile being clearly controlled by the jointing. The connection between jointing and glaciated surface in such instances means that plucking has played a large part in glacial erosion over the surface, as well as on the lee side of the boss and that a process of pluck and heal has been going on, the ice breaking out great blocks along planes determined by jointing, and then rounding off the broken edges by glacial abrasion. This form of ledge surface is not a matter of occasional outcrops; in the middle part of the valley the whole valley sides for a distance of hundreds of feet vertically, and for considerable distances along the valley, shows this intimate relation between joints and form of the rock outcrops. On the south side of the valley, on both sides of Crystal Lake Gulch, glaciated rock outcrops (Fig. 7.) rise from the stream to the upper limit of glaciation, and all show glaciated stoss sides rising at an angle of 30° toward the east, and ending in a lee slope plunging steeply to the east. The two structures are determined by the line of jointing in the granite. Farther up the valley,

Fig. 7.—Glaciated ledges on south side of Lake Creek.

near Everett, an extensive area of glaciated ledges on the south side of the valley shows the ledges sloping to the east—again an expression of rock-jointing, which in this case holds a different direction from that farther down-stream. Facts of this kind, occurring through the valley, point to glacial plucking as being as important as, perhaps much more important than, glacial abrasion in the erosion of Lake Creek valley.

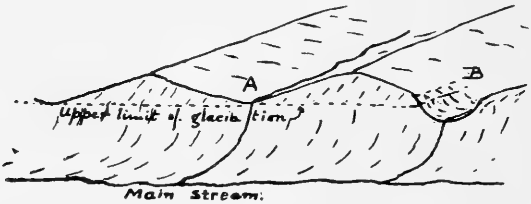

FIG. 8.—Diagram of hanging valley.

Other minor features of glacial smoothing are illustrated at different points in the main valley. Evenly rounded ledges of considerable size, shallow saucer-shaped (in cross-section) furrows, glacial undercutting, and in some cases a smoothing of parts of the protected lee sides of eminences, also occur. A feature noticed in one or two cases was the production of nearly flat, smoothed surfaces intersecting at a small angle, and separated by a sharp ridge, the whole being worked out of sound rock. Evidently some change in the current of the ice had taken place at that point. Of similar nature is the gouging of a flat surface by a shallow groove, much as a shallow groove might be cut in a planed board by a gouge of large curve.

3. *Hanging valleys and truncated spurs.*—When the main valley of a preglacial drainage system has been deepened by glacial erosion, the relations which should exist after the disappearance of the ice may be represented by Fig. 8. The spurs of the old divides and the lower ends of the tributary valleys have been cut away, giving hanging valleys and truncated spurs. It is not essential that the upper limit of glaciation should coincide with the level of the lateral valley, as it does in this figure. The tributary valleys may or may not have been occupied by glaciers. If they have been so occupied, the form of the hanging valley will be like *B* in the figure, broad and U-shaped; if not, like *A*, more or less broadly V-shaped, according to the steepness of the preglacial valley. Terminal facets marking truncated spurs, and both glaciated and non-glaciated hanging valleys, are found along the sides of the Lake Creek valley.

One of the best illustrations of terminal facets separating non-glaciated hanging valleys occurs just above the mouth of the gorge on the south side of the valley. The ice here reduced the valley side to an even curve leaving the wall not at all broken by rock buttresses. In this manner a series of triangular facets was formed against the divides between short tributary valleys, which right here were not occupied by glaciers. Subsequently interglacial and postglacial erosion have cut these valleys further toward the main valley floor, and have furrowed the facet faces, but they still distinctly show their faceted character. The facet shows steeper in the lower three-fourths of its face, a gentler, but still steep slope, above to the apex of the facet. In Fig. 9 the dotted line *AB* marks the upper limit of glaciation; the part of the facet below that line seems to represent glacial abrasion, the upper part the work of glacial sapping. The truncated spurs along the base of Lost Canyon Mountain have already been mentioned (p. 292) while speaking of the moraine.

FIG. 9.—Truncated spur on the south wall of Lake Creek Valley.

Hanging valleys and truncated spurs obviously go together, and hanging valleys are a characteristic feature along Lake Creek. Some of these hanging valleys were occupied by glaciers, some not. Crystal Lake Gulch, La Plata Gulch, and La Plata Basin are glaciated hanging valleys. Willis and Boswell gulches to the east were glaciated valleys, but are not hanging valleys, as the main glacier did not cut below the level of the tributary valleys in this lower part of its course. Of the three mentioned, that of Crystal Lake Gulch is most characteristic. Fig. 10 shows this hanging valley as seen from the opposite side of the main valley. It is a broadly opened U-valley, ending on the side of the main valley about 1,000 feet above Lake Creek. La Plata Basin and La Plata Gulch, the two tributary valleys from the south, next west of Crystal Lake Gulch, and Hayden Gulch, entering from the north opposite Crystal Lake Gulch, are hanging valleys of similar type. The other tributary valleys which enter Lake Creek above Twin Lakes are either short V-valleys, unoccupied by glaciers, or occupied only by masses of ice forming cirques at their head, or else are, like Echo Gulch, U-valleys in their middle and upper course, and V-valleys below, the ice-tongue not having reached the main valley.

4. *Two periods of glacial erosion in the gorge.*—The moraines of the Twin Lakes glacier show two glacial periods separated by a long interglacial period, during which the cutting of the rock-gorge of the Arkansas took place. Only portions of the earlier moraine remain, but they show that certainly in part, and probably on the whole, the earlier glacier reached farther into the valley than did the later glacier. The gravels associated with this earlier moraine are much greater in bulk than those associated with the later moraine. The material of the moraine was obviously derived from the valley of Lake Creek, and the great abundance, in the gravels, of material derived from the valley of Lake Creek indicates that the gravels

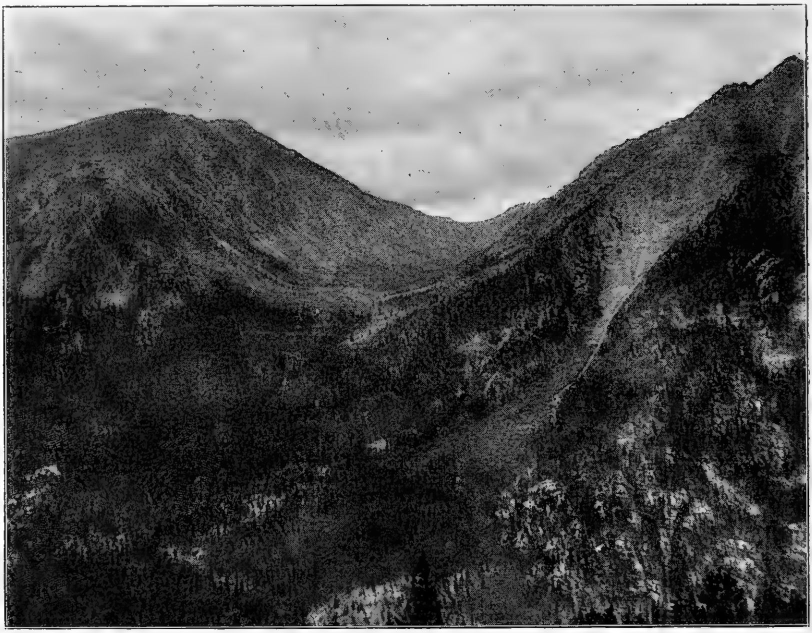

FIG. 10.—Hanging valley of Crystal Lake Gulch.

were largely from this same area. These things suggest strongly that the material removed from the valley during the earlier period of glaciation was as great, and probably greater, in amount than that removed during the later glaciation. The question naturally rises: Is it possible to detect in the rock valley of Lake Creek evidence of these two glaciations, which we know must have occurred? It is not easy, since the work of the later period would continue that of the earlier, and all products of erosion would be removed from the valley. But it is thought that evidence in favor of two periods of glacial erosion, with the larger amount of work done in the earlier period, is found in the relation of the hanging valleys to the main valley.

In typical hanging valleys the contours of the lower slopes of the main valley continue unchanged beneath the hanging valley. A cross-section of the main valley and long profile of the lateral hanging valley is given in Fig. 11, in which *AB* is the longitudinal profile of the hanging valley. But the profile of the typical hanging valley of the Twin Lakes region would be represented by *AECD*, the triangle *ECB* representing a narrower or broader notch which has been cut out from the side of the general valley immediately below the hanging valley. Such a re-entrant could conceivably be cut out by the main glacier, or by the lateral stream. There seems to be no good reason why the ice should favor the side wall beneath the hanging valleys generally, and in some cases these cuts are too sharply re-entrant for ice-work. Further, these notches contain in almost all cases morainic material; and this is the case whether the lateral valleys were occupied by ice or not. They are areas of glacial deposit rather than of erosion. Their origin seems to be as follows: During the earlier period of glaciation the main glacier cut its valleys below the level of the tributary valleys, producing normal hanging valleys, the longer of which were occupied by tributary

FIG. 11.—Profile of hanging valley.

glaciers and became U-valleys, the shorter being hanging V-valleys. During the succeeding interglacial period the tributary streams cut back the mouths of their hanging valleys for a greater or less distance, forming V-valleys or ravines at the lower end of the U-valleys, and deepening the V at the lower end when the valley had not been previously glaciated. The glacier of the second period smoothed the walls of these interglacial stream-cut re-entrants where they were not too sharp, but in practically all cases dumped more or less morainic material into them. Postglacial time has enabled the streams for the most part to cut through this drift, and below the mouth of the hanging valley they follow a steeper course, chiefly in morainic débris, but occasionally cutting into the solid rock. This interpretation of the phenomena at the mouths of the hanging valleys implies that the larger features of the forms of the glacial valleys were assumed in earlier glacial time—an inference in accord with the evidence of the moraines.

POSTGLACIAL CHANGES

Since the final disappearance of the ice, many changes of minor importance have taken place, in the way of both erosion and deposition. Streams flowing across drift and across rock barriers in the valley of Lake Creek have cut their channels. Behind the recessional moraines of Lake Creek considerable deposition has taken place, forming the extensive meadow at the head of Upper Twin Lake, and smaller patches of bottom-land further up-stream. The most conspicuous changes, however, are the rock-weathering and landslides along the main valley of Lake Creek, but especially along and at the head of its tributary valleys. The almost entire destruction of glacially smoothed surfaces in the tributary valleys has been mentioned. Here, at altitudes near and above the timber line, there has been a steady rain of rock fragments from the valley sides, and talus cones are everywhere present, mantling the lower parts of the gulch walls, and in many cases merging to make a nearly continuous talus slope. In addition to this gradual accumulation of fallen blocks to make a talus slope, great masses of broken rock have fallen from the sides and shot out to or beyond the axis of the valley. In one case, in the upper end of Willis Gulch, for a distance of half a mile along the valley side, and for a height of 1,000 to 1,500 feet above the valley bottom, the rock along the side of the gulch has slipped down and out in a series of lobes whose festooned and ridged surfaces express the flow within the mass of the landslide. In a number of instances landslides have dammed up the streams and caused small lakes; indeed, the small lakes in the gulches are almost uniformly formed in this way, and lakes occupying rock basins are rare.

MOUNTAIN FORM

Mountain form is an expression of two factors: rock structure, including original form and internal arrangement, and erosive processes. So far as the first of the two factors is concerned, conditions in the Twin Lakes region are simple. The rocks are all completely crystalline, and are granite, granite porphyries, and granitic gneisses. Their composition is such that no great difference may be expected in resistance to weathering, and their surface distribution bears this out, for they appear to be largely independent of topography. The porphyritic granite has already been referred to as one of the rocks most characteristic of the valley of Lake Creek, and it is possible that its somewhat greater capacity for weathering may have determined the course of the preglacial Lake Creek; but the ridges which separate the valleys tributary to Lake Creek are in places porphyritic granite, in places gneiss, and the difference in the rock seems to make but little difference in the character of the divides. In some instances the jointing of the rock plays a part in shaping minor details of form, the rough serrate ridges about La Plata being worked out on a jointed compact gneiss which holds its form well and gives the peculiarly jagged outlines to the lower divides; but petrographically the Twin Lakes area is a granitic complex, and differences in form are to be explained by differences in the character of the erosive processes.

The erosive processes which have been at work in the area are two, stream-erosion and glacial erosion. The larger features of the region were worked out by streams in preglacial time. These larger features were profoundly modified in places by ice-erosion in Pleistocene time.

The preglacial topography of the Arkansas valley and of the adjacent Park and Sawatch ranges can only be inferred from those portions of the region which were not subject to glacier-erosion during the Pleistocene, and have thus retained their preglacial form essentially unchanged to the present. The character of this topography was suggested in the opening pages of this paper. Briefly it was as follows: the Arkansas was flowing in a broadly opened graded valley between ranges which rose on either side to a height of from 3,000 to 5,000 feet, but which were characterized by relatively gentle and graded slopes. The term most applicable to such mountains is "massive." A view of Lost Canyon Mountain (Fig. 14) from the Arkansas valley is probably typical for the mountain range in general in preglacial time.

FIG. 12.—Lost Canyon Mountain from the Arkansas Valley.

The study of mountain form about Twin Lakes is the question how far in any particular locality this preglacial type of mountain has been destroyed by glacial erosion; how far cliffs, arrêtes, and peaks of glacial origin have replaced the more gentle and even slopes of mature subaërial erosion. Back toward the divide of the Sawatch

Range, where the head-feeding valleys of the glacial streams were working against each other, cirque action was general, sharp forms prevail, and the general view looking west toward the divide from any high point near the Arkansas shows a sea of sharp peaks. The multiplication of tributaries back in the range leaves scarcely any part untouched by glacial action. Fig. 14 is a view taken looking across Lake Creek toward La Plata Peak (14,342 feet), and shows something of the character of the area where little preglacial surface is left, the ridge in the foreground on the right being the only preglacial surface in the view which shows. About Twin Lakes, and nearer the border of the valley, there are considerable areas in which the two types of topography resulting from the two agencies occur together, since here the drainage of the tributaries of the Arkansas is concentrated in trunk channels of their lower course. The general form of Lost Canyon Mountain as seen from the Arkansas valley has been mentioned. Fig. 13 shows the evenly rounded summit of pre-

Fig. 13—Summit of Lost Canyon Mountain, with the upper edge of Boswell Gulch cirque on left.

glacial date at a height of 12,800 feet above sea-level. The steep slope on the left is the upper edge of Boswell Gulch amphitheater, and is of glacial origin, and the view shows the manner in which cirque-action was gnawing into the preglacial topography at the close of the last glacial period.

In using the present topography of the non-glaciated areas about the Upper Arkansas to illustrate the preglacial topography, it is assumed that substantially no change has taken place in those areas since the commencement of glacial time. Strictly this is not true, as these areas were subjected to subaërial erosion during Pleistocene and post-Pleistocene times; but it is not believed that the kind of changes then going on was different from the changes of preglacial time. Nor does it seem probable that the amount of change which has taken place since the commencement of the Pleistocene would be great for an area which had then reached maturity under atmospheric and stream agencies.

FIG. 14.—La Plata Peak from the north side of Lake Creek.

THE VARIATIONS OF GLACIERS. IX[1]

HARRY FIELDING REID
Johns Hopkins University

The following is a summary of the Ninth Annual Report of the International Committee on Glaciers:[2]

REPORT ON GLACIERS FOR 1903

Swiss Alps.—Of the ninety glaciers under the care of the Swiss foresters, fifty-eight were measured in 1903; the larger number, forty-three, are receding or stationary, and this is evidently the condition of the large majority of the Swiss glaciers. The slight tendency to increase shown last year by thirteen glaciers continues. Three glaciers have been certainly increasing for the last three years; twelve have been increasing for a year or two.

Between 1902 and 1903 the Rhone glacier has receded 11.5^{m} and has uncovered an area of $4{,}900^{sq\,m}$. There have been a slight thinning in the lower part of the glacier and a slight thickening higher up.[3]

Eastern Alps.—We have reports from twenty-nine glaciers, eighteen of which are retreating, six are about stationary, and five are advancing.

In the Silvretta group, two glaciers continue to retreat. The Suldenferner in the Ortler group has advanced more than 70^{m} between 1895 and 1903, nearly one-half of which occurred between 1901 and 1903. This glacier is being carefully observed. In the Oetzthal the Hochjochferner and the Hintereisferner are retreating, whereas the Vernagtferner and the Diemferner show slight evidence of advance. The Hochjoch has retreated 2.3^{m}, and the Vernagt has advanced 5^{m}. The Hintereis is growing thinner in the lower part,

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[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XII.

[2] *Archives des sciences physiques et naturelles* (Geneva, 1904), Vol. XVIII, pp. 160–95.

[3] Report of Professor Forel and M. Muret.

but has become slightly thicker in the upper part. The glaciers of the Stubaï group, which, in general, have been retreating since 1891, are now retreating much more slowly; and one of them, the Sulzenauferner, has advanced 6.5^m. In the Zillerthal the Rainbachkees has retreated 4.4^m. Six glaciers of the Venediger group are retreating quite rapidly and three are about stationary. The glaciers of the Glockner are all retreating. Two glaciers of the Ankogel group, the Hochalmkees and the Kleinelandkees, are retreating at the rate of 7 or 8^m per year. The Grosselendkees, on the other hand, lying between the other two, has advanced over 2^m.

Italian Alps.—Two secondary glaciers of the Marmarole group are retreating. The other glaciers of the Venetian Alps are retreating slightly or are stationary. All the snow-fields of the Cavallo have increased considerably in size, whereas those of the western slope of the Zoldo have diminished very much since 1888. The glaciers of the Graian and Pennine Alps, in general, have retreated slightly. There seem to be marked increases in the accumulation of snow in the reservoirs of the Brenva glacier and of the glaciers on the Grivola and Grand-Paradis. A discussion of all the observations at hand regarding the glaciers of Valnontey has shown indirectly, but rather strikingly, the slight advance of 1891 which, unfortunately, was not actually measured.[1]

French Alps.—The second report of the French Commission on Glaciers, published in 1903, contains a detailed account of many glaciers and a very comprehensive review of glaciology.[2]

A number of glaciers of Mount Pelvoux advanced slightly in 1890–91, but have retreated ever since; and many of the smaller glaciers have diminished so much in size as to indicate that they may disappear altogether. The glaciers of the Grandes-Rousses have been retreating for the last thirty years, with a slight interruption for some of them about 1890. The glaciers of the Maurienne and of the Tarentaise have shown changes in opposite directions, but for the great majority the retreat has continued, with a tendency toward a slower retreat for the larger glaciers. It is rather interesting to note that the largest glaciers have retreated the least. A comparison

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[1] Reports of Professors Porro, Marinelli, and Marson.

[2] By M. Charles Rabot.

of the present position of glaciers with their positions indicated on the maps made about forty years ago shows that the average annual retreat during that period has been about three times as great as the annual retreat during the last decade.[1]

Scandinavian Alps: Norway.—The glaciers of the Jotunheim show, in general, a slight advance between 1901 and 1903. In this region the snowfall has been unusually heavy, some of the glaciers being entirely covered with snow throughout the whole summer of 1903. The same can be said for the glaciers of the Folgefon. There has also been an excessive snowfall in the Jostedal, but the glaciers there have continued to recede slightly.[2]

The Caucasus.—A number of new glaciers have been visited and described, but no information is given regarding their variations, with the exception of one on Mount Bazar-Duzi, which seems to be in retreat.

The Tyan Shan.—In this mountain chain the snowfall has increased very materially. In June, 1903, the glaciers seem to have been entirely snow-covered. A record of the rainfall in the neighborhood shows that it was more than twice as great in 1902–3 as in 1900–1. A glacier resembling the Mer de Glace, and as large as any in the Alps, has been discovered and mapped in the Alatau Mountains of Ili.

Canada.—After an almost normal winter, the observed glaciers in British Columbia and Alberta exhibit most interesting changes since last year. Of the four carefully observed, two are advancing and two continue to recede.

The Victoria glacier, Alberta, continues to recede and also to contract in width. The average shrinkage on the northwest side for the past three years is nineteen feet per year. There is a very evident decrease in the thickness of the ice, and an increase in the number of crevasses at the upper part of the left-hand side. The tongue, deeply buried in moraine, is evidently receding.

The Wenchumna glacier, Alberta, has apparently been advancing for a number of years; it has not been visited until recently, so that the rate of advance cannot yet be determined. Its condition is evidenced by inroads into a living forest composed of large trees which

[1] Report of Professor Killian.

[2] Reports of Messrs. Oyen and Reckstadt.

are being plowed down by great masses of moraine advancing before the ice.

The Illecillewaet glacier, British Columbia, continues to recede and to decrease in thickness. The following table shows the yearly recession determined annually in August since 1898:

1898–1899	11 feet
1899–1900	69 feet
1900–1901	15 feet
1901–1902	48 feet
1902–1903	33 feet

A careful triangulation of the plates placed on the ice in 1899 to determine the rate of flow proves that the rate determined in 1900 has subsequently remained almost constant.

While the Asulkan glacier has apparently shrunk in breadth, the tongue continues to advance. The following shows the principal changes yearly since 1899:

1899–1900	recession, 24 feet
1900–1901	advance, 4 feet
1901–1903	advance, 36 feet[1]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1904[2]

Professor George Davidson has made a careful study of all the old charts and narratives relative to the glaciers along the Alaskan coast.[3] He has incorporated in his account copies of some early maps, and has superposed upon them the outlines of the latest maps, and by this means has shown changes that have occurred in the position of the ends of some glaciers. The account is very full, giving, with references, all the descriptions of glaciers by the early navigators. Professor Davidson's general conclusions are practically the same as those arrived at by the Harriman Expedition, namely, that there has been a very marked general retreat of the glaciers,

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[1] Report of Messrs. George and William S. Vaux, Jr.

[2] A synopsis of this report will appear in the *Tenth Annual Report of the International Committee.* A report of the glaciers of the United States for 1903 was given in this *Journal*, Vol. XII, pp. 258–63.

[3] "The Glaciers of Alaska That Are Shown on Russian Charts or Mentioned in Older Narratives," *Transactions and Proceedings of the Geological Society of the Pacific*, Vol. III, Ser. II, pp. 1–98.

with some exceptions, among which are the glaciers southwest of Mount Fairweather.

The two glaciers of Taku Inlet were greatly effected by the earthquakes of 1899, but are apparently making up a part of their losses. (*Davidson.*)

There are a large number of small glaciers at the heads of the valleys tributary to Lake Chelan, Washington. One of these, at the head of Railroad Creek, has retreated 200 feet in recent years; and other glaciers in the neighborhood also have the appearance of being in retreat. (*Rusk.*)

The snowfall in the neighborhood of Mount Hood was unusually large in the spring of 1904, as it has been for the last few years. (*Gorman.*) Nevertheless, the Zigzag glacier on the west side of Mount Hood seems to have become smaller since last year. (*Knapp.*) The snowfall was very heavy in the Sierras this year; in the late summer the Lyell glacier was still almost entirely snow-covered, and deep drifts extended beyond the limit of the ice. It shows no definite retreat since Professor Russell visited it in 1883. The accumulation of snow seems to have been increasing during the last two or three years, and "there is good reason for believing that the glacier is slowly advancing." Lake Mono, at the foot of Mount Lyell, without any outlet, has been slowly rising for many years. This seems to indicate an increase of precipitation in the region and may foreshadow a general increase in the size of the glaciers. (*Lee.*)

The Arapahoe glacier in Colorado shows no definite change since last year. (*Henderson.*) The Hallet glacier, a little farther north, has diminished in the last nine years, but there is no definite information with regard to its more recent changes. (*Mills.*)

The subject of glacial erosion is being vigorously attacked from the standpoint of physiography. Mr. Willard D. Johnson[1] describes the forms of old glacial valleys in the Sierras, dwelling especially on the very low grade, occasionally even reversed, in the upper part of the old glacial troughs. This form bears no relation to the profile produced by stream erosion, and he therefore thinks that it is to be accounted for by the erosion of the ice. He describes a descent into

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[1] "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII (1904), pp. 569–78.

the bergschrund of one of the smaller Sierra glaciers, where he found the rock impregnated with water melted from the ice, and the broken nature of the rock led him to believe that much sapping was accomplished at this point by the frequent freezing and melting of the water. This led to the belief that sapping of this kind explained the glacial erosion. Mr. Johnson has since given up this idea, because the bergschrund must be shallow in comparison with the depth of the ice; but he thinks that the line of the ancient bergschrund can still be recognized by a very steep cliff in the upper part of the walls of the cirques of the Sierras.

Mr. G. K. Gilbert[1] confirms the existence of a "schrundline," and brings out the interesting fact that a distinct difference in slope often exists on opposite sides of ridges in the high Sierras. The steeper side is that on which the snow would naturally accumulate as a result of the prevailing winds and of protection from the snow. He therefore concludes that the glaciers formed from the snow have by erosion steepened the slopes. In the volume of the Harriman Alaska Expedition on *Glaciers and Glaciation*, briefly noticed in last year's report, Mr. Gilbert presents a very strong argument in favor of the great erosive action of glaciers.[2]

Dr. Albrecht Penck[3] discusses the action of glaciers in the Alps, and shows how very difficult it is to explain all the physiographic features of glacial valleys without assuming that these valleys have been eroded by the glaciers.

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[1] "Systematic Asymmetry of Crest Lines in the High Sierras of California," *ibid.*, pp. 579–88.

[2] *Glaciers and Glaciation*, Harriman Alaska Expedition, Vol. III (New York, 1904).

[3] "Glacial Features in the Surface of the Alps," *Journal of Geology*, Vol. XIII (1905), pp. 1–19.

THE ABSTRACTION OF OXYGEN FROM THE ATMOSPHERE BY IRON[1]

C. H. SMYTH, JR.
Clinton, N. Y.

That the affinity between oxygen and iron has been the chief factor in the concentration of the latter into workable deposits is one of the most generally recognized facts of chemical geology, although our knowledge of the details of the various reactions involved is far from complete. Indeed, there are few occurrences of iron ores in regard to whose precise method of formation there is not much diversity of opinion.

With ore deposits and with the details of genetic processes, the present paper is not concerned, its aim being to consider one broad result brought about by the chemical relations of oxygen and iron.

The question at issue is: Has there been a progressive oxidation of iron since the beginning of geologic time, involving the abstraction of oxygen from the atmosphere?

Several questions are suggested by the consideration of the main topic, but at present they can hardly be touched upon. Indeed, it is with considerable hesitation that the main theme is here presented, since the data for its thorough consideration are not yet available. But even if the conclusions reached must be regarded as to a high

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[1] This paper was written in 1903, in the course of a general consideration of the circulation of mineral matter, and was laid aside for subsequent revision and elaboration, with the hope that further data might be obtainable.

The discussion of the same theme by President C. R. Van Hise (*A Treatise on Metamorphism*, Monograph XLVII, U. S. Geological Survey, pp. 950, 951) has suggested the publication of the paper, in spite of its lack of completeness, since the subject treated is of such a nature that a comparison of independently deduced figures, even though quite divergent, may be of value; and since, moreover, in spite of such divergence of numerical results, the final conclusion as to the importance of the problem presented is the same in both cases.

President Van Hise has been so kind as to read the manuscript, and has approved of the publication of its contents, for which courtesy the writer takes this opportunity of expressing his sincere thanks.

degree tentative, it is hoped that the mere formulation of the problem may be sufficiently suggestive to prove of some value.

Under atmospheric conditions, with abundant oxygen, iron is stable in the ferric condition, and during the circulation of mineral matter involved in the processes of denudation and sedimentation there would be, in the absence of opposing agents, a strong tendency toward the conversion of ferrous into ferric compounds, resulting, in the case of thoroughly disintegrated and decomposed materials, in a complete oxidation of the iron. The younger sediments, in so far as they are derived from other sediments, implying a thorough working over of their materials, would contain little or no ferrous iron. But opposed to this process we have the very potent reducing agent, organic matter. Not only does this agent, when present, take up oxygen that might otherwise combine with ferrous compounds, but it is also able to take oxygen from ferric compounds, reducing them to the ferrous state, thus counteracting the tendency toward oxidation above referred to.

According as the one or the other of these processes has predominated during geologic time, there has been a progressive oxidation or reduction of iron, and the rocks of the crust contain more or less ferric iron, while oxygen has been taken from, or added to, the atmosphere. If the processes balance, the ratio between ferrous and ferric iron remains constant, and the atmosphere is unaffected.

It is manifest that a solution of the problem would be afforded by analyses representing, on the one hand, the average composition, so far as ferrous and ferric iron are concerned, of the crust of the earth before denudation and sedimentation began; and, on the other, of the sedimentary rocks.

An approximation to the former is afforded by Dr. F. W. Clarke's[1] estimate of the composition of the "older crust," based upon 880 analyses of crystalline rocks.

For obvious reasons, a reliable estimate of the bulk composition of the sedimentary rocks is much more difficult to obtain, but the figures given by Stoke's analyses[2] are doubtless the best now available, and they are used as the basis of the present discussion. The samples for these analyses were prepared by Mr. G. K. Gilbert, in an effort

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[1] *Bulletin No. 168*, U. S. Geological Survey, p. 14.

[2] *Ibid.*, p. 17.

to get results that might represent the average composition of the sedimentary rocks, and there can be no doubt that the figures give a much closer approximation to the truth than would be afforded by a larger number of analyses taken at random. There is the further advantage that the analytical work is thoroughly reliable—a matter of first importance, and particularly so when it is a question of ferrous and ferric iron.

As in the analyses of limestones, the iron is all given as ferric oxide, the figures are not available for the present inquiry, but the iron content of these rocks is too small to be of great moment. An effort has been made to get from other sources evidence as to whether the correction for limestone would be plus or minus, but as most analyses combine the ferrous and ferric iron, and often the alumina as well, no definite conclusion was reached.

Not only does the small amount of iron in limestones affect the magnitude of this correction, but it is further reduced by the fact that the limestones are of minor moment in the mass of sediments. Gilbert[1] estimates the limestones as making up one-fifth of the total thickness of the sedimentary rocks. Reade's[2] estimate is one-tenth. Therefore, in view of the small percentage of iron in the limestones and their limited amount, they may be neglected without seriously affecting the results.

A more important question is that of the relative masses of shales and sandstones, and the consequent values to be attached to the figures for these rocks. No entirely satisfactory data are at hand to determine this point, but Gilbert's[3] estimate of equal parts of shale and sandstone is here used as being the best available.

As pointed out below, a change of this ratio would affect the magnitude, but not the sign, of the results. In the following estimates, therefore, the figures for shale and sandstone are given equal weight.

According to Clarke's estimate, the older crust of the earth contains 2.63 per cent. Fe_2O_3 and 3.52 per cent. FeO. The analyses of Gilbert's samples, by Stokes, give for shales[4] 4.03 per cent. Fe_2O_3 and 2.46 per cent. FeO. For sandstones[5] the figures are 1.24 per

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[1] *American Geologist*, March, 1894, p. 214.

[2] *Chemical Denudation in Relation to Geological Time*, 1879, p. 53.

[3] *Loc. cit.* [4] *Op. cit.*, p. 17, column C. [5] *Ibid.*, column F.

cent. Fe_2O_3 and 0.57 per cent. FeO. These figures represent the results as stated in five distinct columns, in each of which the direction of the change is the same—an increase of the ratio of ferric to ferrous oxide as compared with the corresponding ratio in the old crust.

By combining the figures for shales and sandstones, we have, as an expression of the iron contents of the sedimentary rocks, excluding limestones, 2.64 per cent. Fe_2O_3 and 1.52 per cent. FeO.

Comparing these figures with those given above for the older crust, the contrast is pronounced. In the older crust the ferrous oxide is in excess, while in the sediments the ferric oxide is markedly preponderant. This relation is expressed by the following ratios:

In older crust, $FeO:Fe_2O_3::3.52:2.63$; or about 1:0.75.
In sediments, $FeO:Fe_2O_3::1.52:2.64$, or about 1:1.75.

In other words, in the old crust there is about three-fourths as much ferric as ferrous oxide, while in the sediments there is about one and three-fourths times as much.

Corresponding ratios for the two chief groups of sediments are as follows:

Shales, $FeO:Fe_2O_3::2.46:4.03$, or about 1:1.64.
Sandstones, $FeO:Fe_2O_3::0.57:1.24$, or about 1:2.17.

Thus, as stated above, the magnitude, but not the sign, of the results for the sediments will vary with the weights given to shales and to sandstones. But even were the figures for shales taken alone, throwing out the sandstones entirely, it is evident that the ratio of ferric to ferrous oxide is double that found in the older crust.

As the shales, sandstones, and limestones represent, in altered form, the materials of the old crust, and as the two latter show, as compared with the old crust, a decrease of iron, while the shale shows no increase, it is clear that, if the analyses are to be used as a basis of calculation, allowance must be made for concentration of iron in ores and other highly ferruginous rocks. Moreover, in the change from old crust to silicious sediments, there must be a loss of calcium and magnesium to form limestones, and of sodium held in sea-water, while there is a gain of carbon dioxide and water.

In view of these facts, it is probable that 4 per cent. is a moderate estimate of the total oxidized iron of sediments, excluding limestones, and it is assumed that the ratio between ferrous and ferric oxides is that above derived from Stokes's analyses.

To determine the amount of oxygen combined with iron in the sediments, Joly's[1] estimate of the mass of silicious sediments, 64×10^{16} tons (of 2,240 pounds) is taken as the amount of shales, sandstones, and ferruginous rocks.

This gives 256×10^{14} tons of iron, which, occurring as Fe_2O_3 and FeO in the ratio 2.64:1.52, requires 96×10^{14} tons of oxygen. The same amount of iron occurring as Fe_2O_3 and FeO in the ratio of the old crust, 2.63:3.52, requires $8,765 \times 10^{12}$ tons of oxygen.

The difference between these two amounts, 835×10^{12} tons, is a measure of the quantity of oxygen taken from the atmosphere and fixed in the silicious sedimentary rocks through the agency of iron. Calculating, from Woodward's[2] statement as to the mass of the atmosphere, the total amount of oxygen as $1,213 \times 10^{12}$ tons, the quantity abstracted by iron is equal to 68.8 per cent. of that now present in the atmosphere.

While this estimate manifestly can lay no claim to even approximate accuracy, it suffices to show that the abstraction of oxygen by iron is a factor that cannot be disregarded in any attempt to work out the geological history of the atmosphere.

[1] *Scientific Transactions of the Royal Dublin Society*, Vol. VII, Ser. II, p. 46.

[2] *Bulletin No. 78*, U. S. Geological Survey, p. 34.

THE FAUNA OF THE CLIFFWOOD (N. J.) CLAYS[1]

STUART WELLER
The University of Chicago

Several papers have recently appeared in which the beds at Cliffwood Point on the south shore of Raritan Bay, New Jersey, have been discussed, and some difference of opinion as to their correlation has been expressed.[2] For the most part the discussion has been based upon the evidence as shown by the fossil flora, although mention of marine invertebrate fossils has been made in several of the papers. During the past two field seasons extensive collections of these invertebrates have been made by the writer from the locality in question, as well as from the clay pits in the neighboring region which have been opened in the same beds. At Cliffwood Point the fossils were collected from smooth, concretionary nodules, which occur in great numbers along the beach at low tide. Although most of the fossils were collected from nodules not *in s tu* a few similar nodules carrying the same fossils have been found imbedded in the clay, and no doubt can be entertained as to the original source of all the nodules being from the clay at the locality in question, from a horizon near or somewhat below high-water level. Their occurrence in essentially the same beds, or even in beds a little lower

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[1] Published by permission of the state geologist of New Jersey.

[2] Arthur Hollick, "The Cretaceous Clay Marl Exposure at Cliffwood, N. J.," *Transactions of the New York Academy of Sciences*, Vol. XVI, pp. 124–36; Edward W. Berry, "The Flora of the Matawan Formation (Crosswick's Clays), *Bulletin of the New York Botanical Garden*, Vol. III, No. 9, 45–103; Edward W. Berry, "New Species of Plants from the Matawan Formation," *American Naturalist*, Vol. XXXVII, pp. 677–84; G. N. Knapp, "The Cliffwood Clays and the Matawan," *American Geologist*, Vol. XXXIII, pp. 23–27; Edward W. Berry, "The Cretaceous Exposure near Cliffwood, N. J.," *ibid.*, Vol. XXXIV, pp. 253–60; W. B. Clark, "The Matawan Formation of Maryland, Delaware, and New Jersey, and its Relations to Overlying and Underlying Formations, *American Journal of Science*, 4th Ser., Vol. XVIII, pp. 435–40; Edward W. Berry, "Additions to the Flora of the Matawan Formation," *Bulletin of the Torrey Botanical Club*, Vol. XXXI, pp. 67–82; Edward W. Berry, "Additions to the Fossil Flora from Cliffwood, New Jersey," *ibid.*, Vol. XXXII, pp. 43–48.

than those containing the plants described by Hollick and Berry, may be safely assumed.

One of the most notable features of the fauna from these Cliffwood nodules is the great number of Crustacean remains. Nearly every one of the concretions, when broken, yields the remains, more or less fragmentary and crushed, of one of these creatures; indeed, a crab of some sort seems to have been the nucleus around which every one of these concretionary nodules in the clay has been formed. In addition to the crustacean remains, which seem to represent several species, the nodules have yielded a goodly number of mollusca, and the following species have been more or less satisfactorily determined:

PELECYPODA

1. **Ostrea** sp. undet. At least two species of oysters have been recognized in the Cliffwood fauna, neither one of which can be identified with any of the species occurring in the other Cretaceous beds of New Jersey.
2. **Anomia tellinoides** Mort.
3. **Amusium** sp. undet. This species is much larger than either of the members of the genus previously recorded from New Jersey, and it seems to be undescribed. It resembles in general form some specimens of *Camptonectes burlingtonensis* Gabb, but lacks the distinctive ornamentation of that shell.
4. **Mytilus oblivius** Whitf. Although this shell attains a larger size in the Cliffwood clays than any specimens observed from the Wenonah sand, the only other horizon where it has been observed, there seems to be no reason for considering the Cliffwood specimens as specifically distinct.
5. **Modiola** sp. undet. A single imperfect specimen may be referred here. It somewhat resembles the shell described from the West as *Volsella attenuata* M. & H.
6. **Pteria petrosa** Con. Whitfield saw but one imperfect specimen of this species during the preparation of his monograph of the New Jersey Cretaceous pelecypods,[1] and Conrad in his original description mentions seeing but a single specimen from the Delaware and Chesapeake Canal. In the Cliffwood fauna it is one

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[1] *Paleontology of New Jersey*, Vol. I, p. 69; also *Monograph*, U. S. Geological Survey, Vol. IX, p. 69.

of the most common forms, and has been seen elsewhere in New Jersey only in the Wenonah sand. It seems to be indistinguishable from *P. linguiformis* E. & S., from the West.

7. **Inoceramus sagensis** Owen. Elsewhere in New Jersey this species occurs most commonly in the Merchantvillle clay marl.
8. **Nemodon brevifrons** Con. This species has been recognized elsewhere in the New Jersey faunas only in the Woodbury clay near Haddonfield and in the same formation in Monmouth County.
9. **Breviarca** sp. undet. This is probably an undescribed form; it is closely allied to, if not identical with, a species occurring in the Woodbury clay fauna of Monmouth County.
10. **Nucula slackiana** Gabb. Specimens of this species in the Cliffwood fauna are indistinguishable from specimens from the Woodbury clay.
11. **Nucula** sp. undet. This species seems to be undescribed, but it is identical with a form which occurs in the Wenonah sand fauna.
12. **Nuculana protexta** (Gabb)? Specimens which seem to be referable to this species are rather common in the fauna.
13. **Nuculana** sp. undet. The specimens here indicated are possibly but a form of the last.
14. **Lucina cretacea** Con. This species, which occurs so abundantly in the Woodbury clay, is one of the rarest forms in the Cliffwood fauna.
15. **Cardium ripleyanum** Con.? Several specimens of a small *Cardium* have been referred questionably to this species, they being too imperfect for certain identification.
16. **Isocardia cliffwoodensis** n. sp. (Figs. 1–3). This is one of the most characteristic, though not the most common, species of the Cliffwood fauna, being present in every locality where the fauna has been observed. A similar, if not identical, species occurs in the Wenonah sand fauna.

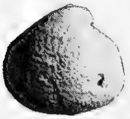

FIG. 1

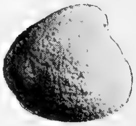

FIG. 2

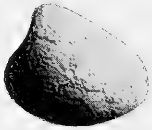

FIG. 3

17. **Dosinia gabbi** Whitf. Several fragmentary specimens seem to be referable to this species, although they are too imperfect for certain identification.

18. **Tellina equilateralis** M. & H.? Several incomplete specimens seem to resemble this species originally described from the Fox Hills beds of the West. The specimens are too imperfect for certain identification.

19. **Veleda lintea** (Con.). This is a rather variable shell, but specimens from the Cliffwood clays are indistinguishable from examples occurring in the Wenonah sand, where the species most commonly occurs.

20. **Veleda transversa** Whitf.? Among the specimens of *Veleda* in the Cliffwood fauna several specimens seem to approach this species in form, and have been so identified provisionally.

21. **Pholadomya occidentalis** Mort. A single incomplete impression of a large shell seems to represent this species. Eleswhere it seems to be quite closely confined to the Merchantville clay marl.

22. **Corbula** sp. undet. The internal casts of this species are rather abundant, but it is difficult to identify them with shells which have been described from external characters. The species seems to resemble the shell illustrated by Whitfield under the name *C. foulkei* Lea, which is in reality not that species, but *C. bisulcata* Con.

GASTROPODA

23. **Pyropsis** sp. undet. This shell resembles *P. naticoides* Whitf., and it is possible that it should be so identified.

24. **Pyrifusus erraticus** Whitf. This species is represented by two specimens. It was originally described from a nodule said to have been collected at Cliffwood, N. J.

25. **Volutimorpha gabbi** Whitf.? This species is represented by a single specimen which most closely resembles Whitfield's[1] *fig. 4*, Plate VIII, referred provisionally to *V. gabbi* Whitf. The Cliffwood specimen is a nearly smooth internal cast and does not show the external markings of the shell.

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[1] *Paleontology of New Jersey*, Vol. II; also *Monograph* U. S. Geological Survey, Vol. XVIII.

26. **Scalaria** sp. undet. A fragmentary specimen of a member of this genus has been observed. It is too imperfect for identification.

27. **Turritella encrinoides** Mort.? Fragments of the internal casts, as well as impressions of the external markings, of a *Turritella* occur in the Cliffwood fauna, which seem to be referable to this species.

CEPHALOPODA

28. **Placenticeras placenta** De Kay. A single fragment of the cast of the chamber of habitation of a large ammonite resembles in all respects similar specimens known to belong to *P. placenta*, and little doubt can be entertained as to the correctness of this identification of the Cliffwood specimen.

29. **Baculites** sp. undet. A fragment of the cast of the chamber of habitation may certainly be referred to this genus. The specific determination cannot be satisfactorily made. It may belong to the common *B. ovatus* of the New Jersey Cretaceous beds, but it seems to possess stronger, oblique, annular ridges than is usual in that species.

CRUSTACEA

30. **Tetracarcinus subquadratus** n. gen. and sp. (Figs. 4–6). Several species of crustaceans, all of them probably undescribed, are present in the Cliffwood fauna. A single one of these forms, however, may be considered in the present connection, for the reason that it is also a common form in the fauna of the Woodbury clay. It has not been possible to place this little crab in any of the described genera, and therefore it may be called *Tetracarcinus* on account of its subquadrangular form, with the specific name *subquadratus*. The dimensions of an average specimen are: length of carapace, 14.5^{mm}; breadth, 14^{mm}; greatest con-

FIG. 4

FIG. 5

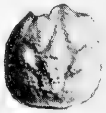

FIG 6

vexity, 5^{mm}. The regions of the carapace are clearly marked by more or less deeply impressed furrows, as shown in the accompanying illustrations. This is one of the common forms in the Cliffwood fauna, and is the only crustacean which has been observed in the fauna of the Woodbury clay.

A sandstone mass was collected on the beach at Cliffwood, eighteen inches in length by twelve inches in breadth and perhaps three inches thick, completely filled with fossils. This mass of sandstone was not *in situ*, and, being different in its lithologic characters from any material imbedded in the clay at this point, it may have been transported to this locality from elsewhere. It is, however, somewhat similar in its lithologic characters to certain sandy, fossiliferous nodules occurring in the clay at the pits of the Cliffwood Brick Company, a little over a mile distant on Whale Creek. The fauna yielded by this sandstone undoubtedly indicates its Cliffwood age, although several species occur which have not been observed elsewhere. The species of fossils identified are as follows:

PELECYPODA

1. **Breviarca** sp. undet. This is apparently the same species as that noted from the fauna of the crustacean nodules.
2. **Trigonarca** n. sp.? This is one of the common species of the fauna, and is apparently undescribed. It has the form of a small *Idonearca*, but is less convex than most species of that genus and has a different hinge structure.
3. **Trigonarca** n. sp.? This is a larger species than the last, and the hinge bears a much larger number of teeth. Neither of the species has been observed elsewhere.
4. **Nuculana protexta** (Gabb)? The specimens of this species are poorly preserved, but they seem to be specifically identical with those from the crustacean nodules which have been identified as *N. protexta*.
5. **Yoldia** cf. **evansi** M. & H. This is a rather common species in the fauna, and is closely allied to, if not identical with, *Y. evansi* from the Fox Hills beds of the West.
6. **Cardium** sp. undet. This species can be identified with none

of the recognized forms from New Jersey, and is probably an undescribed species.

7. **Isocardia cliffwoodensis** n. sp. This is the same form that occurs in the fauna of the crustacean nodules.
8. **Veleda lintea** Con. This is the most abundant species in the fauna.
9. **Corbula** sp. undet. Two or three unidentified species, and possibly undescribed, seem to be referable to the genus *Corbula*.

GASTROPODA

10. **Pyrifusus** sp. undet. This is apparently an undescribed species, and has not been observed elsewhere.
11. **Volutomorpha** sp. undet. This also seems to be an undescribed form which has not been observed elsewhere.
12. **Gyrodes** sp. undet. This is a small species, which apparently cannot be referred to any of the recognized New Jersey species, and may be new.
13. **Scalaria** sp. undet.
14. **Turritella** sp. undet.

At Geldhaus' clay pits, a little over a mile west of Cliffwood Point, on Whale Creek, crustacea bearing nodules similar to those collected on the beach at Cliffwood, occur *in situ* in the clay. Besides the numerous imperfect crustacean remains, the following species have been recognized at this locality:

PELECYPODA

1. **Pteria petrosa** Con.
2. **Nuculana protexta** Gabb.
3. **Lucina cretacea** Con.
4. **Isocardia cliffwoodensis** n. sp.
4. **Veleda lintea** (Con.)
6. **Corbula** sp. undet.

In the Cliffwood Brick Company's south pits, at the crossing of the New York and Long Branch R. R. over Whale Creek, numerous, sandy, abundantly fossiliferous nodules were obtained *in situ*. In the fauna of these nodules the following species have been recognized:

PELECYPODA

1. **Ostrea** sp. undet. A small undetermined species.
2. **Amusium** sp. undet. This is the same species noted in the fauna of the crustacean nodules from the beach at Cliffwood.
3. **Breviarca** sp. undet. This is the same species as that occurring in the crustacean nodules at Cliffwood Point.
4. **Nuculana protexta** (Gabb) ?
5. **Yoldia** cf. **evansi** M. & H.
6. **Cardium** sp. undet. This is the same species noted from the sandstone slab collected at Cliffwood.
7. **Cymella bella** Con. This species is represented by several specimens. Elsewhere it occurs rarely in the Merchantville, more commonly in the Woodbury, and most abundantly in the Wenonah formation.
8. **Isocardia cliffwoodensis** n. sp.
9. **Cyprimeria** sp. undet. This is a small species which cannot be identified with other New Jersey forms, but it is most like a species in the Woodbury clay, where he genus occurs most abundantly. A form apparently identical with this Cliffwood shell occurs rarely in the Wenonah fauna.
10. **Tellina** sp. undet. Several specimens of a shell apparently referable to this genus are present in the fauna. They seem to belong to an undescribed species.
11. **Linearia metastriata** Con. This species rarely occurs in the Merchantville clay, it is abundant in the Woodbury clay near Haddonfield, and is one of the most abundant species of the Wenonah sand.
12. **Veleda lintea** (Con.). This is the most abundant species in the fauna.
13. **Pholadomya occidentalis** Mort. Several fragments which seem to represent this species have been observed.
14. **Corbula** sp. undet. A species of this genus, apparently undescribed, is represented by several specimens.
15. **Leptosolen biplicata** Con. This species has been recognized elsewhere in the Merchantville clay, the Woodbury clay, and the Wenonah sand, it being most common in the last of these formations.

GASTROPODA

16. **Pyrifusus** sp. undet. A single specimen of an undescribed shell is apparently referable to this genus.
17. **Gyrodes** sp. undet. Fragmentary specimens of a small species of this genus are present in the fauna. They are apparently different from any of the recognized New Jersey forms.
18. **Turritella encrinoides** Mort.? Fragmentary specimens of a species of *Turritella*, probably belonging to this species, occur in this fauna.

Several nodules, not *in situ*, were collected in the same pits of the Cliffwood Brick Company as the fauna last recorded. They undoubtedly had their origin in these same clay beds, and the following species of fossils have been recognized in them:

PELECYPODA

1. **Ostrea** sp. undet. One of the same species noted in the fauna of the crustacean nodules at Cliffwood Point.
2. **Anomia tellinoides** Mort.
3. **Amusium** sp. undet. This is the same as the species recorded in the Cliffwood fauna.
4. **Pteria petrosa** Con.
5. **Inoceramus sagensis** Owen.
6. **Breviarca** sp. undet. This is the same form as that recorded from the crustacean nodules at Cliffwood Point.
7. **Nuculana protexta** (Gabb)?
8. **Cardium** sp. undet.
9. **Isocardia cliffwoodensis** n. sp.
10. **Veleda lintea** (Con.).
11. **Corbula** sp. undet. This is the same species as that numbered 22 in the list of species from the crustacean nodules collected at Cliffwood Point.
12. **Corbula**? sp. undet.

GASTROPODA

13. **Pyrifusus** sp. undet.

CRUSTACEA

14. **Tetracarcinus subquadratus** n. gen. and sp.

The data recorded in the preceding lists of fossils are assembled in the following table in order that they may be more readily analyzed.

A separate column is allotted to each of the preceding groups of species, numbered as follows: (1) nodules collected on the beach at low tide at Cliffwood point; (2) sandstone mass from beach at Cliffwood Point; (3) Geldhaus' clay bank; (4) Cliffwood Brick Company's south pits, nodules *in situ;* (5) Cliffwood Brick Company's south pits, ferruginous nodules not *in situ*. The last three columns are assigned to the three higher formations as follows: Merchantville clay (Mv), Woodbury clay (Wb), and Wenonah sand (W); and the occurrence of the Cliffwood species in these formations is noted.

	1	2	3	4	5	Mv	Wb	W
Pelecypoda—								
1. *Ostrea* sp. 1	x	—	—	—	x	—	—	x
2. *Ostrea* sp. 2	x	—	—	—	—	—	—	—
3. *Anomia tellinoides* Mort	x	—	—	—	x	x	—	x
4. *Amusium* sp. undet	x	—	—	x	x	—	—	—
5. *Mytilus oblivius* Whitf	x	—	—	—	—	—	—	x
6. *Modiola* sp. undet	x	—	—	—	—	—	—	—
7. *Pteria petrosa* Con	x	—	x	—	x	—	—	x
8. *Inoceramus sagensis* Owen	x	—	—	—	x	x	—	—
9. *Nemodon brevifrons* Con	x	—	—	—	—	—	x	—
10. *Breviarca* sp. undet	x	x	—	x	x	—	x	—
11. *Trigonarca* sp. 1	—	x	—	—	—	—	—	—
12. *Trigonarca* sp. 2	—	x	—	—	—	—	—	—
13. *Nuculana slackiana* Gabb	x	—	—	—	—	—	x	—
14. *Nucula* sp. undet	x	—	—	—	—	—	—	x
15. *Nuculana protexta* (Gabb)?	x	x	x	x	x	—	—	—
16. *Yoldia* cf. *evansi* M. & H.	—	x	—	x	—	—	—	—
17. *Lucina cretacea* Con	x	—	x	—	—	—	x	—
18. *Cardium* sp. 1	x	—	—	—	x	—	—	—
19. *Cardium* sp. 2	—	x	—	x	—	—	—	—
20. *Cymella bella* Con	—	—	—	x	—	x	x	x
21. *Isocardia cliffwoodensis* n. sp	x	x	x	x	x	—	—	x
22. *Cyprimeria* sp. undet	—	—	—	x	—	—	—	x
23. *Dosinia gabbi* Whitf.?	x	—	—	—	—	—	—	—
24. *Tellina equilateralis* M. & H.?	x	—	—	—	—	—	—	—
25. *Tellina* sp. undet	—	—	—	x	—	—	—	—
26. *Linearia metastriata* Con	—	—	—	x	—	x	x	x
27. *Veleda lintea* (Con.)	x	x	x	x	x	x	x	x
28. *Pholadomya occidentalis* Mort	x	—	—	x	—	x	—	x
29. *Corbula* sp. undet	x	—	—	—	x	x	—	—
30. *Leptosolen biplicata* Con	—	—	—	x	—	x	x	x
Gastropoda—								
31. *Pyropsis naticoides* Whitf.?	x	—	—	—	—	—	—	—
32. *Pyrifusus erraticus* Whitf	x	—	—	—	—	—	—	—
33. *Pyrifusus* sp. undet	—	x	—	—	—	—	—	—
34. *Pyrifusus* sp. undet	—	—	—	x	—	—	—	—
35. *Pyrifusus* sp. undet	—	—	—	—	x	—	—	—
36. *Volutomorpha gabbi* Whitf.?	x	—	—	—	—	—	—	—
37. *Volutomorpha* sp. undet	—	x	—	—	—	—	—	—
38. *Gyrodes* sp. undet	—	x	—	x	—	—	—	—
39. *Scalaria* sp. undet	x	—	—	—	—	—	—	—
40. *Scalaria* sp. undet	—	x	—	—	—	—	—	—
41. *Turritella encrinoides* Mort.?	x	—	—	x	—	x	x	x
Cephalopoda—								
42. *Placenticeras placenta* De Kay	x	—	—	—	—	x	x	x
43. *Baculites* sp. undet	x	—	—	—	—	—	—	—
Crustacea—								
44. *Tetracarcinus subquadratus* n. sp	x	—	—	—	x	—	x	—
						10	11	14

A careful analysis of this fauna of the Cliffwood clays brings clearly to view several important facts. In the first place, the large number of species which are common to the fauna, and to one or more of the faunas of the formations above, emphasizes the close relationship between the Cliffwood fauna and these higher faunas. This relationship is, indeed, so close that they constitute essentially but different faunules of one large fauna. There is no sharper distinction between the fauna of the Cliffwood clays and the Merchantville clay than there is between the Merchantville and the Woodbury clays. However, the Cliffwood fauna does possess characteristics which distinguish it somewhat sharply from the Merchantville fauna, among which may be mentioned the abundance of the species *Pteria petrosa* and *Isocardia cliffwoodensis*, which have nowhere yet been recognized in the Merchantville, and the especial abundance, in some cases at least, of *Veleda lintea*, which is sometimes present, although always rare in the Merchantville. None of the crustaceans which are so abundant in the Cliffwood fauna have been recognized in the Merchantville, although claws and other disarticulated joints of crustacean appendages are not uncommon in the higher fauna at some localities. The distinction between these two faunas is not alone emphasized by the species present in the Cliffwood and absent from the Merchantville, but also by the genera and species which are absent from the Cliffwood and almost universally present in the Merchantville fauna. Among such genera may be mentioned *Idonearca*, *Trigonia*, *Panopea*, *Axinea*, and *Leiopistha*.

On making a careful comparison between the Cliffwood fauna and that of the Woodbury clay, the formation immediately above the Merchantville, a much greater resemblance is noted than between the Cliffwood and the Merchantville; the same Merchantville genera mentioned above as being conspicuously absent from the Cliffwood fauna are also conspicuous for their absence from the Woodbury. Furthermore, several forms are common to the Cliffwood and the Woodbury faunas which have not been observed in the intervening formation, among which may be mentioned *Breviarca*, *Lucina cretacea*, and the little crustacean here called *Tetracarcinus subquadratus*. In making this comparison, however, it must not be overlooked that some of the most characteristic Cliffwood species, as *Isocardia* *cliffwoodensis* and *Pteria petrosa*, have nowhere been observed in the Woodbury fauna.

It is unnecessary to make comparison between the Cliffwood and the Marshalltown faunas, as there is scarcely anything in common between them; but with the fauna of the Wenonah sand the Cliffwood fauna has more in common even than with that of the Woodbury clay. Among the species listed in the table given above, it will be seen that fourteen species are recorded as being common to the Cliffwood and the Wenonah, eleven to the Cliffwood and the Woodbury, and only ten to the Cliffwood and the Merchantville. These numbers do not fully express the relative proximity of relationship between these several faunas, although they do partially, because no account is taken of the relative abundance of the forms noted. As a matter of fact, when the abundance of the different species in the different faunas is taken into account, the similarity of the Cliffwood and Wenonah faunas is accentuated, while that between the Cliffwood and the Merchantville is diminished. Aside from the crustaceans of the Cliffwood fauna, the two species *Pteria petrosa* and *Isocardia cliffwoodensis* are perhaps the most characteristic forms, and both of these occur in the Wenonah fauna. *Veleda lintea* is another conspicuous Cliffwood species which occurs more frequently in the Wenonah sand than in any other of the New Jersey Cretaceous formations.

It is believed that these comparisons which have been instituted make clear the fact that, however much or however little the Cliffwood fauna has in common with the faunas of the higher formations, it does have a unity of its own. Although many of the species occur also in other horizons, the whole assemblage of species, considered as a faunule, possesses characteristics which serve to distinguish it from any of the other faunules with which it has been compared.

The geographic distribution of this Cliffwood fauna differs notably from that of the Merchantville, it being limited, so far as now known, to a small area between Cliffwood Point and the head of Cheesquake Creek. The distribution of the Merchantville fauna is entirely across the state, from the south shore of Raritan Bay to the shores of Delaware Bay; throughout its entire extent it is remarkably constant in its characters, and the Merchantville beds are everywhere marked by constant lithologic characters, yielding fossils, usually in abundance, wherever they are well exposed. There is scarcely a formation in the entire Cretaceous series of New Jersey which is more sharply marked, both lithologically and faunally, than the Merchantville clay. The base of the formation constitutes an easily recognizable and perfectly natural geologic horizon, the beds below being characterized by the great heterogeneity of their lithologic characters, while the beds above are just as strongly characterized by the constancy of their lithologic characters.

The heterogeneous assemblage of sands and clays beneath the Merchantville have been called the Raritan formation, and the fossiliferous clays at Cliffwood which are interbedded with sands and are lithologically allied to the subjacent beds, must certainly be considered as a lens-like body included in the Raritan. The Raritan beds for the most part give evidence of a non-marine origin, but there must have been marine conditions present along the Atlantic border at no great distance during the entire period of their deposition. The non-marine, perhaps estuarian conditions of Raritan time were supplanted in Merchantville time by more uniform marine conditions, but, previous to the initiation of marine conditions in the area entirely across New Jersey, we find evidence here in the Cliffwood clays of a slight transgression of the sea from the direction where marine conditions had continuously existed, and the occupation of a small area where non-marine sediments had previously been deposited.

This occurrence at Cliffwood of marine fossils in the Raritan is not the only case of the kind in New Jersey, although it is the most notable one. Whitfield[1] mentions the occurrence of *Turritella encrinoides*, a not uncommon species in the Cliffwood beds as well as in some of the higher formations, in the clays at Sayersville, which are near the very base of the Raritan; and the slab mentioned by him, bearing many examples of this species, is now preserved in the collections of the Geological Survey of New Jersey. Other specimens of marine fossils from near the same locality have recently been acquired by Mr. J. M. Manley, of New Brunswick, N. J. It is altogether possible, and indeed most probable, that faunas more or less closely allied to those of the higher formations were living, throughout the

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[1] *Paleontology of New Jersey*, Vol. II, p. 144.

entire period of deposition of the Raritan beds, at no great distance from the present shores of Raritan Bay; and, if that were the case, it is not at all surprising that there should be occasional transgressions of marine conditions within the area where non-marine sedimentation was usually in progress, with the consequent deposition of marine beds with marine fossils.

THE HALLOPUS, BAPTANODON, AND ATLANTOSAURUS BEDS OF MARSH

S. W. WILLISTON
The University of Chicago

HALLOPUS BEDS

In the *American Journal of Science* for October, 1891, Professor O. C. Marsh proposed the name "Hallopus beds" for a somewhat indeterminate horizon of vertebrate fossils, as follows:

> Near the base of the Jurassic a new horizon may now be defined as the Hallopus beds, as here alone remains of the remarkable reptile named by the author *Hallopus victor* have been found. Another diminutive dinosaur, *Nanosaurus*, occurs in the same strata. The horizon is believed to be lower than the Baptanodon beds, though the two have not been found together. The Hallopus beds now known are in Colorado, below the Atlantosaurus beds, but quite distinct from them.
>
> The Baptanodon beds have been found in many localities everywhere beneath the Atlantosaurus beds, and having below them, at various localities, a series of red beds, which may, perhaps, contain the Hallopus horizon, but are generally regarded as Triassic.

This reference of Marsh to a vertebrate horizon below the marine Jurassic of the Rocky Mountain region has been wholly overlooked or disregarded by subsequent writers, the fauna itself having been referred to the "Upper Jura." I am now in a position, I believe, to show that the horizon is a distinct one, and that it belongs, not to the Lower Jurassic, but to the Upper Triassic. I, furthermore, believe that the horizon will eventually be found to be widely fossiliferous in the Rocky Mountain region.

Although I cannot be entirely sure, after so long an interval, it is my recollection that the type specimen of *Hallopus victor* was discovered by Mr. M. P. Felch in August, 1877, in Garden Park, near Cañon City, Colo., a few weeks before the time of my first visit to that since famous locality. The precise spot whence the specimen came was pointed out to me, the base of an escarpment of red sandstone, whither the specimen had fallen from the overhanging cliff. Its precise horizon in the cliff was never ascertained, though the block of red sandstone in which the fossil was inclosed left no doubt as to its derivation. This peculiar character of the matrix, so different from anything found in the Atlantosaurus beds, has been mentioned by Marsh, though he never gave definite information as to the location of the discovery.

Of the other specimen, that upon which was based the genus *Nanosaurus* originally, I have no clear recollection, though I have no doubt it was from the same spot and horizon as the type of *Hallopus*. The fact that only one-half of the split slab was obtained, as mentioned by Marsh, indicates that the specimen was not discovered *in situ*. At the time of my first visit to Cañon City, in September or early October of 1877, I searched diligently in the adjacent red sandstones for the Hallopus horizon, but without success.

In July of the past year Mr. W. H. Reed, of the University of Wyoming, informed me that he had, some years previously, discovered vertebrate fossils in the red sandstones of the Red Mountain region, south of Laramie City, Wyo., and very kindly took me to the place of his discovery. We found there numerous fragments of bones, scattered along a thin stratum, near the top of the red beds. The marine Jurassic is here wanting, as at Cañon City, the sandstone of the Morrison or Atlantosaurus beds overlying the red beds without marked unconformity. The lower members of these beds consist of a grayish or yellowish sandstone, and are unfossiliferous, the first vertebrate fossils occurring seventy-five feet or more above the red-beds horizon. Because of an apparent absence of distinctive Triassic fossils among those secured in the short time at our disposal, I was somewhat inclined at the time to refer this horizon to the Lower Jurassic, or possibly as a fresh-water equivalent of the Baptanodon beds; the more so from the fact that the crocodile remains obtained seemed to approach the mesosuchian type.

At my request, however, Mr. Reed spent some time later in a further examination of the deposits, the results of which he has recently sent me. Among the material which he obtained there are very characteristic labyrinthodont plates and vertebræ, proving conclusively the Triassic age of the deposits. Furthermore, the occurrence of the bones in the red sandstone stratigraphically quite conformable with, and undifferentiated from, the red beds below, seems to render any other disposition of the horizon out of the question.

The differences of these fossils from those obtained in the Lander region from an horizon fully two hundred and fifty feet below the top of the beds, are such that their contemporaneity of deposition is very improbable. These differences are especially noticeable, *inter alia*, in the apparent absence of the teeth so characteristic of those and many other American Triassic deposits—teeth usually referred to a somewhat problematical genus of dinosaurs, called *Paleoctonus*. These teeth, however, are of several types, and it is very probable that none of them belong with dinosaurs. Indeed, the association of one of the forms with the genus *Dolichobrachium* Williston seems now assured. This genus, however, seems closely allied to, possibly identical with, the genus *Theriodesmus* from the Karoo beds of South Africa—a problematical genus whose relationships are yet quite unknown. So different, indeed, is the genus, or at least *Dolichobrachium*, that it must be ascribed to a distinct group, perhaps order of reptiles. It is interesting, also, to observe that a recent letter from Dr. Broom confirms the reference of the Anomodont-like reptiles described by me to the true dicynodonts.

Nothing of the kind has been discovered in the Connecticut valley Trias, while the occurrence of true dinosaurs in those beds, as also pseudosuchian crocodiles, none of which have been certainly found in the Triassic deposits of the West, save the Hallopus beds, would indicate that the most eastern deposits are of a different, perhaps later, age. I am much inclined to believe that the Popo Agie beds, which may be contemporaneous with those yielding vertebrate fossils in Utah, Arizona, New Mexico, and Texas, are of early Keuper age, while the Connecticut valley, the Red Mountain, and Hallopus beds of southern Colorado are later in time.

Taking all the facts into consideration, I believe that the horizon of the Red Mountain beds is nearly or quite identical with that of the Hallopus beds of Cañon City.

That the Hallopus beds of Colorado are of Lower Jurassic age there is not a particle of evidence, unless it be in the ornithopodous character of the dinosaur *Nanosaurus*, a type never before found so low, though confidently expected from the Trias. The primitive characters of *Hallopus* are shown especially in the sacrum. The type specimen, as Marsh has said, came from an horizon far below the lowermost of those yielding sauropodous remains. Hatcher has said that "no fossils have been obtained from the Red Beds of Garden Park"—an error.

BAPTANODON BEDS

From the Baptanodon beds of Wyoming three genera and eight species of vertebrates have been described: *Baptanodon discus* Marsh, *B. natans* Marsh, *B. marshi* Knight, *Pantosaurus striatus* Marsh, *Megalneusaurus rex* Knight, *Cimoliasaurus laramiensis* Knight, *Plesiosaurus shirleyensis* Knight, and *Diplosaurus nanus* Marsh. Of these I am not satisfied of the distinction between *Pantosaurus striatus* and *Plesiosaurus shirleyensis.*

On the evidence which seemed to be presented by *Baptanodon*, Hatcher was inclined to refer these beds to the Middle Jurassic: "The vertebrates of these marine beds point to a somewhat greater antiquity than do the invertebrates, for *Baptanodon*, the most abundant and best-known form, has its nearest ally in the *Ophthalmosaurus* of Europe;"[1] from which, as he rightfully says, it is scarcely distinguishable generically. While *Ophthalmosaurus* is typically[2] from the Middle Jurassic, another species[3] has been described from the Cambridge Greensand (Upper Cretaceous). While it is very possible, indeed not improbable, that these two species are not congeneric, it is also apparently quite true that *Baptanodon* seems to be as closely allied to the Cretaceous as to the Jurassic species. Indeed, in speaking of the Cretaceous form, Lydekker says: "This species may belong in *Baptanodon.*" It is therefore evident that, so far as our knowledge yet goes, *Baptanodon* is worthless as a Leitfossil.

In a later, posthumous[4], paper Hatcher has said: "that these beds are of Upper Jurassic has not been questioned, and is abundantly confirmed by both their vertebrate and invertebrate faunas;" from which it is evident that he later placed no value on the relationships

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[1] *Memoirs of the Carnegie Museum*, Vol. II (1903), p. 71.

[2] *O. icenicus* Seeley, *Quarterly Journal of the Geographical Society*, Vol. XXX (1874), p. 696.

[3] *O. cantabrigiensis* Lydekker, *ibid.; Geological Magazine* (3), Vol. V (1888), p. 310.

[4] *Proceedings of the American Philosophical Society*, Vol. XLIII (1904), p. 354.

of *Baptanodon* with the Jurassic *Ophthalmosaurus*, the only vertebrate which hitherto has been considered in their correlation.

I have studied all the types of the described species of plesiosaurs from these beds, and have examined all other material known from this horizon. These species all agree in having single-headed cervical ribs, and broad and short epipodials. From a somewhat careful study of the literature of English plesiosaurs, the earliest recorded occurrence of forms with single-headed cervical ribs that I can find is in the Oxford Clay, as is also the earliest of the short epipodial forms. One species described from the Baptanodon beds and referred to Cimoliasaurus (to which it probably does not belong) has three epipodial bones, as I am satisfied from an examination of the type specimen. The earliest European species having three epipodials, so far as I can ascertain, is from the Kimmeridge. All these characters are specializations, which became predominant in the Cretaceous, the elongated epipodials utterly disappearing. While species with two epipodials continue quite into the Fort Pierre Cretaceous, the length of the bones is materially lessened. The conclusion, therefore, to be derived from the plesiosaurs is that the beds are not older than the Kimmeridge. This conclusion is, of course, not decisive, as it may be that such specializations will yet be found in older forms in Europe, and since we can conceive of a more advanced evolution of the plesiosaurs in the western continent during these times.

The single crocodile described or named from these beds by Marsh presents no trustworthy evidence yet. Marsh referred the species to the genus *Diplosaurus*,[1] probably identical with the Wealden genus *Goniophilis*, and originally described from the Atlantosaurus beds. Should it prove to be rightly determined generically, it would point strongly to the Upper Jurassic, since no brevirostral crocodile is known from older rocks.

ATLANTOSAURUS BEDS

The age of the Atlantosaurus beds of Marsh, the Morrison beds of Cross, the Beulah shales of Jenney, the Como beds of Scott, has been variously discussed by Marsh, Osborn, Knight, Ward,

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[1] *American Journal of Science*, Vol. L (November, 1895), p. 405. See also Marsh, "On the Geology of the Eastern Uintah Mountains," *ibid.*, Vol. I (March, 1871), Sep. p. 7.

Hatcher, and Darton. A résumé of this discussion will be found in Hatcher's recent paper on *Haplocanthosaurus*.[1] It is very evident that the final solution of the problem must be left chiefly to the vertebrate paleontologist, since the evidence presented by the invertebrates and the plants is not only scanty, but also, in the nature of things, insufficient. Aside from the discussions of Marsh, we are chiefly indebted to the late Mr. Hatcher for the presentation of the vertebrate evidence, and it is the views and statements presented by him that I wish to discuss here briefly. I will quote all of importance that he has to say:

> Marsh was wont to correlate the Atlantosaurus beds with the Wealden, which he regarded as of Upper Jurassic age. On just what evidence he relied for this correlation is not quite clear. Nor does a comparison of the dinosaurian faunas of these two horizons seem to warrant such correlation. While from the fragmentary nature of much of the material upon which the different genera and species are based it is clearly impossible to make satisfactory comparisons in many instances between the more closely related genera and species of American and European dinosaurs, nevertheless when comparisons of the faunas as a whole are instituted between the various American and European horizons, most striking and important resemblances and dissimilarities are at once apparent. Thus while in the Atlantosaurus beds the Sauropoda are the predominant forms both as regards size and the number of genera, species and individuals, in the Wealden they are almost entirely replaced by the Predentata and Theropoda. And the Iguanodontia, so abundant in the latter formation, are quite unknown in the former. It is not until we get down into the middle of the Oolite that we find a dinosaurian fauna comparable even with that of the Upper and Middle Atlantosaurus beds.[2]
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> The dinosaurian fauna of the Wealden is certainly quite different and more modern than that of the Atlantosaurus beds. In the Wealden the Sauropod dinosaurs, which form such a conspicuous feature in the faunas of the Middle and Upper Jura, are on the wane, and that group of Predentate dinosaurs known as the Iguanodontia has attained unusual importance, assuming to a certain extent at least, the position formerly held by the Sauropoda. In the Altantosaurus beds, however, the Sauropoda predominate, and the Iguanodont group of the Predentata are represented by smaller and less specialized forms.[3]

From the foregoing it will be seen that Hatcher believed that the lower members of these beds are of real Jurassic age, that is below

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[1] *Memoirs of the Carnegie Museum*, Vol. II (1903), p. 68.

[2] *Ibid.*, p. 72.

[3] *Proceedings of the American Philosophical Society*, Vol. XLIII (November, 1903), p. 353.

the Wealden, and, by inference, that they are even of Middle Jurassic age. Marsh consistently believed that they are equivalent to the Wealden of England, which he, however, in company with other good paleontologists, referred to the uppermost Jurassic rather than the lowermost Cretaceous.[1] These opinions from one who justly earned the distinction of being the chief paleontologic geologist among the students of vertebrate fossils in America are deserving of careful consideration. I must frankly say, however, that I am unable to draw any such conclusions as did Mr. Hatcher.

Cetiosaurus longus Owen is from the Great Oolite, or Middle Jura; *C. glymptonensis* Phillips, imperfectly known, is from the same horizon; while *C. brevis* Owen, also imperfectly known, is from the Wealden, but is referred by Seeley to *Ornithopsis*, by Lydekker to *Morosaurus*. *Ornithopsis* Seeley is from the Wealden; *O. humerocristatus* Hulke, from the Kimmeridge. Other, uncertain forms are from the Wealden of England. *Titanosaurus* is referred by Lydekker to probable Upper Greensand. Remains of the Sauropoda are spoken of as "frequent" in the Wealden, while from the Middle Jura only a few are known, and all these are of one, or at most two, species. I certainly cannot see what evidence these forms present that would lead one to say that the American forms are clearly Jurassic. The range of this suborder, so far as is known, is from the Middle Jurassic to the Upper Cretaceous, though there may be doubt as to the real age of the Indian form. Their known geographic distribution is Europe, India, Madagascar, Africa, South and North America—that is, over the whole world. The generalized characters presented by them are not at all sufficiently well understood to say off-hand that certain forms are older than others. No one has been better acquainted with the known dinosauria than the late Professor Marsh, and his opinions as to their relationships ought certainly to have weight, especially as he was inclined, perhaps, to exaggerate differences:

> Nearly all the American Sauropoda, indeed, show a higher degree of specialization than those of Europe, both in this feature [the relative length of the fore and

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[1] *American Journal of Science*, Vol. I (1896), p. 234; Vol. II (1896), p. 438. "I have studied the Wealden at many localities in England and on the continent, and it contained a reptilian fauna similar to one I have found in the Rocky Mountains and regarded as Jurassic."

hind limbs] and in some other respects. Portions of one Wealden animal, referred by Mantell to *Pelorosaurus*, are certainly very similar to some of the smaller forms of *Morosaurus*, especially in the proportion of the fore and hind limbs, which are unusually short. This fact would at once distinguish them from *Pelorosaurus*, and, until the skull and more of the skeleton are known, they cannot be separated from *Morosaurus*.[1]

It is quite true that the Brachiosauridae of Riggs (*Brachiosaurus* Riggs and *Haplocanthosaurus* Hatcher) have a more generalized structure in this respect than has *Cetiosaurus* even, but we have no reason to assume that all the generalized forms died out with the advent of specialized ones, such as are most of the American Sauropoda. Nor do I think it quite certain that the Brachiosauridae are the most generalized, certainly not if the hypothesis that the Sauropoda have been derived from primitive ornithopoda is at all probable. Furthermore, the genus *Pleurocoelus*, originally described from the Potomac beds, has been recognized in the Atlantosaurus beds by Marsh, and later by Hatcher, and forms from the Wealden have been referred, provisionally at least, to the same genus.

For the most part, the carnivorous dinosaurs have little value in the correlation of the horizons. *Megalosaurus* is reported from Europe from the Lias to the Wealden. In America we have three or four genera of the Megalosauridae in the Atlantosaurus beds, *Creosaurus*, *Allosaurus*, *Antrodemus*, and *Ceratosaurus*, and the family survived to the Laramie Cretaceous. *Coelurus* was described from the Atlantosaurus beds, but is known to occur in the Potomac beds. In the Wealden of England *Aristosuchus* is very closely allied, indeed is supposed to be identical, and all the other genera referred to the Coeluridae are from the Wealden. In the extensive hollowness of the bones of the skeleton, *Coelurus* is not only the most specialized of dinosaurs, but of all vertebrate animals. The evidence then to be derived from the Theropoda is for the contemporaneity of the Wealden with the Atlantosaurus beds.

So far from the evidence of the Iguanodontia being against this correlation, I believe that it is decidedly for the identity of the two horizons. Iguanodonts are found in abundance in the Atlantosaurus beds, and of the largest size and high specialization. Speaking of them, Marsh has said:

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[1] Dinosaurs of North America, p. 184.

> None of the [English] genera are known from America, but allied forms are not wanting. The nearest allied genera are apparently *Iguanodon* [Wealden] and *Camptosaurus*, for the large forms, and *Hypsilophodon* [Wealden] and *Laosaurus* for the smaller forms. . . . . Moreover we have in America a closely allied form [to *Hypsilophodon*] *Laosaurus*, of which several species are known.[1]

And, so far from the American forms being the most generalized, Lydekker says that *Hypsilophodon* is "the smallest and least specialized member of the family!" Perhaps this opinion is not decisive, but *Hypsilophodon* certainly cannot be called the most specialized. Lydekker even refers certain Kimmeridge and Wealden species to the American genus *Camptosaurus*.

Perhaps the best evidence we have for the Jurassic age of the American deposits is that of *Stegosaurus*, which is so closely allied to *Omosaurus* Owen from the Kimmeridge that Marsh believed the two genera to be identical. On the other hand, this type of the predentate dinosaurs seems to range from the Lower Lias in *Scelidosaurus*, to *Paleoscincus* from the Laramie, with four or five genera referred to the group from the Wealden. Its value, then, is slight.

Other evidence offered by the reptiles from the American beds is slight. A genus of crocodiles called by Marsh *Diplosaurus* seems to include *Hyposaurus vebbii* Cope from the Comanche Cretaceous of Kansas. Years ago Zittel referred both of these forms to the genus *Goniophilis* from evidence communicated by Professor Marsh, and *Goniophilis* is said to be "a genus very characteristic of the Wealden" (Lydekker). The recently published figure of the type specimen of *Diplosaurus*, when compared with figures of *Goniophilis*, shows a startling resemblance. Indeed, so far as I can learn, there are no brevirostral crocodiles known from below the Purbeck or lithographic slates. The evidence, then, of the crocodiles is decidedly for the uppermost Jurassic or Wealden age of the American beds.

Of the Chelonia the single species *Compsemys plicatulus* Cope (*Glutops ornatus* Marsh) is not at all decisive. If the species is correctly referred to *Compsemys*, all its related forms are of Cretaceous age. Nor is there any evidence to be obtained from the pterosaurs or birds. Of the mammals I will not venture to speak, save that I think that there are too few forms known from the Wealden to offer

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[1] *American Journal of Science*, November, 1895, p. 411.

any basis of comparison. Of the fishes a few species of *Ceratodus* only are known, and inasmuch as this genus is supposed to range from the Trias to the present time, these species have no correlating value whatever.

To sum up: there is no valid vertebrate evidence pointing to an age greater than the Purbeck for the Atlantosaurus beds, and but very little for a greater age than that of the Wealden.

Unfortunately, in most of the discussions hitherto the Atlantosaurus beds have been considered as of some brief epoch. The faunas of the upper and lower parts have never been differentiated, save in some exceptional cases. Marsh, indeed, rarely ever gave any precise location for his type specimens, referring them simply to Wyoming, Colorado, etc. The term "Upper Jurassic" has been applied indiscriminately to the whole fauna, as it has, indeed, in the textbooks to the fauna of the Hallopus beds. Hatcher was the first to distinctly point out that the uppermost part of the beds might include a part of the Lower Cretaceous; and Darton has recently separated some of the upper part as Lower Cretaceous under the name of "Lakota beds."

I am strongly of the opinion that these deposits, nowhere, so far as known, exceeding a thickness of 500 feet, really represent various epochs between the Jurassic and the Upper Cretaceous, and that sooner or later we shall have evidence to distinguish the later from the earlier faunas.

A year or two ago Mr. N. H. Brown, of Lander, Wyo., sent some fish teeth to Mr. F. A. Lucas, of the National Museum, for determination. Mr. Lucas, after comparison with the type specimens described by me from the Lower Cretaceous of Kansas, identified them as species of *Scyliorrhinus*. In company with Mr. Brown, I later examined the outcrop whence he had obtained his specimens, near Lander, Wyo., and found it to be in the upper part of the Atlantosaurus beds, and some 15 or 20 feet below an outcrop containing leaves which Mr. Knowlton identified as Dakota. A search in this horizon disclosed numerous specimens of shark and crocodile teeth, four species of which I identified with species obtained from the mentor beds of the Lower Cretaceous, of Kansas, together with numerous fragments of dinosaur bones, among which I recognized the genus *Laosaurus* described by Marsh from the Atlantosaurus beds.

It may be objected that the specific identity of fish teeth is too doubtful to correlate such remote horizons, and the objection might be valid for single specimens, or even possibly for single species. In this case, however, I did not find a single form that was not represented in the Kansas beds, and the specimens were abundant. Furthermore, the matrix containing the fossils is so nearly identical with that from Kansas that, had anyone given me specimens, without information of their derivation, I should have unhesitatingly referred them to the Kansas beds. The fact, moreover, is of interest as showing a marine fauna. This horizon in Kansas contains not only these species of fishes, but also crocodiles and dinosaurs which I am unable to differentiate from forms from the Atlantosaurus beds, and the Lander horizon contains fossils described by Marsh from the Atlantosaurus beds. The Kansas horizon is high up in the Lower Cretaceous.

About 50 feet below this outcrop of Lower Cretaceous fossils fragments of Sauropodous dinosaurs occurred in the Lander region. The entire thickness of the Atlantosaurus beds here is not more than 250 feet, to the best of my knowledge.

The upper part of the Atlantosaurus beds is, it seems to me, indisputably Cretaceous; the lowermost part is probably not older than the Wealden, though possibly of Purbeckian age. I therefore strongly protest against the common usage of referring all the fossils from these beds to the Upper Jura. Until more is known of the different faunas contained in it, the only proper designation for the composite faunas included in them is Jura-Cretaceous; this assumes that the Wealden is really Jurassic.

I may add that I cannot agree with Mr. Hatcher in his use of the name "Atlantosaurus beds" for these deposits. The name *Atlantosaurus*, it is generally conceded, has no place in zoölogical literature. His comparison with Fort Union is hardly parallel. Nor can I adopt the name "Sauropoda" for the Opisthocoelia of Owen. No one has ever been in doubt as to what the term Opisthocoelia included, and where every student knew its meaning, a precise definition is superfluous.

Because of certain incorrect statements which have been published recently concerning the discovery of the vertebrate fossils of the Atlantosaurus beds, it will be worth while to give briefly the real history. Probably the first specimen of a vertebrate critically studied by a paleontologist from these beds was that described by Leidy in 1873 in his *Contributions to the Extinct Vertebrate Fauna of the Western Territories*, as *Poicilopleuron valens*, and named *Antrodemus* generically in his plate—a genus apparently identical with that afterwards called *Labrosaurus* by Marsh. This specimen was obtained by Hayden in Middle Park, Colo., where similar specimens were reported to be common. Prior to this time Marsh had observed dinosaur bones at the extreme western end of Lake Como, Wyo., in 1868, but had not appreciated the value of his discovery, nor published anything concerning the fossils. The history of the discoveries later may be given as published by me in the *Transactions of the Kansas Academy of Science* for 1878, as follows. I have substituted only the name of Mr. Beckwith for that of Mr. Berthoud, both of whom had been associated with Mr. Lakes in his investigations.

> To an English geologist, Professor Arthur Lakes, of Golden, Colo., credit is due for first detecting the osseous character and appreciating the scientific value of the fossils. While engaged one day in March, 1877, in company with Captain H. E. Beckwith, in collecting Dakota leaves from the summit of the ridge or "hog-back" near Morrison, he discovered a huge caudal vertebra in bas-relief upon a slab of sandstone. Upon further investigation, a large quantity of bones was collected and shipped to Professor Marsh, of Yale College, by whom they were described under the name of *Titanosaurus montanus*. Almost contemporaneously with this discovery the fossils were made known at Cañon City by Mr. O. Lucas, a school-teacher, and by Mr. William Reed, an intelligent section foreman of the Union Pacific Railway. Specimens from the former locality were sent to Professor Cope, of Philadelphia, by whom they were named *Camerasaurus supremus*. Since then numerous other localities have become known in Colorado and Wyoming, and I doubt not that future explorations will bring to light scores of outcrops rich in these vertebrate fossils.

In June or July, 1877, Professor B. F. Mudge, of Kansas, was sent to Morrison by Professor Marsh to exploit, in connection with Professor Lakes, the fossils of that region. From there Mudge went shortly to assist Mr. M. P. Felch in opening the famous Marsh quarry at Garden Park near Cañon City, afterwards worked by Mr. Hatcher. In early September of 1877 I was sent by Professor Marsh to the Morrison locality, and, a few weeks later, to Cañon City, where I remained until November, when I went to Como, now Aurora, Wyo., to open up the first quarry there, with Mr. Reed, who had discovered bones in this region more than a year before.

A PARTICULAR CASE OF GLACIAL EROSION.[1]

FREDERICK W. SARDESON
Minneapolis, Minn.

It is the purpose of this paper to describe a peculiar phase of glacial work, where a layer of stratified rock of considerable area was shoved forward bodily on its bed, and then thrust up out of horizontality. Use is made of this case to explain the manner in which a number of other known dislocations of bed-rock in the vicinity might have been made, as well as to explain how glaciers in general may affect the subjacent rocks under certain circumstances. The present illustration is found near the University of Minnesota, in Minneapolis, about a mile below the Falls of St. Anthony, on the east side of the gorge of the Mississippi. The conspicuous feature of the displacement is represented in the right (southeast) half of the accompanying profile (Fig. 1). The left (northwest) half of the profile is drawn from notes, aided by photographs taken from time to time as ground was excavated in a stone quarry, which has been working obliquely across the line of the profile. The line of the profile corresponds with the direction of glacial movement. There is also, at the time of writing, an exposed section parallel to and corresponding with that of the left half of the figure.[2]

The section which is represented by the profile (Fig. 1) lies near the 800-foot contour line as established by the topographic map.[3] As shown on the map, a terrace lies between the 780 and 800-foot contour. This terrace belonged to the Mississippi River at a stage when the falls were below this point, instead of above it, as they now are. Besides the terrace contour, the occurrence of the river shingle and well-preserved shells of species of *Unio* shown at *R* (Fig. 1), under a layer of peat (*P*), proves that the river once flowed over the

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[1] This paper was read before the Minnesota Academy of Sciences, January 3, 1905.

[2] Observations on this exposure have extended over several years. Negatives taken are on file in the Department of Geology, University of Minnesota.

[3] St. Paul quadrangle, U. S. Geological Survey.

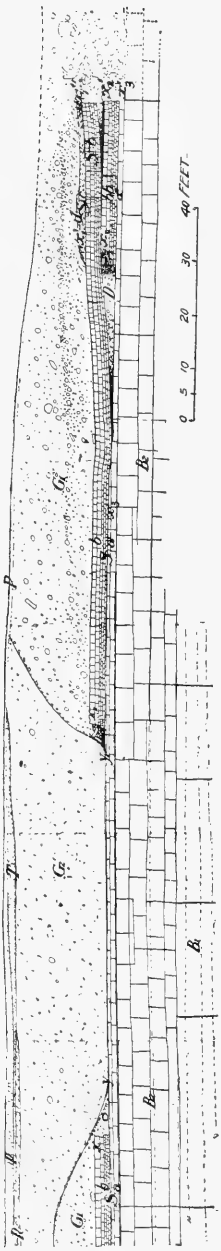

FIG. 1.—Profile showing glacial action from left to right. Strata thrust up on the right or front, and pulled apart on the left. B_1 and B_2, massive limestones; *Sa* to *d*, limestones and shales; G_1, older drift; G_2, newer drift; X to X_3, older glaciated surface, broken; Y to Y_1, newer glaciated surface; *R*, river shingle; *T*, terrace sand; *P*, soil and peat. Vertical and horizontal scales equal.

site. The glacial drift has not, therefore, its original thickness. Twenty feet or more of it have been washed away by the river, and should be restored in interpreting the glacial work in this particular case. In other respects, the accompanying profile explains itself in the main. Below the soil and peat (*P*) is terrace sand, *T*, with the shells of land snails, *Helix*, *et al.*, in it, and the river shingle, *R*, with *Unio* shells. Still lower is the glacial till, G_1 and G_2, overlying beds of the Galena (Trenton) series. Of these, the first (lowest) bed, B_1, and the second, B_2, are massive limestones. The lower part of the third bed, *Sa*, is also limestone, but is distinguished by its color, and hard, pyritiferous, crystalline condition. The upper part, *Sb*, consists of several layers of grayish crystalline limestone, separated by uneven clay-shale seams. *Sc* (at the right of Fig. 1) is clay-shale, overlain by limestone, *d*, belonging to the same third bed. *Sa* to *Sd* comprise about half of the third bed of the series, as seen elsewhere in the vicinity. The upper part, here wanting, is shale, with thin and widely separated layers of limestone.

On the right (southeast) of the section there are three remarkably glaciated surfaces, X_1 (top of *Sb*), X_2 (top of *bb*), and X_3 (base of *bb*), one above the other. It is this phenomenon, noticed more than ten years ago, which led me to study this locality. At that time the part of the profile which is represented in broken lines was exposed by quarrying, while the rest was concealed. This part, represented in broken lines, is drawn from memory.

The part of the section shown in the right half of the profile was exposed several years later, and showed that the glacial movement was from the westward, not from the eastward or southeastward, as was originally supposed. Only during the past year has the left half, as represented in the profile, been cut across in such ways as to reveal the two drift deposits, G_1 and G_2, as well as the undisturbed part of the stratum *Sb*.

It is now evident that the newer till, marked G_2, represents the position of the ice which forced the stratum *Sb* apart, and shoved the one part, *Sb*, with its overlying drift, G_1, from X to X_1. At the same time, the surface between Y and Y_1 was scratched, though not much worn. The glacial deposit G_1 is older than G_2, though the two are in contact. They are essentially alike, though the proportion of pebbles is greater in one than in the other, and the boundary between them is structurally well marked.

The mass of shale and limestone which was moved forward rests on the surface of a stratum which, from Y_1 to X_3, is not glaciated or cut, being protected by a clay lamina, while from X_3 to X'_3 the surface below the shoved block is glaciated, and one thin layer, for the greater part of the distance, has been ground away. In the undisturbed strata at the left (northwest) there is a clay-shale lamina at the base of *Sb*, and it is the lowest of several such partings between the limestone layers. The disturbed mass started to move upon the lowest shaly lamina, and was driven out over a denuded or already glaciated surface X_3 to X'_3.

All the glaciated surfaces, excepting that which is indicated by Y to Y_1, were originally one, running from X on the left, along X_1, to X''_1, which was originally continuous with X_2 and down along X'_3, as we see if we imagine the disturbed strata put back in place. Then with the second till, G_2, eliminated, we obtain the conditions which preceded the movement. In this it will be noted, further, that the interval or gap, from X to X_1, on the left, which should represent the distance traveled, is less than the distance from X_2 to X'_2 plus that from X_3 to X'_3, which should also represent the distance traveled.

Before this relation is explained it should be noted that the drift-wedge, marked *D*, represents a clay-shale and till intermixture entrapped under the upturned strata.

To explain how the block *bb* came to lie under the main block (*Sb*) in the section, the following details are given. The major joints in the rock strata run generally in north-to-south and east-to-west directions. The glacial movement was oblique to those directions, in this case, from the northwest, and the blocks were therefore driven in a diagonal direction. A side thrust may have been given as the one sheared upon the other. The under part or block, *bb*, also probably rotated in front of the drift, *D*, as it shoved forward. As the result of the rotation, the distance traveled by the mass seems greater than it probably was. On the other hand, the distance of the gap, *Y* to Y_1, owing to the direction of glacial movement not being exactly diagonal to the blocks, may be a little shorter than the whole distance traveled.

The most conspicuous feature in the exposed section—viz., the disjoined under block, *bb*—is not the matter of first importance. Its position is incidental, as is shown by comparison with another part of the same mass, which still lies on the other side of the boulevard. In this there is normal drift merely, in place of the block, *bb*, and the larger body of limestone has moved upward quite the same.

One feature of special significance is the upturned front of the transported mass of limestone and till. Altogether, the front appears to have the shape of the point of a spoon. Another significant feature is the abrupt disjoining of strata at the rear. The strata were pulled apart. These features appear in other occurrences. In other exposures, beds of clay-shale and included limestones, now in place, are seen to end abruptly against the glacial till, as the stratum *Sb* does on the left of this section. One such exposure which is to be seen at the time of this writing is in another quarry, half a mile to the southeast of the locality of the section shown in Fig. 1, on the west bluff of the river. Here the clay-shale beds, some 10 feet thick, are cut off nearly vertically by the till, the latter lying on the leeward side in relation to glacial movement. Several other similar occurrences have been seen in the vicinity. They differed, however, in having the abrupt end of the clay-shales more or less sloping.

The two chief features in this case were, I think, formed under the following circumstances: At an early stage, glacial erosion cut the stratified bed-rock unevenly, so that, when deposited, the till, G_1 rested at the left on the clay-shales, *Sc* (now shoved over to the right), in the middle on the limestone with shaly seams *Sb*, and toward the right on the limestones *Sa* and B_2. The later ice-movement was over the till G_1. Its friction with the till produced stress, which was transmitted to the stratified rocks, and they yielded along the lowest clay-shale seam, moving forward. The initial disjoining of the stratum (*Sb*) and the till $(G)_1$, may be ascribed to unequal stress from unequal friction of the glacier on its bed. After the gap began to open, the ice settled into it, while the rock-mass was moving forward. The upward thrust in front and the gap at the rear may be correlated through a compensating movement in the glacial ice, as illustrated in Fig. 2. In this diagram the original position of the ice, the older drift, and the subjacent stratified rocks are represented in solid lines, while the result of the movement is indicated by broken lines and dots. Ice filled into the gap, *L*, as the drifted mass *M* tended to fill the position at *O*, in its stead. The horizontal line (1–2) indicates the original direction, while the other (3–2) indicates the subsequent direction, and the angle (1–2–3) the relative rotation of the ice-mass in compensating.

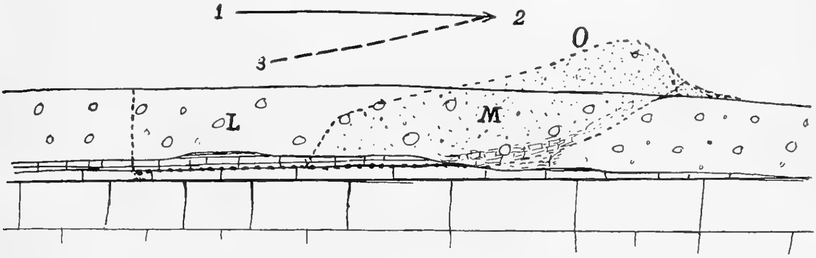

FIG. 2.—Diagram showing change of direction of ice-movement from 1–2 to 3–2 as the mass *M* moves from *L* toward *O*. Original position of ice and subjacent rocks in solid line; change by movement, in broken lines.

Whether this work of the glacier was done far from or near to the front of the ice-sheet does not appear. The reason why the drifted mass stopped where it is now seen is also not evident, and may be a very incidental matter. Notably, however, the manne in which a start could have been made by those masses which were carried much farther, is shown.

It may also be argued that a series of masses could, under repeated cause, lodge one behind the other. An explanation for the entrapped drift-wedge, *D*, in the section (Fig. 1) may be that the block *bb* was set forward, and a gap behind it filled with till before the main mass started. As to general application of this particular case, any mass of till, resting on a lamina of clay, might be started and then rotated forward in like manner; but with no stratified rocks as a distinctive mark, such cases might be difficult to interpret.

Evidence tending to prove that the glaciers have elsewhere plowed up the bed-rock of the region is not rare. It has been seen in the excavations for buildings, stone quarries, and road-gradings in Minneapolis and St. Paul, where the underlying rock is of Ordovician age, and is exposed along the gorge of the Mississippi. Elsewhere it is generally concealed by the glacial drift. In these exposures, blocks of limestone are often seen scattered or grouped in the bowlder-clay, as if the rock had been torn up in large masses, and are so exactly like the rock which exists *in situ* in this region as to be unmistakable. While they might have come from miles away, so far as the kind of rock is concerned, they are more probably torn from the sides of preglacial valleys now buried under the glacial deposits in this vicinity. Of more particular importance here are certain clay-shale masses which occur in the bowlder-clay. By the character of the clay and of the included lenticular masses of crystalline limestone, and by the contained fossils, the original position of these clay-shale masses may be determined. One or more of the beds whence they came are still in place over a great part of this area, under the drift and above the limestone. The shale-masses in the drift have presumably been torn up not many miles from the place where they now lie.

These drifted clay-shale masses are generally not weathered, and retain their original blue color. They are often unmixed with pebbles of northern drift, and in a few cases they retain their original stratification, as well as their fossils. Small masses are most common and least distinct. The largest are 100 feet or more in horizontal diameter, and 50 feet or less thick. They generally have upturned fronts, which are also relatively more disrupted than are the rears. As an example I may mention an occurrence in St. Paul, already briefly described.[1] At that place a mass of shales, representing recognized beds of the Galena (Trenton) series, covers about an acre of surface. As shown in the grading of the streets which cross it, the shale is surrounded by northern drift, which lies over part of it, and probably under all of it. Other cases of similar import were cited in the article referred to.

The manner in which the glacier transported these large masses, without overturning them, was a matter of wonder until the discovery of the case here described. This particular occurrence shows at least how the great clay-shale masses may have been plowed up.

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[1] *Journal of Geology*, Vol. VI, p. 688.

NOTE ON THE GLACIER OF MOUNT LYELL, CALIFORNIA[1]

WILLIS T. LEE
Washington, D. C.

The writer had the privilege of visiting the glacier on Mount Lyell on August 17 and 18 of the present year (1904), and of securing the photographs accompanying this note. Mount Lyell is one of the well-known peaks of the High Sierra, although it is by no means the highest, the elevation being only 13,090 feet. On the northern face of the mountain lies a body of ice something over a mile in east-and-west length, and extending down the slope about half a mile. It consists, in reality, of two glaciers lying side by side, and separated in part by a narrow tongue of rock. The present aspect of the glacier is shown in the accompanying photographs.

Two phenomena seem especially worthy of note. First, there is an absence of any large amount of morainal material except at the immediate terminus of the ice. Lyell Canyon, which was formerly occupied by the extended Lyell Glacier, was examined for a distance of about fourteen miles, and only scattered bowlders and small beds of morainal material were noted until the present terminal moraine was reached. Abundant evidence of glacial action, however, is present throughout the valley in the form of polished and grooved surfaces, *roches moutonnées*, and domes. The retreat of the glacier to its present position must have been rapid. It is doubtful if the volume of glacial débris now found in Lyell Canyon is much greater than the volume that would be contained at any one time in a glacier filling this canyon to the extent which Lyell Glacier did in former times.

The second phenomenon to which I call attention is apparent on examination of the photographs. In contradistinction to its former rapid retreat, the front of Lyell Glacier has remained at or near its present position for a considerable length of time. It will be noted

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

that the ice crowds closely upon the terminal moraines. There is no space between the face of the glacier and the moraine to indicate recent recession. It will also be noted that a very small portion of the old ice is exposed, the greater part of the surface being covered with last winter's snow. At that altitude no great amount of snow will melt after August 18—the date of my visit—before a fresh snowfall begins the winter's accumulation. It will be noted, especially in Fig. 1, that fresh snow in large quantities lies outside of the moraines as well as covering the greater part of the glacier. The terminal moraine of the western lobe of the glacier is largely concealed from view by fresh accumulations of snow. The foreground is occupied by a lake nearly covered with ice which has remained all summer, and which is buried on the glacier-ward side beneath many feet of snow. The large mass of snow in the foreground, since it has nothing to do with the main glacier, although it has glacial motion of its own,

FIG. 1.—Lyell Glacier, western lobe. (The snow in the foreground is not a part of the glacier, and the first two masses of rock are not moraines. The moraine is nearly covered with snow.)

can be neglected. Considering, then, only the masses of snow immediately outside of the moraines, the quantity indicates that it must be due to several years' accumulation. In some cases the extra-morainal masses are several hundred feet wide and, judging from the topography, must be forty feet or more in depth.

Turning to an examination of Fig. 2, there is less recent snow than appears in the western lobe, and a larger portion of the old ice is exposed, perhaps because this lobe descends considerably lower than the western lobe. The nose of the glacier is here pushed hard upon the moraine, so that the front of the ice and the moraine form a single slope. The loose morainal material is accumulated in a steep slope, with its base forming a comparatively sharp outline with the rock on which it rests. The relations are such as strongly to suggest that this lobe of the glacier is overriding its terminal moraine and dropping the fresh material at the front.

During the summer of 1883, I. C. Russell photographed this glacier, and his photographs were published in the *Eighth Annual Report* of the U. S. Geological Survey. Twenty years later, during the summer of 1903, G. K. Gilbert secured photographs of the same glacier and published them in the *Bulletin of the Sierra Club*, in an article entitled, "Variations of Sierra Glaciers." In comparing his photographs with those of Professor Russell, Mr. Gilbert says:

> The glacier seems now to have almost precisely the same size as at an earlier date, the only suggested change being a slight shrinkage near the west end. The arrangement of the numerous moraine ridges is precisely the same as in 1883, from which it may be inferred that the glacier has not in any later year been materially larger than then. It might, however, have diminished and afterward increased.

Later he observes: "Lyell Glacier was quite as free from snow in the summer of 1883 as in 1903."

From a comparison of Russell's photographs, taken in 1883, Gilbert's, taken in 1903, and the writer's, taken in 1904, it is evident that little change has taken place since 1883. All the main features are the same. Careful comparison, however, indicates that small arms of ice reaching up the rock faces are slightly larger than they were twenty-one years ago, and certain small areas of rock, which then appeared above the surface, are now covered. A comparison of Mr. Gilbert's photographs of the western lobe with the writer's, taken only one year later, indicates an increase which can be detected from the photographs. For example, in Fig. 1 it will be noted that the snow near the top of the peak above the Bergschrund is continuous to the top. In Gilbert's photograph, taken only one year earlier, a continuous line of rock appears across the arm above the Bergschrund. It is very evident, from the clothing of new snow remaining on the glacier through the summer, that the snowfall of last winter has increased the volume of the glacier. It is evident, from the relation of the ice to the moraines, and from the records above quoted, that little or no recession has occurred in recent years. The relation of the morainal front to the underlying rock at the eastern lobe, and the large accumulations of extra-morainal snow in the western lobe, suggest that the glacier may be slowly advancing. It may be confidently stated that for the past twenty-one years there

FIG. 2.—Lyell Glacier—eastern lobe.

has been, on the whole, no decrease in volume. It may be further confidently stated that since the formation of the present terminal moraines there has been a somewhat marked increase in the volume of ice, as indicated by the large masses which have accumulated in front of the moraines.

EXAMPLES OF JOINT-CONTROLLED DRAINAGE FROM WISCONSIN AND NEW YORK

WILLIAM HERBERT HOBBS
University of Wisconsin

I. THE RICHLAND CENTER QUADRANGLE OF WISCONSIN

A neighboring district to the one under consideration and bordering on the upper Mississippi has been cited by Daubrée[1] as one where the influence of joints upon drainage lines has been manifested in a striking manner.

> Scattered and cuboidal blocks (bluffs and knolls) resemble ruins, deep crevasses, networks of nearly vertical valleys, of which the picturesque form strikes all of the travelers to the upper Mississippi.[1]

Farther up the Wisconsin, Van Hise has ascribed the location of the well-known Dells, or side valleys, to the position of joint planes within the underlying rocks.[2] Subsequently Buckley[3] has made an extended study of joint planes developed in the quarry rocks of the state as respects their bearings, which he has summarized as follows:

> The joints in the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is northeast and southwest. The other directions are northwest and southeast, east and west, and north and south.

Inspection of Buckley's map discloses the fact that the diagonal bearings do not represent single, but several joint series.

Under the writer's direction, Mr. E. C. Harder, a member of the senior class of the University of Wisconsin, has undertaken an investigation of the joint series which are developed within the Paleozoic rock formations of southwestern Wisconsin, and has noted correspondences in orientation between the drainage lines and the joint planes. The investigation has covered districts distributed over an

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[1] *Géologie expérimentale* (Paris, 1879), Vol. I, pp. 337, 355–57.

[2] C. R. Van Hise, "The Origin of the Dells of the Wisconsin," *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters,* Vol. X (1895), pp. 556–60.

[3] E. R. Buckley, *Bulletin IV,* Wisconsin Geological and Natural History Survey, 1898, pp. 456–60.

area comprising about 7,000 square miles in the southwestern part of the state, and has also included areas surrounding the cities of Madison and Milwaukee. In all cases the joints are in vertical series, particularly well developed in the more compact limestones. Mr. Harder's report upon the area will soon be published, and it is possible here to refer to but a single area among those examined.

For a considerable portion of the Richland Center Quadrangle[1] Mr. Harder's summary of the joint directions which he observed is as follows:

JOINT SERIES OCCURRING NEAR RICHLAND CENTER, WISCONSIN

N. 5° W.–1
N. 10° W.–2
N. 12° W.–2
N. 15° W.–14
N. 20° W.–3
N. 25° W.–16
N. 28° W.–3
N. 30° W.–5
N. 35° W.–23
N. 40° W.–1
N. 45° W.–14
N. 50° W.–5
N. 55° W.–23
N. 60° W.–9
N. 65° W.–9
N. 70° W.–5
N. 72° W.–2
N. 75° W.–11
N. 80° W.–4
N. 82° W.–2
N. 85° W.–5

N. and S.–7
E. and W.–11

N. 5° E.–19
N. 15° E.–5
N. 20° E.–5
N. 22° E.–2
N. 25° E.–12
N. 30° E.–2
N. 35° E.–35
N. 40° E.–1
N. 45° E.–20
N. 46° E.–2
N. 50° E.–6
N. 52° E.–1
N. 55° E.–9
N. 60° E.–5
N. 65° E.–12
N. 70° E.–5
N. 72° E.–3
N. 75° E.–24
N. 80° E.–2
N. 85° E.–9

It appears that in order of approximate numerical superiority the more important joint directions of the Richland Center district are: N. 35° E., N. 75° E., N. 55° W. (or N. 55°–65° W.), N. 85°–90° E., N. 35° W., N. 45° E., N. 5° E. (or N.–N. 5° E.), N. 25° W., N. 15° W., and N. 45° W. The tendency of the five-degree interval to appear is noticeable, and indicates that here, as elsewhere, the observations of slightly curving planes become adjusted to the larger unit of the

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[1] Surveyed, but not yet published.

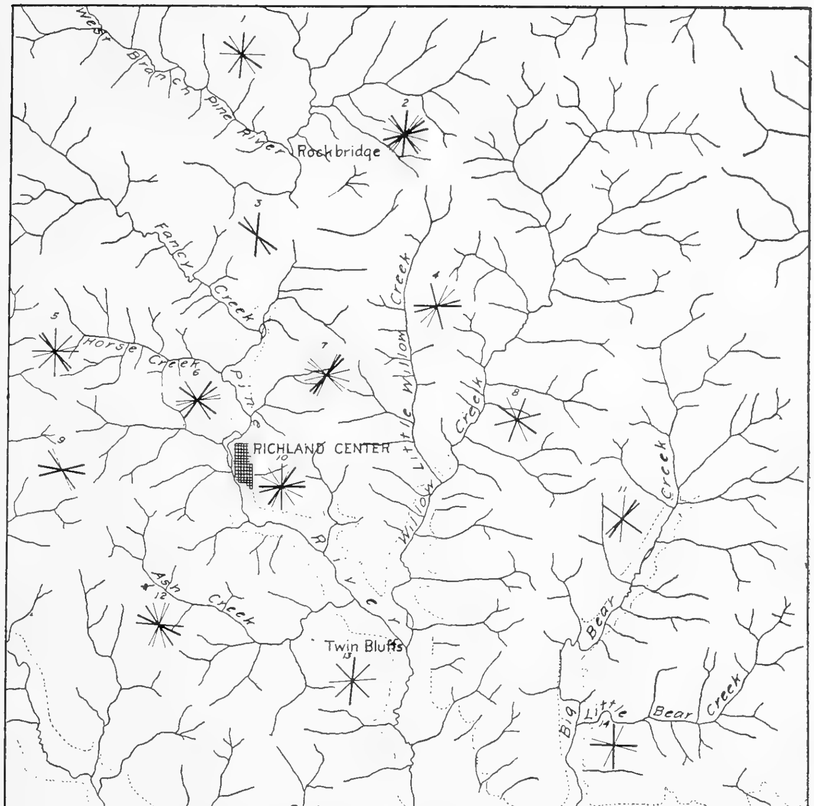

FIG. 1.—Joint and drainage map of a portion of the Richland Center Quadrangle in southwestern Wisconsin. (Prepared by Mr. E. C. Harder.) Scale, 5 miles to the inch. The dotted lines represent bluffs, while the stars indicate the local importance of joint series.

compass dial. The order of importance of the series for the local district is not quite the same as that for the larger district of which it is a part, for beyond all question the east-west direction is the predominant one. Of the entire region, also, so far as it contains ores, the mineralized crevices are mainly equatorial and meridional, less frequently "quartering" (corresponding to a diagonal series).

A glance at the map of Fig. 1 is sufficient to show that there is more than an accidental coincidence of joints and drainage systems. The map further reveals the distribution of the observations, from which distribution their relationship to near-lying drainage lines may be made out. That the correspondences were not due to mere coincidence is further attested by actual disclosures in the stream valleys where the zigzags of the course follow actual joint planes (see Fig. 2).

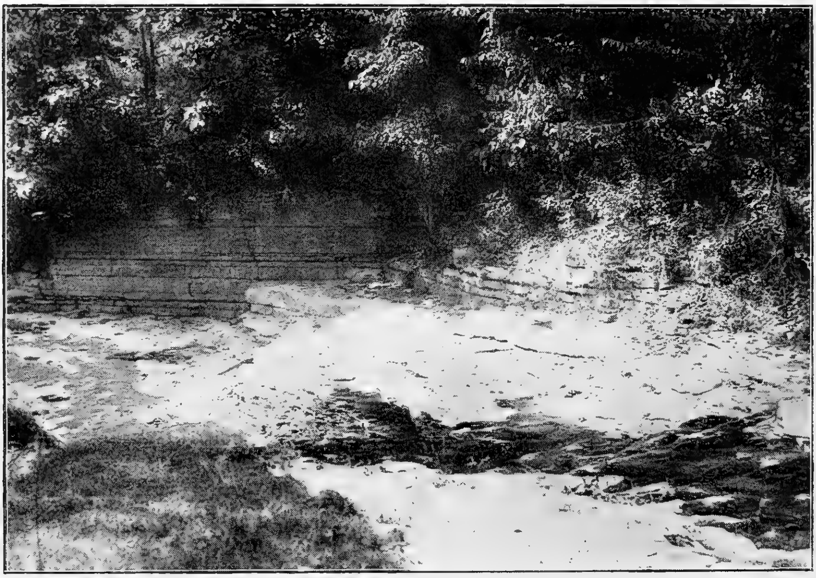

FIG. 2.—Control of direction of a stream by prevailing joint planes in southwestern Wisconsin. (Photograph by Mr. E. C. Harder.)

The Richland Center district is included within the driftless area of Wisconsin. Evidence of joint-controlled drainage is also furnished by a district lying within the glaciated area of western New York.

II. THE FINGER LAKES DISTRICT OF WESTERN NEW YORK

The Finger Lakes district has long been a classical one for the perfection of its joint planes, a cut from the locality having been used by Dana in his *Manual of Geology* as the type illustration of

FIG. 3.—Canyon formed along a joint plane. Enfield Gorge near Ithaca, N. Y. (Photograph furnished by Professor R. S. Tarr.)

joint structures. Later photographs, which the writer owes to the courtesy of Professor Tarr, of Cornell University, show beyond question that the joint system has exercised an important control over the water courses. Striking examples of this kind are furnished by Figs. 3-5 and 4, while Fig. 5 brings out with special clearness the dominant rectangular system which is developed on the shore of Cayuga Lake.

This region about the lakes in western New York has been made the subject of many papers, owing to its topographic peculiarities and the curious distribution of the lakes themselves. Among the more important of these are papers by Lincoln,[1] Brigham,[2] Tarr,[3] and Dryer.[4]

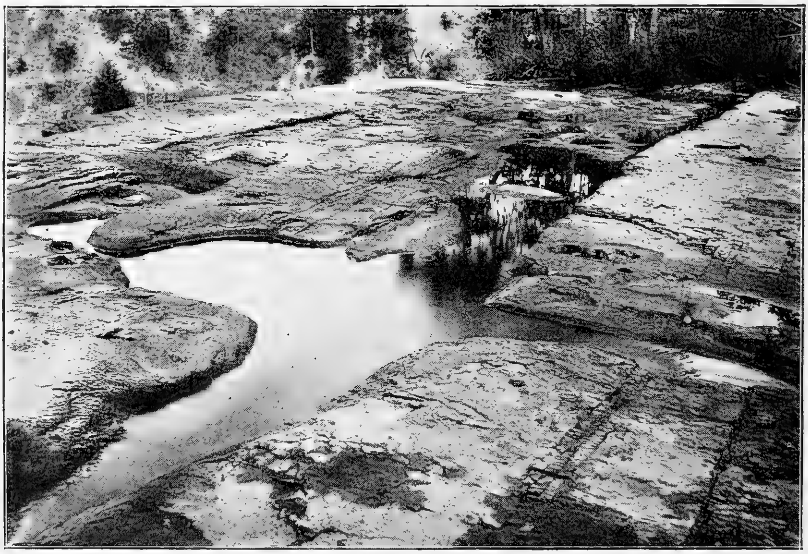

FIG. 4.—Control of direction of water course by joint planes within the basin of Cayuga Lake. (Photograph furnished by Professor R. S. Tarr.)

In these papers the peculiar topography of the lake basins is, on the one hand, ascribed to sub-aërial water erosion, and, on the other

[1] D. F. Lincoln, "Glaciation in the Finger Lakes Region of New York," *American Journal of Science* (3), Vol. XLIV (1892), pp. 290–301.

[2] Albert P. Brigham, "The Finger Lakes of New York," *Bulletin of the American Geographical Society*, Vol. XXV (1893), pp. 203–23.

[3] Ralph S. Tarr, "Lake Cayuga, a Rock Basin," *Bulletin of the Geological Society of America*, Vol. V (1894), pp. 339–56, Plate XIV.

[4] Charles R. Dryer, "Finger Lakes Region of Western New York," *ibid.*, Vol. XV. pp. 449–60, Plates 37–41.

hand, to glacial erosion. At the St. Louis meeting of the Geological Society of America, held in December, 1903, the writer pointed out that, irrespective of which of the two agents had performed the major part of the work of excavating the valleys, the cause of the striking rectilinear extension of the valleys and their peculiar arrangement necessarily called for a control of whichever of the agents accomplished the work. From Professor Tarr, who was present at the meeting, it was learned that Mr. Charles G. Brown, editor of the *Holstein-Frisien World*, had undertaken the measurement of joint directions within the Cayuga Lake Basin as a thesis for graduation when a student at Cornell University. Mr. Brown has very kindly placed his results at the writer's disposal, and from a somewhat extensive survey of literature the writer is convinced that they constitute not only the most extensive, but also the most consistent, series of observations of the kind that has yet been made. This is probably in part to be explained by the perfection of the joint system within the district studied.

FIG. 5.—Vertical rectangular joint set on east shore of Cayuga Lake, Ithaca, N. Y. (Photograph furnished by Professor R. S. Tarr.)

Mr. Brown has measured the direction of a total of 1,004 joints, most of which are in the vicinity of Ithaca, N. Y. Some of the localities examined are Six Mile, Cascadilla, Fall, and Buttermilk Creeks; the Bates, Sheehey, Driscoll, and Veder quarries; Coy's, Shugar's, and Estey Glens; and other localities in and about Lansing, Taughannock, Portage, Genesee, and Hamilton. Another set of observations is taken from the Cayuga Creek gorge, Havana and Watkins Glens, the west shore of Seneca Lake, and localities about Norwich. The results of this investigation are not published, but through the courtesy of Mr. Brown I am permitted to make use of his results in this article. After a careful enumeration of the joint directions observed, Mr. Brown says in his thesis:

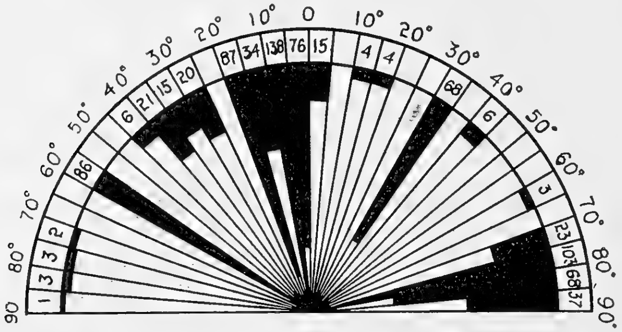

FIG. 6.—Diagram to show the orientation of joints in the Cayuga Lake basin of western New York (Brown).

> The correlation presented in Fig. 4 seems to indicate that these joints constitute two orthogonal systems. Those whose direction trend N. and N. 45 degrees W., and N. 70 degrees E. and E., constituting the major system; while those whose direction trend between N. and N. 20 degrees E., and N. 70 degrees W. and W., constitute the minor system. It will also be seen that the major system contains 551 of the 572 joints correlated,[1] or 96 per cent. of the whole number; while 374, or 67 per cent., of those constituting the major system lie between N. and N. 45 degrees W.

Mr. Brown's results covering this area I have brought together below in a single table, in order to show their orientation as respects the entire area:

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[1] This does not include the later work.

N. 2° W.	1		N.-S. 15	N. 4° E.	1	
N. 4° W.	**30**	**43**				
N. 5° W.	**6**			N. 5° E.	1	
N. 6° W.	**7**			**N. 10° E.**	**2**	
N. 8° W.	2			N. 12° E.	2	
N. 10° W.		**139**		N. 16° E.	4	
N. 12° W.	14			N. 20° E.	2	
N. 15° W.	**54**	**88**		**N. 30° E.**		**68**
N. 16° W.	**34**					
N. 18° W.	4			N. 45° E.	6	
N. 20° W.		**288**		N. 60° E.		**3**
N. 24° W.	5					
N. 26° W.	1					
N. 30° W.	**20**	**35**				
N. 34° W.	**15**			**N. 70° E.**	**21**	**131**
N. 40° W.		**51**		**N. 72° E.**	**8**	
N. 44° W.	6			**N. 74° E.**	**90**	
N. 60° W.		**86**		**N. 75° E.**	**12**	
N. 74° W.	1			N. 78° E.	1	
N. 76° W.	1			**N. 80° E.**		**62**
N. 80° W.	3			**N. 85° E.**		**35**
N. 84° W.	1		E.-W. 1	N. 88° E.	2	

Making use of five-degree intervals the above results are graphically summarized in Fig. 6.

In order of relative numerical importance the joint directions of the district are thus found to be: N. 20° W. (288), N. 10° W. (139), N. 70°–75° E. (131), N. 15°–16° W. (88), N. 60° W. (86), N. 30° E. (68), N. 80° E. (62), N. 40° W. (51), N. 4°–6° W. (43), N. 30°–34° W. (35), N. 85° E. (35), and N.–S. (15). These twelve directions include 941 of the 1,004 measurements, and, with the exception of the directions N. 12° W., whose fourteen observations should perhaps be added to the 139 directed N. 10° W., no other direction is represented by more than six measurements.

From the above figure it will also appear that there is an orthogonal joint set having directions N. 30° E., and N. 60° W. There are also two other near-lying orthogonal sets, the one having direction N. 74°–75° E. and N. 10°–16° W., and the other N. 80°–85° E. and N. 4°–6° W. In the vicinity of Watkins Glen, the first-mentioned set is the dominant one, while at the other localities this set is rarely observed, the other sets taking its place.

These data collected by Mr. Brown make it possible to see whether any correspondences exist between the dominant hydrographic lines of the district and the underlying fracture system. A map of the district based on the one prepared by the College of Engineering of Cornell University is reproduced in Fig. 7.

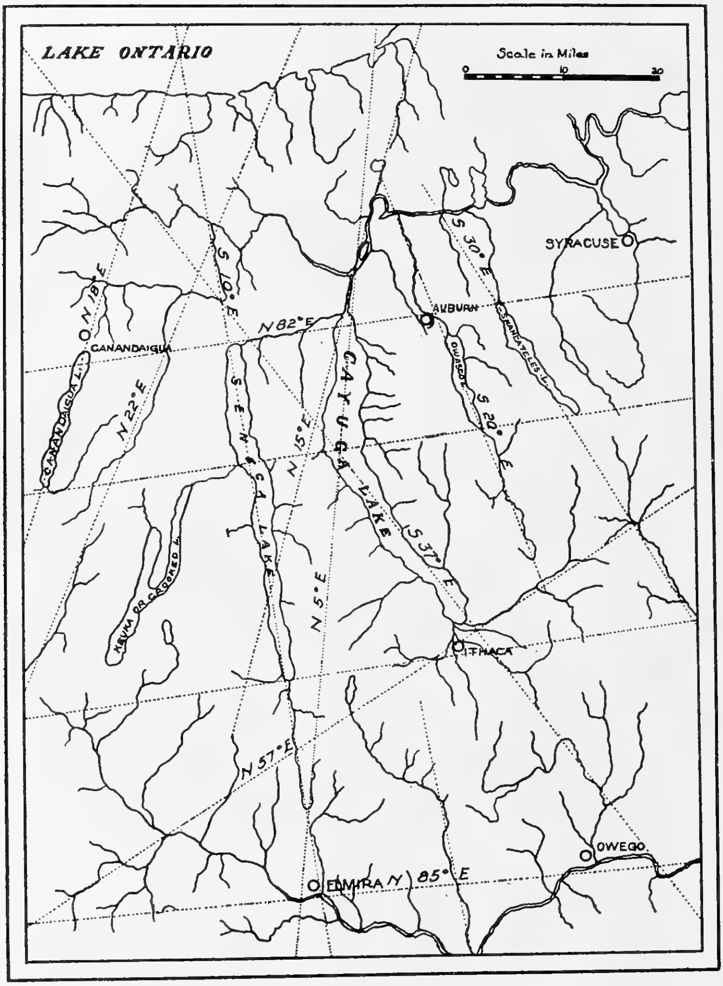

FIG. 7.—Map of the Finger Lake region of western New York, with indication of the more striking hydrographic lines.

The most striking hydrographic line of the district may be called the Seneca line, which is directed about N. 10° W., and which for a distance of nearly 60 miles is outlined in part by Seneca Lake itself, to the south by an open valley which extends as far as Elmira, and to the north by a reach of Canandaigua Outlet. Three lineaments, nearly parallel, are directed in a nearly perpendicular direction to the Seneca line, and may be designated respectively as the Seneca Falls line, the Penn Yan line, and the Watkins Glen line. For a portion of their extent these lines correspond to the boundaries of formations, and the fact that they are fall lines is thus in part explained. Their alignment, however, is no less significant, since the joint planes have so largely determined the areal limitation of the formations. The line of Owasco Lake is directed N. 20° W., and may be followed in the drainage for a distance of about 40 miles. The line of Skaneateles Lake and Tioughnioga River together make a prominent lineament directed N. 30° W., and followed for a distance of about 40 miles. Upper Cayuga Lake and its extension in drainage lines to the northwestward and southeastward mark out a lineament whose direction is N. 37° W., and which may be followed for some 70 miles. Less striking lineaments are directed along Canandaigua Lake (N. 18° E.), Cayuga Outlet (N. 15° E.), and along Flint and Twelve Mile Creeks (N. 22° E.).

Comparing, now, these lineaments with the joints observed by Mr. Brown, we have:

Lineament and its Bearings	Approximate Length Indicated	Number and Bearing of Joints Observed by Mr. Brown
Seneca line (N. 10° W.)	60 miles	139 (N. 10° W.)
Owasco line (N. 20° W.)	40 miles	288 (N. 20° W.)
Upper Cayuga line (N. 37° W.)	70 miles	66 51 (N. 40° W.) 15 (N. 34° W.)
Skaneateles line (N. 30° W.)	40 miles	35 (N. 30° W.)
Seneca Falls line (N. 82° E.)	40 miles	97 62 (N. 80° E.) 35 (N. 85° E.)
Penn Yan line (N. 82° E.)	40 miles	
Watkins Glen line (N. 82° E.)	20 miles	
Cayuga Outlet line (N. 15° E.)	20 miles	4 (N. 16° E.)
Canandaigua line (N. 18° E.)	15 miles	

The directions of the Seneca, Owasco, Upper Cayuga, and Seneca Falls lines are respectively those of the second and first in relative numerical importance among the joints observed in the district, as will be seen by comparing with the table on p. 371. The Skaneateles line is also along one of the most prominent directions of jointing. Of the less strongly indicated directions (Canandaigua line and Flint and Twelve Mile Creeks line, N. 18°–22° E.) no strong indication of control by jointing is observable, though the direction N. 16° E. is that of four observed joints, whereas no other directions between N.–S. and N. 30° E. have more than two representatives among those recorded.

REVIEWS

Vermont Geological Survey: Mineral Industries and Geology of Certain Areas. By GEORGE H. PERKINS, PH.D., State Geologist and Professor of Geology, University of Vermont. (Fourth Biennial Report.) Pp. 1–227; Plates I–LXXXI.

This report contains a description of the investigations conducted by the Survey during 1903–4. The report proper is prefaced by a sketch of the life and work of Charles Baker Adams, the first state geologist of Vermont, and a list of the publications on the geology of Vermont.

The chapter on the mineral resources of the state, by the state geologist, concerns itself chiefly with the various building and ornamental stones of the state. A map shows the approximate location and extent of the various granite, marble, and slate areas. The nonmetallic minerals, soapstone, talc, kaolin, fireclay, and asbestos, and the metallic minerals, gold, silver, copper, and platinum, are briefly treated.

C. H. Hitchcock discusses the glaciation of the Green Mountain Range. It is evident from a review of the facts that all the New England and northern New York elevations were swept over by the Hudson River lobe of the Labrador glacier as it advanced down the St. Lawrence, Lake Champlain, and Hudson River depressions, filling these great valleys, and spreading eastward and westward over the elevated mountain districts on either side.

W. F. Masters, in a preliminary report on a portion of the serpentine belt, shows that the serpentines are largely confined to a broad belt of talcose, micaceous schist. Three distinct types of rock occur—talcose micaceous schist, amphibolites, and serpentine, the latter resulting from the gradual alteration of the amphibolite. Serpentine occurs in two localities, Lowell and Belvidere. In both places the rocks have been sheared and crushed. The maximum amount of crushing and fracturing occurred near the upper and lower limits of the zones, and along fault planes. It is along these fracture lines that the asbestos has developed in paying quantities.

The chapter on the geology of Grand Island County, by the state geologist, describes the various formations and their economic importance. The county comprises Alburg peninsula, three large islands, North Hero, Isle La Motte, Grand Isle, and a group of smaller islands which nearly fill the northern end of Lake Champlain. The surface rock of Alburg and North Hero is Utica shale, while on Isle La Motte and Grand Isle patches of the Beekmantown, Chazy, Black River, Trenton, and Utica formations occur. The entire region is underlain by Ordovician rocks. A large part of Isle La Motte is covered by glacier clay and beaches. The southern end of Grand Isle has numerous dikes. The chapter closes with a description of the Stromatoceria, and similar forms of the Chazy, of Isle La Motte.

The report on the lignite or brown coal of Brandon and its fossils, embraces a brief résumé of the literature relating to the discovery age, origin, geological occurrence, and fossils of the lignite deposits. To this is added a note on the geological relations of the Brandon lignite, with map, by T. N. Dale, of the United States Geological Survey, and a note on the Brandon clays, by J. B. Woodworth, of the New York State Survey. The age of the Brandon formations is not determined. The discussion closes with a description of the fossil forms of the Brandon lignite, and plates illustrating most of the species studied.

The chapter on hydrology, also by Dr. Perkins, states that springs are the chief source of Vermont water-supply. Wells 10 to 30 feet in depth are used in a few localities. Deeper wells are seldom used, and are limited to the western part of the state. In Champlain Valley several flowing wells have been drilled. The joint investigation of the underground water-supply in Vermont by the state and United States Geological Surveys is still in progress.

A. R. S.

The Manufacture of Hydraulic Cements. By ALBERT VICTOR BLEININGER, B.Sc., Instructor in Ceramics, Ohio State University. Geological Survey of Ohio, Fourth Series, Bulletin No. 3 (1904). Pp. xiv+391.

This volume embodies the results of four years' work, and is a valuable contribution to the subject of cement manufacture. Some idea of the scope of the bulletin may be gained from the headings of the chapters, which are as follows: "General Considerations on the Hydraulic Cements;" "Raw Materials of the Cement Industry;" "Analysis and Testing of the Raw Materials;" "Manufacture of Puzzuolane and Natural Cements;" "On the Nature of Portland Cement;" "The Compounding of Portland Cement Mixtures;" "Winning and Preparation of the Raw Materials;" "The Burning of Portland Cement—the Grinding of the Clinker and General Arrangements of Plants;" "The Properties of Portland Cement and the Testing of Cement." Several of these chapters are of more than ordinary interest, and the volume will be useful to all who are interested in the manufacture of cement.

The various methods of making chemical analyses of the raw materials are given in detail. Following the chemical analyses is a series of mechanical analyses. These mechanical analyses are given because the physical character of the clay has an influence on its chemical activity when the cement is burned.

The chapter on "The Nature of Portland Cement" contains the results of investigations since 1887. The preparation of this summary must have required considerable labor, for many of the original papers are printed in French or German. The results of the author's investigations form a valuable contribution to the subject.

Every detail of cement manufacture is explained from the mining of the raw materials to the pulverizing and testing of the finished product. One of the most important features of the volume is the series of contributions made by the author to various problems of cement manufacture.

On pp. 155–57 the author gives a list of the unsolved problems connected with the chemical and physical analysis of cements. A perusal of this list indicates that there is a large field open to the investigator who has a thorough knowledge of chemistry and physics.

A few pages are devoted to a description of Ohio cement plants, with a statement of the raw materials used and the size and capacity of each plant.

G. C. M.

Preliminary Report on the Ohio Co-operative Topographic Survey, November 15, 1903. By C. E. SHERMAN. Pp. 227.

This work has been in progress three years, the average appropriation by the state being $25,000 per year. To this appropriation the United States Geological Survey adds an equal amount, besides bearing all the expense of engraving and printing the maps. It is estimated that the entire state will be mapped within five years at a cost, to the state, of $25,000 per year.

The maps are made in accordance with the general plan of the United States Geological Survey, the only exceptional feature being the numbering of the sections. It is proposed to indicate the areas of woodland after the maps are printed. Numbering the sections and indicating the wooded areas will add much to the value of the maps.

G. C. M.

Recent Publications.

—Bain, H. Foster, Zinc and Lead Deposits of Northwestern Illinois. [Bulletin No. 246, U. S. Geological Survey.]

—Bauer, L. A., Terrestrial Magnetism; Results of Magnetic Observations Made by the Coast and Geodetic Survey Between July 1, 1903, and June 30, 1904. [Appendix No. 3, Report for 1904.]

—Bleininger, A. V. Manufacture of Hydraulic Cements. [Bulletin No. 3, Geological Survey of Ohio, 4th series.]

—Clough, C. T., and Harker, Alfred. The Geology of West-Central Skye, with Soay. Explanation of Sheet 70. [Memoirs of the Geological Survey of Scotland, 1904.]

——Corstorphine, Geo. S. The History of Stratigraphical Investigation in South Africa. [Reprinted from the Report of the South African Association for the Advancement of Science, Johannesburg Meeting, 1904.]

——— The Geological Relation of the Old Granite to the Witwatersrand Series (Read March 9, 1904). [Reprinted from the Transactions of the Geological Society of South Africa, Vol. VII, Part I, 1904.]

—Davenport Academy of Sciences, Proceedings of the, Vol. IX, 1901–1903. [Davenport, Iowa, 1904.]

—Hatch, Frederick H., and Corstorphine, Geo. S. The Petrography of the Witwatersrand Conglomerates, with Special Reference to the Origin of the Gold (read November 14, 1904). [Reprinted from the Transactions of the Geological Society of South Africa, Vol. VII, Part III, 1904.]

——— The Geology of the Bezuidenhout Valley and the District East of Johannesburg (read August 8, 1904). [Reprinted from *ibid.*, Part II, 1904.]

—Hatch, Frederick H. The Oldest Sedimentary Rocks of the Transvaal (read December 12, 1904). [Reprinted from *ibid.*, Part III, 1904.]

—Hobbs, Wm. Herbert. The Frontier of Physiography. [Reprinted from Science, N. S., Vol. XVIII (1903), No. 460, pp. 538–40.]

——— Lineaments of the Atlantic Border Region. [Bulletin of the Geological Society of America, Vol. XV (1904), pp. 483–506, Plates 45–47.]

——— The Tectonic Geography of Eastern Asia (reviews and translations). [From the American Geologist, Vol. XXXIV (1904), pp. 69–80, 141–51, 214–26, 283–91, 371–78.]

—Maitland, A. Gibb. Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield. [Bulletin No. 15, Geological Survey of Western Australia; Perth, 1904.]

—Maryland Geological Survey, Highway Division. The New State and Road Law; How Improved Roads May be Secured under its Provisions. [1904.]

—Maryland Geological Survey. Miocene Plates. [1904.]

—Maryland Geological Survey. Miocene Text. [1904.]

—Orton, Ed. Uses of Hydraulic Cements, Eno, 1904. [Geological Survey of Ohio, 4th series, Bulletin No. 2.]

—Perkins, G. H. Report of the Vermont State Geologist, 1903–1904.

—Prosser, Chas. S., assisted by Cumings, Edgar R. The Waverly Formations of Central Ohio. [From American Geologist, Vol. XXXIV, December, 1904.]

—Reis, Heinrich, and Kummel, Henry B., assisted by Knapp, Geo. N. Clay Industry. [Geological Survey of New Jersey, Vol. VI.]

—Russell, Israel C. Co-operation among American Geographical Societies. (An address before the Section of Geology and Geography, American Association for the Advancement of science, Philadelphia meeting, December 27–31, 1904.) [Advanced pages from the Proceedings of the American Association for the Advancement of Science, Vol. LIV (1905).]

—Schwarz, E. H. Index to the Annual Reports of the Geological Commission, for the Years 1896–1903. [Cape Town, 1904.]

—Van Hise, C. R. The Problems of Geology. [Reprinted from the Journal of Geology, Vol. XII (1904), No. 7.]

—Wisconsin Academy of Sciences, Arts and Letters, Transactions of the, Vol. XIV, Part II, 1903. [Madison, Wis., 1904.]

—West Australian Mining Industry. [Issued as a special edition of the Australian Mining Standard, December 8, 1904.]

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THE GEOGRAPHICAL CYCLE IN AN ARID CLIMATE

W. M. DAVIS

Normal and special cycles.—The scheme of the geographical cycle is usually developed with respect to a land surface under ordinary climatic conditions, not so dry but what all basins overflow and all parts of the surface have continuous drainage to the sea, nor so cold but what the snow of winter all disappears in summer. The term "normal climate" has been applied to such conditions, and "normal cycle" to the scheme that embodies them. It is chiefly this scheme that I have elsewhere treated on various occasions (*a*, *b*, *c*, *h*).[1]

The general scheme of the geographical cycle needs adaptation to two special climates: one, glacial; the other, arid. The glacial cycle received brief attention in one of my papers (*d*) five years ago, but now needs supplement in view of the later studies by Richter, de Martonne, Lawson, and others, as to the forms of glaciated mountains, and in view of the theory announced by Gilbert that glaciers are not buoyed up while they rest on the sea bottom, and that they may therefore erode their channels deep below sea-level. The arid cycle has not been considered as a whole, although special studies of desert conditions have been made by various observers, notably by Walther. The following general considerations are based on the work of others as well as on my own observations in the arid regions of the western United States and of western Asia; they are presented for the most

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[1] See list of references at the end of this article.

part in an intentionally and avowedly deductive manner, but they are checked by facts from stage to stage. My especial indebtedness to Passarge is stated below.

The arid climate.—The essential features of the arid climate, as it is here considered, are: so small a rainfall that plant growth is scanty, that no basins of initial deformation are filled to overflowing, that no large trunk rivers are formed, and hence that the drainage does not reach the sea.

The agencies of sculpture and their opportunities for work in arid regions are peculiar in several respects. The small rainfall and the dry air reduce the ground water to a minimum. In its absence, weathering is almost limited to the surface, and is more largely physical than chemical. The streams are usually shorter than the slopes, and act as discontinuously at their lower as at their upper ends. The scarcity of plant growth leaves the surface relatively free to the attack of the winds and of the intermittent waters. Hence, in the production of fine waste, the splitting, flaking, and splintering of local weathering are supplemented rather by the rasping and trituration that go with transportation than by the chemical disintegration that characterizes a plant-bound soil.

No special conditions need be postulated as to the initiation of the arid cycle. The passive earth's crust may be (relatively) uplifted and offered to the sculpturing agencies with any structure, any form, and any altitude, in dry as well as in moist regions.

Initial stage.—Let consideration be given to an uplifted region of large extent over which an arid climate prevails. Antecedent rivers, persisting from a previous cycle against the deformations by which the new cycle is introduced, must be rare, because such rivers should be large, and large rivers are unusual in an arid region. Consequent drainage must prevail. The initial slopes in each basin will lead the wash of local rains toward the central depression, whose lowest point serves as the local baselevel for the district. There will be as many independent centripetal systems as there are basins of initial deformation; for no basin can contain an overflowing lake, whose outlet would connect two centripetal systems: the centripetal streams will not always follow the whole length of the centripetal slopes; most of the streams of each basin system will wither away after descending from the less arid highlands to the more arid depressions. Each basin system will therefore consist of many separate streams, which may occasionally, in time of flood or in the cooler season of diminished evaporation, unite in an intermittent trunk river, and even form a shallow lake in the basin bed, but which will ordinarily exist independently as disconnected headwater branches.

Youthful stage—In the early stage of a normal cycle the relief is ordinarily and rapidly increased by the incision of consequent valleys by the trunk rivers that flow to the sea. In the early stage of the arid cycle the relief is slowly diminished by the removal of waste from the highlands, and its deposition on the lower gentler slopes and on the basin beds of all the separate centripetal drainage systems. Thus all the local baselevels rise. The areas of removal are in time dissected by valleys of normal origin: if the climate is very arid, the uplands and slopes of these areas are either swept bare, or left thinly veneered with angular stony waste from which the finer particles are carried away almost as soon as they are weathered; if a less arid climate prevails on the uplands and highlands, the plants that they support will cause the retention of a larger proportion of finer waste on the slopes. The areas of deposition are, on the other hand, given a nearly level central floor of fine waste, with the varied phenomena of shallow lakes, playas, and salinas, surrounded with graded slopes of coarser waste. The deposits thus accumulated will be of variable composition and, toward the margin, of irregular structure. The coarser deposits will exhibit a variety of materials, mechanically comminuted, but not chemically disintegrated, and hence in this respect unlike the less heterogeneous deposits of humid climates from which the more easily soluble or decomposable minerals have been largely removed. The finer deposits will vary from sand and clay to salt and gypsum. The even strata that are supposed to characterize lake deposits may follow or precede irregular or cross-bedded strata, as the lake invades or is invaded by the deposits of streams or winds. While many desert deposits may be altogether devoid of organic remains, others may contain the fossils of land, stream, or lake organisms.

The Basin Range province of the western United States gives examples of dissected mountains from which descend many withering streams that belong to separate drainage systems of the kind above described, and of basins aggraded with the waste from the dissected mountains. Trunk streams are rare. The initial relief has been decreased, although the basin floors are from 3,000 to 5,000 feet above sea-level. Persia and Tibet give further illustrations of the same relation. In the latter region the intermont basins often contain saline lakes; but the stage of development there reached is not yet clear, because the origin of the ranges and basins is not, as a rule, considered by Tibetan explorers. It should not, however, be inferred that the separation of the many drainage systems in regions such as those of Persia and Tibet is the result of any special peculiarity in the initial deformation of the surface, essentially unlike the deformation of other regions of normal climate, where large unified drainage systems are the rule. The latter regions may initially have had as many basins of deformation as the former, but the more plentiful rainfall of normal climate has enabled their rivers to cut down the basin rims. This principle has been pointed out by Penck (*a*, p. 87; *b*, p. 159) and others. The initial relief may be of coarse pattern, as in central Asia, where the vast aggraded plains of eastern and western Turkestan are separated by a broadly uplifted and deeply dissected mountainous area; or of finer pattern, as in the Basin Range province just mentioned, where many small ranges separate nearly as many small basins. The progress of evolution through the cycle, and the arrangement of forms at successive stages, will be much affected by these unlike initial conditions.

Streams, floods, and lakes are the chief agencies in giving form to the aggraded basin floors, as well as to the dissected basin margins in the early stages of the cycle; but the winds also are of importance: they do a certain share of erosion by sand-blast action; they do a more important work of transportation by sweeping the granular waste from exposed uplands and depositing it in more sheltered depressions, and by raising the finer dust high in the air and carrying it far and wide before it is allowed to settle. Wind-action is, moreover, peculiar in not being guided by the slopes or restrained by the divides which control streams and stream systems. It is true that the winds, like the streams, tend in a very general way to wear down the highlands and to fill up the basins; but sand may be drifted uphill—dunes may be seen climbing strong slopes and escarpments in Arizona and Oregon—while fine dust carried aloft in whirlwinds and dust-storms is spread about by the upper currents with little regard to the slopes of the land surface far below. Sand may be drifted, and dust may be in this way carried outside of the arid region from which it was derived. Wind-erosion may, furthermore, tend to produce shallow depressions or hollows; for the whole region is the bed of the wind, and is therefore to a certain extent analogous to the bed of a river, where hollows are common enough; but in the early stages of the cycle in a region where the initial relief was strong, the action of the wind is not able to make hollows on the original slopes that are actively worked upon, and for a time even steepened, by streams and floods. Hence in the youthful stage wind-blown hollows are not likely to be formed.

It is important to notice that a significant, though small, share of wind-swept or wind-borne waste may be carried entirely outside of or "exported" from an arid region. It may be deposited on neighboring lands, where it will be held among the grass of a less arid climate, as long ago suggested by Richthofen; it may even be held down on coastal lands by the dew, as has been suggested for certain districts in Morocco by Fischer; it may fall into the sea, as is proved by the sand that gives a ruddy tinge to the sails of vessels in the Atlantic to leeward of the Sahara, and by the sand grains that are dredged up with true pelagic deposits from the bottom of that part of the Atlantic. It may therefore be expected that the progress of erosion and waste exportation in a desert region should be associated with the deposit of fine waste, as in loess sheets, on the neighboring less arid regions, especially down the course of the prevailing winds. In regions of weak and variable winds the process of sand and dust exportation must be extremely slow; in regions of steady winds it must still be vastly slower than the ordinary rate of waste removal in young or mature regions of plentiful rainfall and normal rivers. Yet it is by this slow process of exportation that the mean altitude of an arid region, such as is here considered, will be continually decreased; hence the earlier stages of the arid cycle are expectably longer than the corresponding stages of the normal cycle.

In the normal cycle the youthful stage is characterized by the headward growth of many subsequent streams, chiefly along belts of weak structures that are laid bare on the valley sides of the larger consequent streams. In the arid cycle subsequent streams have a smaller opportunity for development; first because all the belts of weak structure under the basin deposits are buried out of reach; second, because, in the absence of deep-cutting trunk rivers, many belts of weak structure are but little exposed. In so far, however, as the highlands are dissected by their headwater consequent streams, subsequent branches may grow out and diversify the slopes and rearrange the drainage.

Mature stage.—Continued erosion of the highlands and divides, and continued deposition in the basins, may here and there produce a slope from a higher basin floor across a reduced part of its initial rim to a lower basin floor. Headward erosion by the consequent or subsequent streams of the lower basin will favor this change, which might then be described as a capture of the higher drainage area. Aggradation of the higher basin is equally important, and a change thus effected might be described as an invasion of the lower basin by waste from the higher one; this corresponds in a belated way to the overflow of a lake in a normal cycle. There may still be no persistent stream connecting the two basins, but whenever rain falls on the slope that crosses the original divide, the wash will carry waste from the higher to the lower basin. Thus the drainage systems of two adjacent basins coalesce, and with this a beginning is made of the confluence and integration of drainage lines which, when more fully developed, characterize maturity. The intermittent drainage that is established across the former divide may have for a time a rather strong fall; as this is graded down to an even slope, an impulse of revival and deeper erosion makes its way, wave-like, across the floor of the higher basin and up all its centripetal slopes. The previously aggraded floor will thus for a time be dissected with a bad-land expression and then smoothed at a lower level; the bordering waste slopes will be trenched and degraded. At the same time, the lower basin floor will be more actively aggraded. If there is a sufficient difference of altitude between the two basins, all the waste that had been, in a preliminary or youthful view of the case, gathered in the higher basin, will in time be transferred to the lower basin; and thus a larger relation of drainage lines, a longer distance of intermittent transportation, a more continuous area of bed-rock in the higher areas, and a more general concentration of waste in the lowest basins will be established. The higher local baselevels are thus, by a process of slow, inorganic natural selection, replaced by a smaller and smaller number of lower and lower baselevels; and with all this go a headward extension of graded piedmont slopes, a deeper dissection of the highlands, and a better development of their subsequent and adjusted drainage. The processes of drainage adjustment are, however, at the best, of less importance here than in the normal cycle, because of the absence of main valleys, deep-cut by trunk rivers, and the resulting deficient development of deep-set subsequent streams, as has already been suggested.

Some changes of this kind have probably taken place in the Basin Range province of Utah and Nevada, but more field work will be needed before they can be safely pointed out. Indeed, it seems to be the case that certain changes of an opposite kind have taken place; the long intermont troughs appear to be here and there subdivided into separate basins by the undue growth of certain detrital fans where large valleys have been opened in the neighboring ranges; but this condition of things will pass when the mountains are worn lower and the waste is discharged from them less actively.

As the coalescence of basins and the integration of stream systems progress, the changes of local baselevels will be fewer and slower, and the obliteration of the uplands, the development of graded piedmont slopes, and the aggradation of the chief basins will be more and more extensive. The higher parts of the piedmont slopes may be rock-floors, thinly and irregularly veneered with waste, as has been described by Keyes for certain basins (bolsons) in New Mexico; here, as well as upon the aggraded slopes and plains, sheet-flood action will prevail, as explained by McGee. The area occupied during early maturity by the three different kinds of surface—dissected highlands or mountains, graded piedmont slopes of rock or waste, and aggraded central plains with playas, salinas, or lakes—will depend on the initial relief, on the rock structure and its relation to desert weathering, on the percentage of material exported by the winds, and on the climate itself.

It is worth noting that, although the activity of streams and floods decreases with the decrease of relief and of slope, the activity of the winds is hardly affected as maturity advances. The winds do not depend on the gradient of the land surface for their gravitative acceleration; they may blow violently and work efficiently on a level surface. Whirlwinds are, indeed, most active on true plains. It may be that smooth plains are never swept by winds so violent as the blasts which attack highlands and mountains; but it is probable that the effective action of the winds is greater on a generally plain surface than on one of strong relief, where the salient ridges and peaks consist largely of firm rock, and where the loose waste is sheltered in re-entrant valleys. Moreover, it is in very great part on the plains that the winds of ordinary strength drift the sand about, and from the plains that whirlwinds and dust-storms raise the finest waste high enough for exportation. It may therefore be concluded that the work of the winds is but little, if any, impaired by the general decrease of relief that characterizes advancing maturity; and hence that their relative importance increases. Moreover, the scanty rainfall of an arid region will be decreased as its initial highlands, which originally acted as rain-provokers, are worn down; hence, as the relief weakens, the winds will more and more gain the upper hand in the work of transportation. It is conceivable that the rate of exportation of sand and dust by the winds in maturity and all the later stages of an arid cycle is more rapid than the removal of fine soil, partly or largely in solution, from a plant-covered peneplain in the later stages of a normal cycle; thus the slower work of the earlier stages of an arid cycle may be partly made good by the relatively more active work in the later stages.

As the processes thus far described continue through geological periods, the initial relief will be extinguished even under the slow processes of desert erosion, and there will appear instead large, rock-floored plains sloping toward large waste-floored plains; the plains will be interrupted only where parts of the initial highlands and masses of unusually resistant rocks here and there survive as isolated residual mountains. At the same time, deposits of loess may be expected to accumulate in increasing thickness on the neighboring less arid regions. The altitude at which the desert plain will stand is evidently independent of the general baselevel—or sea-level—and dependent only on the original form and altitude of the region, and on the amount of dust that it has lost through wind transportation.

The most perfect maturity would be reached when the drainage of all the arid region becomes integrated with respect to a single aggraded basin-baselevel, so that the slopes should lead from all parts of the surface to a single area for the deposition of the waste. The lowest basin area which thus comes to have a monopoly of deposition may receive so heavy a body of waste that some of its ridges may be nearly or quite buried. Strong relief might still remain in certain peripheral districts, but large plain areas would by this time necessarily have been developed. In so far as the plains are rock-floored, they would truncate the rocks without regard to their structure.

There is no novelty in the idea that a mountainous region of interior drainage may be reduced to a plain by the double process of wearing down the ranges and filling up the basins, and that the plain thus formed, consisting partly of worn-down rock and partly of built-up waste, will not stand in any definite relation to the general baselevel of the ocean surface; yet the idea has seldom been applied in the interpretation of uplifts by the physiographic method. In the case of the plateaus that are now trenched by the Colorado river in northern Arizona, for example, it has usually been tacitly postulated that the baselevel with respect to which they were widely denuded in the pre-canyon cycle was the normal baselevel of the ocean, and from this postulate it has been argued that the cycle of canyon erosion was introduced by a strong uplift. My own opinion has agreed with that of Dutton and others in this respect. Yet it is not today easily demonstrated that the Arizona plateaus had exterior drainage at the time of their wide denudation; and until exterior drainage is shown to have obtained, the altitude of the plateau region during its denudation must remain uncertain. There are, however, several facts which point to the correctness of the generally accepted view: the course of the Colorado river through the Kaibab cannot easily be explained as having originated in the present cycle; it appears to have been established earlier; and it is doubtful whether there are late Tertiary basin deposits within the desert area, or wind-carried sand and loess deposits in the area to the eastward (leeward) of sufficient volume to represent the great volume of material removed in the degradation of the plateaus.

In the case of truncated uplands elsewhere—that is, uplands whose surface truncates their structure, as in the central plateau of France—it is generally a tacit postulate, if not a proved conclusion, that the climate during their truncation was not arid, and hence it is inferred that they were worn down as peneplains with respect to normal baselevel, and that they have been uplifted since; this aspect of the problem will be considered farther on. In the meantime, there is another aspect of erosion in arid regions which, to my knowledge, has not, until recently, received attention.

The beginning of old age.—During the advance of drainage integration the exportation of wind-borne waste is continued. At the same time, the tendency of wind-action to form hollows wherever the rocks weather most rapidly to a dusty texture would be favored by the general decrease of surface slopes, and by the decrease of rainfall and of stream-action resulting from the general wearing-down of the highlands. Thus it may well happen that wind-blown hollows should be produced here and there, through the mature and later stages of the cycle, and that they should even during early maturity interfere, to a greater or less degree, with the development of the integrated drainage, described above. In any case, it may be expected that wind-blown hollows would in late maturity seriously interfere with the maintenance of an integrated drainage system. Thus it appears that, along with the processes which tend toward the mature integration of drainage, there are other processes which tend toward a later disintegration, and that the latter gain efficiency as the former begin to weaken. A strong initial relief of large pattern, a quality of rock not readily reducible to dusty waste, and an irregular movement of light winds might give the control of sculpture to the intermittent streams through youth and into maturity; in such a case maturity might be characterized by a fully integrated system of drainage slopes, with insignificant imperfections in the way of wind-blown hollows. In a second region an initial form of weaker relief, a quality of rock readily reducible to dust, and a steady flow of strong winds might favor the development of wind-blown hollows or basins, and here the process of drainage disintegration would set in relatively early and prevent the attainment of mature drainage integration. In any case, as soon as the process of drainage disintegration begins to predominate, maturity may be said to pass into old age.

This feature of the arid cycle has no close analogy with the features recognized in the normal cycle. In the latter case, the drainage systems of maturity tend on the whole to persist, even though the streams weaken and wander somewhat—and according to theory lose some of their adjustments—in very advanced old age; in the former case, as old age advances, the integrated and enlarged drainage systems of maturity are broken up into all manner of new and local, small and variable, systems. The further results of drainage disintegration in the later stages of the cycle are even more peculiar.

Leveling without baseleveling.—The later consequences of erosion in an extensive arid region have been, as far as my reading goes, first and recently stated by Passarge, in connection with his studies of the arid regions of South Africa, as is more fully indicated below.

As the dissected highlands of maturity are worn down, the rainfall decreases, and the running streams are weakened and extinguished; thus, as has been suggested above, the winds in time would appear to gain the upper hand as agents of erosion and transportation. If such were the case, it would seem that great inequalities of level might be produced by the excavation of wide and deep hollows in areas of weak rocks. As long as the exportation of wind-swept sand and of wind-borne dust continued, no easily defined limit would be found for the depth of the hollows that might thus be developed in the surface, for the sweeping and lifting action of the wind is not cotrolled by any general baselevel. In an absolutely rainless region there appears to be no reason for doubting that these abnormal inequalities of surface might eventually produce a strong relief in a still-standing land of unchanging climate; but in the actual deserts of the world there appears to be no absolutely rainless region; and even small and occasional rainfalls will suffice, especially when they occur suddenly and cause floods, as is habitual in deserts, to introduce an altogether different régime in the development of surface forms from the rock hills and hollows which would prevail under the control of the winds alone. The prevailing absence of such hill-and-hollow forms, and the general presence of graded wadies and of drainage slopes in desert regions, confirm this statement.

As soon as a shallow wind-blown hollow is formed, that part of the integrated drainage system which leads to the hollow will supply waste to it whenever rain falls there; the finer waste will be blown away, the coarser waste will accumulate, and thus the tendency of the winds to overdeepen local hollows will be spontaneously and effectively counteracted. As incipient hollows are formed in advancing old age, and the maturely integrated drainage system disintegrates into many small and variable systems, each system will check the deepening of a hollow by wind-action; hence no deep hollow can be formed anywhere, so long as occasional rain falls.

It is conceivable that, in some special cases, there might be a peculiar balance of the various factors involved which would result in the development of wind-carved hills and hollows, even if the region were not absolutely rainless. The occurrence of permeable sandstones might favor such a result, because the rain falling on them would sink into the ground instead of running off of it, while fine grains weathered from the sandstone would be disposed of by the winds. But for the present no desert sandstone region with hills and hollows is known while such regions with hills and valleys are common. Hence it must be inferred that even in sandstone deserts the occasional rains suffice to wash the surface and to prevent the formation of anything more than very shallow depressions.

As the drainage becomes more and more disintegrated, and the surface of the plain is slowly lowered, rock masses that most effectually resist dry weathering will remain as monadnocks—*Inselberge*, as Bornhardt and Passarge call them in South Africa. At the same time, the waste will be washed away from the gathering grounds of maturity and scattered in the shallow hollows that are formed here and there by the winds as old age approaches. The removal of the basin deposits by the winds may be delayed where the hygroscopic action of saline clays keeps the surface firm; but wherever the integrated centripetal slopes are locally reversed by the hollowing action of the wind, some of the central deposits will be washed back again and exposed to renewed search for fine material by the wind, and thus a larger and larger part of the central waste will be redistributed and exported. As there is no relation of parts in the winds analogous to that of small branch and large trunk streams in river systems, the surface eroded by the winds need not slope toward any central area, but may everywhere be worn down essentially to the same level. The surface ever wearing down, the waste ever washed irregularly about by the variable disintegration of the drainage system and continually exported by the winds, a nearly level rock-floor, nowhere heavily covered with waste, and everywhere slowly lowering at the rate of sand and dust exportation, is developed over a larger and larger area; and such is the condition of quasi-equilibrium for old age. At last, as the waste is more completely exported, the desert plain may be reduced to a lower level than that of the deepest initial basin; and then a rock-floor, thinly veneered with waste, unrelated to normal baselevel, will prevail throughout—except where monadnocks still survive. This is the generalization that we owe to Passarge; it seems to me secondary in value only to Powell's generalization concerning the general baselevel of erosion. So long as the sea is held out, it would seem that a desert surface might be worn even below sea-level, as certain writers have pointed out in a general way (Penck, *b*, p. 167); but that such a desert should persistently maintain a plain surface while it is slowly worn lower and lower is a surprising result of deduction. Little wonder that an understanding of the possible development of rock-floored deserts of this kind, independent of baselevel, was not reached inductively in western America; for there has been so much disturbance in the way of fracture and uplift in that region during Mesozoic, Tertiary, and Quaternary time that the attainment of arid old age has not been permitted; but that the problem was not solved deductively by the present generation of American physiographers before it was encountered and solved by others in Africa serves to show how insufficient still is the use of the deductive method among us.

Passarge writes that his attention has been called to the difficulty of explaining the vast plain surfaces of South Africa by wind-action, because the wind has no baselevel of erosion, and it therefore can and must excavate considerable hollows in rock areas whose waste it can easily remove. He adds that this difficulty disappears as soon as rain works with the wind, since the rain constantly seeks to wash waste into the hollows formed by the wind, whose tendency to make hollows is thereby counteracted.[1]

The verity of the arid cycle.—The deductive method by which most of the preceding paragraphs are characterized may be regarded by some readers as reaching too far into the field of untestable speculation. It is true that the examples of observed forms, by which the deduced forms of every stage should be matched, are as yet not described in sufficient number; but this may be because desert regions have not yet been sufficiently explored with the principles herein set forth—particularly Passarge's law—in mind. On the other hand, the examples of desert plains in South Africa, described by Passarge as plains of the Bechuana (Betschuana) type, suffice to show that the stage of widespread desert-leveling has actually been reached in that region, and thus justify all the earlier stages; for, however many land movements may have interrupted the regular progress of preceding cycles, the occurrence of widespread rock plains proves that at least the present cycle of arid erosion has been long continued without disturbance.

The levelness of the plains over wide areas is especially emphasized. Isolated mountains rise above the plains; and the combination of the two unlike forms is described under the term *Inselberglandschaft*, suggested by Bornhardt. Passarge states that these desert plains are not undulating with low hills, but true plains of great extent, from which the isolated residual mountains rise like islands from the sea. The residuals may be low mounds, only a few meters high, or lofty mountain masses, rising several thousand meters above the plains. The plain surrounds the steep slope of the mountains with a table-like evenness; there is no transitional belt of piedmont hills, and no intermediate slope (*b*, p. 194). The mountains consist of resistant rocks, such as granite, diorite, gabbro, quartzite, etc.,

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[1] "Herr Geheimrath v. Richthofen machte mich auf die Schwierigkeit aufmerksam, die riesigen, faktisch ebenen Flächen durch Windwirkung zu erklären, dafür der Wind kein 'baselevel of erosion' bestände und er aus Gestein, das sich leicht abtragen lässt, bedeutende Vertiefungen ausarbeiten könne und müsse. Diese Schwierigkeit fällt fort, sobald spülender Regen mitarbeitet. Denn dieser sucht die durch den Wind geschaffenen Vertiefungen beständig mit Schutt—Sand, Lehm, etc.—auszufüllen, arbeitet also dem Wind entgegen" (Passarge, *b*, p. 208).

granite being the most frequent; the plains are of more easily eroded rocks, such as gneiss, schists, slates, sandstones, and limestones. The bedding of the rocks is not flat, but disturbed; the plain therefore truncates the rock structures. The rocks are not deeply decomposed, but are relatively fresh. The products of weathering are usually spread as a thin veneer on the plain; the waste does not lie in place, on the rocks from which it was weathered, but has been drifted about by wind and flood, and has gathered in slight depressions. The waste veneer increases the smoothness of the plain, but the rock surface is also a plain, as may be seen in the edge of water channels, as well as where the veneer is absent (*b*, p. 195). Neighboring areas contain extensive deposits of irregular strata, whose composition and want of fossils indicate their desert origin, as will be referred to again below. Various additional details are given, with the conclusion as above quoted: these rock-floored plains are not uplifted peneplains, but are the product of desert erosion unrelated to normal baselevel, in which occasional water-action has co-operated with more persistent wind-action.

The scheme of the arid cycle thus seems to be as well supported by appropriate facts as is the scheme of the normal cycle; it is, indeed, in one respect even better supported, for while the arid African plains are examples of old desert plains now growing still older, it is difficult to point out any large peneplain that still stands close to the baselevel with respect to which it was worn down.

Contrasted consequences of normal baseleveling and desert-leveling.—While the theory of marine planation was in vogue, it was customary to interpret all evenly truncated uplands—that is, uplands whose surface truncates their rock-structure—as uplifted plains of marine abrasion, more or less dissected since they were uplifted. When the efficacy of subaerial erosion was recognized, it became equally customary to interpret truncated uplands as once baseleveled and afterward uplifted peneplains. If Passarge's views be now accepted, it follows that no truncated uplands should, without further inquiry, be treated as having been eroded when their region had a lower stand with respect to baselevel; the possibility of their having been formed during an earlier arid climate as desert plains, without regard to the general baselevel of the ocean, must be considered and excluded before baseleveling and uplift can be taken as proved.

It may at first appear sufficient to say that high-standing desert plains can have been made only in those regions which are now desert, but this easy solution of the problem is hardly convincing. Climatic changes are known to have occurred in the past, and inasmuch as they did not all affect areas in a way that is sympathetic with the present arrangement of the zones, the possibility of a former different distribution of deserts from that which now occurs seems to be open. Pleistocene climatic changes of the glacial kind were so modern and short-lived that they have little bearing on the possibility of earlier climatic changes of another order. The more ancient records of glaciation are so distributed as to demand significant rearrangement of the present climatic conditions. The existing deserts are, moreover, of two kinds with respect to cause: some deserts, like those of Africa and Australia, are arranged chiefly with respect to the trade-wind belt; other deserts, like those of central Asia and the southwestern United States, are dependent for the most part on the extent and configuration of the surrounding highlands. When we go back as far as Cretaceous time, it should only be by evidence and not by assumption that we are led to regard a truncated upland of that date as having been baseleveled during a cycle of normal climate and afterward uplifted and dissected, instead of having been leveled above baselevel during a cycle of arid climate, and dissected in consequence of a change to a normal climate. A century ago demonstrated movements of the earth's crust were matters of astonishment; witness the surprise then felt at the discovery of fossilized marine shells in some of the loftier Alpine ranges. Today the crust is raised and lowered on the evidence of dissected peneplains, as in the Appalachian region, without exciting remark; it is now the shifting of climatic conditions that would cause dissenting surprise. It is difficult to determine how far such surprise is well founded, and how far it simply reflects the fashion of our time. Even if the climatic zones have always belted the earth as they do now, the desert areas that depend on the configuration of land and water, and of highlands and lowlands, have certainly varied through the geological ages. It is therefore desirable, wherever the question of "uplifted and dissected peneplains" is raised, to scrutinize it carefully, and to determine, if possible, whether it is really the attitude of the earth's crust or the condition of climate that has been changed. It is likewise important to scrutinize desert plains, now standing above baselevel, to see if they may not have been formed normally as lowland plains of erosion and afterward uplifted. It is therefore necessary to inquire into these features by which baseleveled peneplains and rock-floored desert plains may be distinguished, even though the former may be uplifted with a change to an arid climate, or though the latter may be depressed with a change to a humid climate.

Passarge holds the opinion that the plains of the *Inselberglandschaft* are smoother than any peneplain can be; for he describes the desert plains as true plains, not as gently undulating surfaces. He states that water is not competent to produce such plains; its power of erosion works chiefly downward, and only by exception laterally; and he concludes that, although long-continued normal erosion may produce a peneplain—that is, a low, undulating hilly surface—it nevertheless cannot produce a surface like that of the plains in the *Inselberglandschaft*.[1] But, however difficult it may be to wait, in imagination, through the ages required to wear a low hilly region down to less and less relief by the weakened processes of weather and water erosion in the latest stages of the normal cycle, there are certainly some truncated uplands, ordinarily taken to be uplifted peneplains, whose interstream uplands are astonishingly even, and whose surface must have been, before dissection, very nearly plain over large areas; hence it does not seem to me altogether certain that a greater and a less degree of flatness can be taken to distinguish the two classes of plains.

A plain of erosion lying close to sea-level in a region of normal climate, and therefore traversed by rivers that reach the sea, but that do not trench the plain, might conceivably be a depressed desert plain standing long enough in a changed climate to have become cloaked with local soils; but it is extremely unlikely that the depression of a desert plain could place it so that it should slope gently to the

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[1] Wasser ist nicht imstande solche Ebene zu erodieren. Seine Erosionskraft wirkt hauptsächlich in die Tiefe, nur ausnahmsweise in die Breite. . . . . Bei sehr lang andauernder Abtragung kann wohl eine 'Peneplain' zustande kommen, d. h. ein flaches welliges Hügelland, aber keine Fläche, wie die Ebenen der Inselberglandschaften" (*b*, p. 196).

seashore, and that its new-made rivers should not dissect it, and that there should be no drifted sands and loess sheets on adjoining areas, and no signs of submergence on neighboring coasts. An untrenched plain of erosion in such an attitude would be properly interpreted as the result of normal processes, long and successfully acting with respect to normal baselevel. There would therefore appear to be no serious danger of confusing an actual peneplain of normal origin, still standing close to baselevel, with a depressed plain of desert origin. For the reasons above given I am not disposed to follow Passarge in the suggestion that the old land mass of Guiana may be an *Inselberglandschaft* in the process of destruction. He cites it as a flat, gently undulating surface of gneiss, above which rise knobs and mountains of granite; the divides are so low that one may pass in canoe between the headwaters of the Orinoco and Amazon systems (*b*, p. 194). Until further details are given, it would seem appropriate to regard this region, like the interior of Brazil to which Lapparent refers (*a*, p. 148), as an example of a normal peneplain, not raised so as to be attacked by its rivers.

In the same way a high-standing plain of erosion in a desert region might be possibly explained as an evenly uplifted peneplain whose climate had in some way been changed from humid to arid, whose deep weathered soils had been removed and replaced by thin sheets of stony, sandy, or saline waste, and whose residual reliefs had been modified to the point of producing shallow basins. But in this case there should be some indications of recent uplift around the margin of the area, either in the form of uplifted marine formations whose deposition was contemporaneous with the erosion of the peneplain, or in the form of fault-escarpments separating the uplifted from the non-uplifted areas. Moreover, it is extremely unlikely that the uplift of an extensive peneplain could place it in so level a position that it should not suffer dissection even by desert agencies; hence a high-standing desert plain is best accounted for by supposing that it has been leveled in the position that it now occupies. According to Passarge, there are no sufficient indications of elevation associated with the South African desert plains, and their explanation as the product result of long-continued desert erosion in a still-standing region would therefore seem to be assured.

Whether an appropriate deposit of wind-borne waste is to be found on neighboring regions is not yet made clear.

It should not, however, be overlooked that there is some danger of misreading the history of a depressed desert plain which has been by a moderate amount of normal weathering and erosion transformed into a normal peneplain; and of an uplifted peneplain which has been by a moderate amount of arid weathering and erosion transformed into a typical desert plain; the danger of error here is similar to that by which a peneplain, wave-swept and scoured during submergence, might be mistaken for a normal plain of marine abrasion. The consequences of error in these cases of actual plains are, however, not so serious as in those which may arise in connection with dissected plains; for this class of forms is of common occurrence, and mistakes in explaining their origin as uplifted peneplains or as changed-climate desert plains might therefore be of frequent and widespread occurrence. It is therefore desirable to search out those features by which normal peneplains, uplifted and dissected, may be distinguished from desert plains, dissected after a change to humid climate.

If a normal peneplain be uplifted, its already adjusted streams will carry their adjustments still farther in the new cycle. The high degree of adjustment of streams to structures in the Pennsylvania Appalachians and in the mediæval coastal plain of central England therefore suggests that the former surface of truncation, beneath which the present lower lands have been etched out, was a normal peneplain, uplifted. If a normal peneplain be tilted, its depressed part will soon be submerged and covered with marine deposits; and this part may, by later uplift, be associated with the elevated and dissected part. The marine deposits of our Atlantic and Gulf coastal plain, certain basal strata of continental origin excepted, seem to lie upon a depressed part of the Appalachian peneplain, and thus confirm the evidence of normal baseleveling derived from the adjusted drainage of the uplifted and dissected part of the same peneplain; the basal strata just mentioned contain fossil land plants of normal climate and confirm the conclusion. The now dissected uplands of Brittany and of the Ardennes are adjoined or overlapped by marine deposits which give strong suggestion of normal peneplanation, as shown by Lapparent (*b*). Disturbances of the arid cycle are followed by consequences of other kinds.

Interruptions and modifications of the arid cycle.—A land mass suffering erosion under an arid climate may, as in the normal cycle, suffer interruption in the regular progress of its changes by movement of any kind at any stage of development. If, for example, integration of drainage has advanced so far that the number of original basins is reduced by half, the number may be increased again by renewed deformation; or if the integration of drainage has reached a mature stage, the drainage may be thrown into disorder again by a more or less gentle warping of the region. In all such cases a new cycle may be regarded as having been initiated; its initial forms will be the eroded forms developed during the preceding incomplete cycle, and displaced by the movements through which the preceding cycle was closed. The work of the new cycle, thus initiated, then goes on as before; but with interruptions of this kind we are not here particularly concerned, because they offer no special difficulty of explanation or interpretation.

It is otherwise when interruptions or modifications of the arid cycle occur after old age is well advanced, for the desert plains then developed may, under certain conditions, come to imitate uplifted undissected peneplains, as has already been partly considered in the preceding section.

Uniform uplift or depression, by which a normal peneplain is so immediately and significantly modified, will not interrupt the regular process of degradation on a desert plain in an arid cycle. It is perhaps in part for this reason that actual examples of rock-floored desert plains appear to be more common than actual examples of peneplains. Depression would drown a peneplain, and elevation would cause its dissection; but, unless carried to an extreme, neither of these movements would greatly affect the slow degradation of a desert plain. Unequal movements, whereby a desert plain is warped or slanted, are of more importance and are probably of more common occurrence.

If an old rock-floored desert plain be gently warped or tilted, marine submergence is not likely to follow immediately, but the regular continuation of general degradation will be interrupted. The patches and veneers of waste will be washed from the higher to the lower parts of the warped surface; the higher parts, having an increased slope, might be somewhat dissected, and would certainly be exposed to more active degradation than before, until they were worn down to a nearly level plain again. The lower parts would receive the waste from the higher parts, and the continuance of this process of concentration would in time cause the accumulation of extensive and heavy deposits in the lower areas. Such deposits will be, as a rule, barren of fossils; the composition, texture, and arrangement of their materials will indicate the arid conditions under which they have been weathered, transported, and laid down; their structures will seldom exhibit the regularity of marine strata, and they may reach the extreme irregularity of sand-dune deposits. If warping continues, the desert deposits may gain great thickness; their original floor may be depressed below sea-level, while their surface is still hundreds or thousands of feet above sea-level.

Passarge gives a number of instances which he groups under the Banda type (*b*, p. 200) that seem to illustrate this phase of the arid cycle, although he ascribes the barren sandstones of this type to a weakening in the activity of the winds, rather than to a tilting of the region. Here the upper parts of monadnocks—*Inselberge*—rise above a broad deposit of barren continental sandstones; the intermont plains, being buried, are matters of interference. Examples of this type are mentioned in West Australia as well as in Africa.

If a change from an arid toward a moister climate causes a drainage discharge to the sea, a dissection of the plain will ensue. The valleys thus eroded cannot expectably exhibit any great degree of adjustment to the structures, because the stream courses will result from the irregular patching together of the pre-existing irregularly disintegrated drainage. This peculiar characteristic, taken together with the absence of neighboring uplifted marine deposits, will probably suffice in most cases to distinguish desert plains, dissected by a change to a moister climate, from peneplains dissected in consequence of upilft; but there still might be confusion with peneplains dissected by superposed streams.

Passarge gives two types of desert plains with a modified climate. The first or Kordofan type (*b*, p. 200) is marked by a slight increase of rainfall, sufficient to introduce a steppe vegetation, but not sufficient to form rivers that shall reach the sea. In this case the larger residual mountain masses come to be surrounded by washed deposits coarser near the mountain base, finer farther forward, and at last grading into swampy areas with dark rich soil. Such deposits are said to be well developed in Kordofan, where the buried eroded plain between the mountains has been revealed by well borings, and where basins in the buried plain are indicated by certain unusual accumulations of ground water. The second or Adamaua type (*b*, p. 201) includes an example of more abundant rainfall, and therefore exhibits the dissection of what is taken to have been a desert plain with *Inselberge;* but the relation of streams to structures is not mentioned. Finally a Rovuma type (*b*, p. 202) is instanced on the authority of Bornhardt, in which marine Cretaceous strata of moderate thickness lie upon a plain whose erosion is ascribed to pre-existing desert conditions.

Diversion of desert drainage to exterior discharge.—The development of desert plains without regard to normal baselevel is possible only so long as they are interior basins, without drainage discharge to the sea. The maintenance of this essential condition is imperiled by small area, great altitude, no inclosing mountains, strong exterior slopes to the sea, and the occurrence of heavy rainfall on the exterior slopes. A small desert island would have no room for the production of interior basins by the processes of initial deformation, or for their maintenance against the attack of exterior streams. The absence of inclosing mountains around a continental arid region would permit the development of escaping drainage systems, so that when mature integration was reached, it might be developed with respect to normal baselevel, instead of with respect to a local interior baselevel; the Sonoran district of Mexico, as described by McGee, seems to offer examples of this kind. Great altitude of an arid region and strong exterior slopes would give strength to attacking exterior streams, and no advantage to the interior drainage; some of the basins of Tibet have already been invaded by the headwater erosion of Himalayan streams, for here the unfavorable conditions of great altitude in the basins, strong exterior slopes, and heavy exterior rainfall are all combined.

On the other hand, great area, moderate altitude, inclosure by mountain barriers, and small exterior rainfall are favorable to the leveling of interior desert plains; and to these favoring conditions should be added a long geological period of quiet. The greater the area and the less the altitude, the less the opportunity that exterior streams will have to establish relations with the interior streams. The higher the inclosing mountains, the longer the interior region will be left to itself, but the more dust it will have to export before a general rock-floor can be developed; the desert of Gobi offers an example of this kind, for its surface must long continue to suffer aggradation before the lofty ranges around its depressed surface are worn down to its level. South Africa would seem to offer, according to the descriptions by Passarge, excellent opportunity for the successful advance of the arid cycle far into old age, because of the large extent of the land area, its sufficient height and inclosure, its long-undisturbed history, and its persistently arid climate.

It thus seems evident that the conditions necessary for desert-leveling are actually present in greater or less degree in different parts of the world.

The scheme of the arid cycle as an aid to observation.—The normal cycle has now been practically used by so many observers, and with so many advantageous results, that it is not unfair to expect similar advantage from the use of the arid cycle as an aid to observation in regions where it may be appropriately applied. Certain it is that many observations now on record with regard to arid regions do not suffice to indicate clearly the stage of erosion in the arid cycle there reached; and this, not because the observers had either reason or wish to dissent from the principles of the scheme, but because it was not consciously present in their minds when the observations were made. The same is often true of the scheme of the normal cycle. In both cases the failure of the observant explorer to refer the facts that he finds to some comprehensive scheme for their systematic treatment not only results in the accidental overlooking of certain significant facts and in the insufficient description of others, but it leaves the reader in great difficulty when he tries to visualize what the observer has seen. It is as if the writer and the reader had no common language in which the observations and thoughts of the one should be transmitted to the other. It would be far otherwise if the description of a desert region were undertaken systematically in view of what seems to be the essential sequence of changes in all deserts; that is, if the mountains and basins, the rock plains and waste plains, the stream channels, the playas and the lakes, were all treated in view of their place in the cycle of changes through which they must be running. It is chiefly as an aid to observation and record, and as an aid to the understanding of observations thus recorded, that the scheme of the arid cycle may come to be of service.

It would be fitting to accompany an article of this kind with a larger number of actual examples than have been here introduced; but in the endeavor to find appropriate examples, the interpretation of the observations of various writers in view of the scheme here submitted has not seemed safe enough to make it worth while to undertake it. Safe interpretation needs the conscious application of the scheme by the observer in the field. When thus applied, it is to be hoped that the scheme of the arid cycle may lead to the detection of many facts concerning the evolution of land forms in desert regions that have thus far escaped notice. In the meantime, the scheme must remain in great part speculative.

The bearing of the arid cycle on theories of elevation and depression.—There is another aspect of the case which, to my mind, not only gives sufficient justification for all the speculation here presented, but makes one regret that it was not undertaken sooner; for in that case certain theoretical discussions would have earlier gained a firm foundation.

In a recent discussion of "The Bearing of Physiography on Suess' Theories" (*f*), I have urged that the occurrence of high-standing and isolated peneplains could not be the result of the depression of the surrounding lands—as is advocated by Suess—unless all the oceans and their associated lowlands on other continents were also depressed at the same time and by the same amount. The necessity of accepting world-wide crustal movements may, however, be avoided, if the high-standing truncated uplands are regarded as the result of local uplifts of formerly low-standing peneplains. This alternative conclusion is so simple and economical that it is accepted by many geologists and geographers; and it seems well based as long as one believes that the even uplands can have been truncated only by peneplanation close to sea-level. As soon, however, as it is recognized that leveling may be accomplished in an arid region without baseleveling, it is no longer necessarily the case that truncated uplands represent uplifted peneplains; the uplands may perhaps be parts of ancient desert plains, originally denuded at their present altitude; and until this possibility is excluded, their isolated position may be explained by the depression of the surrounding lands, as Suess has supposed, without corresponding change in the level of the oceans and the other continents.

In the case of the truncated uplands or *horsts* of central Germany, there appears to be good geological reason for associating them with the denuded areas of the Ardennes and of Brittany, as described by Lapparent (*b*), and thus concluding that they were all low-lying peneplains before they were uplifted. In the case of the plateaus of northern Arizona, the evidence of normal peneplanation is less complete; yet, as above stated, it still seems probable that these plateaus were denuded with respect to normal baselevel, and that the canyon was cut across their surface in consequence of a later uplift with respect to sea-level. The Bural-bas-tau, a flat-topped range, and the associated plateau-like highlands in the Tian Shan system, also need reconsideration in view of the possibility of desert-leveling. I have treated the Bural-bas-tau (*e, f, g*), and Huntington has treated the associated highlands as uplifted peneplains. Friederichsen, on the other hand, while recognizing the highland region as a *Denudationsfläche*, has hesitated to treat it as a once low-lying peneplain, because of the possibility of its erosion above baselevel in a region of inland drainage. If such were the case, it need not have had that close relation to baselevel that is to be expected in a normal peneplain. Nevertheless, the truncated highlands and mountain tops in the Tian Shan seem to be closely related to the still low-lying plains of erosion that are drained by the Ili river to Lake Balkash, and also to the still lower-lying plain of erosion—apparently a true peneplain—that is drained by the Irtysh and the Ob to the Arctic ocean; hence the probability still seems great that the even highlands of the Bural-bas-tau represent a greatly uplifted plain, even though that plain may have been, at the time of its erosion, a desert plain, and not a normal peneplain. It is therefore exceedingly improbable that the even-topped Bural-bas-tau, standing 12,000 or 13,000 feet above sea-level, gives any close measure of the altitude which the whole region possessed while the great erosion that it has suffered was accomplished.

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NOTE ON BAKED CLAYS AND NATURAL SLAGS IN EASTERN WYOMING

E. S. BASTIN
Chicago

A striking feature of the country just to the east of the Big Horn Mountains, and one which adds greatly to its picturesqueness, is the widespread development of red beds and slaglike materials in consequence of the burning-out of lignite beds in the Laramie division of the Cretaceous. The baking and accompanying reddening of the sandstones and clays have in some districts been so extensive that the landscape somewhat resembles that of the typical "Red Beds" of Jura-Trias age.

Explorers and geologists who have visited this region, from the times of Lewis and Clarke down to the present day, have noted the occurrence and characteristics of these beds, and have in most cases properly interpreted their origin. Mr. J. A. Allen, who accompanied the Northern Pacific Railroad Expedition, has given us an excellent account[1] of these beds, and has summarized the previous literature. It is the intention here merely to add a few notes on the field occurrences and something as to the microscopic characters.

At the suggestion of Professor R. D. Salisbury, Mr. A. E. Taylor and the writer spent a few days in the study of these beds during the summer of 1903. These studies were confined to the district between Gillette and Buffalo, Wyo., but beds of a similar nature give color to the landscape and exert a notable influence upon the topography over a much more extensive region. Their occurrence has been reported over practically the whole northeastern quarter of the state of Wyoming, and over an area of about equal size in southeastern Montana and adjacent parts of the Dakotas—a total extent of at least 100,000 miles. This vast region is characterized by horizontal or gently inclined strata, made up largely of clays and fine sands, with occasional seams of lignitic coal, the latter usually only a foot or two

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[1] *Proceedings of the Boston Society of Natural History,* Vol. XVI (1874), pp. 246 ff.

in thickness, but occasionally reaching a thickness of eight or ten feet. The beds have been sculptured by erosion into typical "Bad Lands" forms, giving the coal beds a large area of outcrop, and thus greatly facilitating their combustion.

The ignition of the coal has in certain cases taken place through human agencies, as in the case of a bed now burning (summer of 1903) six miles west of Gillette, Wyo., which was set on fire in 1902 by laborers at work on the railroad; in most cases, however, we must attribute their ignition to spontaneous combustion, or, at any rate, to agencies other than human. At the locality above referred to, the coal outcrops along the sides of a deep gulch, and its burning is accompanied by the emission of much heat and of considerable volumes of sulphurous gases.

The unburned strata are typically of a gray or buff color, but upon the burning-out of an underlying coal seam they assume most gaudy hues of bright yellow, pink, or deep brick-red; the stratum beneath the coal is usually but little affected. Frequently a red layer may be traced from butte to butte, in each case underlain by the ash of the burned-out coal seam. With the change in color go incipient fusion and an increase in the coherence and resistance of the strata. This increased resistance has had a marked influence upon the topography, and it is common to find buttes capped with a layer of this baked material which has served to retard the progress of normal erosion.

Rocks resulting from the baking and fusion above described have been referred to by German geologists under the names *Porzellanit* and *Porzellanjaspis*[1] and have been observed by them in a number of the European coal fields. Similar materials have been observed by the writer in the Coal Measures near La Salle, Ill. The principal varieties of altered material observed in the Wyoming region are described below.

1. By far the largest part of the metamorphosed beds consists of buff, brick-red, or indian-red argillaceous material. Much of this is fissile along bedding-planes, and incloses lamellibranch shells and shows impressions of leaves in great perfection; other portions are more massive and show a somewhat conchoidal fracture; still

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[1] Zirkel, *Lehrbuch der Petrographie*, Vol. III, p. 775.

other portions, especially near the slaglike masses (No. 3, below), are extensively and very irregularly fractured. The metamorphism of these rocks finds a parallel in the artificial process of the burning of bricks, and consists simply in an oxidation of the iron from the ferrous to the ferric state, and in incipient fusion which greatly increases the coherence.

2. The coal itself leaves behind a typical ash upon burning; most of this is loose and incoherent, but some parts are clinker-like.

3. Slaglike masses make up only a small proportion of the beds, but are striking because of their close resemblance to lavas. They form very irregular, dark brown or mottled, vesicular masses, and usually inclose numerous fragments of shale and sandstone. Occasionally the slag occurs as an uneven layer just above the burned-out coal bed, but in most of the localities visited by the writer it formed isolated masses which in many instances seemed to be almost surrounded by the baked clays described above. Allen[1] also describes "chimney-like" forms a few feet in diameter capping buttes because of their superior resistance. The forms of the slaglike masses, and the sharp transition to beds which have been but slightly metamorphosed, suggest that they represent channels of easy exit for the hot gases and vapors, along which the metamorphism was much more considerable than in any other portion, except immediately above the coal bed, where slags are also occasionally developed. The ropy surfaces exhibited by some of the slags show how fluid much of the material must have been.

4. The inclosing argillite near the slaglike masses has in most cases been much brecciated, and one of the characteristic types of rock is formed by the penetration of the crevices of such breccia by the slag. The process usually results in the induration of the breccia fragments to hard, flintlike masses, red, buff, or gray in color.

A microscopic examination of one of these slag veins in red argillite showed a central, relatively coarsely holocrystalline mass about one-tenth of an inch across. This was bordered on each side by a zone about one-fiftieth of an inch wide, fine-grained, prevailingly gray in color, and apparently representing the contact effect of the slag on the argillite. Outside this narrow zone the argillite shows

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[1] *Ibid.*, p. 250.

a reddish tint. In passing from the reddish argillite towards the center of the vein, the contact zone shows a gradual decrease in the normal shale constituents and a development, in increasing amount and coarseness, of purplish-blue, pleochroic cordierite. Next the coarser part of the vein this mineral is present to the exclusion of all others. In this contact zone the red iron oxide of the argillite has been wholly reduced to magnetite. The central portion of the vein is a somewhat vesicular, holocrystalline mass, consisting of abundant magnetite in irregular masses, some hematite, usually lining the vesicles and following fractures, and abundant cordierite, feldspar, and pyroxene. The cordierite occurs in good-sized grains, some of which have a very irregular outline, while others show very definite crystalline forms, occurring in short prisms whose very perfect hexagonal cross-sections are the result of characteristic repeated twinning, as is shown by the optical properties. The feldspar occurs in narrow lath-shaped crystals with irregular terminations, and often with irregular lateral boundaries. No crystals were found which showed more than two twinning lamellæ. The index of refraction is slightly above that of the balsam, and about equal to that of cordierite. This character, and the low extinction angles (less than 3°), fix its composition as oligoclase. Pyroxene occurs, sometimes in grains, but mainly in long, prismatic crystals, whose length ranges from ten to almost fifty times their width. The pleochroism is moderately strong; the colors for rays vibrating parallel to the prism length range from deep green to greenish-yellow, with occasional portions of the prism which are reddish-brown; for rays vibrating perpendicular to the prism, the color is usually greenish-yellow. Cross-sections show typical pyroxene cleavage, and the extinction angles range up to 32°.

5. A small proportion of the beds are fine-grained, porous sandstone which, upon baking, assumes the brilliant colors observed in the clayey members. Microscopically the slag is seen to penetrate this porous rock so thoroughly that it is impossible to draw a sharp line between the slag and the original sandstone. The sandstone, consisting of small angular quartz grains, fine argillaceous material, and hematite in scattered grains and as a fine coating on the other minerals, passes into a glassy mass inclosing scattered quartzes and

abundant minute crystals of hematite, the latter frequently grouped in aggregates; this in turn passes into a vesicular, dark gray mass in which distinct quartz fragments are absent, the iron largely in the form of magnetite, and cordierite very extensively developed; some feldspar may perhaps be present, but could not be identified.

The complete crystallization of a vein of slag one-tenth of an inch across, and the perfect development of many of the crystals, are probably to be explained by high temperature of the rock walls when the slag flowed in, and a consequent slow cooling. In general, the physical conditions under which the metamorphism took place are similar to those in the slag furnace, and the resulting products are slaglike in appearance. The materials involved are, however, somewhat different from those of most slags. They are typical pelites, and it is not surprising that one of the minerals most abundantly developed, cordierite, should be a mineral rarely found in artificial slags, but one of the commonest minerals developed in the contact metamorphism of pelitic sediments.

THE DELAWARE LIMESTONE[1]

CHARLES S. PROSSER
Ohio State University

CONTENTS

HISTORICAL REVIEW

The division and correlation of the Devonian limestones of Ohio have been a subject of consideration by geologists for many years, and there have been decided differences of opinion. Recently Dr. Charles K. Swartz, of Johns Hopkins University, and the writer have studied these limestones, in the main working independently, but arriving at quite similar general conclusions. The following rather brief chronological review of the most important opinions will probably acquaint the reader with an outline of the subject under consideration.

In 1838 Professor Locke adopted the name "Cliff limestone" "for the very extensive deposit of limestone above the blue limestone"[2] (the latter limestone he described as alternating with layers of marl in southwestern Ohio, and it belongs in what is now known as the Cincinnatian series). In 1842 Dr. A. Clapp, in describing the rocks at the Falls of the Ohio and vicinity, stated that "under the name Cliff limestone is here included all the group above the blue limestone and marls of Cincinnati, to the black slate."[3] The

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[1] Published by permission of Edward Orton, Jr., state geologist of Ohio.

[2] *Second Annual Report of the Geological Survey of Ohio*, p. 211.

[3] *Proceedings of the Academy of Natural Science*, Philadelphia, Vol. I, p. 178.

black slate mentioned by Dr. Clapp is now known as the New Albany black shale, which in a general sense may be regarded as the western continuation of the Ohio shale. It was, furthermore, reported that Dr. Clapp made the following correlations between divisions of the Cliff limestone and certain New York formations:

> The lower and middle portions of the Cliff limestone he conjectures to be equivalents of the Niagara limestone and Gypseous shales; the entire mass called the Cliff limestone represents therefore the Niagara limestone, Gypseous shales, water-lime, Onondaga limestone, etc., to the Marcellus shales.

It is stated by Dr. Newberry that the Corniferous limestone was first identified in Ohio by Professor Hall in 1841;[1] but in his paper entitled "Notes upon the Geology of the Western States," Professor Hall's statement is simply this: "In examining the upper part of the 'cliff limestone' I found it, so far as lithological characters are concerned, a continuation of the Helderberg group;" and the Niagara limestone is mentioned as occurring in "the vicinity of Columbus."[2] In another article, however, published the following year, Professor Hall reported the occurrence of the Corniferous limestone in the vicinity of Columbus, stating that

> a short distance to the west of that place [Columbus] the Corniferous limestone of New York appears, presenting its characteristic fossils. This mass is the upper part of the cliff limestone formation of Dr. Locke, the name by which it is generally known in Ohio.[3]

In 1847 de Verneuil stated that the Devonian system in New York

> is principally composed of schists and argillaceous sandstones, which, as we have said, are lost and disappear in the West; it thence results that in the states of Ohio, Indiana, and Kentucky it is reduced to the black schists, which represent the Genesee slate, and to a calcareous band which represents at once the Corniferous and Onondaga limestones and the Hamilton group of the state of New York.[4]

Under Dr. Newberry's direction, the Devonian limestones, which he called the Corniferous, were carefuly studied during the progress

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[1] *Report of the Geological Survey of Ohio*, Vol. I, Part I (1873), p. 142.

[2] *American Journal of Science and Arts*, Vol. XLII (1842), p. 58.

[3] *Transactions of the Association of American Geologists and Naturalists* (1843), p. 273.

[4] Hall's translation in *American Journal of Science and Arts*, second series, Vol. V (1848), pp. 369, 370. The original is in the *Bulletin de la Société géologique de France*, second series, Vol. IV (1847), p. 680.

of the Second Geological Survey of Ohio, and in his first report their distribution was shown on the "Preliminary Geological Map of Ohio,"[1] together with some account of their occurrence, lithology, and fossils;[2] while the chapter on the Devonian system in the first volume of the Geological Survey of Ohio contained a more elaborate description.[3] He made two divisions of this limestone: the upper one, termed the *Sandusky limestone,* described as blue and thin-bedded, from fifteen to twenty feet thick, quarried at Sandusky and Delaware; and the lower division, called the *Columbus limestone,* well shown in the quarries near that city, and described as a very light-colored limestone often containing chert.[4] Dr. Newberry stated that the upper portion of the Sandusky limestone contained several characteristic Hamilton fossils in considerable abundance, as *Spirifer mucronatus, Cyrtia* [*Cyrtina*] *hamiltonensis,* etc.; and on account of the presence of these fossils he was for a long time in doubt

> whether the Sandusky limestone should not be considered as a representative of the Hamilton rather than of the Corniferous group; but, on gathering all the fossils of this formation, the list was found to include a much larger number of Corniferous than of Hamilton species.[5]

Dr. Newberry concluded that the limestones were to be correlated with the Corniferous of New York, while the Hamilton was restricted to a bed of marl and marly limestone which at Prout's Station, south of Sandusky, was stated to be from ten to twenty feet in thickness, containing "great numbers of Hamilton fossils, with none which are peculiar to the Corniferous." At Delaware, in central Ohio, a light-gray marl between the Black shale and Corniferous limestone was thought to probably represent the Hamilton, but it was stated that south of this locality no trace of it had yet been found.[6]

On the contrary, Professor N. H. Winchell, who described several of the counties in central and northwestern Ohio, came to the conclusion that the upper Corniferous was probably to be correlated with the Hamilton formation. Under his description of Delaware County we find the following:

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[1] Geological Survey of Ohio, *Report of Progress in 1869* (1870), frontispiece.

[2] *Ibid.,* pp. 17, 18.

[3] *Report of the Geological Survey of Ohio,* Vol. I, Part I (1873), pp. 142–49.

[4] *Ibid.,* p. 143.

[5] *Ibid.,* p 144.

[6] *Ibid.,* p. 150.

> The lithological characters of the Michigan Hamilton are the same as those of the upper Corniferous in Ohio, and it is hardly susceptible of doubt that they are stratigraphically identical.[1]

In his sections Professor Winchell used the names "Tully limestone," and "Hamilton," followed in the descriptive part by an interrogation point, and "Corniferous limestone."[2] The upper limestone is also mentioned under the name of "Delaware stone"[3] and "Delaware limestone,"[4] but apparently without the intention of considering it as a formation name. Later, however, in describing Paulding County, in the northwestern part of the state, Professor Winchell stated that close "attention was paid to the solution of the question, 'Do Hamilton fossils extend through the whole of the blue limestones?'"[5] and the conclusion was "that the beds that hold these Hamilton fossils are very near the bottom of the blue limestone."[6] Professor Winchell accepted this as sufficient proof of the correctness of his correlation with the New York formations, consequently on his "General Section of the Rocks of Paulding and Defiance Counties" appear the names "Tully limestone" and "Hamilton limestone of New York," below which are given the "Corniferous and Onondaga limestones of New York."[7] In the legend of the geological maps of Delaware, Paulding, and Defiance Counties, all by Professor Winchell, appears the name "Hamilton group,"[8] which is given a distinct area on the maps.

This correlation was opposed by Dr. Newberry, who said:

> The Tully limestone? of Professor Winchell's sections is certainly Hamilton, as I have obtained from it *Tropidoleptus carinatus*, *Pterinea flabella*, *Nyassa arguta*, *Spirifera mucronata*, etc.

And regarding the Hamilton limestone of Professor Winchell he wrote as follows:

> I think it will be seen that the weight of evidence is decidedly in favor of its being of Corniferous age. The cherty layers which lie between the Huron shale and the quarry-stone at Delaware are probably Hamilton, but the quarry-stone

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[1] *Ibid.*, Vol. II, Part I (1874), p. 289.

[2] For example, see the section "through the Olentangy Shale and Hamilton Limestone, Five and a Half Miles below Stratford," on pp. 293, 294.

[3] *Ibid.*, pp. 293, 302. [4] *Ibid.*, p. 294. [5] *Ibid.*, pp. 341, 342.

[6] *Ibid.*, p. 343. The statements just quoted also appeared on pp. 395, 397, of the excerpt from the report on Paulding County, entitled "On the Hamilton in Ohio," published in the *American Journal of Science*, third series (1874), Vol. VII.

[7] *Ibid.*, p. 342. [8] *Ibid.*, facing pp. 272, 336, and p. 422.

itself, though containing some fossils which are common to the Hamilton and the Corniferous, has never yielded me any exclusively Hamilton fossils.[1]

In 1875 Professor Winchell read a paper "On the Parallelism of Devonian Outcrops in Michigan and Ohio" before the American Association, in which he gave a table of parallel "Devonian Outcrops in Michigan and Ohio," in which Sandusky, Delaware, Marion, and sec. 17, Defiance, Defiance County, Ohio, are correlated with the Hamilton blue limestone as exposed in the vicinity of Thunder Bay, Lake Huron, and near Charlevoix, Lake Michigan, in the northern part of the Lower Peninsula.[2]

Dr. Newberry's objection was restated in the succeeding state report under the "Review of the Geological Structure of Ohio," where he expressed this opinion:

> In regard to the position of the Sandusky limestone, it must be said that the weight of evidence is in favor of retaining it in the Corniferous. . . . . There is even in New York much in common between the fossils of the two groups, and all the fossils which Professor Winchell relies upon as criteria for distinguishing the Hamilton from the Corniferous, are found in both; hence their presence in the Sandusky limestone is no proof of its Hamilton age. It should also be said that quite a number of fossils are found in the Sandusky limestone which are regarded as characteristic of the Corniferous.[3]

This volume contains Dr. Orton's report on the geology of Franklin County, in central Ohio, in which he followed Dr. Newberry in correlating all of the Devonian limestone with the Corniferous. The upper division, however, of thirty-two feet of blue limestone he states is, "from its occurrence at Delaware, and the extensive use made of it at that point, well named the *Delaware limestone;*"[4] and this name was used in place of Newberry's older one of "Sandusky limestone." For the lower division Dr. Orton retained the name "Columbus limestone," and described a six-inch stratum named the "bone-bed" containing large numbers of the teeth, plates, and

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[1] *Ibid.*, footnote, p. 290. For similar statements see Dr. Newberry's criticism of Professor Winchell's geological classification of Paulding County (footnote, pp. 337, 338); and Dr. Newberry's description of the Corniferous limestone of Erie County (pp. 191, 192).

[2] *Proceedings of the American Association for the Advancement of Science*, Vol. XXIV (1876), Part II, p. 59.

[3] *Loc. cit.*, Vol. III, Part I (1878), p. 11.

[4] *Ibid.*, p. 606.

bones of fishes, which occurs at the top of the Columbus and separates it from the Delaware limestone.[1]

In discussing the correlation used by Professor Winchell in his report on Delaware County, Dr. Orton said:

> The Columbus and Delaware limestones probably cover the age in which the Corniferous limestone, and the Hamilton group, in part, of New York were forming; but there seems no warrant whatever for identifying the subdivisions of our scale with the subdivisions recognized five hundred or a thousand miles away.[2]

In 1877 Professor Hall visited the Falls of the Ohio, near Louisville, and correlated the hydraulic and encrinal limestones, which are the higher limestones of the section, with the Hamilton group of New York, and said that "in the state of Ohio similar conditions may be inferred, from the fact that certain species of known Hamilton fossils are published in the Ohio Geological Reports as from the Corniferous group."[3]

In 1878 Professor Whitfield visited Franklin County, and on the banks of the Scioto River, six miles northwest of Columbus, made the most important discovery relating to the classification of the Devonian limestones that had been made in central Ohio. In a bed of dark-brown, bituminous shale, in the lower part of the Delaware limestone, flattened specimens of *Liorhynchus limitaris* (Van.), *Discina minuta* Hall, and *Lingula manni* Hall were found, the two former being strictly characteristic species of the Marcellus shale of New York. On the following day the same shale was found farther north, nearly opposite Dublin, containing *Liorhynchus limitaris* (Van.) and *Discina lodensis* (Van.). This shale was reported only a few feet above the "bone-bed," and Professor Whitfield stated: "I have no hesitation in pronouncing [it] the equivalent of the MARCELLUS SHALE of New York."[4] This discovery seemed to confirm Professor Winchell's opinion that the Delaware limestone of Delaware County represented the Hamilton formation of New York.

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[1] See *Ibid.*, pp. 605, 606, 610.

[2] *Ibid.*, p. 634.

[3] *Transactions of the Albany Institute*, Vol. IX (1879), p. 179. The same statement was published in *Palæontology of New York*, Vol. V, Part II, text (1879), pp. 146, 147.

[4] *Proceedings of the American Association for the Advancement of Science*, Vol. XXVIII (1880), pp. 297, 298.

Professor Whitfield published later a list of the fossils found in these shales, together with a description of two new species, under the title of "Species from the Marcellus Shales."[1] A more complete account of their stratigraphy was also published under the title of "Note on the Marcellus Shale and Other Members of the Hamilton Group in Ohio, as Determined from Palæontological Evidence."[2] In this article Professor Whitfield positively identified the shales as of Marcellus age, stating that

> only a few feet above the "bone-bed" occurs the dark-brown shale in question, with the peculiar fossils, which I have no hesitation in pronouncing the equivalent of the Marcellus shales of New York. Admitting this—and there certainly appears to be no alternative—the rocks found above this limit should represent the Hamilton group of the New York system.[3]

In the Ohio report Professor Whitfield stated that in August, 1879, he

> read a notice of the occurrence in Ohio of rocks representing the Marcellus shales of New York . . . . in which it was shown that a considerable thickness of the limestones previously recognized as "Corniferous" in Ohio, were above the horizon of the beds which I had recognized, from palæontological and lithological evidence, as of the age of the Marcellus shale, and would be of necessity equivalents of the Hamilton group.[4]

Finally, Professor Whitfield published descriptions of several "species from the limestones above the 'bone-bed,' in the vicinity of Columbus, Ohio, and not known to occur below that horizon," which included such well-known Hamilton species as *Spirifer ziczac* Hall, *Pterinea flabella* (Con.) Hall, *Nyassa arguta* H. & W., and *Grammysia bisulcata* (Con.) H. & W.[5]

Dr. Orton, in describing the geological scale of Ohio in the volume on petroleum and natural gas, changed the name of the formation from the "Corniferous" to the "Upper Helderberg limestone," and assigned the following reason:

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[1] *Annals of the New York Academy of Sciences*, Vol. II (1883), pp. 212–15. Descriptions of all the species were published in the *Report of the Geological Survey of Ohio*, Vol. VII (1893 [1895]), pp. 441–47.

[2] *Annals of the New York Academy of Sciences*, Vol. II (1883), pp. 233–41. This article, with additions, was republished in *Report of the Geological Survey of Ohio*, Vol. VII, pp. 432–41.

[3] *Ibid.*, p. 235, and *Report of the Geological Survey of Ohio*, Vol. VII, p. 433.

[4] *Report of the Geological Survey of Ohio*, Vol. VII, p. 434, footnote.

[5] *Ibid.*, pp. 447–52.

> All of the limestone of the Devonian age in Ohio has been referred by Newberry, to the Corniferous limestone, and this term is in general use at the present time. It may be questioned whether it is wise to break in upon this here, but inasmuch as several geologists hold that the Devonian limestone of Ohio covers more than the single epoch known as Corniferous in New York, a more comprehensive term, viz., the Upper Helderberg limestone, is counted preferable. A twofold division of the series is possible and proper in Ohio, the division being based on both lithology and fossils. The divisions are known as Lower and Upper Corniferous, or as Columbus and Delaware limestones. For the upper division the term Sandusky limestone is sometimes used.[1]

On the "Geological Map of Ohio," accompanying this report, the "key to formations" mentions the Upper Helderberg limestone, Marcellus shale, Hamilton limestone, and Hamilton shale, which are all represented by one color on the map.

The substitution of the name "Upper Helderberg limestone" for "Corniferous limestone" did not meet any of the objections raised by Winchell, Hall, and Whitfield to the Newberry classification of the Devonian limestones of Ohio, because, so far as the later formations are concerned, it is not a more comprehensive term than the "Corniferous limestone," and in its classic locality, the Helderbergs of eastern New York, has never been applied to rocks above the base of the Marcellus shale. The name "Helderberg division" was proposed by Vanuxem in 1842, and included all the formations occurring between the top of the Niagara limestone and the base of the Marcellus shale.[2] In the following year Mather's report appeared, in which the rocks of the Helderberg mountains are described, and it is stated that, on account of their excellent development at this locality, "forming a natural group, strongly marked in their lithological and paleontological characters from the strata lying above and below them, the term of *Helderberg division* is used to designate them."[3] In the northern Helderbergs nearly all of the subjacent Ontario division is absent, and Mather's Helderberg division included all the formations found at this locality between the top of the Hudson

[1] *Ibid.*, Vol. VI (1888), pp. 20, 21. "Upper Helderberg limestone" is also used by Dr. Orton for the formation in his article on "The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana" (*Eighth Annual Report of the United States Geological Survey*, Part II (1889), p. 568.)

[2] *Geology of New York*, Part III (1842), pp. 13, 15, 16.

[3] *Ibid.*, Part I (1843), p. 325.

(Lorraine beds) and the base of the Marcellus shale. Later studies, however, have shown that the "Pyritous slates," forming the basal member of his Helderberg division, are probably of Salina age;[1] while Mather's succeeding division—the Water limestone—which he gave as composed of two members, the Water limestone and Tentaculite limestone, now called the Rondout waterlime and the Manlius limestone, is also separated from the Helderbergian series as defined by Dr. John M. Clarke, and put in the subjacent Cayugan series.[2]

Professor Hall in 1859 divided the rocks of the Helderberg mountains into the Lower and Upper Helderberg groups, which were separated by the Oriskany sandstone and Cauda-galli grit.[3] The Upper Helderberg group was composed of the Schoharie grit and Onondaga and Corniferous limestones; or, in other words, it included the rocks between the top of the Cauda-galli grit (now called Esopus grit) and the base of the Marcellus shale.

Regarding Whitfield's discovery Dr. Orton said:

> At a few points in central Ohio the upper division [Delaware limestone] has been found in a shaly state and carrying characteristic fossils of the Marcellus slate. This fact was first noticed in its true significance by Whitfield.[4]

The name "Upper Helderberg limestone" was used by Dr. Orton for the formation, and the same reasons for its use were published in his first annual and final report of the Geological Survey of Ohio;[5] but in his last review of the "Geological Column of Ohio" he returned to the earlier name of "Corniferous limestone."[6]

In the last edition of Dana's *Manual* the Delaware limestone is apparently considered as of Hamilton age, for in giving the distribution of its beds it is stated that "they appear also in Ohio, as

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[1] Hartnagel, New York State Museum, *Bulletin No. 69* ("Report of the State Paleontologist," 1902), 1903, pp. 1116, 1170, 1171.

[2] New York State Museum, *Handbook No. 19* (1903), pp. 8, 9, 14.

[3] *Palæontology of New York*, Vol. III, Part I (1859), p. 97.

[4] *Report of the Geological Survey of Ohio*, Vol. VI (1888), p. 22.

[5] *First Annual Report of the Geological Survey of Ohio* (1890), pp. 24–26; *Report of the Geological Survey of Ohio*, Vol. VII (1893 [1895]), pp. 18, 19.

[6] *Nineteenth Annual Report of the United States Geological Survey*, Part IV (1899), pp. 638, 646, 682.

twenty-five feet of impure bluish limestone,"[1] although under the account of the Corniferous limestone the Delaware is mentioned as the upper division in Ohio.[2]

In 1898 Professor John A. Bownocker published a paper on "The Paleontology and Stratigraphy of the Corniferous Rocks of Ohio," in which is given a number of sections of the limestone as shown in various quarries, accompanied by lists of fossils collected at twelve different localities in the state. The Corniferous limestone of this article includes both the Columbus and Delaware divisions, and at the close of the discussion on the "Relation of the Fauna above the Bone-Bed to that Below" it is stated:

> It appears, therefore, that the difference between the faunas above and below the bone-bed in the central Ohio area is not great, that this difference is most conspicuous at Delaware and diminishes to the north, being least at Sandusky.[3]

Dr. Edward M. Kindle carefully studied the Devonian limestone of southern Indiana and northern Kentucky, and stated that near the Ohio River it "is readily separated into two divisions, which are easily distinguished from each other both by lithological and paleontological characters."[4] The lower division he named the "Jeffersonville limestone" and the upper one the "Sellersburg beds." Kindle's *Bulletin* was based on a thorough study of the fossils, and in discussing the "Correlation of Faunas" he stated:

> The Corniferous fauna of New York suffers no very important modifications in its western extension. The large number of species common to the faunas of the Corniferous limestone of New York and the Jeffersonville limestone, especially among the corals, leaves no doubt as to the equivalence of the two faunas. . . . . In southern Indiana we find in the Sellersburg beds a fauna containing many of the most characteristic species of the Hamilton of New York. . . . . This fauna is not mingled with the Corniferous, as was once supposed, but occurs above that fauna in the Sellersburg beds. The presence in it of such characteristic Hamilton fossils as those mentioned seems to leave no doubt of its equivalence to the New York Hamilton.[5]

It will be noticed that this conclusion regarding the correlation of these limestones is in perfect harmony with the later views of Professor Hall.

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[1] *Manual of Geology*, 4th ed. (1895), p. 592.

[2] *Ibid.*, p. 581.

[3] *Bulletin of the Scientific Laboratories of Denison University*, Vol. XI, p. 39.

[4] *Bulletin of American Paleontology*, No. 12 (1899), p. 8.

[5] *Ibid.*, p. 110.

A further elaboration of this work by Dr. Kindle was later published in an Indiana *Report* which contained an account of the Devonian stratigraphy of Indiana, together with descriptions and figures of its fossils. Dr. Kindle's conclusions regarding the correlation of Devonian limestones of Indiana are stated as follows in this report:

> The problem of the correlation of the Devonian limestones with the New York scale is much more difficult for some parts of the Indiana province than for others. In the vicinity of the Falls of the Ohio we find two quite distinct and well-marked faunas. These are the *Spirifer granulosus* and the *Spirifer acuminatus* faunas, and represent respectively the Hamilton and Corniferous faunas of New York. Near the Falls of the Ohio, the Sellersburg beds, and the Jeffersonville limestone, which carry these faunas, are sharply differentiated lithologically, the Jeffersonville limestone being a nearly pure limestone, and representing clear water conditions during its deposition, while the Sellersburg beds are composed of an impure argillaceous limestone. In the northern part of the southern Indiana area these two formations cease to be sharply differentiated lithologically, and merge into each other in a limestone which is neither so pure as the Jeffersonville limestone nor so argillaceous as the Sellersburg beds near the Falls. Associated with the loss of individuality of these two formations occurs a mingling of their two faunas which renders them indistinguishable as separate faunas.
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> In the Wabash area the faunas of the Devonian limestone are even more distinct than that at the Falls of the Ohio. In the lower one *Spirifer acuminatus* is an abundant fossil, and the fauna does not differ greatly from that in the Jeffersonville limestone at the Falls of the Ohio. The upper fauna is a distinctly Hamilton fauna, but entirely different from the Hamilton fauna of southern Indiana.[1]

At an early date Hamilton fossils were identified by Professor Alexander Winchell from the northern part of the Lower Peninsula of Michigan and the rocks referred to the Hamilton group. In 1870 he named it the "Little Traverse group,"[2] which in 1895 was shortened by Dr. Lane to the "Traverse group."[3] The southern part of the state is so heavily mantled by drift that formerly it was not known whether the formation occurred there or not; but later study of well sections has shown its presence with a thickness of about eighty feet. On a recent geological map of the Lower Peninsula the formation is shown crossing Monroe and Lenawee Counties

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[1] *Twenty-fifth Annual Report of the Department of Geology and Natural Resources of Indiana* (1900), p. 570.

[2] *Report of Progress,* State Geological Survey of Michigan, p. 28.

[3] *Geological Survey of Michigan,* Vol. V, Part II, p. 24.

in the southeastern corner of the peninsula,[1] and entering Ohio at about the locality where the Hamilton or upper part of the Corniferous has been represented on the state maps. Since then Professor Sherzer has given a more detailed account of the "Traverse (Hamilton) group" of Monroe County, Mich., in his geological report of that county.[2]

In 1902 Professor Weller published a paper on "The Composition, Origin, and Relationships of the Corniferous Fauna in the Appalachian Province of North America," in which he stated that "in Ohio the fauna occurs in the Columbus limestone."[3] The Delaware limestone was not mentioned, and apparently he did not consider its fauna as that of the Corniferous. Professor Claypole, in his account of "The Devonian Era in the Ohio Basin," stated near the close of the section devoted to "The Corniferous Limestone," that

> what has already been said must not be referred to the whole mass of strata which have usually been classed under the name Corniferous in Ohio geology, but only to that part lying below the bone-bed and to the bone-bed itself.[4]

The division succeeding the bone-bed Professor Claypole called "the Corniferous-Hamilton period," and stated that "the period was, in Ohio, evidently one of transition."[5] His correlation of the several members of the two periods is shown in the following table:

Shale at Prout's Station	Hamilton
Blue limestone, thin-bedded	Corniferous-Hamilton
Dublin blue [brown] shale	Marcellus
Bone-bed	Corniferous
Gray and buff limestones	Corniferous[6]

The same year Professor Schuchert, in his paper on "The Faunal Provinces of the American Middle Devonic," apparently accepted Whitfield's correlation of the Devonian limestones of central Ohio.[7]

Finally, in New York state, which is the standard one for the correlation of the American Devonian, the geographic name of "Onondaga limestone" has been adopted in place of "Corniferous

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[1] *Water-Supply and Irrigation Papers*, U. S. Geological Survey, No. 30 (1899), Plate VI.

[2] *Geological Survey of Michigan*, Vol. VII, Part I (1900), pp. 31–35.

[3] *Journal of Geology*, Vol. X, p. 424.

[4] *American Geologist*, Vol. XXXII (1903), p. 31.

[5] *Ibid.*, p. 35. [6] *Ibid.*, p. 35. [7] *Ibid.*, p. 148.

limestone," which was based upon a lithologic character of the formation.[1]

DESCRIPTION OF THE DELAWARE LIMESTONE

The principal object of this paper is to consider the upper formation of the Ohio Devonian limestones, and decide upon the name which shall be applied to it. The name "Delaware limestone" was first definitely applied to this division as a formation name by Dr. Orton, and published in 1878. He briefly described it as "the blue limestone, thirty-two feet in thickness, which is, from its occurrence at Delaware, and the extensive use made of it at that point, well named the *Delaware limestone*."[2] So far as the writer is aware, the term "Delaware limestone," when published by Dr. Orton in 1878, was available for the name of a geological formation, and was definitely described in Franklin County, so that there is no doubt regarding its limits. Since 1878 the name "Delaware," forming all or part of the designation, has been applied to at least three other geological divisions; but these names, if considered identical, will not replace Dr. Orton's "Delaware limestone," but will be abandoned because of preoccupation. The names are as follows: (1) *Delaware river beds*, applied by Dr. I. C. White to an upper Devonian terrane of northeastern Pennsylvania;[3] (2) the identical term, so far as the geographical part of the name is concerned—*Delaware stage*—was given by Professor Calvin to the lower part of the Niagaran series in eastern Iowa;[4] and (3) the name "Delaware mountain formation" has very recently been given by Mr. George B. Richardson to a Permian formation of southwestern Texas.[5]

Although Dr. Orton's name for this formation apparently referred to the exposures in the vicinity of Delaware, still the section giving its entire thickness which he described, and which may therefore be considered his type section, is in the Scioto valley, about one

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[1] Clarke and Schuchert, *Science*, N. S., Vol. X (1899), p. 876; Clarke, N. Y. State Museum, *Handbook No. 19* (1903), pp. 8, 21, 22.

[2] *Report of the Geological Survey of Ohio*, Vol. III, Part I, p. 606.

[3] *Second Geological Survey of Pennsylvania; G*^{6} (1882), p. 99.

[4] *Iowa Geological Survey*, Vol. V (1896), pp. 49, 50.

[5] University of Texas Mineralogical Survey, *Bulletin No. 9* (November, 1904), p. 38.

mile north of Dublin, in the northern part of Franklin County.[1] This region may, therefore, be considered as typical as that in the vicinity of Delaware, and has the advantage of showing clearly in several sections both the upper and lower limits of the formation. It will be interesting, therefore, to describe somewhat carefully a section to the south and another one to the north of the one described by Dr. Orton.

Fig. 1.—Shale zone forming the lower part of the Delaware formation, as shown on Slate Run. Its top is indicated by the hammer.

SLATE RUN SECTION

In Perry Township, on the eastern side of the Scioto River, three and one-half miles north of Marble Cliff, is a locality known as Slate Run Hollow, on the farm of Mr. George Matthews. The run is one and one-half miles north of Fishinger's bridge, and about five and one-half miles in a direct line northwest of the Ohio State University, and in the lower part of the stream is the pond of the Columbus Fish-

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[1] Dr. Orton named it the "section of Corniferous limestone near Corbin's mill Perry Township," Vol. III, p. 604.

ing Club. Formerly the upper part of the Columbus limestone was fairly well shown in the bluff of the Scioto River for some distance below this locality, while Slate Run affords a good section of the Delaware limestone and the overlying Olentangy shale. At this locality Whitfield first noticed the brownish shales containing a Marcellus fauna, although in the description it is not located more definitely than "six miles northwest of Columbus." A section was furnished by Dr. Orton, which was published in Whitfield's paper.[1]

No.		Thickness (Feet)	Total Thickness (Feet)
13.	*Ohio shale.*—On the northwest bank, immediately above the outcrop of Olentangy shale, is about 6 feet of the typical black, thin, arenaceous shale of this formation. The line of contact is sharp between these two shales. Farther up the stream, near the fence, the top of the Olentangy shale is near water-level, above which is about 11½ feet of the Ohio shale. A little farther up the run, and above the fence, are a number of concretions of various sizes imbedded in the Ohio shale.	11½±	107
12.	*Olentangy shale.*—Bluish or greenish to drab argillaceous shale, with the lithological appearance of typical exposures of Olentangy shale in Delaware County. One thin layer of brownish shale occurs at about the middle of the cliff, and two layers near its base. There are also thin layers of impure limestone, especially in the lower part of the formation, one of which, about 6 feet above its base, is 5½ inches in thickness. On Dr. Orton's section the Olentangy shale is given as 15 feet in thickness,[2] but this is obviously an underestimate.	22⅔	95½−
11.	Top of *Delaware limestone.*—A rather thin-bedded bluish-gray limestone, with occasional layers of chert, which extends to the top of the cascade. It may also be seen on the steep southeast bank farther down the stream, which is the best place for measuring its thickness.	13+	72¾

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[1] *Proceedings of the American Association for the Advancement of Science,* Vol. XXVIII (1880), p. 298.

[2] *Ibid.,* p. 298.

No.		Thickness (Feet)	Total Thickness (Feet)
10.	Brownish-gray thin-bedded limestone, alternating with layers of chert, shown to best advantage on the southeast bank, a little above the contorted layer in the bed of the stream. This zone is conspicuous in the glens farther north, in the southern part of Delaware County.	6¾±	59¾
9.	Rather heavy-bedded grayish to brownish limestone.	2⅓	53
8.	Zone of contorted thin limestone and chert shown in the bed of the run and on its banks farther down the stream. This corresponds to the contorted stratum noted by Professor Winchell in sections of this limestone in the southern part of Delaware County.[1]	2⅔	50⅔
7.	At the base of the limestone, directly on top of the shale zone, is a thicker layer of chert, followed by layers of brownish limestone 2½ inches or more in thickness. The measurements for this zone vary from 1 foot 6 inches to 2 feet.	1½+	48
6.	Brown, bituminous shales weathering to a light gray or ash color. The layers are even and thin, rather arenaceous in places, interrupted by several layers of chert, and contain a considerable number of fossils, especially in the lower part, although the number of species is small. The measurements of this zone vary from 5 feet 10 inches to 6 feet 6 inches, and it is well exposed on the southeastern bank of the run, where it has the general appearance of a bank of shale. It is shown in Fig. 1, the top of the zone being indicated by the hammer. This is the shale which Whitfield correlated with the Marcellus of New York, and it forms the base of the Delaware formation in this section, which has a thickness of 32¼ feet.	6±	46½
5.	*Columbus limestone.*—In the upper part of the top stratum are numerous fragments of the teeth, plates, and bones of fishes, the *bone-bed* which is well shown on the southeastern bank of the run a little above the fall. In the quarry wall, 5+ inches below its top, *Spirifer acuminatus* (Con.) Hall occurs, and 7 feet 3 inches lower is the "smooth layer," which is found from 9 feet 2 inches to 10 feet 5 inches below the top of the Columbus limestone in all of the sections in the Columbus region. In the upper Casparis quarry there are apparently two such layers, the upper one 9 feet 7 inches, and the lower one 10 feet 6 inches, below the top of the formation.	7¾+	40½−

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[1] *Geological Survey of Ohio*, Vol. II, Part I (1874), p. 289, No. 22.

No.		Thickness (Feet)	Total Thickness (Feet)
4.	From the "smooth layer" to the level of the Fishing Club pond, which is mainly rather dark gray, fairly massive limestone.	$10\frac{1}{3}$	$32\frac{2}{3}$
3.	Mostly covered from the level of the pond to the top of the cliff just below the highway bridge.	$9\frac{1}{3}$	$22\frac{1}{3}$
2.	Zone of light gray, very fossiliferous limestone, at the base of which are numerous specimens of *Spirifer gregarius* Clapp.	$3\frac{2}{3}$	13
1.	Rather dark gray, fairly massive limestone to the base of the exposure, which formerly was about 7 feet above the level of the Scioto River. Zones 1 to 5, inclusive, are all in the Columbus limestone.	$9\frac{1}{3}$	$9\frac{1}{3}$

In the brown shales of No. 6 of the above section the writer has collected the following species:

1. *Liorhynchus limitare* (Van.) Hall.
2. *Orbiculoidea lodiensis* (Van.) Hall and Clarke.
3. *Orbiculoidea minuta* (Hall) Beecher.
4. *Martinia maia* (Billings) Schuchert.
5. *Tentaculites scalariformis* Hall.
6. *Crinoid* stem (small one).

At this locality Whitfield found:

1. *Liorhynchus limitare* (Van.) Hall.
2. *Orbiculoidea minuta* (Hall) Beecher.
3. *Lingula manni* Hall.[1]

The range of the above species in New York is as follows: *Liorhynchus limitare* (Van.) Hall is, perhaps, the most characteristic species of the Marcellus shale; *Orbiculoidea lodiensis* (Van.) Hall occurs in the Hamilton beds and Genesee shale; *O. minuta* (Hall) Beecher, Marcellus shale; *Martinia maia* (Billings) Schuchert is reported in the Onondaga limestone of Ontario; *Lingula manni* Hall, in the Delaware limestone of Ohio; and *Tentaculites scalariformis* Hall, in the Onondaga limestone of New York. Of these species *Liorhynchus limitare* is abundant, occurring more frequently than any other; *Orbiculoidea lodiensis* and *O. minuta* are common, and the remaining ones rare. It is to be noted that the abundant species

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[1] *Proceedings of the American Association for the Advancement of Science,* Vol. XXVIII, p. 297.

of this zone occur in the Marcellus shale and later Devonian formations of New York, instead of the Onondaga limestone, and therefore supports Whitfield's conclusion that it is the "equivalent of the Marcellus shale of New York."[1]

DEEP RUN SECTION

In the southern part of Delaware County a number of small streams entering the Olentangy River afford good sections of a part or all of the Delaware limestone. One of the best of these is the small stream known as Deep Run, on the Matthews farm on the eastern side of the river, which enters the river at the ford opposite the Armstrong farm. The stream is rather more than three-fourths of a mile north of the Powell road and bridge, about one-half mile south of the Orange road and bridge, and may be readily reached from Stop No. 42 on the Columbus, Delaware & Marion Electric Railway.

No.		Thickness (Feet)	Total Thickness (Feet)
10.	*Ohio shale.*—Mainly black, thin, somewhat gritty shale, but there are thin layers of greenish or mottled shale. The barometer indicates that 95 feet is shown, in the lower 40 feet of which are numerous concretions, some of which are of large size.	95	175½+
9.	*Olentangy shale.*—Mainly greenish shale, the top of which is sharply shown in a small fall in the stream, and a little below in a steep bank of shale on its northern side, where 10⅓ feet of Olentangy shale is shown. Calcareous concretions occur in the upper part of this shale, which are well shown in the bank just mentioned, where one layer occurs about 3½ feet below its top, another 7½ feet below, and a third 9 feet below, of impure calcareous material which nearly forms a layer. These concretions contain plenty of marcasite or iron pyrites. There is also a brownish layer of shale a foot or so above the lower line of concretions. The measurement is by hand level from the top of the limestone over the covered valley and up the bank to the northeast to the base of the Ohio shale, as shown in a small lateral ravine; but there is a heavy dip in the same direction, so that the measurement of 25 feet is less than the true thickness, probably to the extent of 5 feet.	25+	80½+

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[1] *Ibid*, p. 298.

No.		Thickness (Feet)	Total Thickness (Feet)
8.	*Delaware limestone.*—Upper portion thinner-bedded than the lower part of this zone, impure dark colored limestone containing considerable chert. Lower part is fairly massive, impure bluish-gray limestone weathering to a brownish color and containing nodules of chert. This zone is shown on the southern bank of the stream at the upper end of the gorge, where the measurement was made. This zone is not especially fossiliferous, and at the base is a shaly parting.	9½	55½
7.	Layers of brownish limestone, alternating with thick layers of chert, all of which are undulating, giving a contorted appearance to the entire zone.	4½	46
6.	Brownish, fairly thick-bedded limestone, with chert partings, in which is a small abandoned quarry on the northern bank of the run. Thickness, about 6 feet 5 inches.	6½–	41½–
5.	Heavy layer of quarry stone at base of quarry.	1½	35
4.	Shaly to thin-bedded brownish limestone, with layers of chert.	8⅚	33½
3.	Brownish, massive bituminous limestone, which is fossiliferous. Base of the Delaware limestone, but there is no shale zone as in the sections farther south. This gives a thickness of nearly 35½ feet for the Delaware limestone in this glen, which is about 5 feet more than in the Franklin County sections.	4⅔	24⅔
2.	*Columbus limestone.*—Light gray, massive, fossiliferous limestone. The bone-bed is fairly well defined here at the top of this formation, but the change of color from the brownish Delaware to the light gray Columbus is conspicuous. The smooth layer was noted by Mr. G. F. Lamb at a distance of 10 feet below the top of the Columbus.	18½	20
1.	Covered interval to level of Olentangy River.	1½	1½

Mr. G. F. Lamb recently measured this section and made it twenty-one and one-half feet from the river level to the top of the Columbus limestone. The rocks forming the Delaware limestone in this section are quite sharply folded, so that some care is required in obtaining an accurate measurement of their thickness, while at the lower end of the Delaware part of the gorge is a faulted block on the southern side. Zone No. 4 of the above section, showing the alternation of shaly to thin-bedded limestone with layers of chert, is well exposed about one and one-half miles farther up the river and about one-half mile south of the Lewis Center road, in a run on the farm of Mrs. Amelia Case, a view of which is given in Fig. 2.

Professor Winchell in the Delaware County report described an exposure in the southern part of the county, under the heading of a "Section through the Olentangy Shale and Hamilton Limestone, Five and a Half Miles below Stratford."[1] Professor Winchell described a small quarry not far below the ravine of his section, and such an abandoned quarry and river bluff occur a few rods south of Deep Run; so it is believed that the localities are identical. Professor Winchell gave the thickness of the Olentangy shale as thirty feet, which is probably not greater than its true thickness in this glen, and the combined thickness of what he called the Tully limestone (?) and Hamilton (?) (our Delaware limestone) as thirty-seven feet, with seventeen feet of Corniferous (Columbus) limestone below.

FIG. 2.—View of the zone of alternating limestone and chert in the lower Delaware on the farm of Mrs. Amelia Case.

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[1] *Report of the Geological Survey of Ohio*, Vol. II, Part I (1874), p. 293.

The Tully limestone is a formation succeeding the Hamilton beds of central New York, but as a limestone it does not extend west of Canandaigua Lake. Zone 8 of my section represents Nos. 3 and 4 of Professor Winchell's section, which he called the "Tully limestone (?)." The beds are impure limestone, differing to some extent from the middle and lower Delaware, but not particularly resembling the Tully limestone; and to the writer there does not appear to be sufficient proof, from either the lithological or paleontological standpoint, to warrant the correlation of this zone with the Tully limestone of New York.

THE SANDUSKY LIMESTONE

In 1873 Dr. Newberry briefly described the upper division of the Devonian limestones of Ohio, which he called the "Corniferous," and named it the "Sandusky limestone." His description was as follows:

> In the northern and middle portions of the state the Corniferous limestone shows two well-marked and several less conspicuous subdivisions. Of these the uppermost is a blue, thin-bedded limestone, from fifteen to twenty feet in thickness, and is the rock quarried at Sandusky and Delaware. This I have designated as the *Sandusky limestone.*[1]

Dr. Newberry did not mention any particular locality at Sandusky as typical for the Sandusky limestone, but conversation with Mr. Charles Schoepfle, who has been in the quarrying business for fifty-two years in that city, and who distinctly remembers Dr. Newberry and accompanied him to some extent in his investigation of the quarries, has acquainted the writer with the exposures that were then available. At that time, in 1869 and the early seventies, the principal quarries in Sandusky were those on Hancock Street, in the vicinity of the present quarry of Charles Schoepfle & Son. The present large quarries south of the Soldiers' Home and Sandusky—Wagner Stone Co. and the Hartman quarry—were opened much later than the Hancock Street quarries. The oldest of the quarries south of Sandusky is the Wagner, which, according to Mr. Alex. M. Wagner, was first opened in a primitive manner about twenty-five years ago, the Soldiers' Home quarry about sixteen, and Hartman's nine years

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[1] *Ibid.*, Vol. I, Part I, p. 143.

ago. Mr. Schoepfle, however, stated that the first one opened on the Soldiers' Home grounds was the one on Hancock Street in 1877.

LAKE SHORE AND MICHIGAN SOUTHERN RAILROAD QUARRY

So far as known to the writer, none of the quarries in Sandusky or its immediate vicinity affords an excellent continuous section of the Columbus and its overlying limestone. Such an exposure of their contact, however, is to be found in the Lake Shore & Michigan Southern Railroad quarry, two and three-quarters miles southwest of the Lake Shore station in Sandusky, and two and one-half miles northeast of Castalia, in Margaretta Township; and for this reason it will be first described. According to Mr. Wagner, it was worked as much as twenty-five years ago, and my attention was first called to it by Dr. Charles K. Swartz, of Johns Hopkins University, who stated that the contact of the Columbus and Delaware limestones was to be seen in its western part. The upper part of the following section was obtained near the western end of the southern wall of the quarry, and the lower portion near its angle in direction:

No.		Thickness (Feet)	Total Thickness (Feet)
10.	Brownish-gray limestone, which contains fossils as *Leptæna rhomboidalis* (Wilckens) and *Glyptodesma erectum* Hall.	1 +	$19\frac{1}{4}$
9.	Chert zone.	$\frac{1}{6}$	$18\frac{1}{4}$
8.	Brownish-gray limestone, but not encrinal, in which *Leptæna rhomboidalis* (Wilckens), *Chonetes mucronatus* Hall, *Glyptodesma erectum* Hall, and *Grammysia bisulcata* (Con.) were found.	$\frac{3}{4}$	$18\frac{1}{12}$
7.	Chert zone.	$\frac{1}{4}$	$17\frac{1}{3}$
6.	Crinoidal limestone of brownish-gray color, which separates into several layers. *Leptæna rhomboidalis* (Wilckens) occurs, but the zone does not contain many fossils, with the exception of the Crinoid segments, which form an appreciable part of the rock. Shale parting at the base.	$4\frac{5}{6}$	$17\frac{1}{2}$
5.	Compact massive limestone, with crinoidal band near its center; but in other parts of the quarry the entire zone is more of an encrinal limestone. The thickness varies from 1 foot 9 inches to 1 foot 10 inches.	$1\frac{3}{4}$	$12\frac{1}{4}$

No.		Thickness (Feet)	Total Thickness (Feet)
4.	Layer of brownish, calcareous shale, weathering to an ash color, in which part of a fish tooth was found. Lithologically very similar to the shale at the base of the Delaware limestone in Franklin County.	$\frac{1}{4}$	$10\frac{1}{2}$
3.	In upper part of layer, fragments of teeth and fish bones similar to bone-bed at top of Columbus limestone in central Ohio. Lower it is more crystalline in structure, grayish in color, and contains cup corals and other fossils. This contact is shown in Fig. 3, where the collecting bag rests on top of this zone, and the hammer indicates the superjacent shale of No. 4.	$2\frac{1}{12}$	$10\frac{1}{4}$
2.	At this horizon generally a conspicuous zone of *Eridophyllum verneuilanum* E. & H. from 4 to 6 inches in thickness.	$\frac{1}{2}$	$8\frac{1}{6}$
1.	Exposure at angle of southern wall, which extends about as low as in any part of the quarry. This limestone is rather bluish-gray, weathering to a lighter color, somewhat crystalline and fossiliferous. At the angle all of the rock belongs in the Columbus limestone, but there is quite a heavy dip to the west, so that farther along the wall the Delaware limestone is shown as described in the upper part of this section.	$7\frac{2}{3}$	$7\frac{2}{3}$

The brownish limestone alternating with layers of chert, which form the upper part of this section, closely agrees in lithologic characters with the second zone of the Delaware limestone, which succeeds the brownish shales or limestones in the sections in the northern part of Franklin and southern part of Delaware Counties. In the upper part of No. 3 of the above section are a considerable number of fragments of teeth and bones of fish, forming something of a bone-bed, which is overlain by a three-inch layer of brownish shale. Two feet one inch below the top of the bone-bed is a conspicuous *Eridophyllum* zone, similar to the one occurring in the exposures of the Columbus limestone, near Columbus, from two feet eight inches to three feet below its top. It therefore appears to the writer better to draw the line of division between the Columbus and Delaware limestones in this section at the top of No. 3, and refer the five feet ten inches of rock between it and the base of the lowest chert zone, or No. 7, to the Delaware limestone. This will agree lithologically with the sections in the southern part of Delaware and northern part of Franklin Counties, where there is from four feet eight inches to six feet of limestone or shale intervening between the base of the lowest conspicuous chert layer and the bone-bed at the top of the Columbus limestone. On the other hand, there is evidence favoring the reference of the crinoidal layers to the Columbus limestone which is the view taken by Dr. Swartz. He has written me as follows regarding this point:

> I became convinced that the best ground of separation is the faunal break, and it seemed to me that probably the encrinital rock is more nearly related to the underlying than to the overlying strata, especially as it contains *Elæacrinus verneuili*, a characteristic form in the encrinital rock at Columbus. Yet in my dissertation I noted the fact that the encrinital rock may be above the horizon of the Columbus "bone-bed."[1]

It is to be noted, however, that Dr. Bownocker reported the Blastoid—*Nucleocrinus verneuili* (Troost)—from above the bone-bed in the quarries near Marion.[2]

SCHOEPFLE & SON'S QUARRY

This quarry is located on the eastern side of Hancock Street in Sandusky, and is the only one of the various quarries in that section of the city which is now actively worked. The following section was measured on the southern wall toward its western end:

No.		Thickness (Feet)	Total Thickness (Feet)
9.	Rather crinoidal limestone, which in the upper part is quite light gray in color. It contains *Spirifer duodenarius* Hall, and other fossils and corals are quite frequent near its top.	$2\frac{3}{4}$	$15\frac{3}{4}$
8.	Shale parting.	$\frac{1}{6}$	13
7.	Somewhat brownish-gray layer as weathered, containing crinoid segments, some corals, and small *Spirifers*.	$1\frac{7}{24}$	$12\frac{5}{6}$
6.	Shale parting.	$\frac{5}{24}$	$11\frac{13}{24}$
5.	Bluish-gray limestone, not so even-bedded as lower layers, which also weathers rougher on exposed surfaces and contains a considerable number of cup corals, Crinoid segments, and small *Spirifers*.	$2\frac{7}{12}$	$11\frac{1}{3}$
4.	Shale parting.	$\frac{1}{6}$	$8\frac{3}{4}$
3.	Bluish-gray, compact, fairly even-bedded limestones, the upper part of which is thinner-bedded. Building stone, moderately fossiliferous.	$3\frac{5}{6}$	$8\frac{7}{12}$

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[1] Letter of January 14, 1905.

[2] *Bulletin of the Science Laboratories of Denison University*, Vol. XI (1898), p. 27.

No.		Thickness (Feet)	Total Thickness (Feet)
2.	Black carbonaceous layer at top, with hackle tooth structure. *Tentaculites scalariformis* Hall is very abundant in the lower part of this zone, but decreases toward its top.	$\frac{3}{4}$	$4\frac{3}{4}$
1.	Massive bluish-gray limestone for building, about 1 foot of which is shown in this part of the quarry. Farther east there is an anticline shown in this wall of the quarry, and at its base beneath the crest about 4 feet of bluish-gray, compact limestone is shown beneath the Tentaculite zone to water-level. There are some *Tentaculites* in this lower rock, and in lithologic character it is not very different from No. 3 above the Tentaculite zone.	4±	4±

The surface of the layer forming the floor of the quarry on the northern side shows conspicuous ripple marks, which run about N. 30° W. and S. 30° E., with an average distance apart from crest to crest of about two feet. In the main, they measured from twenty-two to twenty-six inches apart, but they are not all uniform in separation, and occasionally two run together. This layer with the ripple marks is apparently about five feet three inches below the Tentaculite one. All of the rock in the walls of this quarry is of bluish-gray color, and weathers smooth until the base of the coral and crinoidal layers is reached. On the southern wall of the quarry these layers are conspicuous and project over the smooth underlying bluish-gray rock.

On the western side of Hancock Street, to the southwest of the Schoepfle quarry, and not far from the Lake Erie & Western Railroad, is a small abandoned quarry which, according to Mr. Schoepfle, was opened in 1874 by John Carr and Philander Craig. Near the top of the old quarry wall is a massive layer of bluish-gray limestone, the upper part of which contains fish bones, while its upper surface is rather rough and iron-stained, similar to the top of the Columbus limestone in central Ohio. Below the bone-bed the limestone contains numerous specimens of Brachiopods and corals, although they are not well preserved. The distance of this excavation from the southwest corner of the Schoepfle quarry is only a few rods, and the dip is apparently in that general direction, so that probably the rock of the Schoepfle quarry underlies the bone-bed of the Carr & Craig quarry. A heavy storm, however, prevented the writer from determining this point, and perhaps the rather crinoidal limestone at the top of the Schoepfle quarry represents the lower part of the crinoidal limestone overlying the bone-bed. This latter view is the opinion of Dr. Swartz, who gives the total thickness of the strata in the Schoepfle quarry as nineteen feet.[1] In the next pit, a short distance to the southwest and nearer the railroad track, succeeding the layer containing the bone-bed is a massive, very crinoidal limestone, which on fresh fracture is brownish-gray to bluish-gray, but weathers on the exposed surface to a light gray color. There is shown above the bone-bed at least three feet of this crinoidal limestone when a layer of chert appears, and in part of the ledge six inches higher is another chert layer. Mr. Schoepfle also stated that, in working for other parties to the southwest of his quarry and west of Hancock Street, he found a considerable quantity of chert in the rock above the horizon of his quarry. Above the crinoidal zone the rock is thin-bedded to shaly, and *Leptœna rhomboidalis* (Wilckens) is abundant. This crinoidal zone apparently corresponds stratigraphically to the similar one noted in the Lake Shore & Michigan Southern Railroad quarry between Nos. 3 and 7 of that section.

To the south of the Carr & Craig quarry, between the two railroad tracks, is another old and abandoned quarry. The dip, however, is reversed, and the Schoepfle quarry limestone appears in this excavation with the bone-bed apparently at the top of the southern wall.

Still farther south, on Pipe Creek, by the northern side of the cemetery, is bluish-gray limestone, some of which is quite massive, which also belongs in the same division as that of the Schoepfle quarry. There is a heavy dip down-stream to the east at this locality, and the massive limestone is exposed up the creek well toward the western line of the Lake Shore Electric Railroad.

To the south of Sandusky, and about one-fourth mile south of the Soldiers' Home, is the quarry of the Wagner Stone Co. About eleven feet of rock is shown in this quarry, the upper three feet of which splits into thin layers from one and one-half to four inches in thickness, although not very even. The rocks of this portion are brownish-gray in color, and weather to a light gray or buff color.

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[1] Letter of February 4, 1905.

The remaining part of the quarry has thicker-bedded layers, up to eighteen inches in thickness, although there are thinner ones used for flagging. The thicker layers which are used for building stone are brownish on fresh fracture, but, according to Mr. Wagner, weather to a bluish tint, and do not contain iron. In the lower part of the quarry is quite a massive layer, in which *Chonetes* sp. is common; but above this layer there are comparatively few fossils. In the upper layers, however, which are somewhat crinoidal, occasional specimens of *Stropheodonta demissa* (Con.) Hall, *Pholidostrophia iowaensis* (Owen) Schuchert, *Liorhynchus laura* Billings (?), and *Paracyclas elliptica* Hall (?) were seen. Much of this upper rock is marked with lines of bedding, and it is apparently quite an impure limestone.

To the west of the Wagner quarry, and just south of the Soldiers' Home, is the Hartman quarry, in which eighteen feet of rather even-bedded brownish rock is shown. This quarry extends stratigraphically about seven feet deeper than that of the Wagner Stone Co., and the rock is used largely for building. Fossils occur with about the same frequency as in the Wagner quarry, and the upper part of the rock is slightly crinoidal, similar to the upper layers in the former quarry. Both quarries show very little chert in any of the layers or partings.

CORRELATION OF LIMESTONE IN AND NEAR SANDUSKY

The Wagner and Hartman quarries just south of the Soldiers' Home and outside of Sandusky are correlated with the Delaware limestone of central Ohio.

The limestone in the Schoepfle and adjacent quarries in the city of Sandusky was named the "Sandusky limestone" in 1873 by Dr. Newberry,[1] who gave the localities at which it is quarried as Sandusky and Delaware. It has already been stated in this paper that at the time of Dr. Newberry's investigations the Schoepfle quarry was opened and studied by him; but the present quarries in the Delaware limestone to the south of the Soldiers' Home had not been opened. In Dr. Newberry's "Review of the Geological Structure of Ohio," published in the last strictly geological report issued under his direction, the name "Sandusky limestone" is retained for the upper division

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[1] *Report of the Geological Survey of Ohio,* Vol. I, Part I, p. 143.

of what he called the Corniferous limestone, and the quarries at Sandusky and Delaware are given as localities of its occurrence.[1] It will be remembered that in this same volume Dr. Orton, in his "Report on the Geology of Franklin County," named the upper division the "Delaware limestone," "from its occurrence at Delaware."[2] In a paper describing fossil plants from the Corniferous limestone of Ohio, published by Dr. Newberry in 1889, occurs the following sentence: "They [the fossil plants] are all from the Delaware limestone, the upper division of the Corniferous." A little farther on he speaks of "the white or Sandusky limestone below," apparently applying this name to the lower division of the Corniferous limestone; while he also stated that "the Delaware limestone is much darker and more earthy than the lower division of the Corniferous, and it is evident that it was deposited in shallower water when

FIG. 3.—Contact of Columbus and Delaware limestones in Lake Shore & Michigan Southern Railroad quarry two and one-half miles northeast of Castalia. The collecting-bag is on top of the Columbus, and the hammer indicates the superjacent shale.

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[1] *Ibid.*, Vol. III, Part 1 (1878), p. 11.

[2] *Ibid.*, p. 606.

the land was nearer and the land-wash more abundant."[1] The above statements apparently indicate that Dr. Newberry had abandoned his earlier opinion and now correlated the limestone in Sandusky with the lower division of his Corniferous or the Columbus limestone of central Ohio, instead of the upper division or Delaware limestone. There is, however, no definite explanation of this change of opinion in any of Dr. Newberry's works, as far as the writer is aware, and perhaps the above interpretation of this paper does not correctly represent him in this matter.

Dr. Charles K. Swartz, of Johns Hopkins University, in the fall of 1903 correctly determined the stratigraphic position of the limestones in the city of Sandusky, and correlated them with the Columbus limestone of central Ohio. He has thoroughly studied the various exposures of the Devonian limestones in Ohio, collected extensively in them, and carefully identified the fossils. Dr. Swartz has written me as follows regarding this subject:

> I find that nearly 87 per cent. of the species reported from the "blue rock" at Columbus and vicinity (including the section from the "smooth rock" to the "bone-bed") occur in that part of the Sandusky limestone in the Lake Erie region which I have referred to the Columbus formation. This includes the more diagnostic forms especially. I think the correlation thus rests on sufficient faunal evidence. Most of these forms do not pass above what I have termed the Columbus formation, or are quite rare in the upper division.[2]

In September, 1904, the writer studied the exposures in Sandusky, and fully agrees with Dr. Swartz in correlating all of the limestone, except the very highest layers, in the Hancock Street quarries with the Columbus formation. It is not improbable that the bone-bed noted in the old quarry on the western side of Hancock Street represents the well-known one in the Columbus region, which occurs at the top of the Columbus limestone, and at least the dividing line between the Columbus and Delaware limestones occurs not more than from three to six feet higher.

Since it is proved that nearly all of the rock to which Dr. Newberry gave the name "Sandusky limestone" belongs in the *lower* instead of the *upper* division of what he called the "Corniferous limestone,"[3]

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[1] *Journal of the Cincinnati Society of Natural History,* Vol. XII, pp. 49, 50.

[2] Letter of January 14, 1905.

[3] *Report of the Geological Survey of Ohio,* Vol. I, Part I (1873), p. 143.

it appears to the writer that the name *Sandusky limestone* ought to be dropped. If it were now applied to the lower formation, it would cause serious confusion, since that was named at the same time the *Columbus limestone*, under which designation it is well known in geological literature. It is to be noted that in Dr. Newberry's classification and definition of these two limestones the name "Sandusky" appeared *first*, but on the same page as that of Columbus.[1] It is thought, however, that the above decision is in accordance with Rule 7 of the United States Geological Survey regarding "Nomenclature and Classification," which states that "in the application of names to members, formations, and larger aggregates of strata, the law of priority shall generally be observed, but a name that has become well established in use shall not be displaced by a term not well known merely on account of priority."[2] "Delaware limestone," published by Dr. Orton in 1878, is the next name applied to the upper division of the Devonian limestones of Ohio, and this is now adopted for this formation. In my paper on "The Nomenclature of the Ohio Geological Formations," published in the *Journal of Geology* in 1903,[3] "Sandusky limestone" was used for the upper formation of the Devonian limestones, because, as there stated, it antedated "Delaware limestone" by five years, and the error in correlation between the limestones of Sandusky and Delaware was not known to the writer. The thickness of the Delaware limestone in the Sandusky region, according to Dr. Swartz, is between forty and fifty feet, which is greater than that in central Ohio.

[1] *Loc. cit.*

[2] *Twenty-fourth Annual Report of the Director of the U. S. Geological Survey* (1903), p. 24.

[3] Vol. XI, p. 519, and see pp. 521 and 537.

MEGACEROPS TYLERI, A NEW SPECIES OF TITANOTHERE FROM THE BAD LANDS OF SOUTH DAKOTA

RICHARD S. LULL
Massachusetts Agricultural College, Amherst, Mass.

(WITH PLATES III AND IV)

The Amherst College Palæontological Expedition of 1903, under the leadership of Professor F. B. Loomis, was remarkably fortunate in securing the greater part of a huge titanothere, apparently representing a species unknown to science which, aside from this, has the additional value of having the skull and limbs of one individual associated beyond doubt. The specimen was therefore deemed worthy of careful description, the privilege of which has been granted the writer through the courtesy of Dr. Loomis.

GEOGRAPHICAL AND GEOLOGICAL LOCALITY

The specimen was found by Mr. T. C. Brown, Amherst College 1904, near the head of Bear Creek, a tributary of the Cheyenne River in South Dakota. The exact locality was on the north side of Spring Draw basin, about ten miles from the mouth of Bear Creek. Here some two hundred feet of titanothere beds were found, lying upon Fort Pierre deposits, in which titanothere bones were discovered from a point six feet above the contact upward; the specimen under consideration lying thirty-five feet above the base of the beds, hence in the upper part of the lower division.[1]

If one may judge from the summary of characters given by Hatcher and others, the specimen would be considered a middle-bed form with some upper-bed characteristics, as it is far from being primitive.

CHARACTER AND CONDITION OF THE SPECIMEN

The skeleton, which is No. 327 of the Amherst College Zoölogical Collection, consists of a skull and jaws, the atlas, axis, and the fourth, fifth, and sixth cervical vertebræ. Nine dorsals, most of them spine-

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[1] J. B. Hatcher, *American Naturalist*, Vol. XXVII (1893), p, 218.

less, are preserved, together with thirteen ribs. The lumbar, sacral, and caudal vertebræ are missing. Of the fore-limbs the proximal end of the left and the distal end of the right scapular are preserved, together with the distal ends of both humeri and the proximal end of the right.

The radius and ulna of the left limb and fragments of the right ulna represent the second segment; while of the manus all the bones of the right, except the pisiform, the trapezoid, and a few phalanges, are preserved, the left being less perfect, but supplementing the first so that, with the exception of a part of the humerus, our knowledge of the entire limb is complete.

The hind limbs are more complete, as both fermora, tibiæ, and fibulæ are preserved most admirably. Of the pes, that of the left limb is perfect as to the tarsus, while the right lacks only the ecto-cuneiform, that of another specimen being substituted in the mount. Both metatarsi are perfect, though several phalanges are missing. A number of sesamoids of both manus and pes are preserved, together with the left patella.

With the exception of the vertebral spines, the bones are for the most part in admirable condition, though the skull and jaws have been subjected to a peculiar shearing strain, which has brought the left side in advance of the right, as shown in the figures.

DETERMINATION OF THE SPECIES

The specimen under consideration is evidently a Megacerops, as the generic characters given by Osborn[1] and by Marsh[2] are well marked. The skull is moderately brachycephalic, with expanded zygomata; the horns are rather short, without a prominent connecting-crest, oval at the summit and transversely elongate oval at the base. The nasals are of moderate length, with well-rounded extremities. The dental formula is I.$\frac{2}{2}$; c.$\frac{1}{1}$; p.$\frac{4}{4}$; m.$\frac{3}{3}$; the two median superior and all of the lower incisors being represented by deep unclosed sockets, as though the teeth had been lost after death. There is a diastema behind the canines, and the internal premolar cingulum is less pronounced in the center of the tooth.

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[1] H. F. Osborn, *Bulletin of the American Museum of Natural History*, Vol. XVI (1902), Art. VIII, p. 96.

[2] O. C. Marsh, *American Journal of Science* (3), Vol. XI (1875), p. 245.

Specifically the creature most nearly resembles *Megacerops bicornutus* Osborn and *Megacerops* (*Diploclonus*) *amplus* Marsh, having certain characters suggestive of each; but there are enough important differences to render it distinct and to warrant the erection of a new species for its reception.

Megacerops tyleri *sp. nov.*

Type No. 327 of the Amherst College Zoölogical Collection. Horns well in front of orbits, directed somewhat forward and outward, an elongate oval in basal section with the long axes in line, rounded oval at the summit. Hornlets quite conspicuous, on the inner face of the horns midway between the base and summit. Connecting-crest low and inconspicuous. Nasals broad, well rounded in front, and but slightly arched beneath. Zygomata expanded and deep, with a well-rounded outer face. Dentition: Superior incisors represented by the deep and well-defined median alveoli, and by the lateral teeth which remain in place, and which have hemispherical crowns which show little sign of wear. The canines are lanceolate, with a well-developed postero-internal cingulum. There is a short diastema in front of, and a longer one behind, the canine. Premolars with a smooth internal cingulum, less pronounced in the middle of the tooth, and with no external cingulum. The deuterocone is well developed, while the tetartocone, especially of premolar four, is inconspicuous.

The jaw is deep and robust, with the alveoli of two incisors, probably of the second and third, deep and distinct. There is no space between the lateral incisors and the canine, though between the two median alveoli a considerable gap occurs. There seems to have been a small diastema behind the lower canines, which are lanceolate, though with a less prominent cingulum, and not so strongly recurved as the upper ones.

COMPARISON WITH ALLIED SPECIES

The form under consideration resembles most closely *Megacerops* (*Diploclonus*) *amplus* Marsh and *M. bicornutus* Osborn, agreeing with both in the possession of hornlets, and with one or the other in minor characters, but differing in general contour of the skull and horns. The table on next page shows the main points of resemblance or contrast in the three species.

Professor Osborn, in his description of *M. bicornutus*, mentions as a cotype skull No. 1081 of the American Museum—a specimen with a somewhat checkered career, as it was first described and figured by Osborn in the *American Museum Bulletin*[1] as "*Titano-*

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[1] Vol. VIII, Art. IX, pp. 176, 177.

M. tyleri, n. sp. Type No. 327, Amherst College	*M. bicornutus*, Osb.[1] Type No. 1476 A. M. N. H.	*M. amplus*, Marsh[2] Type in Yale Museum
Skull rather broad.	Skull narrow.	Skull rather broad.
Zygomata expanded.	Not expanded.	Expanded.
Outer face of zygomata rounded.	Rounded.	Acute.
Horns directed forward.	Nearly erect.	Directed forward.
Basal section elongate transverse oval.	Slightly oval sub-transverse.	Compressed transversely.
Hornlets on inner face half way to summit.	On anterior face less than half way to summit.	On inner face, one-third way to summit.
Connecting-crest low.	No connecting-crest.	Connecting-crest high.
Nasals broad, relatively short, rounded extremities.	Narrow, relatively elongate.	Short and narrow.
Nasals not highly arched beneath.	Highly arched beneath.	
Malar bridge not conspicuously sharp.	Sharp malar bridge in front of orbit.	Sharp ridge at base of horn core on the outside.
Canines lanceolate.	Rounded.	Lanceolate.
Diastema behind canines.	No diastema.	No diastema.
Premolars without external cingulum.	With external cingulum.	With external cingulum.

therium torvum (or *robustum*)." This skull resembles that of the specimen under consideration in general proportions, though in the former the horns are longer and more projecting. The teeth are badly worn and broken, but the one remaining premolar lacks the cingulum on the outside, as in the Amherst specimen. The canines are lacking, so that their character cannot be ascertained. Professor Osborn accounts for the differences between the type, No. 1476, and No. 1081 by the assumption that the former is a female skull, while the latter is that of a male. He states, however, that "the shape of the canines is the same in both sexes, but the male tusks are much more powerful than in the female."[3] Between the lanceolate canine of *M. tyleri* and the rounded canine of the *M. bicornutus* type there would seem to lie a specific distinction which, together with the other differences mentioned in the table above, would probably bring No. 1081 into the new species.

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[1] H. F. Osborn, *loc. cit.*, p. 99.

[2] O. C. Marsh, *American Journal of Science* (3), Vol. XXXIX (1890), p. 523, Fig. 5; figured by Osborn, *loc. cit.*, Fig. 7.

[3] *Loc. cit.*, p. 173.

GENERAL DESCRIPTION

The skull (Plate III, Figs. 1–4).—The skull was partially exposed as it lay in the quarry, so that the occiput and the left zygomatic arch have been destroyed by weathering. The remainder is in admirable preservation, except for the distortion noted above. In spite of the fact that the union of the epyphises with the vertebral centra is as yet imperfect, which, as Marsh has shown, occurs rather late in the titanotheres as in the elephants, the sutures are almost obliterated from the skull, as one can only distinguish the squamoso-jugal suture of the zygomata, and that on the inferior side of the nasals. The general contour of the horns is well shown in Plate III, Fig. 3, and in the sections here shown, though allowance must be made for the crushing backward of the right and the crushing forward of the left horn.

FIG. 1.—Basal section of the horns of *Megacerops tyleri* taken in a plane perpendicular to their axes. One-quarter natural size.

Toward the summit the horns become rounder in section, and they terminate in a much-roughened area, which is somewhat flattened, and which Osborn describes as "incompletely ossified." Another roughening of a similar character, though not so pronounced, marks the summit of each hornlet, and there is an entire absence of any vascular impressions over the surface of the horn, as in the horn cores of the hollow-horned artiodactyls and the Ceratopsia among dinosaurs. This leads the author seriously to doubt the accuracy of those restorations of the animal wherein these prominences are represented as sheathed with horn. On the contrary, it would seem, from the similarity of the roughened patches to those on the rhinoceros nasals, as though the entire prominence had been clothed with skin

FIG. 2.—Vertical section through the zygomatic arch at the point of its greatest expansion. One-quarter natural size.

with two rhinoceros-like horns, a larger one at the apex and a smaller one on the summit of the hornlet.[1]

The missing portions of the skull have been restored from photographs of the American Museum skull No. 1081, already alluded to, which were loaned through the courtesy of Professor Osborn.

The skull measurements are as follows:

Premolar-molar tooth series	0.363
Premolars	.139
Molars	.227
Canine (crown) anterior length	.045
Canine (crown) antero-posterior diameter	.035
Premaxillaries to condyles (estimated)	.768
Nasals to mid-vertex (estimated)	.740
Transverse width of zygomatic arch	.583
Depth of zygomatic arch (buccal process)	.157
Nasals, free length	.084
Nasals, free breadth,	.140
Outside length of horn	.170
Expanse of horns	.393

Those of the jaw are:

Length, symphysis to condyle	0.685
Premolar-molar tooth series	.375
Premolars	.140
Molars	.235
Canine (crown) anterior length	.042
Canine (crown) antero-posterior diameter	.031
Depth of jaw	.355

In the lower premolar series a tooth is missing on each ramus, on the left the first, and on the right the second premolar, the missing ones being indicated by their roots. The molar series is well developed below and above, the hypocone of the third superior molar being well formed.

The atlas.—The atlas is a broad, heavy bone, with wide articular facets and expanded transverse processes. The spine is extremely low, and the short truncated hypopophysis extends backward. Of the foramina, only that for the dorsal root of the first cervical nerve is present, the ventral one, well shown in Palaeosyops,[2] being here

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[1] Restoration of the Titanothere Megacerops. R. S. Lull, *American Naturalist*, Vol. XXXIX (July, 1905), p. 423, Figs. 2, 3.

[2] Charles Earl, *Journal of the Academy of Natural Science*, Philadelphia, Vol. IX, 2d series, Art. VI, p. 294.

represented by a deep notch as in the rhinoceros, which our specimen also resembles in the lack of a vertebraterial canal and in the relative widths of the anterior and posterior facets.

The dimensions of the atlas are:

Total width	0.320
Width across atlar-occipital facets	.204
Width across atlar-axis facets	.255

The axis.—The axis is a massive bone with a high neural arch, the spine being an equilateral triangle in mid-section. On its posterior face a shallow groove arises between the zygopophyses which fades out about two-thirds of the way to the summit. The prezygopophyses overhang the atlas in front, but present no articular facets. The odontoid process is a truncated cone, and is not so prominent relatively as in Palæosyops, being about one-third the length of the centrum measured along its inferior face. The latter exhibits a low longitudinal ridge below, but is not deeply excavated on either side, as in Palæosyops. The transverse processes of the specimen are broken away, but the bases of its two supports are seen, indicating the position of the vertebraterial canal, which is placed rather high on the centrum, though not on a line with its upper surface, as is Palæosyops.

The postzygopophyses look downward and outward; their horizontal axes, if continued, would intersect at an angle of 90°. Altogether both atlas and axis resemble those of a rhinoceros much more than those of Palæosyops.

The measurements of the axis are as follows:

Total height to summit of spine	0.295
Greatest breadth	.241
Length of centrum including odontoid	.133

The remaining *cervicals* are distinctly opisthocœlous, with zygopophyses which widely overlap one another. With the exception of the sixth, they are quite poorly preserved, and the sixth is so badly crushed as to make measurements very unreliable.

Of the *dorsals*, nine only are referable to the type specimen, though three others are added in the mount. The opisthocœlous centra are preserved, but the spines and transverse processes are lacking.

The ribs.—Portions of thirteen ribs from both sides of the body are preserved. In general form they are quite rhinoceros-like, being somewhat widely expanded in the shaft. The capitulum is nearly spherical in most of the ribs preserved, and the two facets are separated from each other by a deep groove. In an anterior rib, the second or third, the tubercular facet, while mainly on the posterior side, arches over so as to lie in part on the anterior face. The other ribs have the tubercular facet entirely on the posterior face. The resemblances again are with the rhinoceros rather than with Palæosyops.

THE APPENDICULAR SKELETON

Fore-limb.—While both scapulæ are incomplete, they supplement each other so that our knowledge of them is fairly perfect. The proximal half of the left with its spine is well preserved, while of the right nearly the entire distal border is present.

The glenoid is deeply concave antero-posteriorly, and is broadly elliptical in outline. The corocoid process is conical, somewhat downwardly curved at the tip, separated by a deep notch from the glenoid border, and not arising directly from it, as in Palæosyops, but separated by an interval of 0.038 m. The spine is high in the middle, with a broad roughened border. It lowers insensibly into the general level of the scapular face above and below, with no indication of an acromion. The tuberosity is not very pronounced, and the distal border is nearly straight.

The dimensions of the scapula are:

Total length (estimated) - - - - - - - -	0.690
Width of superior border (estimated) - - - - -	.405
Fore and aft diameter of glenoid fossa - - - - -	.133
Height of spine - - - - - - - - - -	.095

The humerus.—The distal portions of both humeri are preserved, but of the proximal portions that of the right only, and as there is a portion of the shaft missing, the length cannot be measured. The distal end is broad and heavy, the external condyle being especially prominent and roughened for muscular attachment. The inner trochlear is much the larger and is higher than the outer one, thus indicating an outward flexing of the elbow joint. The aconeal fossa is large and deep, but there is no foramen. The breadth of the extremity measured at right angles to the axis of the shaft is 0.210.

Breadth of shaft	0.085
Fore and aft diameter of shaft	.077

The radius.—That of the left side is well preserved, except that its distal end is somewhat weathered. It is not notably heavy, and has a well-rounded shaft, but slightly compressed fore and aft at the distal end. The radio-scaphoid facet is prolonged upward on the posterior face, indicating a considerable range of flexion of the wrist.

The principal dimensions of the radius are:

Length	0.490
Antero-posterior diameter of mid shaft	.060
Lateral diameter of mid shaft	.065
Lateral diameter of lower end	.110

The ulna.—The entire left and fragments of the right are preserved, except for the distal end of the former, which is badly weathered. The ulna is notable for its huge compressed olecranon, which widens out distally into a heavy roughened tubercle.

The ulna measurements are as follows:

Length (estimated)	0.620
Antero-posterior diameter of olecranon from the humeral facet	.170
Lateral diameter of olecranon tubercle	.140
Fore and aft diameter of mid shaft	.080
Lateral diameter of mid shaft	.080

The manus (Plate IV, Figs. 1–3).—The general proportions well shown in the figure, are somewhat broad rather than slender and in direct correlation with the proportions of the skull. As has often been stated, the manus shows some distinctly artiodactyl features, the most notable being the retention of four digits with the main axis between digits 3 and 4, rather than lying in the third itself. Another remarkable feature is the extreme flexibility of the carpus, especially in the development of a true ginglymoid joint between the proximal and distal row of carpals. This is paralled in the carpus of *Rangifer caribou*, and is quite distinct from the condition found in the horse and camel, where, while the proximal facets of the distal carpalia indicate a certain range of flexion, there is no development of special pully-like ridges or keels, as in the titanothere and caribou. How this articulation is formed in the rhinoceros and tapir the author unfortunately has not had the opportunity to observe, but a comparison would be most interesting. All of the elements are present in the carpus, with the exception of the trapezium, of which the last vestige has disappeared. The proximal facets are shown in Fig. 1 of Plate IV, though the limits of the radial and ulna areas are not with certainty definable.

The scaphoid articulates with the lunar by two facets separated from each other by a roughened trough. The superior scapho-lunar facet is long and narrow, its short axis vertical and straight, while its longer axis sweeps to the rear in a gentle convexity. It has the same antero-posterior extent as the scapho-radial facet above. The inferior scapho-lunar facet is much smaller, having but half the fore and aft extent of the superior. Distally the scaphoid articulates with the trapezoid and the magnum, and together with the lunar forms the deep groove into which the pully-like pivot of the magnum fits.

The lunar is a somewhat larger bone than the scaphoid, articulating distally both with the magnum and the unciform. The articulation between the lunar and cuneiform is again double, the two facets being separated by a well-defined channel, which runs backward and slightly upward. The two lunar-cuneiform facets are about equal in area. One can form a very good idea of the distal lunar facets by the study of their complementary facets figured in Plate IV, Fig. 2.

The cuneiform is about half the bulk of the lunar, and presents two facets on its inner face in every way the complements of the lunar-cuneiform. On the proximal face there is a large, saddle-shaped facet for the ulnar, and a smaller, semicircular, cuneiform-pisiform facet in the rear, set almost at right angles with the plane of the first. Distally there is a large cuneiform-unciform facet, having the general form of an equilateral triangle with rounded angles. It is again saddle-shaped, concave in its fore and aft axis.

The pisiform is lacking from the right manus, but that of the left is present and well preserved. It is much compressed laterally, with a deep vertical expansion of the distal end which is decidedly rugose. The bone presents a gentle, sweeping curve through an arc of nearly 90°. Proximally it bears two well-defined contiguous facets for articulation with the cuneiform and ulna respectively.

Of the distal row of carpals the trapezoid is absent, having been replaced in the mount by that from another individual. It is not a precise fit, there being some variation between its facets and those of the original bone.

The articular faces are well shown in the figure, and it will be noted that lateral movement is impossible, while a remarkable range of flexion is indicated.

The magnum has on its lower face facets for the articulation of meta-carpals 2 and 3, that for 2 being rectangular, about four times as long as wide. The pivot of the magnum is high and prominent, as indicated in the figure.

The unciform is the largest bone in the carpus, with the possible exception of the lunar. Distally it bears two facets for metacarpals 4 and 5, while on the radial side there is one which articulates both with the magnum and with metacarpal 3, the limits of the two articulations not being discernible.

A study of the distal carpal facets and the proximal metacarpal ones gives evidence again of more or less fore and aft movement, but in the case of the median metacarpals no lateral movement at all. The lateral metacarpals, on the contrary, were capable of lateral as well as fore and aft movement, so that, while the foot would spread somewhat when the creature's weight was borne upon it, it was all in the lateral bones. This would seem to be still further evidence that the true axis of the foot was between digits 3 and 4, as in the artiodactyls.

The principal dimensions of the manus are:

Width of proximal facets - - - - - - -	0.170
Width of distal carpals - - - - - - - -	.170
Depth, lunar to summit of metacarpal 3 - - - -	.080
Length of metacarpal 3 - - - - - - - -	.250

THE HIND LIMB

The entire limb is figured in Plate IV, Fig. 4. There was no trace of the pelvis found associated with No. 327, though the limbs are in excellent preservation and give but little evidence of distortion by crushing.

The femur.—This is a fine bone, notable for its extreme flatness, which indicates the pillar-like posture of the bone, as in the elephant, as the shaft would not have been sufficiently rigid to withstand springing, had the thigh been flexed. Another interesting feature is the absence of a third trochanter—a character given by Marsh in his definition of the genus Megacerops. There is a ridge on the outer side of the femur continuous above with the great trochanter, which probably represents the vestige of the third.

The measurements are:

Length	0.785
Width of proximal end	.236
Width of distal end	.204
Width of mid shaft	.117
Depth of mid shaft	.060

The tibia.—The general form of this bone is well shown in the figure, and calls for no special comment.

The measurements of the tibia are:

Length	0.446
Width of proximal end	.200
Depth of proximal end	.132
Width of mid shaft	.080
Depth of mid shaft	.077

The fibula is quite slender with expanded articular extremities.

Length	0.395

The pes.—The general proportions are in keeping with those of the manus. All of the tarsal elements are represented, with the exception of the entocuneiform which is entirely lacking.

The calcaneum.—The tuberosity is rather long and very rugous at its distal end, and with a much-flattened shaft which is about one-half as wide as long. The calcaneum bears facets for articulation with the cuboid, the astragalus, and on its upper outer face a small one for the articulation with the fibula.

The calcaneo-astragalar facet is somewhat saddle-shaped, its fore-and-aft axis being a reversed curve, first concave, then convex. The sustentacular facet, however, is deeply concave, the transverse axis curving through an arc of 90°, while the fore and aft axis is straight. Below there is but one facet, the calcaneo-cuboid, somewhat semilunar in shape, extending about half the width of the bone. Except for the articulation with the fibula, there is little evidence of movement between the calcaneum and the adjoining bones.

The astragalus presents a beautiful hour-glass-shaped, astragalo-tibial facet, bearing on its outer face a clearly defined fibula facet. The range of flexion and extension in the tibio-tarsal joint is considerable. Distally two facets are indicated, that for the navicular being by far the larger, and somewhat flattened, and with a small, prominent, downwardly projecting process, which effectually limits any fore-and-aft motion. A prominent ridge divides the two facets, that for the cuboid being an elongated triangle, first convex, and then concave from before backward.

The navicular is very flat and presents two distal facets, that for the ectocuneiform being the larger, and somewhat triangular in shape, while that of the mesocuneiform is semilunar, the line of demarcation between the two being almost straight.

The cuboid has a thickness equal to that of the navicular and ectocuneiform combined, and exhibits proximally two contiguous facets, the lesser for the calcaneum and the greater for the astragalus. Distally there are two facets, the external, the area of which is about four times the greater, being for metatarsal 4. This is somewhat saddle-shaped, while the other, that of metatarsal 3, is nearly flat.

The ectocuneiform is absent in the right pes, though present in the left, being replaced in the former by that of another individual. It articulates distally with metatarsals 3 and 2, though the latter articulation almost fades out anteriorly, broadening as one goes to the rear. This is markedly different from most titanothere feet which the author has seen, in which a wide line of contact is indicated on the face of the tarsus. There is, however, no possibility of contact between the mesocuneiform and metatarsal 3, as the former articulates distally with metatarsal 2 only.

The whole pes is remarkably rigid when compared with the manus, as there is little indication of any intertarsal movement, none between the tarsus and the median metatarsal, and no lateral and but little fore-and-aft play between the tarsus and the lateral metatarsals.

The principal dimensions of the pes are:

Width of astragalar facet	0.105
Length of calcaneum	.208
Width of the distal row of tarsals	.140
Height, astragalus to proximal end of the third metatarsal	.108
Length of the third metatarsal	.205

CONCLUSION

The general proportions of the skeleton would indicate a huge animal, seven feet four inches in height to the withers, and something over twelve feet in length, somewhat rhinoceros-like in aspect, but with more massive, pillar-like limbs, which, as Professor Osborn has shown, are correlated with great weight. The extreme flexibility of the carpus seems to indicate an elephant-like habit of kneeling on the wrists when rising and lying down. The creature was hardly adult, as indicated by the unossified vertebral epiphyses, though probably of full stature, and it indicated a form in the middle stage of evolution—a noble example of a splendid, though unfortunate, race. It is the author's privilege to dedicate this species to Professor John M. Tyler, of Amherst College, a teacher of men, who, by his earnest efforts as well as by his own generosity, was mainly instrumental in making possible the expedition which secured the specimen.

DESCRIPTION OF PLATES

PLATE III

FIG. 1.—Dorsal aspect of the skull of *Megacerops tyleri.* Drawn from the type specimen, No. 327 of the Amherst College Zoölogical Collection. The missing portion restored in outline. One-eighth natural size.

FIG. 2.—Lateral aspect of the skull and jaw of *Megacerops tyleri,* drawn from the type. One-eighth natural size.

FIG. 3.—Anterior aspect of the horns and nasals of *Megacerops tyleri,* drawn from the type. One-eighth natural size.

FIG. 4.—Incisor, canine, premolar series of upper teeth of *Megacerops tyleri,* drawn from the type. One-fourth natural size.

PLATE IV

FIG. 1.—Proximal aspect of the proximal row of carpals of *Megacerops tyleri,* drawn from the type specimen, No. 327 of the Amherst College Zoölogical Collection. One-fourth natural size.

sc., scaphoid; *lu.*, lunar; *cn.*, cuneiform.

FIG. 2.—Proximal aspect of the distal row of carpals of *Megacerops tyleri,* drawn from the type. One-fourth natural size.

td., trapezoid (drawn from that of another specimen); *mg.*, magnum; *unc.*, unciform; *sc. f.*, scaphoid facet; *lu. f.*, lunar facet; *cn. f.*, cuneiform facet.

FIG. 3.—Right manus of *Megacerops tyleri,* drawn from the type specimen. Lettering as above. One-fourth natural size.

FIG. 4.—Right hind limb of *Megacerops tyleri,* drawn from the type. One-eighth natural size.

cal., calcaneum; *as.*, astragalus; *cb.*, cuboid; *na.*, navicular; *cn*^{2}., mesocuneiform; *cn*^{3}., ectocuneiform.

FIG. 1

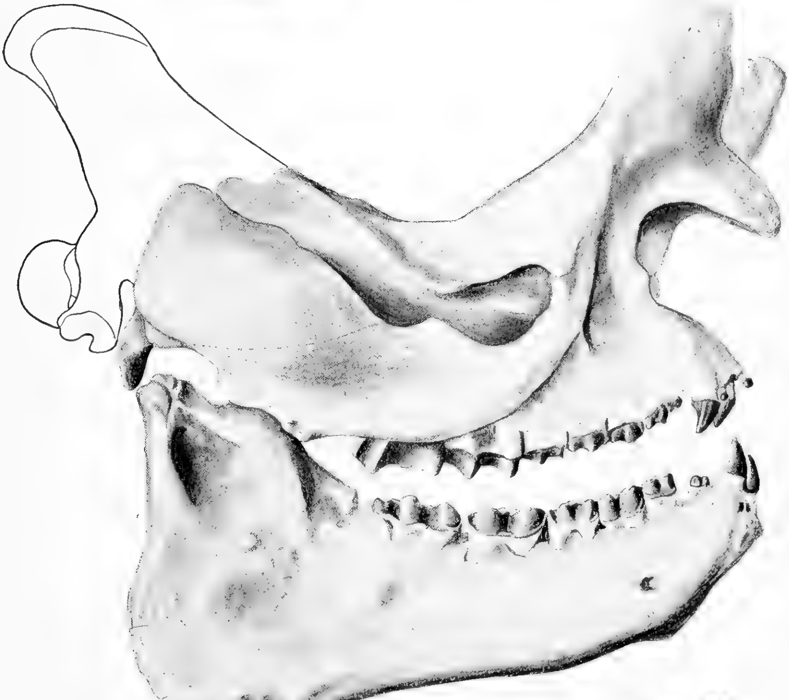
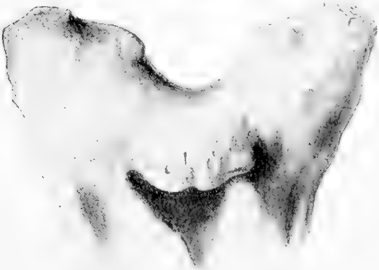


FIG. 2



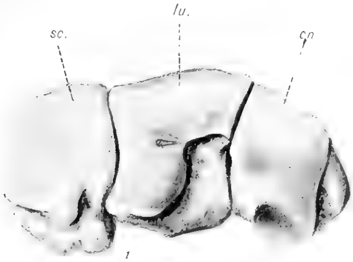


FIG. 1

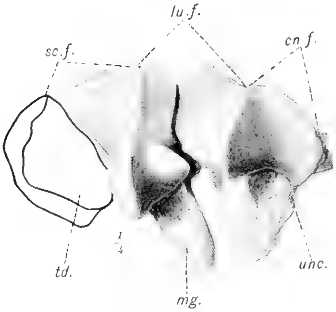


FIG. 2

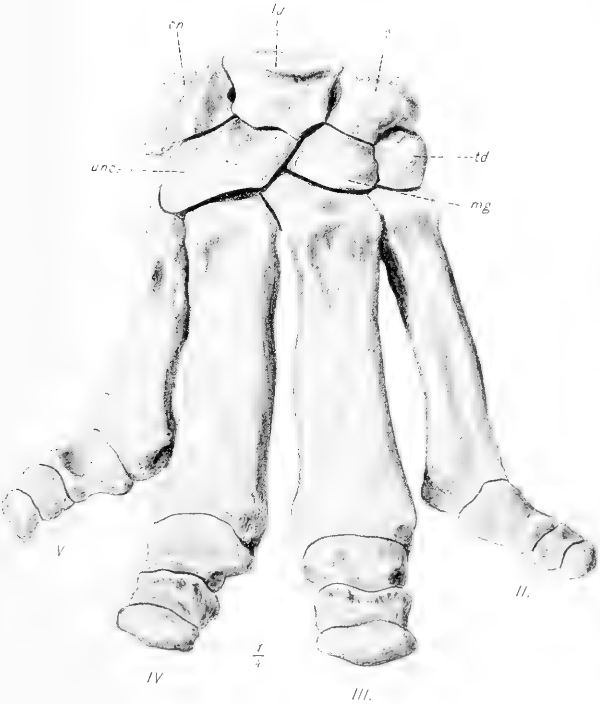


FIG. 3

FIG. 4

R. S. LULL, del. ad. nat.

COMMENT ON THE "REPORT OF THE SPECIAL COMMITTEE ON THE LAKE SUPERIOR REGION"

ALFRED C. LANE
Lansing, Mich.

In signing and assenting to the publication of the "Report of the Special Committee on the Lake Superior Region,"[1] it was agreed that the various members of the committee should have a right to add, or to publish elsewhere, notes explanatory of their subscription to the official creed. It may perhaps be worth the cost for me to explain why I was willing to accept "Laurentian" as a term apparently stratigraphic and co-ordinate with stratigraphic terms, though the formation is separated from the Keewatin (and Huronian?) by eruptive rather than unconformable contact—a kind of contact that I take not to have stratigraphic meaning.

If I had believed that this committee or any committee could make a final and binding determination of names, I should not have signed it, for I think the scheme will probably not prove to be final; but I did sign it as being the best practical working arrangement, with our present knowledge. Words are but labels for concepts, and our concepts must vary more or less as our knowledge increases, while it is desirable that our labels should remain as fixed as possible. I hope that the decision of the committee will prove to be the best that could have been done at present toward naming the rock formations so that future modifications will still apply the same names to most of the rocks involved. In the first place, I may frankly say that I have yet to see any rocks in the Laurentian, as defined by the committee, that I should class as a softened underlying formation. The granite and gneisses, etc., are crystallized from aqueo-igneous fusion, and have been at a temperature (under conditions) considerably beyond the consolidation point, as it seems to me,[2] as their grain shows.

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[1] *Journal of Geology*, Vol. XIII, pp. 89–104.

[2] *American Geologist*, February, 1905.

At the same time, one who accepts Chamberlin's planetesimal theory must, I suppose, believe that all molten rocks have come from fusion earlier or later. But that would apply to all igneous rocks, and I do not see why it should involve a separate stratigraphic treatment of any, and these Laurentian granites, instead of being an immediately older formation, might be eras older. We find, however, able geologists, represented on the committee, who hold the subcrustal fusion theory probable or possible, and we find this theory implied in previous use of some of the Lake Superior stratigraphic terms; and I frankly own that I know of no conclusive arguments against it. Any agreement we may make as to the use of "Laurentian" is likely to be more or less of a compromise, and the problem is so to define terms that their application should be as far as possible the same, their extent represented by closely overlapping circles, whatever each man may privately think about the true inwardness of the connection of the rocks thus grouped.

The two terms the application of which we really had to delimit were Logan's terms "Huronian" and "Laurentian," and we have arrived at a temporory *modus vivendi* by using Lawson's "Keewatin" (Irving's "greenstone schists," Van Hise's "Mareniscan," Wadsworth's "Cascade," Rominger's "Dioritic group") as a buffer state.

One cannot fairly deny that Logan's idea of the Laurentian was a purely stratigraphic one, since it was divided into an upper and lower division, and that our proposed use of the term restricts it to part of the lower part of the same only. But the fact is that Logan founded the Laurentian and its divisions in eastern Canada. Then he came to Lake Huron, and for very good reasons erected another system, the Huronian, which in its most typical part is, we all agreed, younger than his Laurentian. So far we were led to the conventional arrangement of Archean, divided into Huronian and Laurentian, which one finds in most of the geological textbooks.[1] But, unfortunately (as it seems to me), Logan included in his original Huronian area a series of rocks, there relatively insignificant, green chloritic schists (3 *c* of Logan), which the committee report calls the Thessalon series. This series is, as we have said, intruded by granites, and it seems to me that the rocks are stratigraphically as low and temporally

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[1] Dana, Giekie, Lapparent, Credner, Kemp's *Ore Deposits*, etc.

as old as any rock series that we now know. So here we have a clear case of overlap between the definitions of "Huronian" and "Laurentian." Moreover, we do not really know how far up in the Huronian the overlap extends, and this fact weighed much in my mind in favoring the final compromise. The Hastings series of the upper Laurentian is largely a limestone-dolomite series. So is the Mesnard series (or lower Huronian of the report) from the Gogebic Range through the original Huronian area north of Lake Huron, and it seems to me possible that the Mesnard series may prove to connect with the original upper Laurentian. If this should be so, it should of course be taken into account in drawing the line between Huronian and Laurentian.

Another factor complicates the situation, I am informed. Just as in going west from New York, through Ohio to Michigan, the only part of the original New York Lower Helderberg remaining was the Waterlime, the rest being absent by unconformity, and so the typical Lower Western Helderberg of Orton and Rominger corresponds to a member that some of the New York geologists are now inclined to prune off from the Helderberg entirely; so it has been with the Huronian. The chloritic schist type, so comparatively insignificant in the original Huronian area, if we have made no mistake, covers great regions and becomes very important elsewhere, and is essentially the formation Lawson called Keewatin, but has often been mapped as Huronian, while granite and light-colored gneisses have been mapped as Laurentian, without knowing or caring (so far as the mapping was concerned) whether they cut the green chloritic schists or not. To call these chloritic schists Laurentian would be to upset the nomenclature very extensively.

Moreover, we do not really *know* that the upper Laurentian may not be a formation older and beneath these chloritic schists, though I have not the slightest suspicion that it is. Thus it seemed well to retain for these chloritic green schists, so different in many ways from the Huronian, a name of their own, and among those used for them Lawson's seemed to have clear priority among geographical names. I must confess I am enough of a heretic to yearn personally for the good old descriptive terms like "greenstone schists."

"Laurentian" is thus left out in the cold as an accurately defined stratigraphic term. It is a residual term under which all large old (or ill-known) batholiths or plutonic rocks may be grouped, and I presume will prove very convenient in this elastic sense. I shall use it about as Brooks used it. Those who believe in sub-crustal fusion will, however, use it, applying it to very much the same rocks, but implying more, that they are softened parts of the basement of the Huronian. It is hardly likely that the term will stay in this stage of definition very long. As the original Laurentian area is more carefully studied and its connections with Lake Superior made out, I presume we shall find out just about what proportion of the original Huronian must be taken from the bottom to be equivalent to the original Laurentian, and we should then revert to the original division of the Archean into the Huronian above and Laurentian beneath.

A few words, in conclusion, as to the top of the pre-Cambrian. Here, as usual throughout the geological column, there is difficulty in fixing the exact line of division. That the main part of the Lake Superior sandstone is Cambrian I have no question. It is, in fact, upper Cambrian apparently. A specimen with trilobites from the Menominee Range, Mr. C. D. Walcott determined as of the Ptychaspis zone. Wells at Grand Marais and Lake Linden show that at those points it has over a thousand feet of thickness.

Dr. Hubbard has proved conclusively to me that it overlaps unconformably on the base of the Keweenawan.[1] But does that imply that the Keweenawan belongs to a different system? Neither Seaman nor I think so. For while there is the unconformity with the base of the Keweenawan, and the Keweenawan is very thick, this thickness of thousands of feet is composed of rocks which accumulate with extreme rapidity. They are almost wholly sandstones, conglomerates, and traps. Geologically, the Keweenawan may represent no more time than some of our present volcanoes lasting from Tertiary times. Moreover, in such a series intra-formational, and even more intra-systemic discordances may be expected. As a matter of fact, we find bowlders and even agates of the Lower Keweenawan traps in the Upper Keweenawan. Yet there is a steady approximation, (1) in dips, (2) in stratigraphic distribution, (3) in disturbances,

[1] Vol. VI, Part II, pp. 110 ff.

(4) in lithological character, from the base of the Keweenawan to its upper portion, in the direction of likeness to the Lake Superior sandstone. (5) The deposition of this immense series must have been an era of subsidences, and the Lake Superior sandstone seems to have been formed through an area of subsidence; and outside certain limited areas like that near the Keweenawan fault there appears to have been no reversal of this subsidence between the Lake Superior sandstone and the Keweenawan, for the Lake Superior sandstone has but very little material that may be fairly supposed to have come from erosion of the Keweenawan. Its lithological character may be best explained as that of a bed mantling over the Keweenawan and deriving its material (frequently microcline) from the Laurentian granite bosses. But if the subsidence was not extensively broken and the Keweenawan is not Cambrian, then where are the middle and lower Cambrian?

The lithological character of the beds is such that fossils will hardly be found to help us. Of course, if Winchell proves to be right in saying that the Animikie is Cambrian, all the more would the Keweenawan be. But the Animikie is the kind of formation in which Cambrian fossils should be found, if present. I have never found them. The distribution of the Animikie and Keweenawan is quite discordant, and I think the Keweenawan much more closely associated with the Lake Superior or Potsdam sandstone.

Still, the argument above is not a coercive one. The true correlation of the Keweenawan is still an open question. And as the U. S. Geological Survey has consistently classed the Keweenawan as pre-Cambrian, I should not expect those at present in charge to change until convinced beyond question that in changing they were right. On the other hand, as my predecessors have classed the Keweenawan as Cambrian, and I believe them right, I cannot change. The only thing to do is to use the term "Keweenawan" or "copper-bearing," which is unambiguous, and avoid committing oneself, except in those formal classifications, where a formation must be placed in one pigeonhole or the other, and then only with due reserve.

REVIEWS

Géosynclinaux et régions à tremblements de terre ("Geosynclines and Earthquake Regions"). By F. DE MONTESSUS DE BALLORE. Bulletin de la Société Belge de Géologie. Brussels, 1905. Pp. xviii + 243–67.

This *mémoire* was read before the Société Belge de Géologie on December 20, 1904. The views presented are so suggestive that they are given here at some length, in order that the geologists of this country may promptly consider the theories advanced. M. de Ballore is well known as the compiler of the earthquake catalogue published in *Beiträge zur Geophysik*, Vol. IV, and the statistics have been turned to account in the article here mentioned. The author lays stress at the outlet upon the apparent influence of relief upon stability in the earth's crust, whether that relief be land or sea bottom. He then adds:

> The seismic description of the globe has afforded two general results of great importance. One of them, the independence of seismic and volcanic phenomena, was already suspected. The other and quite unexpected one was the grouping of the earthquake regions of the earth into two narrow zones lying along two great circles of the globe. This purely geometric relation demanded a geologic interpretation. It was found at once on the maps: *These zones embrace the earthquake regions which coincide exactly with the geosynclines of the secondary epoch*, as represented by M. Haug in his well-known *mémoire* on the geosynclines and the continental areas.
>
> Here is a general synthetic law clearly placing seismic phenomena under the direct control of the principal movements of the earth's crust, for it is along these lines that they have attained their greatest amplitude, both positive and negative. Depending entirely upon statistics and observations, and without the introduction of hypotheses, the law may be stated as follows:
>
> The geosynclines, or the most yielding belts of the earth's crust where the sediments deposited to the greatest thickness have afterward, during the Tertiary epoch, been strongly folded and raised for the formation of the principal present chains or geanticlines, alone include, with only two or three doubtful exceptions, all the seismic regions. . . . .
>
> Seismic instability cannot be uniform along these belts on account of the nonsynchronism of the movements and of the differences of amplitude. They include here and there peneseismic, and sometimes even aseismic, regions, the reason for which may be found in the details of geologic history. . . . .

The folded structure of geosynclines is unstable, while the tabular structure of continental areas is stable, and probably always has been so. Such is the law suggested by looking over the surface of the globe. It is therefore proper to divide the subject into several paragraphs corresponding to the five continental areas and the geosynclinal areas whose limits may be taken as known from the work of M. Haug. These are as follows, with the number of quakes in percentages of the total:

		Number of Earthquakes	Per Cent.
I.	North Atlantic continent	8,939	5.21
II.	Sino-Siberian continent	3,479	2.03
III.	Australo-Indo-Malgache continent	374	0.22
IV.	Africano-Brazilian continent	457	0.27
V.	Mediterranean geosyncline	90,126	52.57
VI.	Circum-Pacific geosyncline	66,026	38.51
VII.	Pacific Ocean	2,033	1.19
	Total	171,434	100.00

The geosynclines thus include 91.09 per cent. of the earthquakes that have been reported, as against 8.92 per cent. only for the continental areas, and that, too, in spite of their much larger land surface.

It may be objected that seismic observations are not old and not sufficiently known, except only for the North Atlantic continent, and that consequently this enormous preponderance of seismicity in favor of the geosynclines is more apparent than real, and that it is misleading on account of the lack of information regarding other continental areas. To this it may be replied that the complexity of geographic and geologic conditions of the North Atlantic continent as compared with the other four is not inconsistent with the larger number of quakes observed in the former, namely, 5.21 per cent. as against 3.71 per cent. noted for the last four. And even if we do not wish to take this argument into account, it must be admitted that at most the five continental areas cannot furnish more than 25 per cent. of the earthquakes, which would reduce to 75 per cent. in place of 91.08 the seismicity of the geosynclines, as compared with 8.92 per cent. of the continental areas. . . . .

It is not expected that the seismic problem will be completely settled by means of this synthetic law. But it is an important result that we can affirm on the strength of statistics the close relation between earthquakes and the zones of the earth's crust where the folds have attained their greatest energy at the same time that the vertical movements have reached their greatest amplitude. . . . .

There follows a brief discussion of the several continental and geosynclinal areas as listed above. The "North Atlantic continent" is defined by him, for purposes of discussion, as comprehending the region lying between the Rocky Mountains and the Urals and north of the Alps and the Antilles. The "Sino-Siberian continent" lies between the Urals and the circum-Pacific and Mediterranean geosynclines. The "Australo-Indo-Malgache continent" is bounded on the east by the circum-Pacific geosyncline, on the north by the Mediterranean geosyncline, and on the west by the Mozambique channel. The "Africano-Brazilian continent" is spoken of as being astride of the South Atlantic and is bounded on the east by Mozambique, on the north by the Mediterranean, and on the west by the circum-Pacific geosyncline.

The Mediterranean geosyncline extends from Java and Sumatra across India, the Gulf of Persia, the Mesopotamian depression, southern Europe from the Caucasus to the Pyrennees, and the Mediterranean Sea to the Atlantic.

The circum-Pacific geosyncline extends from Cape Horn to Behring Strait and New Zealand, including the Antilles.

J. C. BRANNER.

STANFORD UNIVERSITY,
April 12, 1905.

Grundzüge der Gesteinskunde. Teil II, "Spezielle Gesteinskunde." By ERNST WEINSCHENK. Freiburg: Herdersche Verlagshandlung, 1905. Pp. 331, 8vo.

This work places in printed form a course of lectures given by Professor Weinschenk in the University of Munich, and designed to meet the needs of students already somewhat grounded in the general principles of petrology brought out in Part I, "Allgemeinen Gesteinskunde," which appeared several years ago. The volume is divided into three parts, treating respectively of the eruptive rocks, the sedimentary rocks, and the crystalline schists.

The eruptive rocks are treated in general according to the system of Rosenbush, each of the principal types being discussed in a very systematic manner under the following heads: (1) macroscopic characters; (2) mineral composition and structure; (3) chemical characters, and (4) occurrence and geological age.

The sedimentary rocks are treated under the usual divisions of mechanical, chemical, and organic sediments, and the principal types of rocks under each of these are quite fully discussed.

About thirty pages are devoted to the crystalline schists, the leading types being treated rather less systematically and in less detail than the types of eruptive rocks.

The illustrations are unusually good and are judicially selected; they include eight plates, and numerous illustrations and diagrams in the text. The characteristics of the various types of igneous rocks are well brought out in two tables. While valuable in a descriptive and historical way, many of the more theoretical portions of the book willl be regarded by American students as not entirely in accord with modern notions. This is particularly true of the author's treatment of metamorphism, which is still dominated by the older ideas of a stiff liquid condition during metamorphism, and into which the newer ideas of the continuance of a rigid condition do not enter.

E. S. B.

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"FOR BATH
& TOILET"
PEARS

THE
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THE MINERAL MATTER OF THE SEA, WITH SOME SPECULATIONS AS TO THE CHANGES WHICH HAVE BEEN INVOLVED IN ITS PRODUCTION

ROLLIN D. SALISBURY
The University of Chicago

It has been calculated that if the salt now in the sea were precipitated, it would make something like 3,500,000 cubic miles. If to this be added all the other mineral matter in solution in the sea water, the amount would be swollen to about 4,500,000 cubic miles.[1] This amount of mineral matter is equal in amount to nearly one-fifth of all the material in all lands above the sea at the present time; that is, equal to all the material in North America, Europe, and Australia, and most of the islands of the sea. If the mineral matter of the sea were precipitated on the ocean bottom, it would make a layer about 175 feet deep. If it were precipitated and concentrated in the shallow water of the ocean about the borders of the continents, building up the bottom to sea-level, this amount of mineral matter would add something like 19,000,000 square miles to the land—an area equal to about one-third that of all existing land. Most of this mineral matter in solution in the sea has probably come from the rocks of the land and of the sea bottom, chiefly the former.

Amount of mineral matter extracted from the sea.—These figures may perhaps give some idea of the amount of mineral matter in solution in the sea, but they give no more than a hint of the importance

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[1] *Scottish Geographical Magazine*, Vol. XXI, p. 133.

of the solvent work of water, for most mineral matters carried to the sea in solution by rivers are extracted from the water about as rapidly as they are supplied. It is probable, indeed, that the amount of mineral matter which has been extracted from the sea water far exceeds all that remains in solution. This conclusion may be reached either (1) by calculating the volume of rock material which has been extracted from the sea water, or (2) by comparing the proportions of the various sorts of mineral matter in sea and in river water.

1. The rock matter extracted from the sea includes most of the limestone, the gypsum, and the salt, and much of the cementing material of all other sorts of sedimentary rock. Data concerning the thickness of such materials beneath the sea are not available, but some calculations concerning their average thickness in land areas, most of which have been beneath the sea at times, have been made. Dana estimated the average thickness of limestone (presumably for the continents) at about 1,000 feet.[1] This figure appears to take no account of the calcium carbonate which forms an important constituent of many shales and some sandstones, and it is not clear whether it was meant to include dolomites.

Reade estimates the thickness of the limestones for the globe (not for the continents merely) at about 528 feet;[2] but this figure, like the preceding, appears to take no account of the calcium carbonate in the sandstones and shales.

Van Hise, attempting to underestimate rather than overestimate, assigns a thickness of 328 feet to the limestones of the continents in the zone of katamorphism, and estimates that about an equal amount of calcium carbonate exists in the shales and sandstones.[3] This gives an aggregate of 656 feet of calcium carbonate for the continents above the zone of anamorphism.

If the estimates of Dana and Reade be increased to make allowance for the calcium carbonate in the shales and sandstones, and if the estimate of Van Hise be increased to include the limestones below

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[1] Dana, *Manual of Geology*, 4th ed., p. 485.

[2] T. Mellard Reade, *Chemical Denudation in Relation to Geological Time* (London, 1879), p. 53.

[3] *Monograph 47*, U. S. Geological Survey, pp. 940, 941.

the zone of katamorphism—and limestone is known to exist there—all the above figures will be increased.

No careful estimate of the amount of limestone beneath the sea is possible, but its amount must be great. It probably forms a larger proportion of the sediment than on land, but it does not follow that its average thickness is greater. If we assume that the average thickness of limestone beneath the sea is half as great as that on the land, and that the amount of calcium carbonate in other sedimentary rocks beneath the sea is, on the average, half as great per square mile as on land, we may derive from the figures representing the estimated thickness of limestone material on the continents, figures representing an estimated average for the earth. These figures are 420 (based on the estimate of Van Hise) and 850 feet (based on the estimate of Dana). The estimate of Reade, increased to allow for the calcium carbonate in clastic rocks, becomes 738 feet.

Even if these large figures be correct, they represent less than the total amount of mineral matter which has been extracted from the sea, since they deal with one sort of mineral matter only. How much they should be increased to include all the mineral matter ever extracted from the waters of the sea cannot be stated; but the silica, the various sulphides and sulphates, the chlorides, etc., which have been extracted from the sea water, would swell them appreciably.

Much material, such as that of limestone, has been extracted from the sea water and deposited, and then re-dissolved, re-extracted, and re-deposited. Some material, indeed, has probably gone through this cycle many times. The aggregate result of the solvent work of water is therefore not represented by the amount of existing rock matter which has been extracted from the sea, plus that which still remains in solution. Furthermore, the considerations adduced take no account of the deposition of material from solution on the surface of the land, or beneath it, or in the lithosphere under the sea. The amount of mineral matter deposited from solution in these situations is certainly great, though it cannot well be estimated. It must, however, be recognized, in attempting to gain the proper conception of the solvent work of ground water.

2. By comparing the mineral matter in the sea water with that in average river water, Tables I and II, it is seen that calcium car-

bonate is about 20 times as abundant as sodium chloride in river water, but only $\frac{1}{225}$ as abundant in sea water. If the calcium carbonate which has been taken to the sea in solution by rivers had remained in solution as calcium carbonate in the same proportion that the sodium chloride has remained in the sea water, the figures representing the amount of common salt which the sea contains would seem almost insignificant in comparison. Even if calcium carbonate is changed to calcium sulphate in the sea, as is sometimes thought, the case is not seriously altered, for the amount of calcium sulphate in the sea is but a small fraction of the amount of sodium chloride. In order that the sodium chloride should have attained such predominance, it is necessary to suppose that enormous quantities of the compounds of calcium have been extracted, if the salt of the sea has been derived from the land.

The average river water contains about seven times as much magnesium carbonate as sodium chloride, four and a half times as much silica, twice as much calcium sulphate, twice as much sodium sulphate, more potassium sulphate, and more sodium nitrate; yet the combined volume of all these substances in the sea water is but a small fraction of the amount of sodium chloride.

By either of these lines [(1) and (2)] of approach, we reach the conclusion that the amount of mineral matter which the sea has lost from solution far exceeds that which it has held until the present time.

TABLE I

AMOUNT OF MINERAL MATTER IN SOLUTION IN ONE CUBIC MILE OF SEA WATER[1]

Constituents	Tons
Chloride of sodium ($NaCl$)	117,434,000
Chloride of magnesium ($MgCl_2$)	16,428,000
Sulphate of magnesium ($MgSO_4$)	7,154,000
Sulphate of calcium ($CaSO_4$)	5,437,000
Sulphate of potassium (K_2SO_4)	3,723,000
Bromide of magnesium ($MgBr_2$)	328,000
Carbonate of calcium ($CaCO_3$)	521,000
For sea water, total dissolved matter	151,025,000

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[1] Dittmar, *Challenger Reports*, Physics and Chemistry, Vol. I, p. 204.

TABLE II

MINERAL MATTER IN SOLUTION IN ONE CUBIC MILE OF AVERAGE RIVER WATER[1]

Constituents	Tons
Calcium carbonate ($CaCO_3$)	326,710
Magnesium carbonate ($MgCO_3$)	112,870
Calcium phosphate ($Ca_3P_2O_8$)	2,913
Calcium-sulphate ($CaSO_4$)	34,361
Sodium sulphate (Na_2SO_4)	31,805
Potassium sulphate (K_2SO_4)	20,358
Sodium nitrate ($NaNO_3$)	26,800
Sodium chloride ($NaCl$)	16,657
Lithium chloride ($LiCl$)	2,462
Ammonium chloride (NH_4Cl)	1,030
Silica (SiO_2)	74,577
Ferric oxide (Fe_2O_3)	13,006
Alumina (Al_2O_3)	14,315
Manganese oxide (Mn_2O_3)	5,703
Organic matter	79,020
Total dissolved matter	762,587

Time necessary for the accumulation of the mineral matter of the sea.[2]—The discharge of water into the sea by rivers is estimated at 6,524 cubic miles per year.[3] This volume of water is estimated to carry to the sea 0.433 cubic miles of mineral matter in solution.[4] At this rate, it would take about 10,500,000 years for the streams to carry to the sea an amount of mineral matter equal to that which it now contains, and at this rate it would take about 54,000,000 years for an amount of mineral matter equal to all that is now above the sea, to be dissolved and carried to the oceans.

The sodium chloride makes up about 2.2 per cent. of the mineral matter in solution in river water. The same substance constitutes nearly 78 per cent. (77.758 per cent.) of the mineral matter in the sea water. The 2.2 per cent. of 0.433 cubic miles is 0.0095 of one cubic

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[1] Murray, *Scottish Geographical Magazine*, Vol. III, p. 77.

[2] Most of the following computations have been made or verified by Messrs. J. H. Lees and E. W. Shaw.

[3] Murray, *op. cit.*, Vol. IV, p. 41.

[4] Murray, *loc. cit.*, states that the amount of mineral matter carried to the sea annually by rivers is 1.183 cubic miles; but the data on which this calculation is based (*op. cit.*, Vol. III, p. 76, 77) give only 0.433 cubic miles.

mile, which represents approximately the amount of salt brought to the sea per year by rivers, assuming that the specific gravity of salt is the same as the average specific gravity of the mineral matter in solution in the sea and rivers; while 77.758 per cent. of the total amount of mineral matter of the sea (4,532,110 cubic miles) is 3,524,078 cubic miles, the approximate amount of salt in solution in the sea water. This amount divided by 0.0095 is more than 370,000,000, which represents roughly the number of years it would take for the amount of salt now in the sea to have been brought to it by rivers, at the present rate.

This figure is, however, not to be taken as representing the age of the sea. There are several reasons for avoiding this conclusion. These are as follows: (1) The rate at which salt has been brought in by rivers has probably not been constant; (2) the salt may have been derived partly from sources other than land waters; and (3) much salt has been extracted from the sea water and deposited. The second and third points tend to offset each other. In spite of the limitations imposed by these considerations, the figure 370,000,000 may give some conception of the order of magnitude of the number which expresses the age of the sea in years.[1]

The calcium carbonate carried to the sea by rivers in solution, at the present time constitutes, according to Table II, nearly 43 per cent. of all the mineral matter taken to the sea in solution. Its amount is therefore about one-fifth of a cubic mile per year. The calcium carbonate now in solution in sea water represents but 0.00345 of the mineral matter which the sea contains. This fraction of 4,532,110 cubic miles is about 15,635 cubic miles, which represents, approximately, the amount of calcium carbonate now in solution in the sea. If this substance is carried to the sea at the rate of one-fifth of a cubic mile per year, it would take only about 84,000 years for the amount now in solution in the sea to be brought down from the land. If the calcium sulphate of the sea water has been derived partly from the calcium carbonate brought to the sea, this

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[1] Professor Joly has calculated, from the salt of the sea, that the time since the ocean began to receive solutions from the land may be 90 to 100 millions of years. He assigns 10 per cent. of the sodium chloride of the rivers to atmospheric sources. (*Transactions of the Royal Society of Dublin*, Vol. VII (Series 11), 1899, p. 23, and *Geological Magazine*, 1900, p. 220.)

period of 84,000 years should be lengthened. Treating calcium carbonate and calcium sulphate as one, it would take the rivers about 740,000 years to contribute what the sea now contains.

The reason for the great discrepancy between these figures and those which represent the time necessary for the accumulation of the salt of the sea, is doubtless found in the fact that the calcium compounds are extracted by the organisms of the sea, to make shells, tests, etc., about as fast as they are brought in, while the salt remains in solution.

The amount of calcium carbonate which may have been in solution in the sea.—The amount of calcium carbonate which would have been carried to the sea by rivers in 370,000,000 years, at the rate at which rivers are now contributing it, is about 68,600,000 cubic miles. In the same time the rivers should, at their present rate, have contributed about 7,200,000 cubic miles of calcium sulphate, or nearly 76,000,000 cubic miles of calcium carbonate and calcium sulphate. Since not more than about 179,000 cubic miles of calcium compounds (carbonates and sulphates) remain in solution in the sea at the present time, it will be seen that an enormous amount must have been extracted.

Most of the calcium deposited in the sea has been deposited in the form of calcium carbonate. If an amount of calcium carbonate and calcium sulphate corresponding to the difference between 76,000,000 and 179,000 cubic miles has been deposited, it would make a layer about 1,920 feet thick over the entire earth. Since, however, some of the calcium carbonate taken in solution to the sea has been redissolved, some of it repeatedly, after precipitation, the average thickness of that which has been deposited must be much less than 1,920 feet. Perhaps this figure should be reduced by one-half on this account.

Sixty-eight million six hundred thousand cubic miles, it may be noted, is about three times the cubic contents of all lands. Assuming that rivers have been supplying calcium carbonate and sodium chloride to the sea at the present rate, and assuming that the land has been the only source of these materials in the sea, it follows that the rivers should have carried to the sea an amount of calcium carbonate equivalent to about three times the cubic contents of all existing land, during the time necessary for furnishing the salt, at the present rate. If some of the salt has been derived from the lithosphere beneath the sea, the figures should be correspondingly reduced, though it is probable that the land has furnished much more salt than the sea bottom has. The reduction on this account is, in some measure, or perhaps altogether, offset by the allowance which should be made in the opposite direction for the salt which has been deposited among the sedimentary rocks of the earth.

Amount of average rock decomposed.—From the amount of salt in the sea, and from the amount of calcium carbonate which the sea is estimated to have had, calculations may be made as to the amount of average rock which must have been destroyed to produce them.

1. The average composition of accessible non-sedimentary rocks has been determined, probably with a fair degree of accuracy.[1] Knowing the percentage of sodium in this average rock, the volume of rock which must have been decomposed in order to furnish the sodium necessary to make the salt of the sea may be calculated. The average rock contains about 2.53 per cent. of sodium, and of rock containing this amount of sodium nearly 55,000,000 cubic miles would need to be decomposed, to yield enough sodium to form the salt now in the sea. The salt of the sea, therefore, seems to imply the decomposition of some such quantity of average rock. Since only about 23,500,000 cubic miles of rock now remain above sea-level,[2] and since much of this is sedimentary rock derived from the original rock, and since much of the non-sedimentary rock is not decayed, and still holds its sodium, it would appear that the larger part of the 55,000,000 cubic miles of rock necessary to yield the requisite amount of sodium must have been removed from the land to the sea.

2. A similar line of inquiry may be based on the amount of calcium carbonate which the sea has had in solution. The average rock contains about 4.90 per cent. of CaO.[3] On p. 471 the figures 420, 738, and 850 feet were deduced as perhaps representing, as well as they are now known, the limiting average thicknesses of limestone material for the earth. The largest of these figures is about twice

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[1] F. W. Clark, *Bulletins 168* and *228*, U. S. Geological Survey.

[2] Murray, *op. cit.*, Vol. IV, p. 40.

[3] Clark, *op. cit.*

the smallest. For convenience of calculation, and in view of the somewhat uncertain nature of the data on which they are based, no further error of great magnitude will be involved if the smallest of these figures be regarded as half of the largest, that is, 425.

If 425 and 850 feet be assumed to represent the maximum and minimum average thickness of limestone material, as nearly as it is now known, and if four-fifths of this be assumed to be calcium carbonate,[1] the amounts of calcium carbonate in the earth's crust would be equivalent to nearly 12,700,000 cubic miles in the one case, and to 25,400,000 cubic miles in the other. These figures are much smaller than that given on p. 475, but that includes the calcium carbonate re-dissolved, and carried anew to the sea, after being once deposited. These do not.

The amounts of average rock the decomposition of which would be needed to yield the amount of calcium necessary for these amounts of calcium carbonate, supposing all the calcium to be separated so as to be available for union with carbonic acid gas, would be 145,000,000 cubic miles and 290,000,000 cubic miles, respectively. These results, it will be seen, are about 2.6 and 5.2 times as large, respectively, as those derived from the calculation based on salt of the sea. Even after allowance is made for the salt which has been deposited, the figures are far apart. This means that some of the sodium does not unite with chlorine to produce salt, or that more of the sodium chloride has been deposited than is known, or that there is some other discrepancy in the data. In spite of the discrepancy, however, it will be noted that the figures belong to the same order of magnitude.

The same problem may be approached in another way. We have seen that the amount of calcium carbonate which should have been carried to the sea in the time necessary for the accumulation of the salt, assuming all of the latter to have come from the land, and at the present rate, is more than 68,000,000 cubic miles, and, if the calcium sulphate be added, about 76,000,000 cubic miles. To yield the calcium called for by these volumes, the decomposition of about 777,000,000 cubic miles of average rock would be necessary, if the calcium carbonate only is taken into consideration, and more than 60,000,000

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[1] The rest being magnesium carbonate. Clark, *Bulletin 228*, U. S. Geological Survey, pp. 20, 21.

cubic miles more, if the calcium sulphate be included. Seven hundred and seventy-seven million cubic miles is more than 33 times the estimated cubic contents of the land, while 837,000,000 cubic miles (777,000,000 + 60,000,000) is about 36 times the estimated cubic contents of the land. These figures should be reduced to make allowance for the calcium carbonate which has been redissolved after having been precipitated. If half the calcium carbonate which the ocean water has had has been re-dissolved after having been once precipitated, the last figures should be divided by 2. Reduction should also be made for the calcium carbonate which has been derived from the rocks beneath the sea.

Assuming that 2 is the proper divisor, the amount of average igneous rock which must have been destroyed to produce the amount of calcium carbonate carried to the sea, at the present rate, in 370,000,000 years, is about 388,500,000 cubic miles, or, if calcium sulphate be included, 418,500,000 cubic miles. This amount of rock would make a layer more than 2 miles thick over the entire surface of the earth, and more than 6½ miles thick over the continents and continental shelves. This volume of mineral matter is about 18 times all that is now above the surface of the sea. These calculations, even though the figures involve a considerable error, indicate that an enormous body of rock must have been decomposed.

By both these methods of calculation, based on the calcium carbonate, it will be seen that the amount of average rock needed (pp. 476 and 477) to yield the estimated supply of calcium carbonate is considerably more than that needed to yield the known amount of salt. It is probable that salt furnishes the better basis for the estimates, since the amount which has been formed is probably more nearly known, most of it being presumed to still remain in the sea.

Even the above figures do not represent the full measure of transfer of the material from land to sea. In the decomposition which igneous rock undergoes, before yielding up its calcium in soluble form, it undergoes notable expansion. It follows that the preceding figures great as they are, may not represent the actual amount of average rock material destroyed, and removed from land to sea.

Assigning the average igneous rock a mineral constitution consistent with its chemical composition, its expansion on decomposition may be estimated. The precise changes which such rock undergoes doubtless vary from point to point, and the degree of change before removal by erosion must also vary. It is probably safe to say that if the decomposition is measurably complete, the expansion in volume would be not less than an eighth, and it might be as much as a third. Let it be assumed to be one-fifth. The 55,000,000 cubic miles, the decomposition of which is called for to furnish the sodium necessary for the salt of the sea, would then become 66,000,000 cubic miles, and the 145,000,000 and the 290,000,000 cubic miles, the decomposition of which is called for to furnish the calculated amount of calcium carbonate, would become, respectively, about 174,000,000 and 348,000,000 cubic miles; while the 388,500,000 and 418,500,000 cubic miles (p. 479), increased by one-fifth, become about 466,000,000 and 502,000,000 cubic miles, respectively. These figures represent, respectively, about 3, 7, 14, 20, and 21 times the amount of material now above sea-level.

Since most of the decomposed rock is believed to have been in the land, and since but about 23,500,000 cubic miles now remain above sea-level, and this largely undecomposed, so far as it is non-sedimentary, it follows that an enormous body of rock material must have been removed from the land to the sea. If the rock so removed was not so completely decomposed as to yield up all its sodium and calcium, the total amount would have been greater than if decomposition were complete. When due allowance is made for the uncertainties of these figures, they are still so large as to give a magnified conception of the work which land waters may have done in the later stages of the earth's history. The transfer from land to sea of an amount of material equal to even 3 times all that that is now above the sea is most impressive. The transfer of an amount 21 times as great as that now above the sea, is still more stupendous.

3. The same general results may be approached in another way, though the calculation is based on somewhat speculative data. It has been estimated that the carbonic acid gas of the atmosphere is being consumed, in the original carbonation of rocks, at the rate of 270,000,000 tons per year.[1] On the assumption that four-fifths of this amount of carbonic acid gas goes to the carbonation of calcium

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[1] Reade, cited by Chamberlin, *Journal of Geology*, Vol. VII, p. 682.

oxide,[1] the amount of calcium carbonate produced would be about 490,900,000 tons per year. This would make approximately $\frac{1}{26}$ of a cubic mile. To furnish the amount of calcium oxide necessary for this amount of calcium carbonate, the decomposition of nearly one-half (0.44) a cubic mile of average rock would be required. In 370,000,000 years (p. 474) some 163,000,000 cubic miles of average rock would have been decomposed at this rate.

4. We are not obliged to rely on calculations based on somewhat unobtrusive changes, for our knowledge of the wasting away of the continents. Some conception of its importance may be gained in another way. The amount of sediment which streams carry to the sea each year has been calculated, with some approximation to accuracy. The amount of matter which they take to the sea from the land, including that carried in solution, as well as that carried mechanically, has been estimated as 3.7 cubic miles every year.[2] If this figure be modified to make allowance for the reduced volume in solution (p. 473), it becomes a little less than 3 cubic miles (2.93). Besides this loss to the lands through the erosion of the rivers, the winds blow great quantities of dust and sand into the sea every year, while the waves beat effectively on the coasts, cutting off, in the aggregate, enormous quantities of land material, and extending the dominion of the sea.

If rivers were to continue to wash away the continents at the present rate, they would remove to the sea an amount of material equal to all that is now above sea-level in less than 8,000,000 years, and the work of the winds and waves would shorten this period considerably.

If rivers have been wasting the land at the present rate for 370,000,000 years, they would have destroyed and carried away from the land about 58 times the amount of rock material now above sea-level. These figures take no account of the material blown from the land to the sea, nor of that worn from the shores by waves. If the work of these agents were taken into consideration, the figures given above would be notably increased. On the other hand, the

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[1] F. W. Clark, has shown that the ratio of calcium oxide and magnesium oxide in 345 limestones analyzed is about 5½ to 1. *Bulletin 228*, U. S. Geological Survey, pp. 20, 21.

[2] Murray, *op. cit.*, Vol. IV, p. 41.

present rate of river erosion is probably well above the average for the earth's history, since the lands are now relatively high.

5. There is still another way of approaching this problem. The sedimentary rocks of the continental areas are estimated to have a thickness, on the average, of something like a mile. No estimate of their average thickness in the sea is possible, but it is probably much less. If it be assumed to be one-fourth as great, the volume of sediment for the whole earth would be about 4 times that of the rock in all the lands of the earth. These figures, it will be seen, are near the least of those derived by the other modes of calculation (see p. 479).

Summary.—It appears, then, that we are to think of the decay and removal to the sea of an amount of rock equal to at least several times all that is now above the sea, during the course of the earth's history. The results of the several lines of calculation place the amount at 3 to 21 times all that is now above sea-level. The truth may lie between these extremes. So uncertain is the nature of the data, however, that we must recognize that the truth may lie outside of either, so far as present knowledge goes.

Renewal of the continents.—It is, of course, not to be inferred that the continents were ever large enough to include all the material which has been worn away from them, in addition to that which they now contain. They may never have been much larger than now, and they have certainly often been smaller. As their masses were reduced by erosion, they were renewed, either (1) by the sinking of the sea bottom, which drew the water off the areas which had been covered by shallow water only, or (2) by the rise of the continental areas. The former was probably the more common.

The renewal of the lands has not always kept pace with their reduction, so that the area of the lands and the amount of rock which they have contained, have fluctuated notably from time to time.

Effect of preceding changes on areas of sea and land.—Though great weight is not to be attached to the figures worked out on the basis of the assumptions made, it is believed not only that they are suggestive of the amounts of rock which have been worked over in the earth's history, but that they suggest lines of quantitative study which are worthy of attention. If, for example, a given amount of rock has been removed from land to sea, the resulting change of sea-level may be calculated. If the bottom of the sea were not warped so as to increase or decrease the capacity of its basin, the transfer of 66,000,000 cubic miles of rock from land to sea would raise the level of the latter more than 2,400 feet,[1] if no allowance be made for the increased area resulting from the rise. The transfer of 174,000,000 cubic miles of rock from land to sea would raise its level more than 6,400 feet, while the transfer of 348,000,000 cubic miles would raise its level nearly 13,000 feet, or more than two and one-half miles, if its area remained constant. The increase of area which would be involved would, of course, reduce these figures sensibly.

If the sea-level were to rise 2,400 feet at the present time, about two-thirds of all the present land would be submerged, and if it were to rise 13,000 feet, only about 2 per cent. of the present land would remain above it. Even if allowance is made for the increase of area which its rise would produce, the transfer of 348,000,000 cubic miles of rock material to the sea would leave no vestige of land in North America east of the Rocky Mountains, and all that remained within the area of the western mountains would be a series of islands where the higher mountains now are. On the basis of even the least of these figures, 2,400 feet, reduced so as to make allowance for the increase of area which would be involved, there would be changes of relative level between sea and land, of an order commensurate with those which are known to have taken place from time to time during the earth's history.

There is reason to believe that the continents, at least those whose geological history is best known, have more than once been worn down toward sea-level—worn down so low that rivers became sluggish, and their mechanical erosion relatively slight. Such a condition would exist if the lands of the present time were worn down to an average height of 500 feet. In this case, about 5,000,000 cubic miles

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[1] The materials taken to the sea in solution would not raise the level of the sea so much, cubic mile for cubic mile, as mechanical sediments. Since much the larger part of the sediment taken to the sea has been in the form of mechanical sediments, if we may judge from present conditions, this difference is here neglected; but it seems probable that the amount of dissolved matter has been greater than now, relative to the mechanical sediments, if the whole of the earth's history be considered.

of rock would remain above sea-level, while about 17,000,000 would have been removed. The deposition of 17,000,000 cubic miles of mineral matter in the sea would raise its level between 500 and 600 feet, and such a rise would submerge an area of about 12,000,000 square miles of the present land, or more than one-fifth of its area. Considering the much larger area which would be submerged by an equal rise of the sea-level when the lands had been lowered to the extent indicated, there would be a submergence of continents comparable to those which have repeatedly marked the beginnings and ends of geologic periods.

The facts (1) that the notable changes in relative level of land and sea have been periodic, and (2) that the sea-level seems to have been lowered at times, and not to have been continually rising, as it would be if affected by sedimentation alone, are probably to be accounted for by crustal warpings.

In so far as sedimentation has been a cause of subsidence of the ocean bed, the subsidence has probably lagged behind the sedimentation. In so far as the sinking of the sea bottom is independent of sedimentation, it is unlikely that it always, or even generally, kept pace with sedimentation. It would appear, therefore, that rise of the sea-level due to sedimentation may have been an important factor, or even, perhaps, a chief factor, in the submergence of the continents, at various periods in the earth's history, while the unequal rates at which sediment has been transferred from land to sea may have had an influence on the rate at which submergence was brought about. It is highly probable that crustal warpings, by increasing the capacity of ocean basins, have, on the whole, tended to reduce the amount of change of sea-level which sedimentation alone would have effected. Volcanic material extruded into the sea, on the other hand, has worked in the opposite direction.

Rate of change in relations of sea and land.—It is not to be supposed that such changes in the level of the sea as those mentioned on p. 482 have actually taken place as the result of sedimentation, for the ocean bed has probably been sinking through the ages, though perhaps not continuously, and probably not at a constant rate, even during periods of sinking. Subsidence of the ocean bottom would tend to counteract the effect of sedimentation, so far as its effect on the level of the sea is concerned, for sinking of the bottom increases the capacity of the basin, just as the deposition of sediment in it decreases it. At those periods when sedimentation in the oceans exceeded subsidence of the ocean beds, the sea-level must have risen, and the lower parts of the continents must have been submerged. At those periods when subsidence of the ocean bed increased the capacity of the basin more rapidly than sedimentation decreased it, the water would have been drawn off the continental shelves, and lands would have emerged. It seems not improbable that this has been a main factor in bringing about repeatedly the submergences of great parts of the continental areas, in the course of geological history.[1] The periodic sinking of the continents bodily has doubtless also been a factor leading to the same result.

It is to be understood that all changes of sea-level, due to sedimentation and warping, have probably taken place very slowly—so slowly that their effects, in all probability, would not have been conspicuous to observers, had there been observers to witness them.

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[1] The effectiveness of gradation (degradation and aggradation) in bringing about considerable submergences of land areas was first urged, so far as I am aware, by Professor Chamberlin.

ERRATUM

To accompany the paper by R. A. Daly on "The Classification of Igneous Intrusive Bodies," *Journal of Geology*, Vol. XIII, p. 485.

NOTE.—Through oversight the "explanations" of the figures in the text were omitted.

EXPLANATIONS OF FIGURES

FIG. 1.—Diagrammatic map of a composite dike in Arran.

(After Judd, *Quarterly Journal of the Geological Society*, London, Vol. XLIX (1893), p. 545.)

1. Country rock (granite).
2. Augite andesite.
3. Quartz-felsite.
4. Pitchstone-porphyry.

The andesite was intruded along a fissure in the granite; then the felsite and porphyry were in succession intruded along the middle plane of the andesite dike.

FIG. 2.—Section of the Moyie Sill, British Columbia, at the crossing of the Moyie River and International Boundary.

Illustrating a body which has the form and relations of a true sill, although the thickness is more than 2,500 feet.

FIG. 3.—Section of a composite sill in the island of Skye.

(After Harker, *Tertiary Igneous Rocks of Skye*, 1904, p. 204.) The stratified Lias was cut by the sill of basalt; a later sill, of granophyre, was intruded along the middle plane of the basic sill. The latter itself may have been double.

FIG. 4.—Section of a composite laccolith.

(After Harker, *op. cit.*, p. 209.) The black is basalt, the white, granophyre. The laccolith cuts heavily bedded lava flows. The maximum thickness of the laccolith is 150 feet.

FIG. 5.—Section of an interformational laccolith.

(After Weed and Pirsson, *Journal of Geology*, Vol. IV (1896), p. 412.) The floor of the porphyry laccolith (in black) is composed of Pre-Cambrian crystalline schists; the cover, of Palæozoic sediments. The length of the section represented is about ten miles.

FIG. 6.—Section of a typical volcanic neck.

(After Geikie, *Ancient Volcanoes of Great Britain*, Vol. II. p. 273.)

FIG. 7.—Diagrammatic map of a Tertiary "chonolith" of rhombenporphyry (crosses).

Cutting intensely folded Palæozoic sediments (broken lines) and Tertiary sandstones and conglomerates (white), occurring on the Kettle River, British Columbia. At its northern end the porphyry disappears under a late Tertiary lava-cap (stippled). The Tertiary sediments are tilted and faulted. The faulting was accompanied, or immediately followed, by the intrusion of the porphyry which field evidence shows to have been injected as a body with a highly irregular form.

FIG. 8.—Diagrammatic map and section of Ascutney Mountain, Vermont.

Illustrating a composite stock, composed of successive intrusions, in stock or boss form, of diorite, syenite, and granite. A small boss of syenite (shown in black) cuts the diorite. These bodies cut crystalline schists, the attitude of which is indicated by the conventional symbol for strike and dip.

FIG. 9.—Map of part of the West Kootenay District, British Columbia.

Illustrating a small batholith of syenite (vertical lining) and the southern edge of the great composite batholith of the district. The latter is made up of the "Nelson granite" (thin, widely spaced, horizontal lines), cut by the younger "Rossland Alkali granite" (more closely set horizontal lines) and by the "Valhalla granite" (heavy horizontal lines). The maximum east-west width of the smaller batholith is fifteen miles.

THE CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES[1]

REGINALD A. DALY
Ottawa, Canada

CONTENTS

THE NEED FOR A CLASSIFICATION

At the present time geological science is engaged with no general question more widely and thoroughly discussed than that of the origin of the igneous rocks. The elaborate chemical studies of those rocks, the many new classifications of rock species, the modern experiments in the synthesis of natural silicates, and the experiments on the physical and chemical properties of molten silicates, have as their chief end the demonstration of the facts upon which a stable theory of rock genesis can be founded.

All such studies must be pursued with constant reference to the actual occurrences of igneous rocks in nature. Petrology is dependent upon, knit together with, field geology; the heart of geological philosophy is petrology in its broad sense. On the chemical side the laboratory observations of rock-analysts have been rated as "superior" (excellent, fair, or good) or as "inferior" (poor or bad). Similarly, field observations can be rated as superior or inferior according to the fulness and accuracy with which they supply the data from outdoor nature. Of those facts none is of more importance to petrology than the mode of occurrence of igneous rocks.

The field information required for the great group of the igneous intrusives relates to their shapes, sizes, and methods of intrusion. The statement of field facts depends on the precision of the terms

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[1] Published by permission of the Canadian Commissioner, International Boundary Surveys.

used to describe them. That precision depends on definition. Scientific definition necessarily means classification.

Neither in the definition nor in the classification of igneous intrusive bodies is there at present unanimity or consistency among geologists. The same author defines "dike" or "sheet" or "batholith" in quite different ways on different pages. Of late years "laccolith," "boss," "stock," and practically every other term referring to igneous intrusions, have from different writers respectively received definitions varying in essentials. In several cases the difference of usage has sprung from the subjective influence of theories of intrusion. Some of the most recent definitions of older terms have thus become too intensive in meaning to fill the needs of the great body of field workers who are still in the wholesome attitude of mind that forbids the final adoption of any theory of intrusion for many important igneous bodies.

The writer believes that a comparatively full classification of igneous intrusive bodies is needed. The general adoption of a consistent, well-defined scheme of types—a scheme as complete as possible, but elastic enough to permit of new types—would tend to make field descriptions more scientific than many of them are at present. Such general adoption would mean a gain in precision, the soul of scientific writing; a gain in the ease with which a paper descriptive of igneous intrusions would be understood; and an economy of words induced by the employment of terms of definite, precise meaning. The filling-out of the scheme of classification to an extent quite beyond that now prevailing in standard text-books of geology should further have the effect of sharpening the eyes of the field observer. He may perhaps not be content to describe a given granite intrusion as simply a "mass," or an "area," or an "outcrop," if it be possible by the study of its contents to indicate the real form and relations of the granite body. The use of the term "mass" in that sense is often excellent because of the apparent impossibility of determining the true shape of the granite body; but such justifiable employment of the term implies that that particular body cannot as yet be thoroughly classified. A rather negative name has in such a case a distinct value. Of yet greater value is the positive reference of intrusive bodies to definite categories. A good observer always feels the pressure of the category. If his classification be systematic, his observing power is quickened, his report enriched; if his classification be that in general use, his descriptions will be of the greater service to the science.

The purpose of this paper is to present certain of the current definitions and classifications of intrusive bodies; from the definitions and classifications to attempt the deduction of the various principles underlying them; and, finally, to offer for discussion a classification which shall aim at a systematic and consistent use of the principles which seem best adapted to the case. As far as possible, these principles are the same as those already in common use among leading geologists.

FORMER CLASSIFICATIONS

A few representative classifications of igneous intrusive bodies will serve to show the range of types recognized by recent authors.

I. Sir Archibald Geikie, *Text-book of Geology* (4th ed., 1903), Vol. II, p. 722:
  1. Bosses (stocks).
  2. Sills, intrusive sheets.
     Variety: laccolith.
  3. Veins and dykes.
     Varieties: contemporaneous veins, segregation veins, multiple dykes, compound dykes.
  4. Necks.

II. T. C. Chamberlin and R. D. Salisbury, *Geology* (1904), Vol. I., pp. 476, 477:
  1. Dikes.
  2. Necks or plugs.
  3. Sills.
  4. Laccoliths.
  5. Bysmaliths.
  6. Bathyliths.

III. F. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539:
  1. Gänge.
  2. Lagergänge.
  3. Gangstöcke.
  4. Apophysen.
  5. Stöcke.
  6. Intrusivlager.
  7. Lakkolithen.

DEFINITION OF TERMS DESCRIPTIVE OF INTRUSIVE BODIES

Dike.—The best established of all the terms used in the foregoing lists is "dike;" yet the variation in even recent definitions of it is apparent in such examples as the following:

I. G. K. Gilbert:[1]

> Dikes differ from sheets in that they intersect the sedimentary strata at greater or less angles, occupying fissures produced by the rupture of the strata.

II. G. P. Merrill:[2]

> A dike: "an eruptive mass of varying width included between well-defined walls, and occupying a fissure or fault in previously consolidated rocks. Such are inclined at all angles with the horizon, and are usually of very moderate width, but may extend for miles."

III. T. A. Jaggar:[3]

> A dike is an elongate intrusive igneous body occupying a fissure in any sort of rock, the walls of which at the time of intrusion were vertical or, if inclined, at angles nearer the vertical than the horizontal. A dike must have longitudinal extension much greater than its breadth, but may vary in thickness from an inch to several hundred feet. A dike may be irregular or may follow a sinuous course; it may be intruded between the beds of vertical or steeply inclined sediments; it frequently follows joint surfaces and has smooth and plane bounding walls. It must be noted that a flat igneous mass intruded between horizontal or nearly horizontal strata, and subsequently upturned with them to a vertical position, is not a dike, but a sill.

IV. Sir Archibald Geikie:[4]

> Dykes are veins of eruptive rock, filling vertical or highly inclined fissures, and are so named on account of their resemblance to walls (Scotice, dykes).

V. T. C. Chamberlin and R. D. Salisbury:[5]

> When lava is forced into crevices or rises to the surface through fissures, and the residual portion solidifies in them, it gives rise to dikes.

All the foregoing definitions agree in ascribing to a dike the characteristic form of a fissure-filling. Gilbert, in the quotation; Geikie, and Chamberlin and Salisbury, in their respective contexts, expressly exclude from the category of dikes all sheetlike intrusions thrust

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[1] *Geology of the Henry Mountains* (1877), p. 20.

[2] *Rocks, Rock Weathering and Soils* (1897), p. 50.

[3] *Twenty-first Annual Report of the U. S. Geological Survey*, Part 3 (1901), p. 172.

[4] *Text-book of Geology* (4th ed., 1903), Vol. II, p. 743.

[5] *Geology* (1904), Vol. I, p. 476.

into the bedding-planes of stratified formations, whatever is or has been the angle of dip. The same usage appears in the writings of most field geologists, whether English-speaking or not. Geikie emphasizes the generality (necessity?) of high angles of dip in true dikes. Jaggar makes the angle of dip at the time of intrusion the principal criterion in distinguishing dikes from sills, and advocates a definition of both dike and sill which is not followed by the great majority of geologists. J. D. Dana[1] states that dikes may vary "in position from vertical to horizontal," and it is seen that Gilbert's and Merrill's definitions agree with that usage of the term. Since most dikes are nearly or quite vertical, the difficulty of classifying those eruptive fissure-fillings which lie nearer horizontal than vertical planes has not often been mentioned in geological literature.

Most geologists are thus agreed that dikes in stratified formations are bodies always cross-cutting the bedding planes. Many geologists agree that the angle of dip is immaterial. All agree as to the criterion of form, namely, that of a fissure-filling narrow in proportion to its length and bounded by parallel or nearly parallel walls of country rock.

According to the commonest and best usage, an igneous dike (*a*) is an injected body, (*b*) has nearly or quite parallel walls, (*c*) is narrow in proportion to its outcropping edge, (*d*) cuts across the bedding when the invaded formation is stratified, and (*e*) has any angle of dip.

When stratification and cleavage or schistosity are not coincident, such an intrusive body is generally called a dike, even though it follows the planes of cleavage or schistosity. This usage will be adopted in the classification proposed in this paper.

Multiple dikes are compound intrusions of dike form, due to successive injections of homogeneous material on the same fissure.[2] For illustrations, see Harker, *Tertiary Igneous Rocks of Skye*, pp. 296–304; A. Geikie, *Ancient Volcanoes*, Vol. II, p. 417.

Composite dikes are compound intrusions of dike form, due to successive injections of different materials into the same fissure.[3]

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[1] *Manual of Geology*, 4th ed., 1895, p. 298.

[2] Geikie, *Text-book of Geology*, Vol. II, p. 746.

[3] J. W. Judd, *Quarterly Journal of the Geological Society*, London, Vol. XLIX (1893), p. 536; A. Harker, *Tertiary Igneous Rocks of Skye* ("Memoirs of the Geological Survey of Great Britain," 1904), p. 197.

A. Geikie has used "compound" in the sense of "composite" in the foregoing definition;[1] Lawson has used "multiple" with the same meaning. The nomenclature given in the above definitions is preferred, as it brings out the analogy with "multiple" and "composite" sills and laccoliths—types already well named and established.

A composite dike is illustrated in Fig. 1.

A *dike network* is a reticulate group of dikes simultaneously injected. For illustration see *Bulletin No. 209*, U. S. Geological Survey, 1903, section, Plate 7.

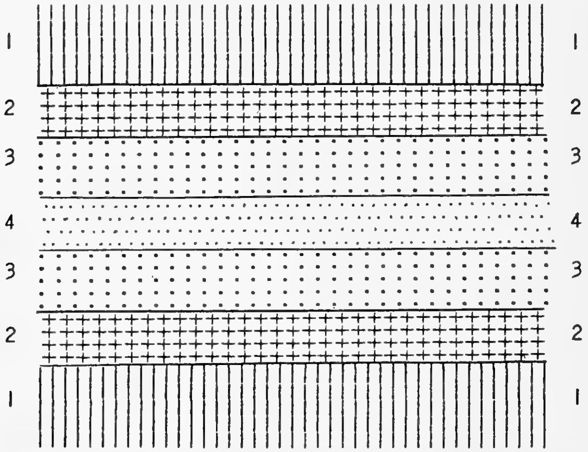

FIG. 1

Intrusive vein.

I. J. B. Jukes:[2]

> When the injected mass has arisen along an opened fissure, and solidified there as a wall-like intrusion, it is called a *dyke*. When its path has been less regularly defined, and penetrates the surrounding rocks in a wavy thread-like fashion, this irregular protrusion is called a *vein*.

II. A. Geikie:[3]

> *Veins* have been injected into irregular branching cracks.

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[1] *Text-book*, Vol. II, p. 746.

[2] *Manual of Geology*, edited by A. Geikie (1872), p. 263.

[3] *Text-book* (1903), p. 744.

Contemporaneous vein.

> Forms part of the igneous rock in which it occurs, but belongs to a later period of consolidation than the portion into which it has been injected.[1]

Apophyses or tongues are dikes or veins which, either directly or by inference from field relations, can be traced to larger intrusive bodies as the source of magmatic supply for dike or vein.[2]

Intrusive sheet.—This familiar expression has generally been defined as equivalent in meaning to "sill."[3] It may well be extended to cover the case of an igneous layer injected on a plane of unconformity in stratified formations, when the igneous layer is thus sensibly parallel to the bedding-planes of one of the stratified formations. This type, for lack of a better term, may be called an *interformational sheet.* For illustration of such a sheet on a colossal scale, see "Map of Northern Nickel Range," Sudbury District, Ontario, by A. P. Coleman.[4]

Sill.

I. A. Geikie:[5]

> A *sill* is a sheet of igneous material which has been injected into a sedimentary series and has solidified there, so as to appear more or less regularly intercalated between the strata.[6]

II. T. A. Jaggar.[7]

> A sill is an intrusive sheet forced between strata which are horizontal or which, if tilted, lie at angles more nearly horizontal than vertical. . . . . Transitions between dike and sill occur when a sill breaks upward at an angle of 45°, or when a dike follows the bedding-planes of strata inclined at that angle.

III. Chamberlin and Salisbury:[8]

> If the lava is forced between beds of rock in the form of a sheet, and solidifies there, it is called a *sill.*

The definition of I and III is that which is adopted by nearly all

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[1] Geikie, *op. cit.*, p. 738.

[2] See A. Geikie, *Quarterly Journal of the Geological Society*, Vol. L (1894), p. 222, and *Ancient Volcanoes of Great Britain*, Vol. II (1897), p. 439.

[3] E. g., Jukes, *Manual*, p. 254; Gilbert, *op. cit.*, p. 20; Iddings, *Twelfth Annual Report of the U. S. Geological Survey*, Part 1, p. 578; Geikie, *Text-book*, p. 732.

[4] *Report of the Bureau of Mines*, Ontario, 1904.

[5] *Geology of Eastern Fife* ("Memoirs of the Geological Survey of Scotland," 1902), p. 189.

[6] Cf Geikie, *Text-book*, p. 732.

[7] *Op. cit.*, p. 172.

[8] *Op. cit.*, p. 476.

authors writing in English on this type of intrusive body. The term "sill" has also its equivalents in this sense in other languages. Definition II is not only contrary to general usage but suffers from special imperfections due to the artificial nature of the chief criterion distinguishing dike and sill. (Compare Definition III of "dike.") Among those imperfections is the difficulty of classifying by Definition II many intercalated sheets now dipping at high angles, for with them it may be impossible to say what were their original dips.

It thus seems best to adhere to the prevailing use of the term "sill" in a systematic classification of intrusive bodies. A sill may be of great thickness, as illustrated on Fig. 2, but it is necessary that the sheet shall hold its thickness for considerable distances along its outcropping edge.

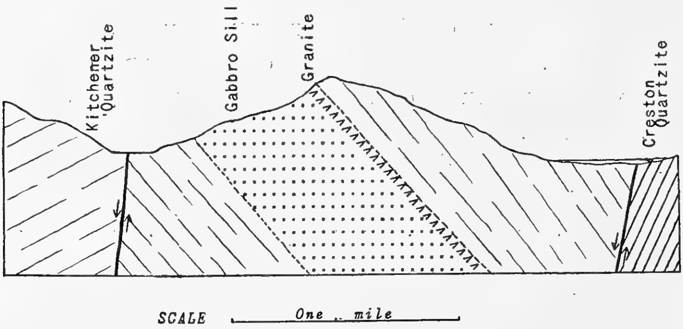

FIG. 2

A *multiple sill* is a compound intrusion of sill form and relations, and is the result of successive injections of one kind of magma along a bedding-plane in a stratified formation.[1] For a remarkable illustration, see Harker.[2]

A *composite sill* is a compound intrusion of sill form and relations, and is the result of successive injections of more than one kind of magma along a bedding-plane in a stratified formation.[3]

A section of a composite sill is illustrated in Fig. 3.

[1] See A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, pp. 318 ff.; and especially A. Harker, *op. cit.*, p. 197.

[2] *Op. cit.*, p. 239.

[3] See Harker and Geikie, same pages as noted for multiple sills.

Laccolith.—Divergence of definition and usage becomes very marked in the case of the term "laccolith."

I. The original definition by G. K. Gilbert:

> The station of the laccolite being decided, the first step in its formation is the intrusion along a parting of strata, of a thin sheet of lava, which spreads until it has an area adequate, on the principle of the hydrostatic press, to the deformation of the covering strata. The spreading sheet always extends itself in the direction of least resistance, and, if the resistances are equal on all sides, takes a circular form. So soon as the lava can uparch the strata, it does so, and the sheet becomes a laccolite. With the continued addition of lava, the laccolite grows in height and width, until finally the supply of material or the propelling force so far diminishes that the lava clogs by congelation in its conduit and the inflow stops.[1]

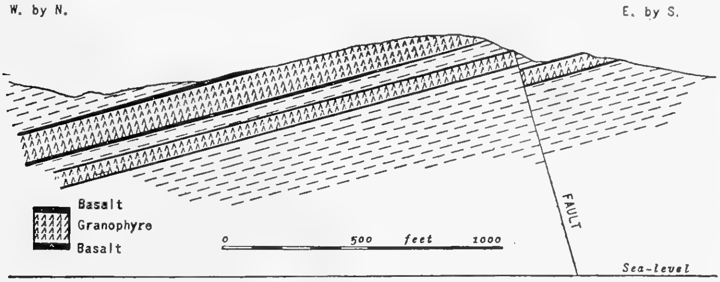

FIG. 3

> As a rule, laccolites are compact in form. The base, which in eleven localities was seen in section, was found flat, except where it copied the curvature of some inferior arch. Wherever the ground plan could be observed, it was found to be a short oval, the ratio of the two diameters not exceeding that of three to two. Where the profile could be observed, it was usually found to be a simple curve, convex upward, but in a few cases, and especially in that of the Marvine laccolite, the upper surface undulates. The height is never more than one-third of the width, but is frequently much less, and the average ratio of all the measurements I am able to combine is one to seven.
>
> The ground plan approximates a circle, and the type form is probably a solid of revolution—such as the half of an oblate spheroid.[2]
>
> The laccolite is a greatly thickened sheet [sill] and the sheet [sill] is a broad, thin, attenuated laccolite.[3]
>
> The laccolite in its formation is constantly solving a problem of "least force," and its form is a result. . . . . A laccolite grows "by lifting its cover."[4]

The clearness and precision of Gilbert's description gives a distinct and unmistakable individuality to his original type. It is a

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[1] *Op. cit.* (1877), p. 95. [2] *Ibid.*, p. 55. [3] *Ibid.*, p. 20. [4] *Ibid.*, p. 91.

greatly thickened sill of compact, domical form, with (*a*) a limital thickness, (*b*) a limital area, (*c*) a flat base, (*d*) an oval or circular ground plan, and (*e*) a specialized method of intrusion, namely, by lifting a stratified cover which thus assumes a dome structure.

Gilbert notes, as a first variation on the simple type, a compound type of laccolith which is "built up of distinct layers. . . . . It is probable that all the larger laccolites are composite, having been built up by the accession of a number of distinct intrusions."[1]

He continues:

> If the strata had experienced anterior displacements so as to be inclined, folded, and faulted, a symmetrical growth of laccolites would have been impossible, and the mountains would not have yielded a knowledge of the type form. But the type form being known, it is to be anticipated that in disturbed regions aberrant forms will be recognized and referred to the type.[2]

II. Cross[3] illustrates many examples of true laccoliths which show aberrant forms in just such a way as was foretold by Gilbert. Cross still holds that the body is a laccolith even if its expansion has taken place from a plane only approximately parallel to the bedding of the invaded strata. He emphasizes the asymmetric dome as more nearly the real shape of a laccolith in nature, and attributes such irregularity of form chiefly to lines of weakness existing in the sedimentary formation before intrusion took place. A more fundamental difference between the definitions of Gilbert and Cross appears in their respective statements as to the method of intrusion. Cross holds that the deformation of the stratified cover is in many cases not simply due to the force of a gigantic hydrostatic press; that the deformation was then incidental to the gaping of strata undergoing lateral, orogenic pressure, the magma being more or less passive as it was injected.

III. Weed and Pirsson[4] agree with the views of Cross, but Pirsson returns to the idea of the hydrostatic press as explanatory of the intrusions in the Judith Mountains. Both authors consider that a horizontal base is not necessary for a true laccolith, and that some laccoliths are doubly convex.

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[1] *Op. cit.*, p. 55. [2] *Ibid.*, p. 98.

[3] *Fourteenth Annual Report*, U. S. Geological Survey, Part 2 (1894), pp. 184 ff.

[4] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3 (1898), p. 581.

IV. Jaggar[1] found that the laccoliths of the Black Hills illustrated conclusions essentially equivalent to those of Cross, states his belief that the magmas were mostly passive during intrusion, the laccolith chambers being opened by orogenic stresses, and remarks that laccoliths may be doubly convex.

V. The recent definition of Chamberlin and Salisbury[2] returns once more to the original type of Gilbert: "If, after rising to a certain point in the strata, the lava arches the beds above into a dome, and forms a great lens-like or cistern-like mass, it constitutes a *laccolith.*"

It is seen that there is considerable diversity of usage for the term "laccolith." On the whole, this diversity is a sign of progress in geological science. Gilbert's ideal type has been supplemented by others that vary from the ideal in one or more particulars, under conditions which Gilbert himself foretold, if it were but in brief expression.

Those who have made actual researches among laccoliths, and have preserved the term "laccolith" with the original meaning of Gilbert's broader definition, are agreed on the following characteristics: (*a*) Whatever the origin of the force involved, a laccolith is always *injected.* (*b*) A laccolith is always in sill-relation to the invaded, stratified, formation; that is, the injection has, in the main, followed a bedding-plane; but, like sills, laccoliths often locally break across the bedding. (*c*) A laccolith has the shape of a plano-convex or doubly-convex lens flattened in the plane of bedding of the invaded formation. The lens may be symmetric or asymmetric in profile, circular, oval, or irregular in ground plan. (*d*) There are all transitions between sills and laccoliths.

For many illustrations of simple symmetric and asymmetric laccoliths, see the cited writings of Gilbert, Cross, Weed and Pirsson, and Jaggar.

Compound laccolith.—In the Judith Mountain type, as in the larger examples of laccoliths in the Henry Mountains, the whole intrusive body is divided by strong beds of the invaded formation. This gives the appearance of a number of distinct intrusions, one of them dominating, the others subsidiary, in size, but all of them composed of the

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[1] *Op. cit.*, p. 173.

[2] *Geology*, Vol. I, p. 476.

same kind of material. If the magma has all been intruded at practically the same time, we have the "compound laccolith" of Weed and Pirsson.[1]

A *multiple laccolith* may be conceived, the name being formed on the analogy of "multiple dike" and "multiple sill." It would differ from a compound laccolith only in the fact that the deformation of the strata, while again similar in character to that produced during the intrusion of a simple laccolith, has been due to distinctly successive injections of the same kind of magma. This case has not yet been described as actually occurring in nature.

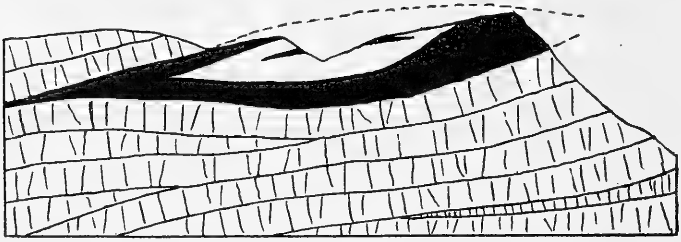

FIG. 4

Composite laccolith.—Harker[2] has noted the occurrence of "composite laccoliths" in the island of Skye. The analogy with composite dike and sill is again perfect. The principal distinction from both compound and multiple laccoliths is found in the heterogeneous nature of the magma successively injected in this last case. (See Fig. 4.)

Interformational laccolith.—Weed and Pirsson[3] have described as a laccolith a great, lenticular mass of porphyry injected along a surface of unconformity, namely, that between pre-Cambrian crystalline schists and a sedimentary Cambrian formation. Such a type is again aberrant from Gilbert's types, but should certainly be classed among the laccoliths; the writer proposes the not altogether satisfactory name "interformational laccolith" for this case. (See Fig. 5, and compare a similar section of an occurrence in the Black Hills of South Dakota, published in the *Annals of the New York Academy of Sciences*, Vol. XII (1899), p. 212.)

[1] *Op. cit.*, p. 580; see figure.

[2] *Op. cit.*, p. 209.

[3] *Journal of Geology*, Vol. IV (1896), p. 402.

Plug.—Russell has described as "plutonic plugs" certain intrusions occurring in the Black Hills of Dakota. They "are composed of igneous matter forced into sedimentary strata and have a plug-like form."[1] He continues: "How the stratified beds below the domes that covered the plugs were displaced, or perhaps fused, so as to furnish room for the passage of the intruded material, is not clear." Again: "None of the plutonic plugs examined by me are associated with dikes or faults."[2] "They occur in a region where the stratified rock into which they were forced are essentially horizontal."[3]

Since neither the form nor the method of intrusion is clearly indicated, it is difficult to classify "plugs" in Russell's sense. It is to be noted that Jaggar[4] and Iddings[5] interpret some of Russell's original types as true laccoliths. Russell's statement does not make clear the distinction between "plugs" and stocks. The name "plug" has been rather commonly used as alternative with the magmatic filling of a volcanic vent.[6] For these various reasons, "plugs" will not be included in the proposed classification of this paper.

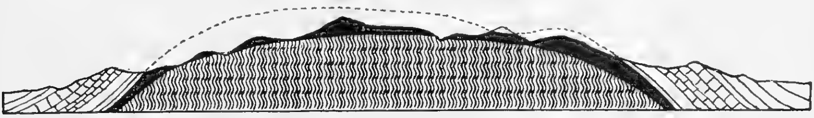

FIG. 5

Bysmaliths.—Allied to "plugs" in Russell's sense is the "bysmalith" of Iddings, described as an injected body filling a "more or less circular cone or cylinder of strata, having the form of a plug, which might be driven out at the surface of the earth, or might terminate in a dome of strata resembling the dome over a laccolith."[7] The downward termination of the original type bysmalith (Mt. Holmes) is found in a hypothetical Archean floor on which the porphyry of the bysmalith rests. See illustrations.[8]

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[1] *Journal of Geology*, Vol. IV (1896), p. 25.

[2] *Ibid.*, p. 42.

[3] *Ibid.*, p. 183.

[4] *Op. cit.*, p. 287.

[5] *Journal of Geology*, Vol. VI (1898), p. 706.

[6] Recently by Merrill, *op. cit.*, p. 51, and by Chamberlin and Salisbury, *op. cit.*, p. 476.

[7] *Monograph No. 32*, Part 2, U. S. Geological Survey (1899), p. 16.

[8] Iddings, *op. cit.*, p. 16; and *Journal of Geology*, Vol. VI (1898), p. 708.

Volcanic neck.—The solid-lava filling of a volcanic vent is evidently intrusive with reference to the formations traversed by the lava, whether those formations are composed of non-volcanic rocks or of agglomerate or tuff which has been pierced by thoroughly molten lava on its way to the surface. (See Fig. 6.)

"*Chonolith.*"—There remains for distinction a class of injected igneous bodies which are not included in any of the above-mentioned categories. In the dislocation of rock formations such as is brought about during mountain-building, actual or potential cavities are formed within the earth's crust. These are commonly filled with igneous magma squeezed into the individual cavity from below, from the side, or, it may be, from above. Dikes, sills, and bodies of laccolithic form (though not strictly of the laccolithic mode of intrusion, as designated by Gilbert) may thus originate. Yet very often the shape of the intruded mass is so irregular, and its relations to the invaded formations so complicated, that the body cannot be classified in any of the divisions so far named. Again, irregular injected bodies of a similarly indefinite variety or form are due to the active crowding-aside and mashing of the country-rock which is forced asunder by the magma under pressure. Or, thirdly, such bodies may be due to a combination of the two primary causes—orogenic stress opening cavities, and hydrostatic or other pressure emanating from the magma itself and widening the cavities.

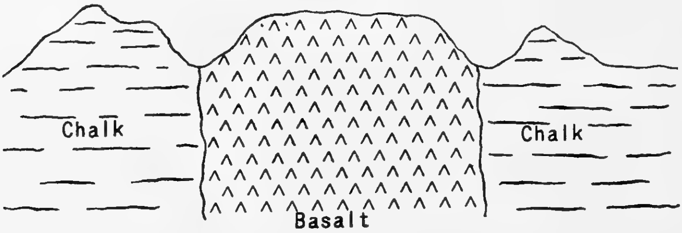

FIG. 6

The number and total volume of these irregular intrusions doubtless greatly exceed the number and volume of all the true laccoliths of the world. In the average mountain range the geologist is more likely to encounter injected bodies of the former kind than he is to discover true laccoliths.

No generally accepted name has yet been proposed for such irregular intrusions. "Laccolith" cannot be used, since that term denotes a definite form, and also implies a special mode of intrusion different from that here conceived. The writer has not been able to find a simple English word for the purpose, and suggests a name formed from the Greek on the analogy of "laccolith," "bysmalith," and "batholith." It is "chonolith," derived from *χῶνος*, a mold used in the casting of metal, and *λίθος* a stone. The magma of a "chonolith" fills its chamber after the manner of a metal casting filling the mold. Like a casting, the "chonolith" may have any shape.

A "chonolith" may be thus defined: "an igneous body (*a*) *in*jected into dislocated rock of any kind, stratified or not;[1] (*b*) of shape and relations irregular in the sense that they are not those of a true dike, vein, sheet, laccolith, bysmalith, or neck; and (*c*) composed of magma either passively squeezed into a subterranean orogenic chamber or actively forcing apart the country-rocks.

The chamber of a "chonolith" may be enlarged to a subordinate degree by contact fusion on the walls, or by magmatic "stoping."

An example of a "chonolith" is illustrated in Fig. 7.

Many intrusive bodies that have been mapped and illustrated with sections seem to belong to this same category. Among these may be mentioned a few taken from works dealing with the western Cordillera of the United States.

In the Little Belt Mountains folio of the U. S. Geological Survey, several "stocks" of granite, diorite, etc., are sectioned with relatively narrow feeding channels from below. The Three Forks (Montana) folio contains a map and section of a "laccolith" in non-laccolithic relations. Section "M–M" of the Ten Mile District Special folio shows a mass of granite injected after the manner of a "chonolith." South of Mount Stuart, Washington, the Mount Stuart folio illustrates an irregular intrusion of peridotite with "chonolithic" relations.

Cross[2] states that the intrusive body of Mount Carbon, Colorado, is injected and irregularly cross-cutting; it is not a true laccolith, but appears to be best placed in such a class as that here proposed.

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[1] The term "injected" is used here and elsewhere in this paper in a sense defined in the third paragraph of the following section on the principles of classification.

[2] *Op. cit.*, p. 191.

Weed and Pirsson[1] describe Judith Peak, Montana, as underlain by a "stock" of porphyry. Their section of the "stock" shows, however, a rapid constriction of the body as the section is followed downward. As will be noted on a following page, the section of a true stock typically enlarges downward so that such a body is "subjacent" rather than "injected" with respect to the invaded formations. On the supposition that the section of Weed and Pirsson correctly represents the actual underground relations, the Judith Mountain body has its nearest relatives among "chonoliths" and not among "stocks."

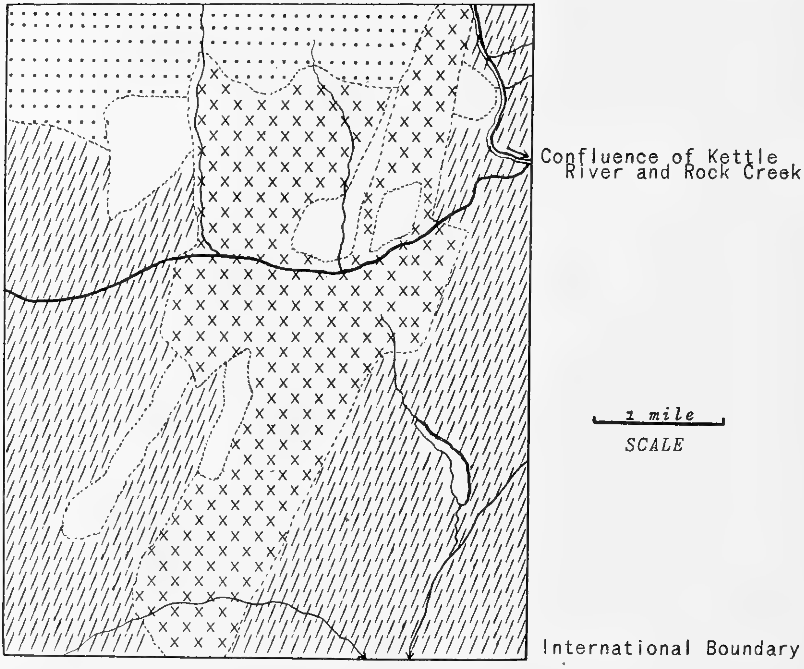

FIG. 7

Jaggar[2] describes the intrusive bodies of Dome Mountain and Whitewood Canyon in the Black Hills as injected bodies of marked irregularity both in shape and in relations to their respective country-rock formations. These bodies seem to be transitional between

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[1] *Eighteenth Annual Report,* U. S. Geological Survey, Part 3, 1898, p. 533.

[2] *Op. cit.,* Plates 20 and 21, and pp. 209 and 217.

true laccoliths and typical "chonoliths," but belong to the latter class rather than to the former. Jaggar also describes the "False Bottom Stock" of phonolite in such terms as to lead one to suspect that it may be another, perhaps typical, body of the "chonolith" class.[1]

Jaggar,[2] collaborating with Howe, has experimentally reproduced the conditions under which some "chonoliths" have originated; namely, such bodies as have been injected primarily through the application of force resident in fluid magma under pressure (hydrostatic force). No attempt was made, in their valuable experiments, to imitate injection concomitant with regional deformation.

Whatever may be the validity of any or all of these several cases as illustrations of "chonoliths," there is no question that they can be called "stocks" or "laccoliths," or by any other of the established names, only at the sacrifice of much of the strength, precision, and usefulness of those names. On the other hand, there are thousands of irregular injected bodies which cannot properly be described by the use of any of the established names. It is to be noted, finally, that some such term as "chonolith" may be useful in suggesting the probable nature of an intrusive body in the case where its whole form is not certainly known. The context should then, of course, indicate that the author using the term has in mind only a probability and is making, as it were, simply a report of progress in the description of that particular body.

Boss.—A Geikie[3] defines bosses as

> masses of intrusive rock which form at the surface rounded, craggy, or variously shaped eminences, having a circular, elliptical or irregular ground plan, and descending into the earth with vertical or steeply inclined sides. Sometimes they are seen to have pushed the surrounding rocks aside. In other places they seem to occupy the place of these rocks through which, as it were, an opening has been punched for the reception of the intrusive material. . . . . In true bosses, unlike sills or laccolites, we do not get to any bottom on which the eruptive material rests.

He makes "stock" and "boss" synonymous.

In his *Text-book*[4] Geikie says: "Bosses (stocks) are amorphous masses that have disrupted the rocks through which they rise."[5]

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[1] *Ibid.*, p. 227.

[2] *Ibid.*, p. 302, and Plate 43, section 2.

[3] *Ancient Volcanoes*, Vol. I (1897), p. 88.

[4] Vol. II (1903), p. 722.

[5] Cf. also A. Geikie, *Geology of Eastern Fife* (1902), p. 189.

In English- and German-speaking countries "boss" and "stock" are almost invariably regarded as synonymous, but the latter term has much the greater vogue.[1] The general connotation of the word "boss" seems to warrant the restriction of its meaning so as to include only those stocks which have circular or subcircular ground plans on the surface of exposure. The word has been used to denote intrusions of the sort up to all diameters from a few hundred feet to several miles.

Bosses are "simple" when composed of material intruded in but one period; they are "multiple" or "composite" when composed of material intruded at two or more distinct periods of irruption. The distinction between the latter types is the same as between "multiple" and "composite" stocks.

An illustration of a simple boss is given in Fig. 8.

Stock.—Prevailing usage has fixed the meaning of "stock" as essentially equivalent to Geikie's definition of "boss." A stock is an intrusive body, but is not as clearly *in*jected as is the case with a dike, sill, or laccolith. A stock more or less conspicuously cuts across the structures of the invaded formations; its contacts are, in general, either vertical or highly inclined; its shape is irregular and not determined by planes of bedding or other structures in the country-rocks. It has no visible floor. Van Hise regards a stock as characteristically smaller than a boss,[2] but the present writer has found that general usage does not support that distinction.

Simple stocks are composed of material intruded in one period of irruption.

A *multiple stock* is composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite stock* is composed of materials demonstrably intruded in two or more periods of irruption, the materials having been originally derived from two or more kinds of magma. (Fig. 8.)

Magmatic differentiation or other influences may render heterogeneous the material composing a simple stock, or each member of either a multiple or a composite stock.

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[1] Cf. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539.

[2] *Monograph No. 47*, U. S. Geological Survey (1904), p. 711.

Batholith.—Suess[1] has finally stated the definition of "batholith" in terms of a theory of intrusion which is at present in discussion. His definition may be freely translated thus: "A batholith is a stock-shaped or shield-shaped mass intruded as the result of fusion of older formations (orig. *Durchschmelzungsmasse*). On the removal of its rock-cover and on continued denudation, this mass either holds its diameter or grows broader to unknown depths (orig. *bis in die ewige Teufe*).[2] The name was invented to describe those largest of all intrusions, generally granitic, which are characteristically found in great mountain ranges; including, thus, "central granites," "intrusive mountain-cores," "Fussgranit," etc. The name has since been commonly used for bodies of intrusive rock with the general characteristics of stocks, but of much larger size than is generally attributed to stocks or bosses. This latter use is, moreover, rarely

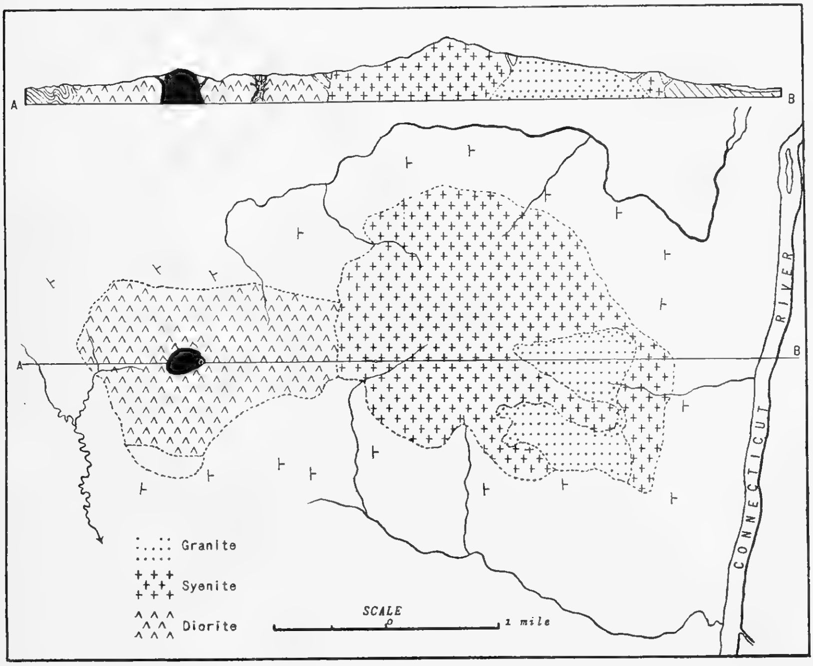

FIG. 8

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[1] *Sitzungsberichte der Wiener Akademie*, Vol. CIV (1895), p. 52.

[2] Compare Chamberlin and Salisbury, *op. cit.*, p. 477; and W. Salomon, Tschermak's *Mineralogische und petrographische Mittheilungen*, Vol. XVII (1897), p. 31.

associated directly with any particular theory of intrusion. There is pressing need for such a term signifying these large bodies, and one that will not commit the field worker to any theory of origins. The later use of the term "batholith" is therefore to be commended, as it renders that term much more useful in actual field descriptions where these cannot be accompanied with certain proofs of the *Durchschmelzung* theory as there applicable. In the proposed classification of intrusives the term "batholith" will have the meaning just noted.

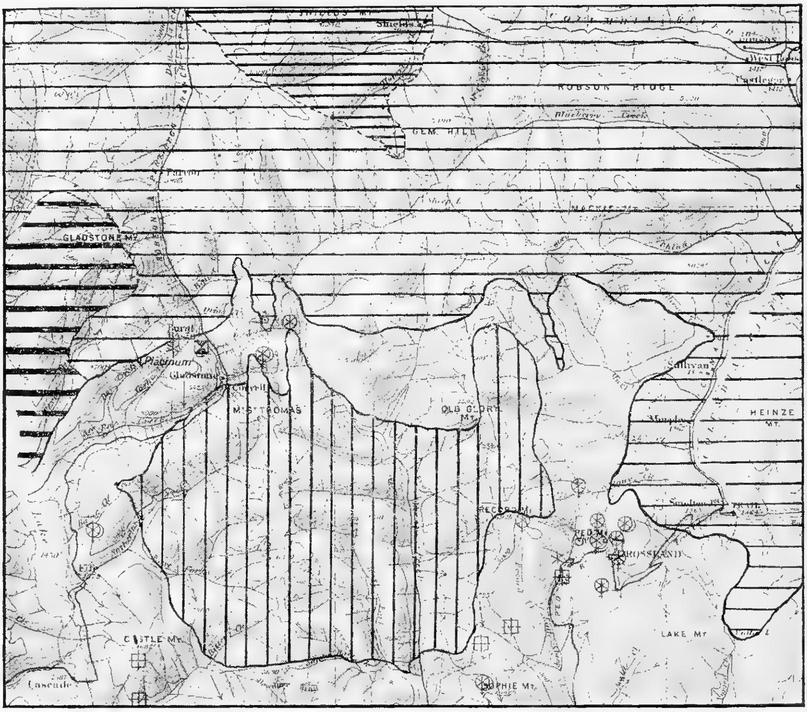

FIG. 9

A *simple batholith* is one composed of material intruded in one period of intrusion. (Fig. 9).

A *multiple batholith* is one composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite batholith* is one composed of materials demonstrably intruded in two or more periods of irruption, the materials being originally derived from two or more kinds of magma. (Fig. 9.)

A multiple or composite batholith may thus be in part made up of stocks.

Magmatic differentiation or other influences may render heterogeneous the material composing a simple batholith; or each member of a multiple or a composite batholith.

No author has attempted to fix a lower limit to the areal dimensions of a batholith. Since there is no certain distinction either in form or relations between stocks and batholiths, an arbitrary limit may be set between the two on the score of areal extent. It may be proposed that a body of the kind exposed in an area of less than 200 square kilometers is a stock; a similar body with a larger area is, accordingly, a batholith.

PRINCIPLES OF CLASSIFICATION

A review of the foregoing definitions shows that each of them has been based on one or more primary features of igneous intrusions, namely:

a) The method of intrusion.

b) The relation of the body to pre-intrusion structures in the invaded formation.

c) The form of the body.

d) The size of the body.

e) The attitude of the body with reference to the horizontal plane.

For a given body the method of intrusion is the most important criterion that could be used in classification. If it might be determined in every detail just how the igneous mass reached its present position, the form of the body and its relation to structural planes in the country-rock would therewith be known. A genetic, and therefore natural, classification should thus be founded on the method of intrusion. In the present state of geological science it is, however, impossible to apply this fundamental principle throughout the established list of intrusive bodies.

The greater number of recognized types are those of bodies of magma which is exotic except for a small, variable portion of it due to contact fusion. In each of these cases the magma has come into its chamber through channels which have fed the growing body from larger, deeper-lying, generally invisible reservoirs. The chamber is due to a parting of the country-rock into which the magma is *in*jected. An injected body is thus one which is entirely inclosed within the invaded formations, except along the relatively narrow openings to the chamber where the latter has been in communication with the feeding reservoir.

On the other hand, stocks, bosses, and batholiths never show a true floor. They appear to communicate directly with their respective magma reservoirs. Each of these bodies shows field relations suggesting that it is a *part* of its magma reservoir. The communication with the magmatic interior of the earth is not established by narrow openings, but by a huge, downwardly enlarging opening through the country-rock. In relation to the invaded formations a stock, boss, or batholith is intrusive, but is *subjacent* rather than injected.

How a magma reservoir is enlarged by the volume represented in the amount of intrusion signalized on the contacts of stock or batholith is a matter permitting as yet of no absolute certainty. In separating intrusive bodies into two primary divisions, one including all injected bodies, the other including subjacent bodies, a classification will do good service in emphasizing the need of further investigation into the mechanics of intrusion. No one has yet proved that any granite mass over 200 square kilometers in area, and characterized by vertical or outwardly sloping contact surfaces, is due to injection. Whatever may be the probabilities, no one has yet proved that such a mass has been intruded by any kind of assimilation of the invaded formations. Some light has been shed on the origin of batholiths and stocks, but they are certainly not understood as are dikes and sills.

So far as the method of intrusion is concerned, therefore, stocks, bosses, and batholiths belong to a primary division of intrusive bodies which may be defined as not demonstrably due to injection. The principle is negative; it leaves the method of intrusion unstated, but it brings into clear relief a principal contrast subsisting between the greatest of intrusions, on the one hand, and dikes, sheets, laccoliths, etc., on the other.

The other principles of classification—viz., *b*), *c*), *d*), and *e*)—are applied in the classification now to be presented in a manner sufficiently obvious to need no discussion. Principle *e*) is less fundamental than the others, excepting *d*,) and is recognized as appearing only occasionally in the scheme: the major diameters of true laccoliths tend to horizontality; a principal axis of a bysmalith, neck, stock, boss, or batholith is characteristically vertical.

It is obvious that transitional forms are to be expected among the related types of the classification. These forms have not been mentioned in the table, which would thus have become overburdened. Magmatic differentiation within the chambers of dikes, sills, stocks, etc., has often produced varietal types of these bodies, but the process has occurred too irregularly to permit of its furnishing a convenient criterion for the general classification.

PROPOSED CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES

A. *Masses due to injection of exotic material.*
 I. *Injection along planes of stratification in invaded formation.*
  1. Intrusive sheets.
   a) Sills.
    (1) Simple.
    (2) Multiple.
    (3) Composite.
   b) Interformational sheets.
  2. Laccoliths.
    (1) Simple.
     Symmetric.
     Asymmetric.
    (2) Compound.
    (3) Multiple.
    (4) Composite.
    (5) Interformational.
 II. *Injection across planes of stratification in invaded formation.*
  1. Dikes.
    (1) Simple.
     Dike-networks.
    (2) Multiple.
    (3) Composite.
  2. Eruptive veins.
   Contemporaneous veins.
   3. Apophyses or tongues.

4. Bysmaliths.
5. Necks.
6. "Chonoliths."

B. *Masses due to processes other than injection; subjacent bodies.*

1. Stocks and bosses.
    (1) Simple.
    (2) Multiple.
    (3) Composite.
2. Batholiths.
    (1) Simple.
    (2) Multiple.
    (3) Composite.

GLAUCONITE

J. K. PRATHER
Waco, Tex.

The samples of glauconite were taken from the (Cretaceous) Greensands of New Jersey.[1]

William B. Clark states that there are "two conditions necessary in the development of glauconite (1) deposition of particles of land derived origin, and (2) the presence of Foraminifera."

Murray and Renard state:

> The chambers become filled with muddy sediment, and if we admit that the organic matter inclosed in the shell and in the mud itself transforms the iron into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid, which would decompose the fine clay, setting free colloid silica and hydrated oxide of iron in a state most suitable for their combination.

Leith says:

> It is difficult to see how so high a percentage of iron as is found either in glauconite or greenalite can be derived from the decomposition of mud filtered into the interior of the shell. The contents of metallic iron shown in the analysis of the greenalite rock is 25 per cent. In the typical glauconite deposits foreign material is present outside of the shells, and there seems to be no reason why all this material should not be drawn upon for the supply of iron.[2]

He further states:

> Where iron is being contributed to ocean waters in considerable abundance, it is possible to conceive of minute organisms abstracting the same and depositing it directly in such form as glauconite or greenalite.

The New Jersey glauconite was deposited in comparatively shallow water, as is shown by the land-derived material present even in the purest samples of glauconite, and the cross-bedding.

In the glauconite I have studied, the casts of shells of Foraminifera seem to be the exception rather than the rule. The grains are

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[1] See The Atlantic Highlands Section of the New Jersey Cretacic, *American Geologist*, 1905.

[2] *Monograph 43* of the U. S. Geological Survey: "The Mesabi Iron-Bearing District of Minnesota," pp. 254.

rounded, but, except for one instance, there seems to be no indication that a shell once surrounded them. In one sample the perfect shells of Foraminifera were found among the glauconite grains, which would seem to oppose the idea that the glauconite was first contained in the shells, which were afterward dissolved by the action of sea water.

While glauconite does not have the concentric lines generally seen in the oölites, yet the similarity in shape and structure to grains of oölite, which do not show the concentric lines, suggests that many of the rounded grains of glauconite are concretions, and formed in a manner similar to that of the oölites. In some grains of glauconite was noted an indication toward concentric lines. The silica, lime, and iron which form the oölites tend to take the concentric structure more readily than does the glauconite.

The New Jersey beds contain glauconite in pockets, masses of glauconite, grains with some cementing clay, or as disseminated grains of glauconite. Where there is much clay present, the conditions are not so favorable for the further concentration of the glauconite as when it is more arenaceous.

The Navesink, a greensand bed from which most of my samples were taken, is composed of grains of glauconite with more or less clay and fragments of the older rocks. It also contains a clay iron stone, concretionary in form, which contains grains of glauconite.

The Redbank sand overlying the Navesink is composed of quartz grains, and contains glauconite which is easily affected by water and oxidizes, and gives the red and yellow colors so prominent in this bed. I have picked out round grains of magnetite with a weak bar magnet from this material which may have been originally grains of glauconite. Limonite is seen filling cracks in the clay bed at the top of the Navesink underneath and replacing fossils.

Pieces of limonite the size of a hand were collected from the Redbank. The slides in which the grains show the greatest alteration are from samples from the Redbank.

Van Hise[1] shows that hematite, limonite, magnetite, greenerite, pyrite, etc., change from one form to the other, so that glauconite altering to one form may be changed into any of the others.

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[1] *Monograph 47* of the U. S. Geological Survey, on "Metamorphism."

By putting some glauconite in a test-tube and heating with conc. HNO_3, and afterward diluting and adding NH_4OH (conc.), an iron test is obtained.

The slides show glauconite grains little altered, in the midst of which is a grain greatly altered. In other slides a few grains are unaltered, while most of the grains are highly altered, indicating two kinds of glauconite, probably deposited at different times. The size of the grains also varies greatly.

Some slides show glauconite altering to limonite; others, glauconite to clay; others, glauconite to hematite; others, glauconite to magnetite; and others, glauconite to hornblende or mica. Glauconite, both solid and fibrous, is found coating grains of quartz, feldspar, mica, pyroxene, etc.

The slides show also clay, quartz, orthoclase, microclene, rutile, and mica. Some slides are almost all clay, with a few grains of glauconite, while others are made up almost entirely of glauconite grains, with the decomposition products filling in the spaces between the grains, and extending from the margins inward toward the center of the grains.

In a slide from a clay ironstone bed in the Navesink are rounded grains of glauconite, grains partly fibrous, rectangular, and broad and irregular oval, so that there is a considerable variation both in the size and in the shape of the glauconite grains.

There is a fibrous kind of glauconite which may, in some instances, be due to the alteration to hornblende, mica, or some allied mineral. In some glauconite grains are rows of small grains of magnetite. All gradations are noted from unaltered glauconite, to glauconite changed to a network of magnetite. In a slide are quartz grains and quartz containing magnetite. Magnetite is seen filling the cracks in glauconite.

In a slide there is a shell of a Foraminifera cut through, which shows the division walls of the shell. The chambers in this shell are filled with what might be called ocean mud filtered in, rather than glauconite, as it differs from the glauconite seen in the same slide both in color and behavior under the crossed nicols, indicating a slightly different mineral composition, as if it (having been inclosed in the shell, and thereby separated from the surrounding material) lacked some of the chemical components which go to make up the glauconite. The slides were prepared by boiling in Canada balsam to render them hard before grinding down.

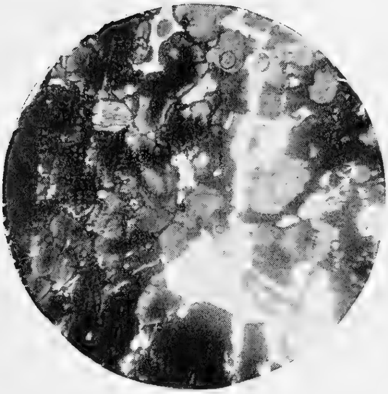
In a sample examined from Bed 2, *Gypheæ vesicularis* bed, of the Navesink, the purest sample of glauconite I had, there were five specimens of Foraminifera (Nautiloid type, Trochoid type, Nucularia type, and Nodosaria type), but the shells were still intact, and the shape and size differed considerably from the glauconite grains.

Some glauconite grains are solid, while others have fine lines running across them, as if they had been further divided up. Some grains would seem to indicate by their shape that they had been formed inside a shell, but other evidence of this seems to be lacking.

TABULAR LIST OF SLIDES

Bed[1]	Slide	
Nav.....	Ca	Two altered grains of glauconite surrounded by fresh grains
Nav.....	E4	Same as above, but with more alteration
Nav.....	Ca	Glauconite altered to magnetite
Mat.....	p	Contains glauconite, muscovite, microcline, quartz, rutile in quartz, glauconite altered to iron
Mat.....	E5	Same as preceding
Mat.....	typ.	Same as two preceding, but smaller mineral particles
Nav.....	gyp.	Fibrous glauconite, gypsum surrounded by glauconite, and inclosing grains of quartz and glauconite.
Nav.....	B1	Altered and unaltered grains and a clay ground-mass
Nav.....	G3	Much clay, alteration to clay, and also to magnetite
Nav.....	G2	Glauconite unaltered, and partly altered to magnetite.
Nav.....	G1	Abundance of quartz and feldspar, and little glauconite
Nav.....	A1	Alteration chiefly to hematite
Nav.....	24	Grains of microcline and mica coated by glauconite, which is also partly altered to magnetite, masses of pyrite (secondary), fibrous glauconite
Nav.....	8	Glauconite coating mica, rounded, oval, semicircular, and rectangular grains of glauconite, and a cross-section of a Foraminifera mentioned above, grains of quartz, orthoclase, microclene, pyroxene, mica, plagioclase, a quartz grain coated by glauconite which is partly altered to magnetite
Nav.....	22	A large grain of glauconite made up of aggregates which readily separate; also contains mica, quartz, gypsum, glauconite, etc.
Nav.....	25	Microclene coated by glauconite and shattered grains of quartz and feldspar
Nav.....	26	Quartz coated by glauconite, round grains of glauconite with small grains of magnetite regularly arranged, also mica, hornblende, and pyroxene
Haz.....	6	Composed of glauconite grains more or less altered; some grains appear to be concretions, while others look as if they may be sections of Foraminifera
Nav.....	28	A feldspar grain covered by fibrous glauconite
Red.....	13	Alteration to hematite and to limonite

[1] Nav. = Navesink; Mat. = Matawan; Haz. = Hazlet Sand; Red. = Redbank.



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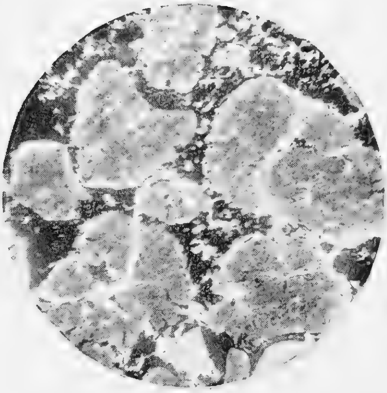

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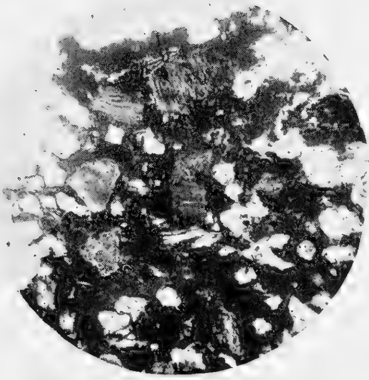

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Some photo-micrographs are given (by way of illustration) which were taken of some slides of glauconite.

No. 1 is taken from material from a greensand pocket in the Redbank, and is intended to show glauconite grains highly altered.

No. 2 is taken from the clay ironstone of the Navesink, and shows fresh glauconite grains. The dark spaces between the grains show the ground-mass of limonite and clay.

No. 3 is also taken from the clay ironstone of the Navesink, and is to show fibrous glauconite.

No. 4 is taken from a sample of Hazlet Sand from near Cliffwood, N. J. It shows fibrous glauconite, and also the size and shape of some of the glauconite grains.

The diameter of the field of the microscope, when these photo-micrographs were taken, was 2.55^{mm}. In the slide from which No. 2 was taken two grains of glauconite were measured, one of which was 1.3^{mm} long and 0.65^{mm} wide; and the other was round and 0.2^{mm} in diameter. Some grains are smaller than this, down to 0.1^{mm} or less, but they are not so common, and the average grain is much larger than 0.2^{mm}.

THE MESOZOIC OF SOUTHWESTERN OREGON[1]

GEORGE DAVIS LOUDERBACK
San Francisco, Cal.

CONTENTS

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[1] This study was made as research assistant of the Carnegie Institution of Washington, and is published by permission of the Institution. Read before the Cordilleran Section of the Geological Society of America, December, 1904.

INTRODUCTION

During the summer of 1904 the writer, in the course of an investigation of the glaucophane schists of California, made a trip into southern Oregon for the purpose of comparing the geological relations of the schists reported as occurring there with those of similar rocks in California. In particular, the Oregon schists were said to occur in a formation corresponding to the Knoxville and Horsetown of California, and were considered as contact products of irruptives which were intruded into the formation, and were therefore considered at least post-Horsetown in age. In California, on the other hand, similar schists are found in the Franciscan, a thick and important series of formations which underlies the Knoxville unconformably, and the greater part of whose basic intrusives, if not all, are pre-Knoxville in age. No schists have yet been found in the California Knoxville or later rocks. It would be of considerable interest, then, to the student of petrographical provinces, if such rocks, which are apparently due to rather uncommon conditions, and which in the United States are, so far as known, limited to this coastal (California and Oregon) region, had been developed in different parts of this territory in formations which differ both in age and in lithologic characters, and in relation to igneous rocks of apparently different ages of intrusion.

The study of the field relations of the Oregon schists, however, have led to the conclusion that they were developed in formations of the same age and lithologic characters, and have the same associations and relationships, as the corresponding schists in California. At the same time, certain important features of the Mesozoic stratigraphy and history of the region were recognized, and a closer correlation between the geological conditions and sequence in southwestern Oregon, and those of the California Coast Ranges, made possible. To set forth these general results is the purpose of the present paper.

HISTORICAL

The region under discussion lies in southwestern Oregon, and is included from east to west between the western foothills of the Cascade Range (long. 123° west), and the Pacific Ocean (about 124° 20′ to 124° 30′ west); and from north to south between the latitude of Roseburg or the head of Coos Bay (about lat. 43° 15′ north), and the Klamath[1] Mountains (about 42° 30′ north). This field has been studied by few geologists. Dana and later Newberry, in their exploration work in the early days, saw but little of the country, and were hardly in position to arrive at any definite conclusions as to even the major events in the geological history of the region. Mr. G. F. Becker,[2] about 1890, studied some of this country in the vicinity of Riddles in conjunction with Mr. W. Q. Brown, and arrived at certain conclusions that were important in extending the knowledge of the Pacific coast Cretaceous. It is to Mr. J. S. Diller, however, that we owe by far the greater part of our present knowledge of southwestern Oregon. He has spent a number of years in the investigation and mapping of considerable areas, and his studies have covered all parts of the region outlined above. His general results are presented most systematically and with the greatest detail in the texts accompanying the Roseburg, Coos Bay, and Port Orford folios[3] of the *Geologic Atlas of the United States*, although certain features are more particularly treated in various memoirs, a number of which will be referred to in the body of this paper.

AREAS STUDIED

The index map, page 518, shows the relative positions of the three geologically mapped quadrangles of southwestern Oregon—the Coos Bay and Port Orford lying in contact on the coast, and

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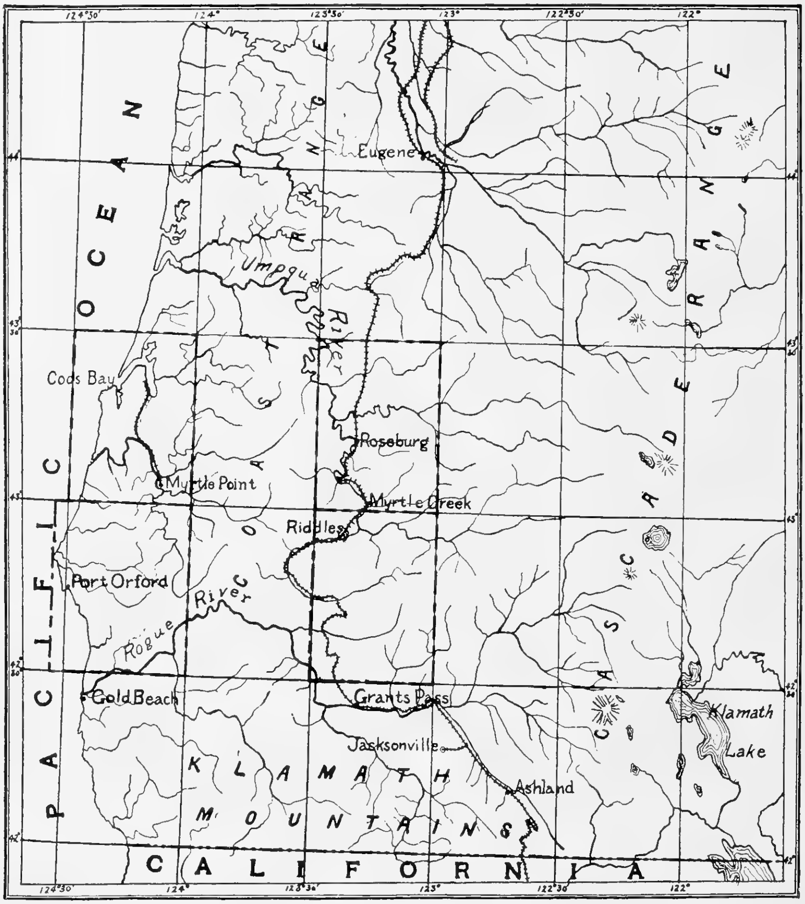
[1] For use of this term see p. 552.

[2] *Bulletin of the Geological Society of America*, Vol. II (1891), pp. 201–6.

[3] U. S. Geological Survey, *Geologic Atlas of the United States*, Folios Nos. 49 (1898), 73 (1901), and 89 (1903).

the Roseburg somewhat inland and in the latitude of the Coos Bay area. Of the Riddles quadrangle which adjoins the Roseburg on the south, and corresponds in latitude to the Port Orford, only a topographic sheet has been issued. It will be noted that these two pairs of quadrangles are separated by a strip, one quadrangle in width. This unmapped area represents what is known as the Oregon Coast Range which runs north and south, and is broad enough to occupy the unmapped strip and extend its foothills a short distance into the Roseburg area on the east, and into the Coos Bay and Port



Index Map of Southwestern Oregon

The areas of the Geological Survey quadrangles are inclosed in heavy broken lines.

Orford areas on the west. Within this region the Coast Range is made up almost entirely of Eocene rocks, and is, therefore, not of particular interest in the present investigation; but in the country both east and west of this range the Eocene sediments have been largely stripped off, and considerable areas of the pre-Tertiary rocks exposed. These in general have a trend from northeast to southwest, cutting obliquely across the Roseburg quadrangle, passing under the Eocene sediments of the Coast Range, emerging with a similar trend on the west side of the range, and continuing to the ocean. The writer's studies were practically confined to the southern parts of the two northern quadrangles and the northern parts of the two southern quadrangles.

PRESENT KNOWLEDGE OF THE MESOZOIC OF THIS REGION

THE MYRTLE FORMATION

Diller has included most of the Mesozoic of this region in the "Myrtle formation." This name was originally given by him to the Mesozoic of the Roseburg quadrangle (published in 1898), because of the fact that it is most typically developed along Myrtle Creek in the southern part of that area, and because in that vicinity was found the greatest range of fossils. The lower part of the Myrtle formation at that locality is stated to be characterized by *Aucella piochi* and *A. crassicollis*, and to correspond, therefore, to the Knoxville (a part of the Lower Cretaceous) formation of California. The upper part is said to be characterized by *Pecten operculiformis*, *Trigonia æquicostata*, and other forms of diagnostic value, indicating that it is of the same geological horizon as the Horsetown beds of California (Lower Cretaceous), including the uppermost horizons immediately below the base of the Chico.

Certain rocks lying southwest of the limits of the Roseburg quadrangle are provisionally referred to the Jurassic, with the statement that they may possibly extend onto the quadrangle; and some cherts occurring within the quadrangle are also made doubtfully Jurassic; but these are both distinctly separated from the Myrtle formation and discussed under a different heading. Moreover, a considerable gap is noted between the Myrtle and the Umpqua (Eocene) formations, and is said to correspond to the Chico (Upper Cretaceous) of California and other parts of Oregon.

It would appear, then, that the "Myrtle formation" as originally described has very definite limits, running from the base of the Knoxville to the top of the Horsetown—an interval named in California the Shasta group by Whitney as early as 1869.

In 1901, Diller referred the pre-Eocene rocks of the southern part of the Coos Bay quadrangle to the Myrtle formation, although no fossils were found in them within the limits of the quadrangle. The nearest fossil localities are some miles south of the southern boundary, and indicate a Knoxville age. Cherts with the same relationships as those of the Roseburg quadrangle are here referred doubtfully to the Cretaceous, but they are not included in the Myrtle formation.

In the Port Orford folio (1903) considerable areas are mapped as Myrtle. This term, in general, has the same significance as in the former publications, and is treated under the Cretaceous. The occurrence of some small areas of Jurassic within the areas mapped as Myrtle is indicated by fossils found in float material, but their occurrence *in situ* could not be determined. There were also some small patches of rock found which contain Chico (Upper Cretaceous) fossils. Almost the whole of the area mapped as Myrtle, however, is described as corresponding to the Myrtle of the original localities in the Roseburg quadrangle, that is, to the Shasta group of California. The wording of some parts of the text, however, make it doubtful whether Diller intended to retain the same limits for the Myrtle formation as was determined in the type locality, or whether he would extend the term to include whatever Upper Cretaceous (Chico) were present, and make it equivalent to the Shasta-Chico series of California. If such had been the intention, it might be expected that the term "Myrtle series" would have been used as comprehending so many groups of formations. It may be added that the cherts of the Port Orford quadrangles, which have the same geological relations as those in the other two quadrangles, are here included in the lower (or Knoxville) part of the Myrtle, so that even with the original limits the term "formation" seems very inadequate, and is likely to produce an incorrect conception of the complexity of the Myrtle.

As the Chico areas are but one or two small spots in the Port

Orford area, none having been yet reported for the other two quadrangles, we may consider the Myrtle formation of Diller, as defined by its original limits, to include those strata from the basal Knoxville to the uppermost Horsetown, that is, to be equivalent to the Shasta group of the California Cretaceous.

OUTLINE OF MESOZOIC AND RELATED HISTORY

In the text accompanying the Port Orford folio Diller gives a general sketch of the events of the geological history of that and related areas, and, as the most recent summary of our knowledge of this region, it may be well to consider in outline the chief events there given which relate to the Mesozoic history, its beginning and end. Arranged in historical order, these are:

1. Ancient sea in which Colebrooke schists were deposited	Pre-Cretaceous. Pre-Devonian?
2. Interval between Colebrooke deposition and that of the "Lower Cretaceous Myrtle formation."	In part Jurassic, including.
2.*a* (Upper Jurassic deposition indicated, the Klamath Mountains probably submerged.)	Late Jurassic.
3. Upraising of Klamath region; coast moved westward beyond present position (probably to margin of continental plateau); important mountain-forming epoch.	Post-Jurassic. Pre-Myrtle. (Pre-Knoxville.)
4. Subsidence, the sea advancing inland until most or all of Klamath Mountains were covered, and waves swept the foot of the Blue Mountains in eastern Oregon, and the Sierra Nevada of California.	Lower Cretaceous. (Myrtle) period. (Shasta.) Continued into Chico.
5. Folding, crushing, intrusion of igneous rocks, and whole raised above the sea; extensive erosion, the Chico being removed except one or two small patches.	Chico in part? and Cretaceous-Eocene interval.
6. Subsidence and marine deposition.	Eocene.

THE HETEROGENEITY OF THE MYRTLE FORMATION

It will be noted that in the above outline the Myrtle formation is considered as representing a period of continuous marine sedimentation, and the igneous intrusives with which it is so abundantly supplied are considered post-Myrtle, indeed post-Chico; that is, post-Cretaceous. And this is the idea which underlies all the descriptions of the Myrtle, both of this and the other quadrangles. The results of the writer's field studies, however, are to the effect that the formations mapped as Myrtle, *sensu stricto*, may be separated into two chief groups or series, each representing quite an extent of geological history, and separated from each other by a distinct interval during which there were various intrusions of igneous rocks, and a period of considerable erosion. In other words, the Myrtle formation is a sort of complex, consisting of heterogeneous parts. Its lower division shows more marked variations in characters and geological history, and probably represents the greater period of time. No word short of "series" seems to represent its thickness and variations. The upper part, if we define the top of the Myrtle as the top of the Shasta group, might very properly be called a group, but if we extend it to include the Chico, it would better also be called a series.

The lithologic characters of the two divisions differ considerably and will be described first.

THE LITHOLOGIC CHARACTERS OF THE SEDIMENTARY ROCKS

THE LOWER SERIES

General composition.—The lower series is made up of the following marine deposits in order of their relative abundance: sandstone, shale, conglomerate, chert, and limestone.

The sandstone.—Sandstone is by far the most abundant rock in this series, and is generally a gray, well-lithified rock, which, on account of its silicious cement, breaks across the grains in such a way that they do not stand in relief on a freshly fractured surface. The material of the grains is of an arkose nature, showing abundant feldspar, etc., and this, combined with its degree of lithification, makes it sometimes, to the naked eye, have a remarkable likeness to an igneous rock. This may be further augmented by the fact that the sandstones have suffered considerable squeezing and crushing, the bedding planes being frequently very difficult to determine, and, if determinable at some point, can generally be traced but a short distance. Large exposures often occur where the sandstone has a thick-bedded or massive appearance, and the only planes determinable are numerous irregular ones of fracture. Not infrequently the pressure to which they have been subjected has flattened the grains along definite planes and caused some recrystallization of the constituents, and occasionally an actual schist has been locally produced.

Besides the development of a silicious cement, much of the sandstone is intersected by small and irregular quartz veinlets. These are sometimes quite abundant, and occasionally larger veins some inches across, or irregular bunches of quartz, are developed. Secondary calcite in small veins or irregular grains, etc., is also found.

Some of the more silicified sandstone stands out in hard and rather fresh exposures, while other parts weather down, assuming a brownish color. Its general massiveness, folded and crushed condition, and other properties make the determination of structural features and measurements of sections exceedingly difficult. Occasionally thin and distinctly bedded sandstones are found which may be considerably less altered than those above described. They are not characteristic, and are generally not traceable any great distance.

The shales.—Shale occurs in subordinate amount associated with the sandstone. It varies in color, being usually a rather pure gray, more rarely greenish-gray, and is generally much crumpled, crushed, broken, and slickensided, although exposures of less disturbed material do occur. Occasionally it takes on a hard, slate-like habit and shows distinct cleavage planes; again, it is so crushed as to show no planes at all. Some parts show irregular secondary silicification, while others seem very slightly altered.

Conglomerates.—Conglomerate lenses are met at a number of places and at apparently different horizons, but they can rarely be traced very far and seem to be of little value in subdividing the series into groups. They are frequently of jasper, quartz, and some other pebbles. These pebbles are generally firmly cemented, so much so occasionally that a fragment broken off by a hammer will show a rather even fracture face passing through both pebbles and matrix, the pebbles neither protruding nor breaking out, and leaving rounded depressions. Faulted pebbles are quite common.

Cherts.—Lenses and irregular masses of radiolarian chert are very characteristic of the lower series. Along the coast quadrangles they may be more abundant than the conglomerates, but in the Roseburg quadrangle they are apparently less so. On account of their hard silicious character, bright colors, and great resistance to weathering, they form very prominent exposures, and are likely to appear more abundant than they really are.

These cherts are of a prevailing red color, but may be perfectly white or green, brown, yellow, or gray—sometimes variegated. They are generally distinctly stratified, the silicious layers varying from an inch or two to a foot or more—two to four inches being the more common values. These are separated by a peculiar, generally dark red ferruginous shale, varying in thickness from little more than a film between the chert layers up to an inch or more. Several hundred alternations of cherty and shaly layers may occur in a single exposure. These layers are sometimes badly crumpled, and not infrequently, in the smaller masses, the stratification may be almost or entirely obliterated.

Small, clear chalcedonic spots are frequent indications of original radiolaria, and sometimes more or less of the structure or ornamentation of the original test is preserved. The bulk of the silicious layers are, however, apparently recrystallized and are very fine-grained (microcrystalline) quartz aggregates. These layers are also traversed in all directions by minute quartz veins.

The cherts occur either as lenses in the sandstones or as inclusions in the basic igneous rocks which cut the lower series.

Limestone.—The only limestone noted occurs in a series of lenses described in the text of the Roseburg folio as the Whitsett limestone lentils. These are in general gray and massive, showing more or less the effects of crushing, and, while some recrystallization is present, there has not been any noteworthy development of a phanerocrystalline-granular structure in the larger lenses at least. Some of the smaller areas appear to be more altered and to have developed a fine-grained to compact crystalline structure. The more altered ones show an abundance of calcite veinlets up to about two inches in thickness. They are also traversed irregularly by a secondary pink chert which shows the effects of fracturing since its formation. The matrix is sometimes colored variously, yellow, brown, etc.; the veins are generally white. In some parts oölitic structures were observed, and in some the more or less abundant remains of microscopic organisms—foraminifera in the calcareous parts, and, in the associated chert, apparently radiolaria.

THE UPPER GROUP

General composition.—In lithologic characters the upper group differs considerably from the lower. The most abundant and characteristic rock type is shale, then sandstones and conglomerates. No trace of radiolarian cherts or cherts of any type, occurs in this group, nor do foraminiferal limestones corresponding in general character to the Whitsett lenses, although there are calcareous shales.

The most striking general difference between the lower and upper divisions is the markedly inferior lithification of the latter. Although it has been compressed into large folds, and to some extent faulted, and even locally crushed, especially where it has been thrust against the more massive older rocks in the course of its folding, yet, in general, its lithologic characters have been comparatively little altered.

Shales.—The shales, which are the predominating rock type, are characteristically of a greenish-gray color, sometimes pure gray, and their stratification and lamination, except occasionally where locally crushed, are always readily discernible, and the dip and strike measurable, and the beds and structures may be traced for considerable distances without great effort. No slaty structures are developed, and hardened facies are rare. A spheroidal structure is not uncommon, but the original lamination is always distinct. Moist samples of these shales smell strongly of clay.

The shales are commonly more or less calcareous, and some are highly so and may be called argillaceous limestones.

Sandstones.—Interbedded with these shales are rather thin-bedded sandstones from two or three inches up to not generally over several feet thick, though occasionally heavier beds occur. They are commonly brown, sometimes buff or greenish, and never show the peculiar gray compact facies so often seen in the sandstones of the lower series. In some parts of the series the shales greatly preponderate over the sandstones; in others they may be in about equal quantity, or occasionally the sandstones may actually prevail. On account of their general thin-bedded character and the regularity of the bedding, the attitude of these sandstones can generally be readily determined and measured.

The material of which the sandstones are composed is, as in the lower series, rather arkose, but, while some of the beds may be quite hard, the induration, in general, has been much less than in the lower sandstones. On a surface of fracture the grains stand out in relief and the clastic character is always readily recognizable. The excessive fracturing and crushing found in the lower sandstones is absent, and the beds maintain their individuality and distinctness for considerable distances, although the thin beds, being lens-like in nature, are less persistent than the structures—folds, etc.—which latter may be traced for many miles. With the absence of the abundant fracturing and of the cementation characteristic of the lower series may be associated the practical non-existence of quartz veins, veinlets, or masses in the upper group. Small calcite stringers are sometimes found, but only rarely a slight local development of secondary silicious material in small veinlets. Phases where the individual grains are flattened into an incipient schistose structure, and actual development of recrystallized facies, were nowhere observed.

Conglomerates.—Conglomerates are rather more common than in the lower series, and are quite indurated and show faulted pebbles. With the exception of showing less the effects of squeezing and crushing, they have very much the general appearance of the conglomerates of the lower series. While very largely made up of chert pebbles, they frequently carry pebbles of some of the other rocks which occur in the lower series, as will be explained later.

The conglomerates occur chiefly in the lower part of the upper group. It is possible that one may be found that marks the beginning of the Horsetown epoch of deposition. However, no attempt was made to discover such a stratigraphic boundary for those beds. Of great interest in determining the relationships of the two major divisions is the heavy basal conglomerate of the upper group—over a thousand feet thick—which in the vicinity of Myrtle Creek can be traced for probably twenty miles or more. This will be more fully described later on.

THICKNESS OF THE SEDIMENTS

The upper division.—The thickness of the upper division is perhaps most simply and satisfactorily measured in the vicinity of Myrtle Creek. It is here folded into a syncline which may be traced for many miles. The lowest horizon for a number of miles is a conglomerate, and the range of fossils indicates that the complete series is represented up to the top of the Horsetown horizon. Diller has estimated the thickness at about 6,000 feet, and the writer's observations confirm this figure as a good approximation.

The lower division.—Unfortunately, the lower series is so broken, and its stratigraphy so obscure, that it was not found practicable to measure its thickness, but the fact that it has been more strongly disturbed than the upper division, and yet covers larger areas in which it has been deeply dissected by streams without exposing the underlying rocks, would seem to indicate that it is at least as thick as, and probably thicker than, the upper group.

PALEONTOLOGIC CHARACTERS

The upper division.—The upper group has yielded a considerable amount of fossil material. Its lowest beds are characterized by the presence of *Aucella piochi*, the characteristic fossil of the lower Knoxville in California, and, as higher beds are examined, they show, in order, fossils of the upper Knoxville and of the Horsetown, as already described on p. 519. In fact, all of the fossils described in the texts of the Roseburg and of the Port Orford folios (no Mesozoic fossils were found in the Coos Bay quadrangle) as characteristic of the Myrtle formation, indeed all fossils described as occurring in the Myrtle formation except the radiolaria of the cherts and the imperfect shells in the Whitsett limestones, occur in the upper group of formations.

The lower division.—The lower or semi-metamorphic series is almost destitute of fossils, except the minute remains of radiolaria, etc., in the cherts and limestones, and these do not definitely indicate the horizon. In the limestone lentils Diller has found a "few, generally imperfect fossils" in which Mr. T. W. Stanton has recognized *Opis californica* and "a species of *Hoplites*, either closely related to or identical with *Hoplites dilleri*." As there is apparently some doubt about the determinations, and as the range of the above fossils is not known, it cannot be said that they indicate the age of these beds with any definiteness, although we may accept them as showing that the limestones are probably Jurassic or Lower Cretaceous. The position of this series, however, stratigraphically below the base of the upper group, whose range is rather definitely determined by the contained fossils, fixes its upper limit and places the whole series below the base of the Knoxville—the zone of *Aucella piochi*—from which it is separated, as will be shown later, by an unconformity.

TERMS USED

Definition of the Myrtle group.—In discussing and describing further the characteristics of the two well-defined and distinctly separable groups of formations, it would conduce to simplicity and clearness to give them names. If we define the Myrtle in terms of the stratigraphic limits set by Diller and determined by characteristic fossils, as that continuous sequence of beds whose base is the zone of the *Aucella piochi*, and whose summit corresponds to the topmost beds of the Horsetown group, then the Myrtle corresponds exactly to the upper group above described. It is proposed, therefore, to use the name "Myrtle group" for the formations so described, and this term is particularly appropriate, as a most simple and complete development of the Myrtle group occurs along Myrtle Creek and about the town of that name—Diller's type locality. If it should seem better to extend the limits of the Myrtle to include the Chico equivalents, as is perhaps Diller's intention in the Port Orford area, the term "Myrtle series" would seem more appropriate.

The Dillard series.—For the lower series, which, while it has been mapped as Myrtle, is entirely below the stratigraphic limits set for that group, the name, "Dillard series" will be used, after a village, on the railroad, situated in the midst of the largest area of this series on the Roseburg quadrangle. This series has already been characterized stratigraphically and lithologically, and will be more concisely defined later.

IGNEOUS AND METAMORPHIC ROCKS
ASSOCIATED WITH DILLARD SERIES

General characters.—The Dillard series is abundantly supplied with igneous rocks which are found at frequent intervals, especially in the areas of the coast quadrangles, cutting it irregularly in all directions. Most of these rocks are quite different from the igneous rocks of any of the later formations and are, indeed, characteristic of the Dillard series. They are so varied and irregularly mixed, and commonly so badly weathered, that their detailed study, especially that of the basic series, would require considerable time. Only their more striking characteristics and more evident field groupings are given here.

The basic series.—The igneous rocks included under this heading are the most abundant, the most varied, and the most difficult to study of any in the region. In the text of the Roseburg folio they have been described under the title of metagabbro. In the Coos Bay map they are incorrectly grouped with the Eocene basalts, and given the same color and letter symbol, although in the text it is stated that certain of the areas are "more highly altered than those already noted, and are associated with the Myrtle formation. They are probably of greater age than those found in the Pulaski formation[1] and are the product of eruptions occurring at the close of the Cretaceous."[2] In the text of the Port Orford folio they are separated into two groups, and described as gabbros and basalts, respectively.

Within the basic series are rocks that are petrographically different, but are probably genetically related. On the other hand, there are included rocks that are not closely related. The briefness of the writer's study does not allow of a satisfactory genetic subgrouping or a complete detailed description of these rocks, but certain general characteristics and more obvious groupings may be given.

The greenstones.—A very characteristic field type in the Dillard series is rather fine-grained, frequently compact, the grain generally not being discernible to the naked eye, and of a dull green color weathering to brown. While sometimes producing prominent outcrops, these rocks frequently weather down to a brownish earth, resembling on superficial examination the weathering products of the sandstones, and the boundaries of their areas then become frequently difficult, or at least require considerable time, to determine; indeed, small areas may easily be overlooked entirely. In texture these rocks vary from compact—perhaps sometimes originally glassy—to fine granular or fine diabasic. The normal or average type may be called basaltic, consisting essentially of pyroxene and

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[1] A division of the Eocene of the Coos Bay quadrangle.

[2] Cretaceous was there used as a synonym for Myrtle, and should now read Dillard, as they were undoubtedly erupted before the deposition of the basal beds of the Myrtle group.

basic soda-lime feldspars with magnetite, etc. This is varied, however, by the partial or even complete substitution of more or less hornblende for the pyroxene, or by the more or less complete disappearance of the feldspar. Alteration is generally very marked, chlorite, calcite, limonite, and kaolin, being common products of the changes; and the rocks are frequently crushed, sheared, slickensided, and traversed by calcite veinlets.

The exact relationship of these rocks to the Dillard series can, in the majority of cases, not be determined, and some of the bodies may represent contemporaneous lava flows. Proof of this was not found in any individual case, but in many areas the fact of intrusion into the sandstones, and especially the cherts, with small apophyses breaking through and spreading between the layers, is perfectly evident. All of these rocks may therefore be intrusive. Some, however, apparently have an original clastic structure and may be tuffs. They are called basalts in the text of the Port Orford folio, but as they vary so much in texture and mineral composition, and as their textures, mineral composition, and exact geological relations are frequently indeterminable in the field, and, finally, as the almost uniform green coloration, especially on a fracture surface, is so universal, the writer has used the comprehensive field term "greenstone" as more expressive of these characters and variations.

The feldspathic granular rocks.—The rocks discussed under this broad title include those described as "metagabbros" in the text of the Roseburg folio (except such as have been described above as greenstones), and the "gabbros" of the Port Orford quadrangle. This is evidently a genetically heterogeneous group, which the briefness of the writer's study has left in a very unsatisfactory state. We may distinguish, however:

a) A group of basic gabbros which are genetically related to the serpentines (altered peridotites, to be described later). These rocks are generally essentially coarse granular holocrystalline aggregates of diallage and a very basic soda-lime feldspar, with various accessory minerals, and from their close association with the serpentines in the field, and the habit of their component minerals and the intermediate forms which exist, they have presumably been derived from the same magma which gave rise to the serpentines.

b) A group corresponding in range to the greenstones described above. They include granular and coarse diabasic rocks made up essentially of pyroxene and a moderately basic soda-lime feldspar, which may perhaps be taken as the average or normal type. The pyroxene is in some forms replaced by hornblende, giving rise to dioritic rocks. These are apparently, sometimes at least, differentiation products, and they may sometimes be due to secondary alteration of the original pyroxenes, as indicated by the term "metagabbro" used in the Roseburg folio. The limit of variation in this group—considered as a genetic group—has not been determined. It may, and probably does, include more acid and more basic members than above described.

This group of coarse-grained rocks may be genetically related to the greenstones already described, and it parallels them very closely in mineral composition, and also in bulk chemical constitution, as shown by the analyses given in the text of the Port Orford folio. Types of intermediate grain also exist and may be considered as physical gradations between the coarse-grained and the greenstone series.

The members of this group are, as far as observed, all intrusive in the Dillard series.

c) A third group, which is probably genetically distinct from the one just described, may be called the quartz-diorite-diorite group. These rocks are granitic in habit and structure, and have as their essential constituents a more acid soda-lime feldspar, hornblende, commonly quartz, and sometimes biotite. Chemically, according to the analyses given for the Port Orford material, they appear to vary from perhaps 50 to 60 per cent. in silica, to be rather low in lime and magnesia (from about 4 to 6 per cent. and 2 to 3 per cent. respectively), and high in alkalies (about 7 per cent. or over). The abundance of original quartz in some of the sections studied would indicate that the maximum silica percentage is above that given in the analyses, and the rocks are very decidedly quartz-diorites—the quartz sometimes making up a third or more of the section. They are classed as acid types of the gabbro group in the text of the Port Orford folio, but in habit, texture, mineral, and chemical composition appear to be more closely related to the diorites and quartz-diorites which are so abundant and well known in various parts of northern and central California. They are therefore provisionally placed in a group by themselves. Their relationship to the Dillard series was not definitely determined. As typical pebbles were found in the Myrtle conglomerate, they are undoubtedly pre-Myrtle.

The ultrabasic rocks.—Serpentines occur abundantly in all of the major areas of the Dillard, sometimes in large masses or elongated areas traceable for miles, frequently in small patches or dikes down to exposures a few yards across, scattered irregularly through different parts of the series. The small dikes do not appear to have any close spacial relationship to any larger or more central masses, but occur sporadically and independently at any point of the areas. Where not badly disturbed, or on fresh fracture of less altered masses, these rocks are dark—almost black, with a brown or green tinge. Most of the material has undergone considerable movement, and is filled with shear zones and slickensided surfaces, with bowlder-like residual masses in greater or less abundance which show the real texture on breaking. The serpentine has generally a more or less massive structure to the eye and was largely derived from olivine. Fresh fractures show, as a rule, a generous sprinkling of foliated crystals, with a pearly to almost metallic luster, and with the appearance of phenocrysts in the compact-looking ground. These are sometimes distinctly bastite, and then presumably derivatives of enstatite or a similar rhombic pyroxene; at other times the more or less altered original pyroxenes—enstatite or diallage. These pyroxenes may locally make up the entire mass and produce pyroxenites. Other transitions occur to a feldspathic rock, and the gabbros described above under (*a*) appear to be differentiation products of the magma which gave rise to these serpentines.

As the serpentines are very resistant to weathering, and give rise to very little soil *in situ,* the greater masses are generally bare of vegetation, and the larger areas, which frequently form hills or ridges, give striking exposures easily traceable by the eye at a distance. The small dikes, however, frequently cause sliding in their vicinity, and are more or less covered with débris from topographically overlying formations, so that they produce very inconspicuous exposures, and their presence and extent may become very difficult to determine.

The serpentine dikes cut into and through the members of the basic series—both coarse-grained rocks and greenstones. This relationship has been observed at a number of different places both in the Roseburg area and in the coast quadrangles.

The dacite-andesite group.—The rocks of the dacite-andesite group are much less abundant than any of the above described igneous series, but they occur at intervals on the Roseburg, Riddles, and Port Orford quadrangles, and show but a comparatively small range of characters throughout these areas. They present in general a rather compact groundmass, which differs from the other fine-grained rocks associated with the Dillard series in its usual pale colors, light yellowish, slightly pink, or white, and in its superior hardness. The most common type shows phenocrysts of quartz corroded by the magma, and a soda-lime feldspar, usually more abundant than the quartz. Ferromagnesian minerals are rare as phenocrysts and of very subordinate development (usually hornblende) in the groundmass. One common type has a fine, even grain, appearing to the eye as if without porphyritic structure. In general appearance it resembles quartzite. Under the microscope, however, its relationship to the distinctly porphyritic types is readily recognized. Analyses given in the text of the Port Orford folio show about 70 to 75 per cent. silica, 4 to 7 per cent. soda, and 2 to 2½ per cent. potash. Both chemically and in mineral composition they belong with the dacites.

A number of the specimens examined exhibit the same structures and general appearance as described above, but with no visible phenocrysts of quartz. In thin sections made of some of these no quartz could be found either as phenocrysts or in the groundmass. Although none of these were analyzed chemically, they may be referred to the andesites. As they are closely related to the dacites in the field, and show gradational forms carrying varying proportions of quartz, the two mineralogical types are considered to be genetically related and placed in a dacite-andesite group.

The rocks of this group occur in small irregular bunches and in elongated, dike-like masses in the Dillard series, and not uncommonly within the serpentines which they appear to cut. They are described and mapped in the Roseburg folio as "dacitic rocks," and in the Port Orford folio as dacite-porphyry.

Glaucophane and associated schists.—A striking feature of the Dillard series is the irregular and sporadic occurrence of small bodies of schists, certain types of which are characterized by the presence of glaucophane. The variations in these schists, due to the presence or absence or varying proportions of quartz, mica, glaucophane, actinolite, and other amphiboles, garnets, epidote, chlorite, and many other minerals, is very great, and it would lead too far, for the present purpose, even briefly to characterize the different petrographical types which are rather numerous in comparison with the areal importance of the rocks. These schists are generally associated with various more or less basic igneous rocks, and have been considered as products of contact metamorphism. The fact of prime importance for the present consideration is that no outcrop of these schists has yet been discovered in the Myrtle areas, while small patches are of frequent occurrence in all areas of the Dillard.

RELATIONS TO THE MYRTLE GROUP

General relations.—While the rocks of the Myrtle group frequently lie in contact with the different groups of igneous rocks just described, careful search failed to bring to light any definite evidence of an intrusive relationship. In every case the beds in contact with the intrusives were apparently deposited upon the surface of the latter, which must have been previously exposed by erosion. No traces of tuff beds or lava flows were found anywhere in this group.

General comparison with the Dillard.—If the areas of the Dillard had been mapped separately from those of the Myrtle, probably the most striking differential characteristics that would have been evident to a student of the folios are the practically entire lack of igneous exposures within the lines of the Myrtle group, while the Dillard areas are broken up and cut through again and again by dikes and masses of the most variable shapes and sizes. The Myrtle area most particularly studied by the writer is the type locality lying along Myrtle Creek and extending a number of miles down through the Riddles quadrangle. Here, as far as observed, igneous rocks are entirely absent from the Myrtle area, except along its edges, where they form the contact for a number of miles. Occasionally near the edge of the syncline a small area of igneous rock appears within the Myrtle boundaries and elongated in the direction of the axis of folding. No trace of contact phenomena was observed in the soft shales or the conglomerates, and these exposures appear to be due to faulting along the line of the structural axis, bringing some of the "rim" rock to the surface.

The Myrtle conglomerate.—In this area the lowest beds carry fossils that are characteristic of the base of the Myrtle and a heavy basal conglomerate rests on the surrounding igneous rocks. This conglomerate is evidently the result of long-continued grinding together of the component rock fragments, for the material of the Dillard formation has been worked over to such an extent that the rock types appear in no wise in proportion to their relative areal abundance, but apparently mainly in proportion to their relative resistance to abrasion.

The cherts are the most abundant pebbles, the dacites (and andesites) next. In some localities the latter are more abundant than the former. They show the same textures, mineral composition, range of variation of characters, and general appearance as the Dillard dacites and andesites, and are undoubtedly the same. The characteristic Dillard sandstone is but sparingly present, as also are the types of the granular basic rocks. Some characteristic quartz-diorite pebbles were found, but greenstone pebbles are exceedingly rare, and glaucophane schist, serpentine, and shale were not found at all. Of these it may be remarked that the greenstones are usually badly decomposed and crushed; the schists occur only in small quantity and are readily disintegrated on account of their fissility; and the serpentine and shales are more or less soft and generally friable.

Other evidence.—The relationships of the above-described igneous rocks are in general so evident that even without the testimony of the Myrtle conglomerate they would be referred to pre-Myrtle eruptions. The serpentines, however, are rather noncommittal. They lie on the Myrtle contact for several miles, and yet are unrepresented in the basal conglomerate. But their absence from this conglomerate appears to be satisfactorily accounted for by the considerations presented in the last paragraph. They are here referred to the pre-Myrtle because they occur so frequently as dikes and masses throughout the Dillard, while they are found only on the border of the Myrtle areas without any evidence of contact action on the practically unaltered shales; and more particularly because they are apparently intruded by the dacites and andesites which are abundantly represented in the Myrtle basal conglomerate and which are evidently pre-Myrtle. The intrusion of the serpentines by the dacitic rocks is claimed by Diller both in the Roseburg and the Port Orford areas, and such observations as the writer was able to make are in accord with his results.

The absence of glaucophane and other related schists from the Myrtle areas, which was stated above on the basis of field observations, may be theoretically correlated with the pre-Myrtle age of the igneous rocks with which they are so frequently associated.

SUMMARY

We may conclude, then, that the time represented by the inter-Dillard-Myrtle interval (perhaps including part or even all of Dillard time) was a period of great igneous activity. On the other hand, during Myrtle time the practically continuous sedimentation was uninterrupted by volcanic eruptions, and even the inter-Myrtle-Arago time interval, although representing a period of uplift and considerable erosion, shows no evidence, in the areas studied, of igneous activity. Vulcanism apparently lay dormant in this province until the Tertiary, when, in the Arago (Eocene), the period of quiescence was terminated by the intrusion and outpouring of basalts and diabases.

ECONOMIC RELATIONS

Purpose of the discussion.—A discussion of the economic geology of this province *per se* would be inappropriate to the purpose of the present paper, but a brief statement of the economic relations may be of some value in bringing out more clearly the contrast in characters between the Myrtle and the Dillard, and the difference in the geological agents and processes to whose activities they have been subjected.

THE MYRTLE GROUP

As far as known to the writer, nothing in the way of ore deposits, veins, mineralized zones, contact areas, or other like phenomena has been observed in the rocks of the Myrtle group. Sedimentary products of special economic value, such as coal, gypsum, iron ores, etc., have practically not developed at any point. At the time of the writer's visit an oil well was being sunk near the village of Myrtle Creek, and not far from the median line of the Myrtle Creek syncline; but it had not yet proved of any value. Similar formations in California have yielded some oil, but are not economic producers.

The sandstones, on account of their general regularity of bedding and fair amount of induration, lend themselves to quarrying and building, and have been used to some extent. The majority are too thin-bedded for this purpose.

As the conglomerates of the Myrtle were formed after the veination of the Dillard and of the Klamath Mountains schists, it is quite probable that in places they carry placer gold, etc. However, on account of the induration of these conglomerates, the concentration of values may never be found high enough to prove of economic value.

THE DILLARD SERIES

General contrast.—In contrast to the above, the Dillard series carries a considerable variety of economic products, especially the results of secondary agents, even though the actual quantities are apparently nowhere in such proportions as to allow of the development of large properties.

Quartz veins.—As has already been said, quartz veins and veinlets are rather characteristic of the Dillard series. The veinlets are very common in the cherts, and in the sandstones, especially near igneous rocks. In general, these are not known to carry "values," although in the sandstones and the igneous rocks they grade into veins which do.

On South Myrtle Creek veins in the "metagabbro" have been found to carry gold, etc., in sulphuret-bearing quartz, and one or two small mining properties have been operated there. A more important field occurs about the headwaters of North Myrtle Creek and some of its tributaries. Placer-mining has been carried on there for years and with quite a satisfactory yield. In the vicinity the basic granular rocks are traversed (as so commonly elsewhere) by small quartz veins, and these are considered the source of the gold in the placers.

Veins occur in the basic igneous rocks of the Port Orford quadrangle, and assume some economic importance in the district in which head Sixes River, and Salmon and Johnson Creeks, and in a few other places. These deposits are described with some detail in the text of the Port Orford folio. In general, they may be characterized as quartz veins—more rarely calcite-bearing—carrying some gold, and frequently stained by iron oxides or iron and manganese oxides. The less oxidized portions carry pyrites—in some cases a little galena and arsenopyrite. They occur chiefly in the granular intrusives, but are sometimes found in the sedimentary rocks—slates and sandstones. Occasionally they are associated with serpentine or dacite.

Economically more important have been the placer mines of this region, which have been worked since the early fifties. The chief areas on the Port Orford quadrangle are along Sixes River and the creeks above mentioned, corresponding closely to the distribution of the best-developed veins in the Dillard and the associated intrusives. It seems quite reasonable, therefore, to consider the gold as derived from these formations.

Effects of structure.—The minor economic importance of the auriferous veins associated with the Dillard and its related intrusives, is in large measure dependent on the character of the earth movements to which these rock masses have been subjected. While the changes they have undergone have been considerable, they have not been of such a character as to favor the production of great lodes. Instead of great fissures, there are innumerable fractures and faults of minute, small, and medium proportions, very local crushing, schistification, or slate production. Minute veinlets and small veins are therefore common. Rarely, however, does a vein maintain a uniform trend or even its existence for any great distance, and the various irregular small veins and "stringers" cannot be grouped into systems with regular attitudes. The mapping shows that intrusive dikes and masses exhibit the same characteristics. The only regularity to be observed in the mapping seems to have been brought about by the post-Cretaceous foldings which affected all the formations together.

If the quartz-diorites shall later be shown to be older than the Dillard, it may follow that some of the above deposits are pre-Dillard.

Copper.—Copper prospects have been found along the ridge near Dodson Mountain southeast of Roseburg. The metal occurs in chalcopyrite and malachite, in disseminated grains or bunches in both the gabbro and serpentine. While some prospecting work has been carried on, no actual mine has yet been developed.

Nickel.—A considerable development of nickel silicate ores has taken place in the serpentine a few miles west of Riddles. This is part of the serpentine belt which extends through the Roseburg quadrangle continuously for over twelve miles, commencing near Dodson Mountain, where the above-mentioned copper prospects occur. There is strong evidence to prove that the nickel in these deposits was secondarily concentrated from the olivines of the serpentine.[1] Nickel in small quantity is a normal constituent of all the serpentines associated with the Dillard.

Chrome iron.—Chrome iron occurs in, or closely associated with, the serpentines at various places, either as disseminated grains or as masses, sometimes of large size. Several deposits occur west of Riddles in the same hills where the nickel is found.

Platinum.—The vicinity of the Klamath Mountains is a well-known American locality for platinum and iridosmine. According to Diller, these materials have been found in noteworthy proportions in the placer mines along Sixes River, being equal to 5 per cent. or more of the gold content. While the platinum has not been found in its original matrix, we may, from the position of the placers, conclude that it is derived from some of the formations that we have under consideration, and by analogy with other occurrences it may be referred to the serpentines.

Limestone.—The Whitsett limestone lentils are of sufficient purity to yield a good lime, and have been more or less used for that purpose. Certain parts have yielded variegated marbles which were cut in slabs and polished; but at present these are not being worked.

Sandstones and cherts.—Despite their superior lithification, the Dillard sandstones are so crushed and irregularly veined and fractured—especially those which have experienced the greater amount of cementation—that they are only occasionally suitable for quarrying or for the purposes of building. Cherts, such as occur here, have in other parts of the coast proved excellent road metal, but the development of this part of the country has not yet produced a demand for good macadamized roads.

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[1] See, further, Clarke, "Some Nickel Ores from Oregon," *American Journal of Science,* 3d series, Vol. XXXV, pp. 483–88.

AREAL DISTRIBUTION IN THE REGION STUDIED

General method of determination.—The writer has determined the distribution of the Dillard and the Myrtle over considerable areas by actual field studies. In certain areas not visited, but which have been mapped and described in the various folios, the relative distribution may be approximately arrived at from an interpretation of the mapping and descriptions by means of the characteristic features which have been described above for each set of formations. The exposition of these field relations is probably best made by considering the folios seriatim as published by the Geological Survey, and indicating which of the areas there mapped as the "Myrtle formation" are occupied by the formations of the Dillard series, and which by the members of the Myrtle group, at the same time referring to their occurrence in neighboring, but as yet unmapped, areas.

THE INTERIOR QUADRANGLES

General distribution in Roseburg quadrangle.—If one turn to the "Historical Geology Sheet" of the Roseburg folio he will see that these formations occur only in the southern half of the quadrangle. The sedimentary rocks occur as three main areas, elongated in a northeast-southwest direction. The northernmost or largest may be called the Dillard area from the village of that name situated in its midst; the second may be referred to as the Myrtle Creek area, and the southernmost, in the southeast corner of the quadrangle, as the Days Creek area, for obvious reasons. There are also a number of small disconnected patches.

The Dillard area.—A large part of the Dillard area was studied by the writer, with the result that everywhere formations characteristic of the Dillard series were found, while no representative of the Myrtle group was recognized. It is probable that this whole area belongs to the lower series, although a more complete study may show subordinate patches or infoldings of the lower members of the Myrtle group. All of the members of the sedimentary series, all of the main types of igneous rocks, and the peculiar schists, described as characteristic of the Dillard series, occur within this area. The Whitsett foraminiferal limestone lentils crop out at intervals from about four miles directly east of Dillard to the northeast extremity of the area.

The Dillard area extends southwest beyond the limits of the map, into the vicinity of Olalla, and finally passes under the later rocks of the Coast Range. On the north also it is limited by the Eocene sediments and volcanics. In common with all the other pre-Tertiary rocks of this and the Riddles quadrangle, the Dillard series and its associated igneous rocks are bounded on the east by the lavas and tuffs of the Cascade Range, which, in the same direction, are followed by the lavas, etc., of the interior plateau region. The area under consideration is the most northern exposure of the Dillard series known.

The structure of the Dillard area cannot be definitely stated, except that the rocks have a general northeast-southwest strike, which, however, is locally varied without limit. In the section D-D of the Roseburg folio, across the strike of the series, it is represented as a succession of folds—three synclines and two anticlines—the whole forming a sort of synclinorium. The section C-C, six or seven miles farther northeast, represents the structure as monoclinal with a northwest dip. No suggestion is offered as to the manner in which the one structure passes into the other.

The Myrtle Creek area.—In contrast with the Dillard area, the Myrtle Creek area is made up almost entirely of the members of the Myrtle group. These occupy all of the area included in the Roseburg quadrangle except a small patch in the upper northeast corner near the head of Bilger Creek. In that corner the characteristic light gray, highly cemented, veined sandstones of the Dillard series occur, with irregular and indefinite structure; and, nearby, the regularly bedded, comparatively unaltered, fossiliferous shales and other members of the Myrtle group. The actual contact between the sedimentary members of the two groups was not observed, but they were exposed within 100 yards of each other.

The Myrtle Creek area has, in general, a simple structure. The strata strike and the area extends in a northeast-southwest direction, and the rocks have been folded into a simple syncline about three miles across as now exposed. This synclinal structure extends throughout the area that is included in the Roseburg quadrangle, and continues to the southwest into the Riddles quadrangle. It there lies on both sides of the Umpqua River, which it leaves in the vicinity of Riddles, and continues along Cow Creek. The writer traced it a few miles above Riddles on Cow Creek, but cannot state how far it extends in that direction.

The boundary contacts of the Myrtle Creek area are generally formed by a heavy conglomerate which usually rests directly on the pre-Myrtle intrusives, sometimes on the Dillard sediments. This conglomerate, along the northwest border of the area, is very thick—over 1,000 feet near the village of Myrtle Creek. It was traced by the writer continuously for over fourteen miles, and, according to Mr. Will Q. Brown,[1] is traceable without a break for over twenty miles. The basal conglomerate is also found on the southeast border of the area, where it is considerably thinner, and was studied only along four or five miles of contact, about three of the miles near Myrtle Creek, and the rest near Riddles. The lithologic characters of this conglomerate have been described in a previous section.[2]

At the northeast extremity of the Myrtle Creek area the conglomerate does not appear to be basal, but is underlain by Aucella-bearing shales (and very thin-bedded sandstone) which rest directly on the igneous rocks without noticeable alteration. This may mean that the syncline represents a trough of deposition, and that along the median line the conglomerate may not be strictly basal, but may be underlain by a deposit of shale, which has been overlapped along the sides by the later deposited conglomerate.

As noted earlier, conglomerates occur at various horizons in the Myrtle group, and may some day serve to delimit its various members, as, for example, the beds corresponding to the Horsetown from those corresponding to the Knoxville. No attempt so to use them has been possible in this investigation.

Smaller areas between the Dillard and Myrtle Creek areas.—Between the Dillard and the Myrtle Creek areas are mapped several smaller ones. The largest of these is about six and one-half miles long, and from about a quarter to a third of a mile wide. It lies partly in the "metagabbro," and partly between the serpentine and the other intrusive. It is also penetrated by small dikes of serpentine and by small masses of greenstone (chiefly intrusive basalts) not shown on the map. Associated with this area at one point is a patch

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[1] Quoted by Becker, *Geological Society of America Bulletin*, Vol. II (1891), p. 203.

[2] See p. 534.

of the same nature, about three-quarters of a square mile in area, entirely inclosed in the serpentine, and apparently torn from the main area by the act of serpentine intrusion. Another small area lies entirely in the "metagabbro" along the Umpqua River (near the railroad), and is also associated with serpentine dikes not shown on the map.

All of these smaller areas are composed of Dillard sandstone, etc., which show their characteristics very distinctly, and are, in general, considerably altered. The form of each of these areas is rather long and narrow, and it can be distinctly seen in the field that they do not merely lie on the intrusives, but in them as included or partially submerged masses.

Contrast between close-lying areas of Myrtle and Dillard.—The strong contrast and abrupt change (i. e., not gradational) between the Myrtle and the Dillard can be well observed on ascending the ridge a few miles southwest of Dodson Mountain, going up from Bilger Creek so as to reach the Dillard areas as close to the Myrtle as possible. After leaving the Myrtle shales, one passes onto the basal conglomerates which are regularly bedded with a very uniform strike for miles, along the higher flanks of the range. Leaving these conglomerates, one passes onto the serpentine, and then shortly onto the disconnected area of Dillard. This shows no trace of conglomerate, but is chiefly of hard gray sandstone, well cemented, and not infrequently traversed by quartz veins and stringers. The strike is irregular. At one point near the border, it is perpendicular to the regular strike of the Myrtle, which is only some 200 or 300 yards distant across the serpentine. The characters of the Dillard would seem to be largely dependent on its intrusion, while in the Myrtle nothing that could be definitely referred to intrusive action was observed.

To the south, in the vicinity of Canyonville, sedimentary rocks of the Dillard group are found on the southeast side of the Myrtle Creek syncline. Their extent was not determined, nor their contact with the Myrtle studied.

The Days Creek area.—The writer did not visit the Days Creek area, but from the statement in the text of the Roseburg folio, which refers to the Horsetown horizon, that "fossils of this horizon have been found . . . . throughout the area along Days Creek," we may infer that it is entirely Myrtle, perhaps all Upper Myrtle.

THE COASTAL QUADRANGLES

The Coos Bay quadrangle.—On the Coos Bay quadrangle there are two main areas mapped as "Myrtle formation," both of which are in the most southern part of the quadrangle, besides some disconnected rocks and small bunches along the coast near Bandon. These are apparently all Dillard. The writer studied the large area in the vicinity of Myrtle Point, and found it made up entirely of typical Dillard formations. No trace of the Myrtle group was found. That all of the areas are Dillard, with no Myrtle, may be inferred from the descriptions and mapping of the folio. No fossils (other than protozoan) were found, and in every small area, radiolarian cherts, greenstones, glaucophane schists, alone or together, are distinctly in evidence, while the semi-metamorphic sandstones make up the main mass.

The Port Orford quadrangle.—Considerable areas have been mapped as the "Myrtle formation" in the Port Orford quadrangle. The writer found time to examine only the northeastern portion within about ten miles of its northern boundary. All of that portion examined is distinctly Dillard, which is covered directly by the Arago (Eocene) without the intervention of the Myrtle. The unconformity between these two formations is well seen on Salmon Creek, about a half-mile above its junction with the South Fork of the Coquille River. The creek there flows on the contact, and the Eocene beds on the east dip off regularly (at about 31° E.) from the highly inclined (74° E. and over) and irregular Dillard beds. Pebbly layers in the Eocene sandstones carry detritus derived from the neighboring Dillard.

Judging from the abundance of basalt, chert, small serpentine dikes, and masses of amphibole schists, it may be inferred that most, if not all, of the northern part of the Port Orford quadrangle is Dillard, as far down perhaps as Sixes River. A considerable area below this, through the midst of which runs Elk River, appears, on the map, remarkably free from these diagnostic rock types, which, however, again appear in part in the southwest corner, and in a north-south belt just east of Iron Mountain.

According to the text of the Port Orford folio, Horsetown and Upper Knoxville fossils are found in the Rogue River section in the southeast corner of the quadrangle. This section is estimated as 1,500 feet thick, and is said to be made up of "much shale mixed with the relatively thin-bedded sandstone, and although the rocks are highly tilted, their stratification is well preserved." Furthermore, "the base of the series on Rogue River below Agnes is a heavy conglomerate, best exposed perhaps in a prominent bluff near the trail one and one-half miles northwest of Agnes. *A. crassicollis*, which is the later form, characterizes this portion of the section where it is separated from the Colebrooke schist by a belt of serpentine." This is evidently a section of the Myrtle group, and we may infer a gradually depressed sea bottom as the Upper Knoxville horizon has overlapped the lower, and lies directly on the pre-Myrtle rocks with a basal conglomerate.

The most extensive fossiliferous section described is on "Elk River, beginning to the east in Copper Mountain with large masses of conglomerate and sandstone overlying shales and sandstones, the whole containing *A. piochii*." Farther down the river, "shales and sandstones are well exposed and contain numerous fossils in place." These are referred to the Upper Knoxville by T. W. Stanton. The Elk River section is, therefore, as already inferred from inspection of the map, chiefly, if not wholly, of the Myrtle group.

In the northwestern part of the quadrangle occurs an outlier of the Klamath Mountains schists, upon which the Myrtle group lies, "and the basal portion is a conglomerate containing many fragments of the schist. The conglomerate commonly contains *Aucella crassicollis*." We had thus repeated the phenomena of overlap of the Upper Knoxville horizon over the lower and onto the schists, as already described for the Rogue River section, which is about twenty-five miles distant.

THE DISCONTINUITY OF THE DILLARD AND THE MYRTLE

Where the exposures of the Myrtle group have been observed in close proximity to those of the Dillard series, there was found no gradation from the lower to the higher formations, but a distinct break in lithologic character and structure. The evidence already presented is to the effect that this break represents a period during which many events were brought to pass which we may believe required considerable time for their accomplishment. To bring this more distinctly before the mind, we may summarize the more important events connected with this interval.

1. There were at least three distinct periods of igneous activity, in each of which rocks of more or less variety and in considerable abundance were produced. These three periods have not been found to overlap, but everywhere have a definite order of eruption over large areas, and probably represent distinct intervals of time.

If these three groups are in any way genetically connected, they must represent deep-seated and general differentiation, and we may note that the basic (to intermediate) group appeared first and in greatest abundance, followed later by the ultrabasic and the comparatively acid groups, apparently in the order named. Within each group there has been distinct and often considerable differentiation, the products being related in lithological characters and by gradational forms. Compared with the hypothetical differentiation between the groups, this intra-group differentiation is more local, less complete, more evident, and does not make the same time demand upon the period under discussion.

The basic series may have been in part contemporaneous with the deposition of the members of the Dillard series.

2. The degree of lithification of the Dillard, which is one of its most marked characteristics, is considerably higher than that of the Myrtle. The Dillard type of alteration, the cementation and quartz-veining, could only have been produced at some depth, and the abrupt change on passing to the Myrtle, and the absence of comparable alteration in the lowest Myrtle, show not only that the alteration was pre-Myrtle, but that the upper unaltered layers of the Dillard had been removed before the deposition of the basal beds of the Myrtle group.

3. The general strike and the elongation of the Dillard area are the same as those of the Myrtle Creek area. This is apparently due to the orogenic disturbances in post-Myrtle time (including pre-Eocene and post-Eocene movements), which affected both groups in the same way. But the marked irregularities of attitude in the Dillard near the base of the Myrtle, and its divergence from the latter within short distances at places where, within the Myrtle, the

structural uniformity may be traced for miles, indicate crustal disturbances and folding in the Dillard series before the deposition of the Myrtle.

A further argument for such physical activities during the Dillard-Myrtle interval may be gathered from a consideration of the fracturing and crushing produced. These are characteristically present in the Dillard exposures and are often excessive. In the Myrtle, however, they are only locally in evidence to any marked degree, as, for example, along an occasional fault plane or where the shales have been folded against hard or massive formations. In the Dillard we may connect this fracturing and crushing in part with the various intrusions, in part with the swelling and moving of the solidified serpentines, but a certain amount can be referred only to crustal movement that was post-Dillard and pre-Myrtle.

We may conclude, therefore, that the Myrtle group was deposited unconformably upon the Dillard series after an interval of varied igneous activity, earth movement, and erosion.

COMPARISON WITH THE STANDARD CALIFORNIA TYPE FORMATIONS

THE MYRTLE GROUP

Identity with the Shasta.—In describing the paleontologic limits[1] and characters[2] of the Myrtle group, and its nomenclature,[3] it has been shown that it corresponds to the Shasta group of California, and that the succession of horizons—Lower Knoxville group, Upper Knoxville, Horsetown—is the same as in the Shasta group, and characterized by the same fossils. It remains to be pointed out that the lithological characteristics are identical, and, considering its distribution in connection with the known distribution of the Shasta group, which is so strongly developed over large areas in northern California, we may safely conclude that it is strictly Shasta, and was deposited in the same sea, during the same period, and under the same conditions of erosion and deposition as the Shasta of California.

THE DILLARD SERIES

General characteristics of the Franciscan.—One familiar with California Coast Range geology will already have anticipated the

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[1] See p. 519.

[2] See p. 522.

[3] See p. 520.

correlation of the Dillard with the Franciscan series. The Franciscan is a thick series of rock formations which is widely scattered over the coastal portion of California and which bears the record of an important part of Californian geological history. Its stratigraphic boundaries so far known are the marked unconformity at its summit, separating it from the base of the Knoxville (zone of the *Aucella piochi*), and the striking unconformity at its base separating it from the older holocrystalline terranes (crystalline limestones, schists, and Coast Range granites, etc.). Lithologically it is characterized by its massive, arkose sandstones and radiolarian cherts—besides which shales, conglomerates, and foraminiferal limestones occur—and by its degree of lithification, which is, as far as known, unique in the coast region. This latter alone separates it from all later and earlier formations with which it has yet been found associated. It is also characterized by being intersected by an abundance of igneous rocks—greenstones, diabases, etc.: serpentines and gabbros; and more acid porphyritic types—and by the presence of glaucophane and related schists. Paleontologically it is characterized by a general absence of fossils, those which have been found leaving the age indefinitely determined, but indicating, in a general way, that they may belong anywhere from the Lower Cretaceous to the Jurassic inclusive.

Identity with the Franciscan.—In all of its characteristics and peculiarities the Dillard series is practically identical with the Franciscan,[1] and it fits into the same stratigraphic position, and it may be concisely defined by the brief description of the preceding paragraph. It was evidently formed under the same peculiar series of physical conditions, has been subjected to very similar series of igneous eruptions, to practically the same degree of lithification, and to about the same amount and character of disturbance and erosion.

The Whitsett limestone fossils.—The two fossils reported by Stanton as occurring in the limestone of the Roseburg quadrangle

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[1] For further comparison of the characteristics and peculiarities of the Dillard with those of the Franciscan, reference may be made to the description of the Franciscan type locality by Professor A. C. Lawson, U. S. Geological Survey, *Fifteenth Annual Report* (1895), pp. 415–35; and to the description of the San Luis quadrangle by Dr. H. W. Fairbanks (U. S. Geological Survey, *Geologic Atlas of the United States*, Folio No. 101), who has mapped a considerable area of Franciscan in the southern Coast Ranges of California, about 8° of latitude south of the Dillard area, but in which the peculiarities are closely the same throughout.

cannot be accepted as throwing much light on the definite age of the Franciscan. The forms were rather imperfect. The *Hoplites* was said to be identical with or near to *H. dilleri* which has been found in the Knoxville. Whether the Franciscan includes representatives of the Lower Cretaceous, Jurassic, or (and) intermediate time, there is no reason why some forms should not range from the Franciscan into the Knoxville with the same, or with but slightly different, characters. Indeed, considering that the Mariposa beds of the Sierra Nevada, now for some time accepted as Jurassic, were believed by White,[1] in the eighties, to be contemporaneous with the Knoxville on paleontological evidence, and both were referred to the Lower Cretaceous by Becker,[2] we have good reason to expect that some faunal similarities would exist.

In connection with the *Opis californica* found in the Whitsett limestone, it may be pointed out that an imperfect fossil from the base of the Franciscan on the northeast slope of Montana Mountain—part of the Franciscan type area—was also referred by Stanton to the genus *Opis*.[3]

In general, it may be added that, as several geologists have at times confused the Knoxville and the Franciscan in various localities, considering the latter a metamorphosed facies of the former, it is possible that certain "Knoxville" localities credited to some of the fossils are, in reality, Franciscan.

The Jurassic question.—At several localities in the region under discussion fossils have been found which have been referred to the Jurassic. At Bucks Peak, some miles southwest of the Roseburg quadrangle, a sandstone carries fossil leaves which have been referred to the Jurassic by Professor Fontaine; and, in the bed of Elk River in the Port Orford quadrangle, loose pieces of shale were found containing plants which he considers of the same age—Lower Oölite. The shales were not recognized in place. On Johnson Creek Diller found fragments of shale containing *Aucella*, which Stanton refers to the Upper Jurassic—Mariposa beds. According to Diller, "the Jurassic sediments closely resemble those of the Myrtle formation,

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[1] U. S. Geological Survey, *Bulletin 15* (1885), pp. 24–26.

[2] U. S. Geological Survey, *Bulletin 19* (1885), pp. 18–20; also *Bulletin of the Geological Society of America*, Vol. II (1891), p. 206.

[3] U. S. Geological Survey, *Fifteenth Annual Report* (1895), p. 443.

and in the field they were not separated." The same is true of the Bucks Mountain locality, although the sandstones there are said to be "somewhat metamorphosed." The "Jurassic" shales of the Port Orford area are sometimes referred to as "slaty shales." This partially metamorphosed character, the association with the Dillard formation, and the fact that they could not in the field at any locality be separated in characters or appearance from the "Myrtle formation," would suggest that they are really Dillard, or that the Dillard (Franciscan) is, in part at least, Jurassic. It is possible, however, that these beds may lie stratigraphically (even unconformably) below the Franciscan, and a careful examination of the field to determine this point is desirable.

EXTENSION OF THE FRANCISCAN

The Dillard not only may be looked upon as a northern extension of the Franciscan, but is of particular interest as extending the area in which obtained *in toto* that congeries of peculiar conditions of sedimentation, life, vulcanism, and diastrophism which characterizes the Franciscan of central California. According to Fairbanks, to whom chiefly we are indebted for statements of the distribution of these Franciscan conditions, "the farthest point to which it can be traced southward is southern Santa Barbara County, where it disappears beneath the Cretaceous."[1] Furthermore, "the series has been recognized by the writer from central Santa Barbara County northwestward through the Coast Ranges to the Klamath Mountains. On the western slope of these mountains it has been traced to the Oregon line, and it undoubtedly extends farther."[2] The present investigation has extended the limit of the Franciscan about eighty-five miles farther north and beyond the Klamath Mountain group, and there it is found to pass under the Eocene sediments at the edge of an extensive Tertiary province. It is possible that the Franciscan conditions will not be found north of the present boundary, but even with this limit, the known extent of this unique sequence of conditions—about 600 miles along the coast—is quite remarkable.

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[1] *Bulletin of the Geological Society of America*, Vol. VI (1895), p. 83. It may be remarked that by "Cretaceous" Fairbanks means the Shasta-Chico series. He considers the Franciscan entirely pre-Cretaceous.

[2] *Journal of Geology*, Vol. III (1895), p. 416.

THE SHASTA (LOWER CRETACEOUS) SEA

It has been shown that the Myrtle group terminates to the north (in the Myrtle Creek area) against a Franciscan territory, with a conglomerate over a thousand feet thick at its base. This conglomerate contains abundant Franciscan detritus. Some of the chert may possibly be derived from pre-Franciscan terranes, but this remains to be proved. Almost nothing that must be referred to the pre-Franciscan was found. No pebble of any of the older schists was observed, and only a very rare one of granite. As this heavy conglomerate can be traced for over twenty miles on the northern limit of the Myrtle, and is thinner on the south flank of the syncline, it may be inferred that the shore-line of the early Knoxville sea was not far distant, with land, made up of Franciscan surface exposures to the north.

The occurrence of Horsetown overlapping the Knoxville and resting unconformably, often with basal conglomerate, directly on the pre-Knoxville terranes, indicates a subsidence and transgression of the sea during the Shasta period. This general relation has been pointed out by Diller, who has shown that in the northern California field, "everywhere beyond the limit of the Knoxville beds, the Horsetown beds rest with a marked unconformity, directly on the metamorphics."[1] He has even been to able show, by the aid of fossils, that the upper part of the Horsetown overlaps the lower.

As the Shasta in the Oregon region here discussed is limited by the Klamath Mountains on the south, against whose older terranes it rests with basal conglomerates, we may conclude that the Knoxville sea entered this region as an arm elongated in an east-west direction, and that with the passing of time the sea transgressed farther and farther, the arm becoming broader, especially toward the south and southeast, until it probably, as also believed by Diller, united with the waters encroaching from south across northern California around the other side of the Klamath Mountains.

The present investigation has, in particular, made it possible to trace more closely the nature and boundaries of the Myrtle arm of the Shasta sea, and to infer the nature of the rocks which formed the coast line.

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[1] Diller and Stanton, *Bulletin of the Geological Society of America*, Vol. IV (1893), p. 214.

THE BOUNDARY OF THE KLAMATH MOUNTAINS

In the vicinity of the Klamath River (in northwestern California) occurs a large area of crystalline rocks which bear, in many ways, resemblance to those of the Sierra Nevada, and which created considerable doubt, when first studied, as to whether this area should be considered part of the Coast Ranges, which topographic continuity would suggest, or part of the Sierra Nevada, to which it appeared geologically related. The Gordian knot was cut by giving it the name Klamath Mountains, and[1] separating it from the Oregon Coast Range on the north, the Cascade Range on the northeast, the Sierra Nevada on the southeast, and the California Coast Ranges on the south and southwest. As this region has a geological individuality, and as the multiplicity and vagueness of local names for its parts tended to considerable confusion, it was a decided step in advance to characterize this province, delimit it, and give it a comprehensive name. For following up this idea and working out the details we are chiefly indebted to Mr. Diller.

The present investigation has shown that in southwestern Oregon, down to about the Rogue River, the geological formation, structures, and other conditions are such as prevail in the California Coast Ranges. The Franciscan series is particularly well developed to the southwest and south of the Klamath Mountains in Humboldt, Mendocino, and Lake Counties (lat. 41°–39° N.), and beyond, in all respects like the Franciscan (Dillard) to the north of the Klamath Mountains in Oregon. It would seem most consistent, therefore, and satisfactory, to omit the Franciscan and Shasta areas on the north from the territory to be included under the title of Klamath Mountains. This would remove the northwest and the northeast lobes as represented on the various maps of the Klamath Mountains,[2] and make the boundary cut across toward the west from near Jacksonville and follow close to the Rogue River until a short distance below the mouth of the Illinois, then west to the coast. In other words, the Klamath Mountains would be that general uplifted region characterized by a nucleus of metamorphic (and associated igneous)

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[1] See Powell, *Physiographic Regions of the United States* (1895), p. 96 (Monograph, National Geographical Society).

[2] E. g., that published in *Bulletin 196* (Plate I) of the U. S. Geological Survey.

rocks.[1] The occurrence of metamorphic outliers—such as the Grouslous Mountain area of the Port Orford quadrangle—and of small areas of unmetamorphosed inliers, cause but slight difficulty, which, however, exists whatever criteria of discrimination be used. It may be added that the two lobes which it seems logical on geological grounds to detach from the Klamath Mountains, are no more related to them topographically than other neighboring parts of the Coast Ranges.

NOMENCLATURE

In approaching this field of study, the term "Myrtle formation" was found applied to a number of formations which are naturally separable into two distinct groups, to the upper of which alone the term "Myrtle," as stratigraphically defined by its author, is applicable. It seemed best, for the development of the subject in this paper, to use a local term—"Dillard," recalling what is perhaps the most typical area in the region—for the lower series as the complement of the existent local term, "Myrtle."

The writer, however, is not in sympathy with the unnecessary multiplying of local names. To correlate, to trace general conditions and relationships, are undoubtedly among the most important aims of science, and multiplicity of terms—especially synonyms—tends to obscure and conceal such relationships. In particular, in the case of geological formations and groups it would seem highly desirable that those which the best evidence indicates as contemporaneous, and which were ushered in and brought to a close by the same sets of physical changes, should be designated by the same name. This is especially true when they occupy the same relative position in closely similar stratigraphic sequences and were formed under the same general physical conditions. The rocks of the Myrtle group, for example, have the same characteristic fossils, and the same stratigraphic position and range, as the Shasta group of California. They occupy corresponding positions in remarkably similar stratigraphic sequences, and their upper and lower limits were apparently determined by the same great diastrophic movements. Furthermore, the character of sedimentation is the same, and the distribution is such

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[1] The term "Klamath Mountains" has been used in this sense throughout this paper.

that they are believed to have been deposited under similar conditions in the same sea during the same period. According to the above principles, therefore, they should be given the same name.

That there is another point of view, however, is shown by the fact that the author of the term "Myrtle formation" has used it in the maps and texts of three different folios, and in other papers, with the distinct understanding and belief for which he presents evidence, that the rocks so designated were formed in the same sea, at the same period, and have the same stratigraphic limits and characteristic fossils as the Shasta. No reason has been given, as far as known, for coining and using the local synonym.

In the writer's opinion, therefore, the best and most practical interests of science would be served, in the present case, by referring to and mapping the formations under discussion as the Franciscan series and the Shasta group, respectively, of the Roseburg quadrangle, or of whatever quadrangle may be under consideration. If, however, for some reason or other, local terms may seem desirable for the Oregon field, it is believed that the names used in the above discussion represent natural groups, and have been sufficiently definitely defined to serve a useful purpose.

SUMMARY OF RESULTS

The rocks of southwestern Oregon which, in the Roseburg, the Coos Bay, and the Port Orford quadrangles have been mapped as the "Myrtle formation," and considered to represent a period of continuous sedimentation corresponding to the Cretaceous from the base of the Knoxville to (at least) the top of the Horsetown, inclusive, are divisible into two natural groups, which differ in their lithological and other characters, and which are separated by an unconformity representing a period of considerable geologic activity.

The older (Dillard) series is pre-Knoxville and of considerable thickness (not measured, but perhaps 8,000 to 10,000 feet), and gives evidence of a sea in which were characteristically developed radiolarian cherts in series of regularly recurring thin beds, alternating with a peculiar ferruginous shale; thick-bedded, arkose sandstones, almost entirely devoid of fossils; and occasionally a foraminiferal limestone. Less characteristic shales and conglomerates were also formed. These deposits were made in Franciscan time, when the

Coast Range region of California was largely under water, at least so far south as about latitude 34° 30′ N. This sea invaded the Oregon coast at least as far north as latitude 43° 15′ N.

Following the deposition of these beds—perhaps in part during it—at least three series of igneous rocks were intruded at separate intervals; a basic series (basalts, diabases, etc.); an ultrabasic series (serpentines, pyroxenites, gabbros); and an acid sodic series (dacites, andesites). There is also evidence of elevation of the Franciscan sediments to dry land, dislocation, fracturing, crushing, considerable cementation and veination, and, finally, a long period of erosion, which stripped the sediments from the granular intrusives over large areas. This whole course of events, of sedimentation, vulcanism, cementation, diastrophism, and erosion, follows closely, in sequence, characters, and intensity, the history of the corresponding time throughout the California Coast Range province, and extends the recognized limits of this province almost 100 miles, making the extreme length now known about 600 miles.

Following the period of erosion came another period of dominating subsidence, and the gradually transgressing sea, which deposited chiefly fine sediments with some sand and well-washed gravels, built up the upper (Myrtle) group of rocks, which reach the thickness of about 6,000 feet near Myrtle Creek. These are more or less fossiliferous and contemporaneous—probably continuous—with the Shasta group of California. The sea entered this Oregon region apparently as an arm elongated in an east-west direction, with its south shore against the Klamath Mountains and its north shore about the latitude of Roseburg. The land to the north showed chiefly Franciscan exposures; that to the south, both Franciscan and the earlier crystalline schists, etc. With the progress of Shasta time this arm broadened, and finally united with the gulf which was advancing over northern California around the other side of the Klamath Mountains, making of this mountain group an island, which may possibly have been finally submerged.

The glaucophane and associated schists of southern Oregon were formed during the same period as the similar schists in California (pre-Knoxville) and are associated with similar rocks of the same (Franciscan) series.

ARAPAHOE GLACIER IN 1905

JUNIUS HENDERSON
University of Colorado, Boulder, Colo.

On August 30, 1904, H. F. Watts and the writer, for the purpose of ascertaining the rate of movement of Arapahoe Glacier, placed upon the ice ten zinc tablets, tying them accurately to bench marks on the granite walls and terminal moraine by triangulation and direct observation. No. 1 was placed 300 feet from the northeast edge of the ice; No. 1 to No. 2, 89 feet; No. 2 to No. 3, 51.7 feet; No. 3 to No. 4, 58.6 feet; No. 4 to No. 5, 65.4 feet; No. 5 to No. 6, 82.8 feet; No. 6 to No. 7, 84.4 feet; No. 7 to No. 8, 73.8 feet; No. 8 to No. 9, 97.2 feet; No. 9 to No. 10, 114.4 feet. On August 30, 1905, we again visited the place and made accurate measurements, ascertaining that No. 1 had moved 11.15 feet; No. 2, 11.9 feet; No. 3, 13 feet; No. 4, 15.9 feet; No. 5, 16.75 feet; No. 6, 18.5 feet; No. 7, 20.6 feet; No. 8, 20.45 feet; No. 9, 21.7 feet; No. 10, 27.7 feet.

We have found each year, since the original survey in 1902, unmistakable evidence of shrinkage all along the lateral margins near where they curve into the terminal moraine, and along the terminus, particularly where the effects of erosion by surface drainage is greatest; but all this time the center of the ice-tongue has shown no shrinkage, either horizontally or vertically. Along the northeast margin the ice has shrunk away from the moraine about four feet since last year, all observations being made at the same time each year.

The snow-line on the ice, which had moved forward a long way during 1903 and 1904, has suddenly receded this year so far that the ice is bare nearly to the Bergschrund, as in 1902. A detailed examination of the summary of weather records of the three nearest United States Weather Bureau stations throws no light upon the cause of this sudden change. Comparison of photographs taken with the same lens at the same time of the year in 1904 and 1905 shows but little change in the extent of the snowbanks of the region, some having decreased in size, a few increased, but mostly stationary or slightly smaller.

PAPERS READ AT THE SUMMER MEETING OF SECTION E, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AT SYRACUSE, N. Y., JULY 19-22

"Stratigraphic and Economic Geology of the Syracuse Region," T. C. Hopkins.

"Glaciation of North America, with Particular Reference to the Effects of the Ice Sheet in Central New York," H. L. Fairchild.

"The Great Lakes in Their Relation to Local Geology," Frank B. Taylor.

"Sudbury Basin Shorelines," F. P. Gulliver.

"Some New Problems in Glaciology," H. L. Fairchild.

"The Physical Character and History of Some New York Formations," A. W. Grabau.

"The Burrow Origin of Arthrophycus and Daedalus (Vexillum)," C. J. Sarle.

"The Occurrence of Glacial Epochs in Paleozoic Time," David White.

"The Age of the Wise and Harlan Formations of Southwestern Virignia," David White.

"The Western Sierra Madre of the State of Chihuahua, Mexico," E. O. Hovey.

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THE

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OCTOBER–NOVEMBER, 1905

FERDINAND, FREIHERR VON RICHTHOFEN

Born May 5, 1833; Died October 6, 1905

By BAILEY WILLIS
Washington, D. C.

Ferdinand von Richthofen is best known in the countries other than his fatherland as the explorer of China, and the author of the theory of the origin of the eolian loess deposits. In Germany his dominant personality carried his influence into many affairs not immediately connected with the sciences of geography and geology, in which he was a specialist. In him the emperor has lost a well-informed and conservative counselor.

Von Richthofen first took up geological work in connection with the *Wiener Reichsanstalt* in 1856, at the age of twenty-three. His earliest publications relate to the structure of the Tyrolean Alps, and the occurrence of certain igneous rocks. In 1860 he was appointed attaché for scientific studies with the Prussian expedition of Graf von Eulenberg to China, a diplomatic mission reinforced by four men-of-war, its object being to persuade the Chinese to enter into treaties with the German powers. Two years passed in diplomatic negotiations, during which the eager explorer found little opportunity to penetrate beyond the coast line of the unknown land; but he availed himself of a voyage made by one of the frigates among the East India islands to visit Formosa, the Philippines, Celebes, and Java. He also made excursions into Siam and farther India.

When the embassy returned, von Richthofen remained in the East, in accordance with the original resolution with which he had left Europe, to solve some problem of broad bearing with reference to the Asiatic continent. His early plans were thwarted, and he finally made a voyage to San Francisco, whence he extended his travels through California and Nevada. Years had passed since he left home, and his original purpose remained unaccomplished, but unshaken, when on New Year's, 1867–68, he discussed with Professor J. D. Whitney those regions of the world of which geological studies were most needed. They agreed that China was, in view of its civilized state and general relations, the land which promised the richest results, and, in spite of the gigantic dimensions of the problem, von Richthofen determined to devote his energies to a study of that country for a number of years. He proposed to himself to explore, with individual resources, a land one-third larger than the United States, of which there were no maps more useful than rude Chinese sketches, and regarding which there was no scientific literature. Although China had been traversed by missionaries for centuries, and in the beginning of the eighteenth century the Jesuit fathers had determined the astronomical positions of nearly all the principal cities of the empire, our ideas of its geography were still an assemblage of myths. The conditions of investigation among a superstitious and unfriendly people, of whose language he was ignorant, might well, even under ordinary circumstances, have deterred the explorer, and they were at this time peculiarly unfavorable in consequence of the Tai-ping rebellion, and of the Mohammedan rebellion in the northwest provinces. Casting about for a companion, who might act as servant and interpreter, von Richthofen found it impossible to secure a Chinese of sufficient education who would submit to the hardships of such a journey as he proposed. There was at the moment in Shanghai a Belgian, Paul Splingaert, who, having killed a Chinese, was on trial and liable to sentence of death. Von Richthofen believed that the act was justified by attendant circumstances, and proposed that the man, who was accomplished in the Chinese dialects, should be released to accompany him. The authorities, being quite willing to yield the responsibility of his execution to some mob of the interior, agreed, and during four years Splingaert was von

Richthofen's constant and loyal companion. Von Richthofen gives him great credit for the success of the expeditions, and no doubt with justice, since the interpreter holds the fate of a party in the hollow of his hand.

With an appropriate sense of caution which, coupled with courage, resolution, and a strict sense of justice, was the basis of his success among the Chinese, von Richthofen made his first journeys by water on the Yang-tzï below Hankow, and the canals and lagoons of its lower course. His third journey was an extended one, by land, through the province of Shan-tung, and it is perhaps not too much to say that during the six weeks he spent there in the spring of 1869 he laid the foundations for the occupation of the peninsula by the Germans, who have developed their enterprises closely along the lines foreshadowed in his geological reports. From Shan-tung he proceeded to the Liau-tung peninsula, which he traversed as far as the borders of Korea, and, returning via Mukden, he reached Peking. The traveler was now reluctantly brought to consider the necessity of returning home, when through the efforts of Mr. Alexander Cunningham, head of the American house of Russell & Co., the Chamber of Commerce at Shanghai became interested in his explorations and undertook to support them. Having made a short trip, which he calls his fourth journey, through Kiang-si and Chö-kiang, von Richthofen began to prepare for the fifth journey, during which he traversed China from south to north, from Canton to Peking, and passed through a number of provinces where the population was believed to be peculiarly inimical to foreigners, and where he was a pioneer. His route from Canton to Hankow, on the Yang-tzï, was that afterward followed by the American engineer, Parsons, and that along which the proposed North-South Trunk Railway of China is to be built. Northward from Hankow he traveled by the Han River to the western margin of the great plains, and thence followed the foothills northward to the Yellow River. After crossing the latter he turned westward into the mountainous province of Shan-si, the province of great coal resources, and pursued thence the imperial highway to Peking. This journey occupied five months, from January to May, 1870. It was an enterprise of the highest daring, and one which yielded a rich treasure of observations in geography, geology, and the natural resources of the country.

Within three weeks of his arrival in Peking von Richthofen was prepared to undertake a still greater journey than the last, into the far southwestern provinces of China, but the massacre of Tientsin checked his plans, and, receiving news of the war between France and Germany, he was again about to return home. He realized, however, that he must arrive too late to be of material service to his country, and finally decided on a journey in Japan, where he became intensely interested in the varied features of that delightful little country. He says:

> I parted from it with regret, and yet I returned with joy to my work in China. For only after I had realized the smallness of the features of that land [Japan] did I become aware of the greatness with which every problem is presented in China. China lacks all of those charms which delight the traveler in Japan. One's mood becomes earnest, the conditions of life are unpleasant, but one's view is widened, and gigantic problems rise before us, of equal importance for the past, the present, and the future.

In this expression we have a suggestion of the spirit of the man, who had early set himself a task beyond the strength of most men, and who rejoiced as he realized its immensity.

His sixth journey in China was undertaken to fill out the months until the climatic conditions should be favorable for the trip to the far western provinces, and was an excursion which occupied some weeks in midsummer, 1871. Late in October he left Peking for his greatest and last journey through northern China, Mongolia, and central China, to the heart of Ssï-ch'uan. His intention of proceeding to Thibet was there thwarted, and, being near the end of his ready money and remote from any point at which he could replenish his purse, he was obliged to return, via the Yang-tzï River, along the route followed a score of years earlier by Abbé Huc.

In December, 1872, after an absence of twelve years, von Richthofen returned to Germany. In 1873 he was elected president of the Geographical Society of Berlin, an office which he also held from 1903 to the time of his death. During the years 1879–83 he was professor of geology at the University of Bonn. From 1883 to 1886 he was professor of geology and physical geography at the University of Leipzig, and in 1886 became professor at the University of Berlin. He was director of the Geographical *Anstalt*, and of the *Museum für*

Meereskunde; and 1903–04, rector of the University of Berlin, a position of honor conferred only upon the most distinguished.

Von Richthofen's scientific activity covered half a century, we may almost say the half-century of geological progress. He himself never stood still, but, advancing, welcomed newly discovered facts, was receptive to fresh ideas. In a letter received from him shortly before his death, he writes:

> Die Anschauungen wandeln sich; die Art, die Dinge zu sehen und zu beurtheilen wird eine andere, bei der Allgemeinheit und bei dem Einzelnen.

And, referring to recent investigations in parts of China which he had described, he says:

> Niemand wird mehr Freude daran haben als ich selbst, auch wo sie mich berichtigen und ergänzen. Ich begrüsse diese Berichtigungen, welche 33 bis 34 Jahren nach meiner einsamen Wanderung in dem damals noch verschlossenen Land gemacht werden.

His contributions to science are characterized by the qualities which distinguish him as an explorer of unknown lands: capacity for painstaking and detailed observation, combined with a broad grasp of his subject, and a daring conception of ideas. His ability to observe and to present his observations in a striking manner is exemplified in his reports on the geology of the Tyrolean Alps, which were written before he was twenty-seven. They are important works, illustrated with many studies of intricate structure, and they show a thorough comprehension of the best methods of geological study and presentation. These methods reappear in his great work, *China.* Upon the internal literary evidence it would be easy to determine that the early papers and the later volumes were written by one and the same hand, even though the name of the author had remained unknown.

Volumes I and II of *China* are by himself; the first deals with the geography of China and central Asia, and presents initially a description of the regions from the standpoint of our knowledge at the time it was written, 1873–76, and, secondly, an account of the development of intercourse between Europe and China since the legendary period of 1122 B. C. The latter subject is discussed through study of Chinese works, of which von Richthofen made extensive use. The book also contains the discussion of the loess, its characteristics and mode of formation. Volume II of *China* is the statement of his observations in the northern provinces, together with the systematic treatment of the material according to geological systems and periods.

Volume III, which was to contain a similar discussion of his observations in the southern provinces, and which would, no doubt, have presented, in a revised form, his views on the systematic questions involved, remains unfinished. Volume IV, "Paleontologie," prepared by the specialists to whom his collections were referred, appeared in 1883.

Von Richthofen's field-work in China and the principal publication of results fall within the decade 1868–77, contemporaneously with the Fortieth Parallel Survey, and there is much besides the coincidence of period to invite a comparison. Each entered a *terra incognita* marvelously rich in geological facts, displayed on a grand scale; each reaped a magnificent harvest, and that gathered by von Richthofen's individual efforts is worthy of a place beside that of his American colleagues; and each elaborated some theoretical views, which the science has outgrown. But though modern research may find much to correct in their early labors, it owes its opportunity to these pioneers; it should not forget the conditions under which they worked; and it should be prepared for the advance which science is making, always ready to say in the words of von Richthofen: "I welcome these corrections."

There is perhaps no better illustration of von Richthofen's method of attacking a problem than the development of his theory of the loess, of which he has given a full account in his various articles upon the subject. He enumerates the extraordinary conditions of its occurrence in China, which seem to preclude its formation by any of the agencies usually invoked to explain the deposition of sediments, and states that as early as his first journey through Shan-si he conceived the hypothesis of deposition by wind under the climatic and geographic conditions of the steppes of central Asia. His later work upon the subject was directed to critical investigation of the regions in which a similar process is now going on, and he was fortified in his view at every step by the close analogy between the deposits of the desert basins and those of the loess-covered districts. He did not shrink from attributing to a generally neglected agency, the wind, effects which are not only actually stupendous, but which he himself overestimated. He pursued the phenomena of the loess districts into the minutest details, and found ingenious and consistent explanations for the most puzzling peculiarities. His views were accepted by those who were most familiar with the loess of Asia, and there is no doubt that they must always constitute a principal part of any explanation of the phenomena. If they be modified, it will be through recognition of the fact that great changes have taken place in the mountain and river systems of China during and since the epochs of the loess.

Von Richthofen's latest contributions consist of four papers, entitled: "Geomorphological Studies of Eastern Asia." In these he pursues the method with which, in his earlier work, he boldly sketched the mountain ranges of China far beyond his field of observation, on the basis of the strike of geological formations; but he enlarges his field from orogenic to epeirogenic problems, and discusses the relations of the great highlands of Asia to the lowlands of its eastern coast and the curving chains of islands which inclose the adjacent seas. These problems are closely related to those to which Suess has devoted his life-work in the search for the *Hauptstruktur-Linien* of the earth, and they are intimately connected with fundamental questions of continental equilibrium and volcanic eruption. The articles are the fruit of the broadest knowledge of the geographical facts and of the most earnest lifelong study of the stupendous phenomena which Asia as a continent presents. They are the last work of the master of the subject.

Von Richthofen was a man of large stature and fine appearance, one who knew well the respect due to scholarship and the dignity of his own position. On occasion his grave courtesy expressed that dignified reserve which marks the deep thinker and the doer of great things. His life had been spent in consideration of large problems not only of science, but of nations and of humanity. His powerful intellect had grown with profound thinking, and in discussion one felt its grasp and penetrating force. But his heart also had grown great with experience, and his natural kindliness led him ever to consider others before himself. He was not only a great man, he was a man to love and honor.

STRUCTURE AND RELATIONSHIPS OF AMERICAN LABYRINTHODONTIDÆ

E. B. BRANSON
The University of Chicago

The term "Labyrinthodontidæ" is used in this paper with the same signification as Zittel uses it in his *Handbuch der Palaeontologie.* A discussion of the genus *Eryops* is included here because it was studied by the writer for comparison with the Labyrinthodontidæ, and some interesting facts were brought out by this study.

The first remains of Labyrinthodontidæ known from America were discovered by Ebenezer Emmons in the Trias of North Carolina, and were mentioned by him in *The Geological Report of the Midland Counties of North Carolina* in 1856. The same year Leidy described these remains and proposed the generic name *Dictyocephalus* for them.[1] In 1866 Cope described some skull bones from the Trias of Chester County, Pennsylvania, and referred them to the European genus *Mastodonsaurus.*[2] Two years later[3] he founded the genus *Eupelor* on these skull bones and some teeth from the same locality, but the following year referred the teeth to thecodont reptiles.[4] In 1868 he described a skull from the Trias of Chatham County, North Carolina, giving to the genus which it represented the name *Pariostegus.*[5] In the *Report of the United States Geographical Survey West of the 100th Meridian* for 1875 he described some fossils from the Trias of northwestern New Mexico, among which were three sculptured plates that he referred to *Typothorax*, a genus of Parasuchians; but they are without doubt fragments of a labyrinthodont skull. In 1892 the same writer mentions the occurrence of a form allied to *Eupelor* from the Docum Beds of northwestern Texas.[6]

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[1] *Proceedings of the Academy of Natural Sciences of Philadelphia*, Vol. VIII, pp. 255, 256.

[2] *Ibid.*, 1866, p. 250.

[3] *Ibid.*, 1868, p. 221.

[4] *Transactions of the American Philosophical Society*, Vol. XIV, p. 25.

[5] *Proceedings of the Academy of Natural Sciences of Philadelphia*, 1868, p. 211.

[6] Geological Survey of Texas, *Fourth Annual Report*, pp. 12, 17.

In 1899 Dr. Lester F. Ward collected, among other things, a fragment of a Labyrinthodont cranial plate from the Trias of northeastern Arizona, near Tanners Crossing on the Little Colorado River. The following year Mr. Barnum Brown obtained from the same locality an interclavicle of a large Labyrinthodont which Mr. Lucas described as *Metoposaurus fraasi.*[1]

In 1902 Mr. Newton H. Brown found various Labyrinthodont bones in the Triassic deposits near Lander, Wyoming. He sent some fragments of these to Mr. Lucas, of the National Museum, and others to Professor Knight, of the University of Wyoming. After the death of Professor Knight, the fragments sent to him were forwarded to Professor Merriam, who recently sent them to the University of Chicago. Among them was the back part of a mandible belonging to one of the skulls described in this paper. Mr. Brown very generously gave the benefit of his intimate acquaintance with the Triassic deposits of the Lander region to a University of Chicago party that collected there in 1904, and it has given the writer much pleasure to name the type species of *Anaschisma* in his honor.

In the fall of 1904 Mr. Reed, of the University of Wyoming, sent to the University of Chicago, for examination, some vertebræ and fragments of cranial bones of Labyrinthodonts obtained from the Trias about forty miles south of Laramie, Wyoming. Dr. Williston, in company with Mr. Reed, had visited this locality a few months previously, and ascertained that their horizon is not far from the top of the Red Beds, and provisionally refers it to the Hallopus Beds of Marsh.

SPECIMENS OF LABYRINTHODONTIDÆ FROM THE LANDER REGION

The material collected by the University of Chicago party of 1904 includes vertebræ, fragments of skulls, breast-plates, ribs, and limb bones. All of the vertebræ have the arches broken away. There are more than forty in the collection, but no two are known to belong to the same animal. The skull bones are fragmentary, and the fragments are usually small, though one specimen includes the frontals, prefontals, and nasals. Fragments of breast-plates are

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[1] *Proceedings of the U. S. National Museum,* Vol. XXVII, No. 1353, p. 194.

numerous, and are usually of larger size than those of the skull, while two nearly complete clavicles and one interclavicle were obtained. The fragments of ribs and limb bones are small, and are referred to Labyrinthodonts with some doubt.

The best material known is two skulls collected by Mr. Brown from the same locality as that mentioned above. The skulls were found closely associated, one slightly overlapping the other. They represent two species here described as *Anaschisma browni* and *Anaschisma brachygnatha*. For convenience in the general descriptions, the skull of the former species is designated as A, and that of the latter as B.

In A most of the left maxillary, the lower part of the left quadratojugal, the left condyle, part of the posterior end of the parasphenoid, part of the outer end of the right exoccipital, a small portion of the posterior margins of the epiotics and prosquamosals, and the right opisthotic are missing. In B most of the right maxillary, part of the right premaxillary, part of the lachrymals, the condyles, and the upward projections of the exoccipitals are not present. About 8^{cm} of the anterior end of the left mandible of A is broken away. The right mandible of B lacks a part of the anterior and part of the posterior end of the dentary, and also most of the surangular.

The skulls were incased in a hard matrix of arenaceous shale, and had been broken in many pieces. This matrix has been removed in the laboratory with considerable labor, and both skulls now present the outer surface of all of the bones.

The inner surface of most of the bones was examined by the writer, but has necessarily been concealed in the restoration of the skulls. Nearly all of the sutures were distinctly traced either on the inside or on the outside of the bones. The skulls are but little distorted.

Anaschisma, *gen. nov.*

Skull large, subtriangular. Bones of the roof all deeply sculptured. Frontals excluded from orbits by the junction of the pre- and postfrontals; all of the bones behind the orbits, excepting the supraoccipitals and epiotics, elongated; lachrymal forming part of the posterior border of the nares. Opisthotics short, not coalesced with the exoccipitals. Parasphenoid with a long, narrow, cultriform process anteriorly; exoccipitals meeting in the median line in the floor of the skull. Parietal foramen small, subcircular; no auditory notches; orbits very large, subcircular, situated in anterior half of skull, and widely separated from each other; premaxillary vacuities large, double, penetrating the roof of the skull at the anterior end of the nares; nares terminal, large, ovate. Base of skull with large quadrate foramina; foramen magnum large, with no inward projections of the exoccipitals. Palatine foramina expanded anteriorly. Teeth with labyrinthine structure much like that of *Mastodonsaurus;* a large tooth on each ramus of the mandible near the symphysis. Mandible broad and thin, breadth and thickness as 4 to 1; a strong postcotylar process present.

Skull.—The skull of *Anaschisma* resembles that of *Metoposaurus* and *Capitosaurus* in shape. It is subtriangular, with the margins gently convex anteriorly, gently concave in the middle, and again gently convex posteriorly. The roof is almost flat in front of the parietal foramen, but from this foramen the surface ascends rapidly to the posterior margin. The margins of the orbits and nares are not elevated. The lateral arching is considerable posteriorly, including the quadratojugals, jugals, prosquamosals, and postorbitals. The underpart of the skull is in one plane, save in the region of the quadrates, the inner ends of which descend about 2^{cm} below the level of the rest.

The shape of the bones in the roof of the skull is well shown in Figs. 6 and 9. They resemble those of *Metoposaurus diagnosticus*, but present some notable differences. The premaxillæ are more elongate and narrower; the supraoccipitals are shorter; and the epiotics are proportionally narrower and shorter. The suture between the lachrymal and jugal has not been definitely determined, but the lachrymal reaches forward to the posterior border of the nares.[1] There is no prominent projection inward of the lachrymal between the orbits and nares. The quadratojugal articulates with the outer

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[1] In the January number of the *Sitzungs-Berichte der Gesellschaft naturforschender Freunde*, Jaekel attempts to show that the prefrontal of the Reptilia is homologous with the lachrymal of the Mammalia, and he gives to the so-called lachrymal of the Reptilia the name "postnasal." The evidence that he presents does not, however, seem strong enough to warrant his conclusions.

upper corner of the quadrate, and takes no part in the articular surface as it does in *Mastodonsaurus*.

The orbits are in the anterior half of the skull and far apart, but they differ from those of *Metoposaurus* in being subcircular instead of oval. In a skull of *Metoposaurus diagnosticus* 405^{mm} long the orbits are 53^{mm} long by 32^{mm} broad.[1] In a skull of *Anaschisma* 415^{mm} long the orbits are 55^{mm} long by 49^{mm} broad. The external nares are ovate, with the apex near the tip of the snout, and they are larger and closer together than in *Metoposaurus*. In the skull of *Metoposaurus diagnosticus* mentioned above the nares are 35^{mm} long, 27^{mm} broad, and 48^{mm} apart; while in the skull of *Anaschisma* they are 49^{mm} long, 36^{mm} broad, and 35^{mm} apart. At the anterior end of the nares there are openings through the premaxillæ for the reception of the mandibular teeth. The parietal foramen is small, subcircular, and located about one-fourth the length of the parietals from the posterior end. No auditory slits are present, but the epiotics and prosquamosals have a slightly concave posterior margin in the region where the slits occur in other genera.

The bones of the roof are sculptured much as in *Metoposaurus*, but with much more of the space pitted, and without such long radiating ridges and furrows as in that genus. The pits are not so large, and the ridges between them are rounded instead of angular. None of the space in the lyra is furrowed.

The mucous canals of the lyra begin in a broad depression slightly inside of the posterior inner border of the orbits, and pass forward about 1½^{cm} inside the orbits, approaching a little nearer at their anterior inner corner. From the posterior inner angle of the prefontals the canals pass forward and outward in a straight line to about the middle of the outer margin of these bones, and thence forward in a straight line to the posterior outer corner of the nares. From here they pass inward and forward, following the margin of the nares. Near the tip of the snout the canals turn outward slightly, become shallower and broader, and end at the margin of the premaxillæ. They are nowhere very deep, and they maintain a width of a little more than 1^{cm} throughout their length.

The canals on the posterior part begin far back on the squamosals,

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[1] *Paleontographica*, Vol. XXXVI, p. 142.

pass straight forward to in front of the middle of the postorbitals, thence outward and forward on the jugals, thence backward on the jugals and quadratojugals to near the base of the skull, where they turn upward slightly on the prosquamosal, and end at its posterior margin. The part running forward on the squamosals and postorbitals is shallow and narrow, while the remainder is deeper and twice as broad.

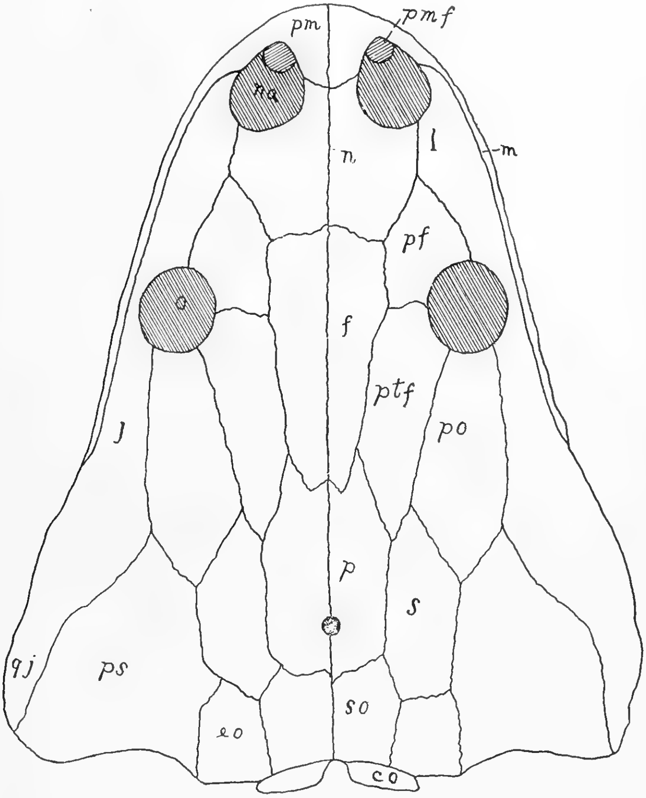

FIG. 1.—*Anaschisma browni;* view of top of skull, one-fifth natural size.

co, condyle; eo, epiotic; f, frontal; j, jugal; l, lachrymal; m, maxillary; n, nasal; na, nares; o, orbit; p, parietal; pf, prefrontal; pm, premaxillary; pmf, premaxillary foramen; po, postorbital; ps, prosquamosal; ptf, post-frontal; qj, quadratojugal; s, squamosal; so, supraoccipital.

The following are the dimensions of the skulls and of the openings in the roof:

	A	B
Skull—		
Total length	490$^{\text{mm}}$	. . .
Length of roof	445	415$^{\text{mm}}$
Breadth at posterior end	405	335
Breadth at posterior end of nares	190	158
Breadth at posterior end of orbits	270	235
Height at base	120	105
Orbits—		
Length	57	55
Breadth	46	49
Distance apart	122	110
Distance from posterior end of skull (median line)	240	220
Distance from anterior end of skull	180	170
Nares—		
Length	55	49
Breadth	42	36
Distance apart	32	35
Distance from anterior end of skull	40	36
Distance from orbits	86	90
Parietal foramen—		
Length	. . .	11
Breadth	. . .	9
Distance from posterior end of skull	. . .	57
Distance from orbits	. . .	155

Under side of skull.—The parasphenoid is long, slender, expanded posteriorly, and with a long, slender, cultriform process anteriorly. Its greatest length in A is 335$^{\text{mm}}$, in B 310$^{\text{mm}}$. The width along the shaft is about 40$^{\text{mm}}$ in A, 38$^{\text{mm}}$ in B. The prevomers articulate with it on each side along the anterior two-fifths of its length. Between the prevomers the width gradually decreases forward to about 15$^{\text{mm}}$ from its anterior end, where it is 8$^{\text{mm}}$ broad. From here to the anterior end its edges are parallel. Its greatest width, 75$^{\text{mm}}$ in A, 70$^{\text{mm}}$ in B, is at the posterior end of the palatine foramina. Posterior to this it is nearly semicircular as seen from below, but it sends out a wing-like process on either side that is overlapped by the pterygoid and exoccipital. At the posterior end on the upper side are two elongated oval pits, one on each side of the median line. They are about 10$^{\text{mm}}$ apart at their closest approach, and extend obliquely backward from the median line.

In general appearance the parasphenoid resembles that of *Metoposaurus*, but differs from it in the rounded posterior part and the slender cultriform process. The posterior part in *Metoposaurus diagnosticus*, as figured by Fraas,[1] resembles the posterior part in

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[1] *Paleontographica*, Vol. XXXVI, Plate XIII.

Anaschisma as seen from above. The anterior part of the cultriform process resembles that of *Capitosaurus*.

The pterygoids form a considerable portion of the back part of the under side of the skull. A long anterior wing, about 32^{mm} wide posteriorly, but broadening abruptly to a width of 52^{mm}, 60^{mm} in advance of the posterior part of the palatine foramina, separates the palatine and infratemporal foramina, and articulates with the parasphenoid and exoccipitals. The posterior outer wing is narrow where it diverges from the main part of the bone, but broadens abruptly, sending up a broad triangular wing, which reaches the prosquamosal above, articulates with the quadrate at its outer end and forms a large part of the base of the skull. In the middle of the lower portion on the posterior side of this broad wing there is a deep, oval pit, with a groove running forward from it.

Passing upward from the pterygoid, just in front of the place where the posterior wing diverges, there is a slender, incompletely ossified bone that ends freely above. If the slender column continued upward, it would articulate with the parietals above. In *Gondwanosaurus*,[1] two slender bones articulate with the parietals above, and it is probable that these are the same elements that occur in *Anaschisma*, though more completely ossified in the former genus. This bone is probably the epipterygoid.

The palatines are long and slender. The posterior part reaches as far back as the hinder part of the orbit, and is wedged in between the maxillary and the transverse. A slender branch, with a minimum width of 1^{cm}, passes inward between the palatine foramen and the internal naris, and articulates with the prevomer. Between the naris and the maxilla the bone is narrow, but it broadens again in front of the naris. About 2^{cm} anterior to the naris there is a large tooth, and just in front of this the palatine articulates with the premaxilla. The palatine bears only the one tooth.

The prevomers are paired. Posteriorly they are separated by the cultriform process of the parasphenoid, but anteriorly they meet in a suture in the median line of the skull. A slender, tapering process runs backward from the posterior inner part of the bone

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[1] *Paleontographica Indica*, Series IV, Vol. I, "The Bijori Labyrinthodont," p. 4, Plate I.

between the parasphenoid and the palatine foramen. From the postero-outer corner a short process projects between the nares and the palatine foramina to articulate with an inward projection of the palatine. In front of the internal nares the prevomers articulate with the palatines as far as the anterior edge of the large palatine tooth. From this point the anterior margin passes inward in a broadly rounded curve to the median line, which it meets about 5^{cm} posterior to the tip of the snout. There is a series of four or more small teeth on the anterior margin of each prevomer.

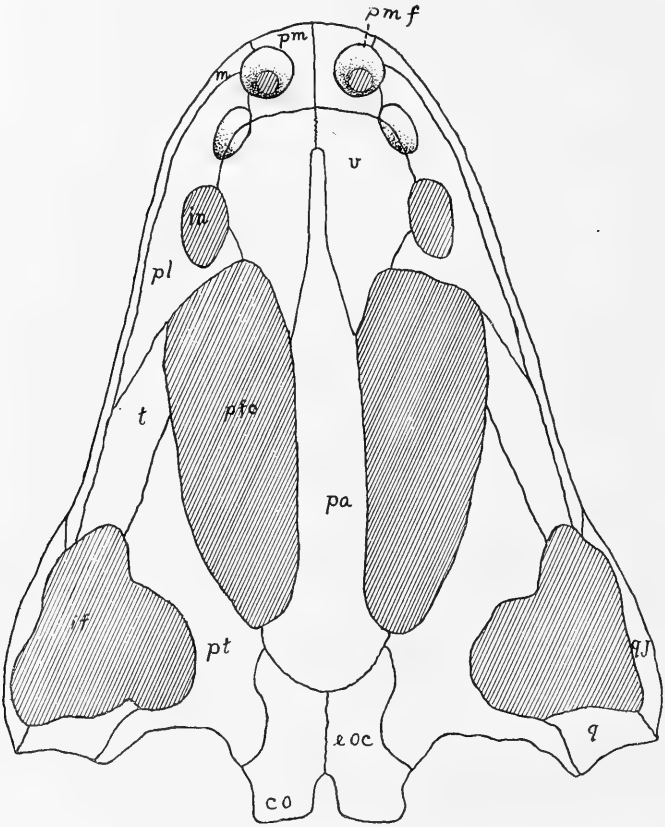

Fig. 2.—*Anaschisma browni;* palatal view of skull, one-fifth natural size.

co, condyle; eoc, exoccipital; if, infratemporal foramen; in, internal nares; m, maxillary; pa, parasphenoid; pfo, palatine foramen; pl, palatine; pm, premaxillary; pmf, premaxillary foramen; pt, pterygoid; q, quadrate; qj, quadrato-jugal; t, transverse; v, vomer.

The transverse is a small bone, about 14^{cm} long by 3^{cm} broad, which articulates with the maxillary on the outside, with the pterygoid on the inside, and with the palatine in front. The suture between the transverse and the pterygoid has been definitely determined only on the right side of A, but it is indicated on the left side of the same skull and on the left side of B, where the bones are not so well preserved. The suture between it and the maxilla is distinct, but the one between it and the palatine is almost indistinguishable; only on the right side of A can it be distinguished with any degree of certainty, and even here a second line back of the one indicated in Plate II has very much the indication of a suture. On the right side of the same skull the bones are partially lost in the place where the palatine and transverse meet, but there is an indication of a suture in the same region as the one shown on the left side.

Viewed from the under side of the skull, the premaxillæ are nearly rectangular in shape. Each is pierced by a large opening for the passage of a mandibular tooth. This opening occupies more than half of the area of the bone. It is conical in shape, with the apex of the cone passing through the anterior end of the external nares. The suture between the premaxillæ and the maxillæ has not been definitely determined, but it appears to be just outside the opening for the mandibular tooth. The teeth are all broken off at the surface of the bone. Their sockets are no larger than those on the anterior part of the maxillæ. The suture between the premaxillæ and nasals is directly between the external nares.

The maxillæ are very slender. They extend from just outside the external nares to the anterior end of the infratemporal foramen. They bear a single series of small teeth that seem to increase gradually in size anteriorly. Only the roots of the teeth are preserved, and unfortunately most of them are badly obscured.

The palatine foramina are long, narrow posteriorly and expanded anteriorly. The infratemporal foramina are short and broad. The internal nares are large, oval, and situated near the anterior end of the palatine foramina. The premaxillary foramina are large and nearly circular.

The openings on the inferior side of the skull are almost perfectly shown in both specimens. The following table gives their dimensions:

	A	B
Premaxillary foramina—		
Length	24mm	22mm
Breadth	28	23
Distance apart	20	20
Distance from tip of skull	14	24
Internal nares—		
Length	50	46
Breadth	30	26
Distance apart	120	110
Distance from tip of skull	...	...
Palatine foramina—		
Length	225	200
Breadth	76	71
Distance from premaxillary foramina	100	105
Distance from internal nares	10	13
Distance from tip of skull	145	145
Distance from end of condyle	125	...
Infratemporal foramina—		
Length	130	115
Breadth	115	82
Distance apart	165	150

Base of skull.—The base of the skull is in an excellent state of preservation in A, but in B the upper part of the exoccipitals, the opisthotics, and the downward projections of the supraoccipitals are missing. The shape is well shown in Figs. 3 and 3*a*. The roof is regularly convex; the under border nearly plane, save for a downward projection at the union of the quadrate and pterygoid.

The foramen magnum is large, oval, and no projections inward from the exoccipitals tend to divide it into two parts as in *Mastodonsaurus* and *Metoposaurus*. The foramen more nearly resembles that of *Capitosaurus stantonensis* Woodward, though even in that form there is a slight projection inward from the sides, while in *Anaschisma* the sides are slightly concave outward. No fragments of cartilage or bone are present to indicate the presence of partially ossified basioccipitals or supraoccipitals, as in *Capitosaurus stantonensis* Woodward.[1] Between the exoccipitals and opisthotics below, and epiotics and supraoccipitals above, there is a small foramen, rounded above and angular below. This foramen is homologous with the posttemporal foramen of reptiles, as will be readily understood by reference to the text-figure of the base of the skull of *Eryops*, in which the relationship of the foramen is the same as in *Anaschisma*, though the opisthotic and foramen are larger.

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[1] *Proceedings of the Zoölogical Society of London*, 1904, Vol. II, p. 172.

At the infra-basal angle of the skull there is an elongate oval foramen which clearly bears the same relation to its investing bones as does the quadrate foramen in the Ichthyosaurs, and nearly the same relation as in Sphenodon, the parasuchians some of the theropod dinosaurs, and *Dimetrodon*. On the outside it is bounded by the prosquamosal and quadratojugal; below and on the inside, by the quadrate. In Sphenodon, the parasuchians, theropod dinosaurs, and *Dimetrodon* the squamosal does not enter into the outer wall of the foramen. Dr. A. S. Woodward figures this foramen, and calls it the posttemporal.[1] The posttemporal in reptiles is bounded on the inside by the exoccipitals and supraöccipitals, below by the exoccipitals or opisthotics or both, on the outside by the squamosal or parietal or by both, and above by the parietal and squamosal. As the relations of this foramen in *Anaschisma* and *Capitosaurus* are entirely different from those of the posttemporal foramen in reptiles, it cannot be homologized with that foramen. On a previous page it is shown that another foramen is homologous with the posttemporal foramen of reptiles. As the relations of this opening are almost identical with those of the quadrate foramen in reptiles, it is here considered as homologous with that foramen.

Case postulates[2] that the quadrate foramen is in its inception in *Dimetrodon*, but its presence in the Labyrinthodontidæ indicates that it is a much more primitive character than he supposed.

The exoccipitals are expanded in the base of the skull, articulating with the parasphenoid in front, with the pterygoids on the outer sides, and with each other in the median line. The two condyles form strong projections from the posterior part. Passing upward and slightly forward from near the end of the condyles, there is a strong column which divides at the upper end, one branch meeting a downward projection of the supraoccipitals, the other articulating with the opisthotic. The lateral margins of the foramen magnum, formed by the inner part of the exoccipitals and the downward projections of the supraoccipitals, curve gently outward. Just above the condyle on the posterior inner side of the upward projection of

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[1] *Loc. cit.*, p. 172.

[2] *Transactions of the American Philosophical Society*, 1905, Vol. XXI, Part I, p. 10.

the exoccipitals a small round foramen for the exit of the vagus and glossopharyngeal nerves appears. Quenstedt figures[1] this foramen in *Mastodonsaurus*, and Fraas figures[2] it in *Cyclotosaurus*, but in both these forms it is on the outer side of the bone.

The opisthotics are separate elements in *Anaschisma*, as in *Cyclotosaurus* and *Capitosaurus*. They are very short and slender. They pass diagonally upward and outward from the exoccipitals to articulate with the epiotic at the outer end. The suture between them and the epiotic is not distinct.

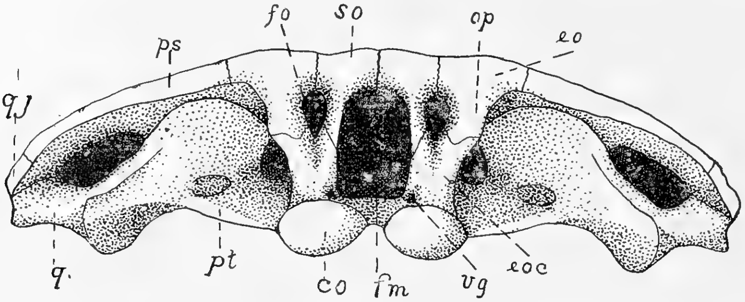

FIG. 3.—*Anaschisma browni;* hinder view of occiput, one-fourth natural size.
co, condyle; eo, epiotic; eoc, exoccipital; fm, foramen magnum; fo, posttemporal foramen; op, opisthotic; ps, prosquamosal; pt, pterygoid; q, quadrate; qj, quadratojugal; so, supraoccipital; vg, foramen for the vagus and glossopharyngeal nerves.

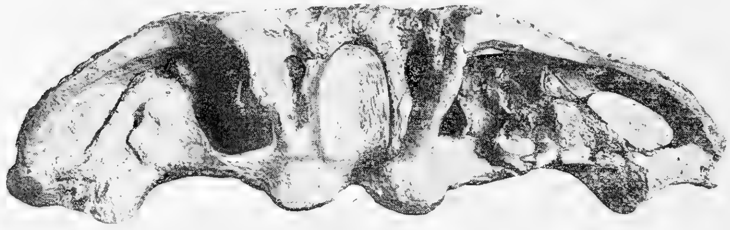

FIG. 3*a*.—*Anaschisma browni;* photograph of hinder view of occiput.

Mandibles.—The left ramus of the mandible of A and the right ramus of B were procured with the skulls. A small part of the anterior end of A is missing, but B is almost complete, and the sutures

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[1] *Die Mastodonsaurier im grünen Küpersandsteine Württemberg's sind Batrachier* (1850), Table II, Fig. 4.

[2] *Paleontographica,* Vol. XXXVI, Plate XI, Fig. 1, p. 132.

between the bones are readily made out. Because B is the more complete, the measurements given in the following description are taken from it.

The total length along the curve of the mandible is 495^{mm}. The greatest breadth, 94^{mm}, is a little in front of the cotylus, but a breadth of 90^{mm} or more is maintained for half the length of the ramus. Thirteen millimeters from the symphysis, the most anterior part where the full width is preserved, it is 65^{mm} broad. It is probable that at the symphysis the width was not greater than 50^{mm}. The greatest thickness is about 50^{mm}, just in front of the cotylus, where the upper part thickens abruptly. Just anterior to this the thickness decreases to 22^{mm}, and remains about the same to the symphysis. The postcotyloid process is well developed.

The articular forms the greater part of the concave cotylus, and appears as a narrow ridge in the upper part of the postcotyloid process. It broadens abruptly as it enters the cotylus, and is of nearly uniform width to the anterior part, where it forms part of the posterior boundary of the supra-meckelian foramen. The greater portion of the inner side of the posterior part of the mandible is formed by the prearticular.[1] It projects from the end of the postcotyloid process to near the anterior end of the supra-meckelian foramen. Its upper edge forms most of the inner boundary of this foramen, and projects above the articular on the inner side. Its lower anterior part forms the boundary of the upper posterior corner of the mandibular foramen. Below it articulates with the angular for most of its length.

The angular extends the full length of the jaw on the outside, but articulates with an element anterior to it about 10^{cm} from the symphysis on the inside. On the inside it is narrow at the posterior end, broadens gradually to the mandibular foramen, where it narrows abruptly to form the part of the jaw between this foramen and the lower margin. In front of the foramen it broadens again abruptly. On the outside of the jaw the angular occupies about half the width anterior to the cotylus, but narrows rapidly behind it. It is coarsely pitted posteriorly, and ornamented with long radiating ridges and furrows anteriorly.

[1] Williston, *Field Columbian Museum Publication* 73, Geological Series, Vol. II, No. 1, p. 32; Kingsley, *American Naturalist*, Vol. XXIX, p. 61 (Dermarticulare).

The surangular is large. It articulates with the angular below in a line that runs diagonally from the postero-inferior angle of the jaw to a point just below the anterior end of the coronoid. Above it articulates with the dentary and articular, and forms part of the outer boundary of the supra-meckelian foramen. It is coarsely pitted posteriorly with coarse ridges running upward and forward from the pitting.

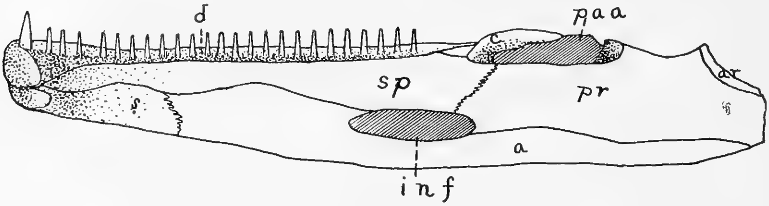


FIG. 4.—*Anaschisma brachygnatha;* right ramus of mandible, one-fifth natural size.

a, angular; c, coronoid; d, dentary; inf, internal mandibular foramen; paa, supra-meckelian foramen; sp, splenial; ?, probably a separate element; pr, prearticular.

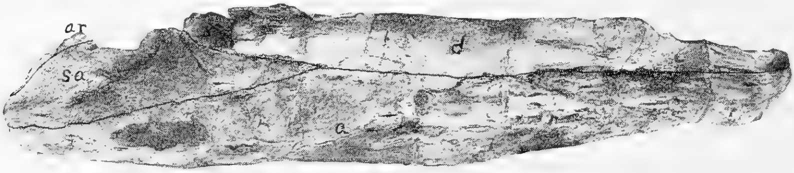


FIG. 4*a*.—*Anaschisma browni;* outer view of right ramus of mandible, one-third natural size.

a, angular; ar, articular; d, dentary; sa, surangular.

The dentary forms the upper half of the jaw in front of the middle of the supra-meckelian foramen. It is not sculptured. The teeth are set on the top of the inner side, and on the outer side there is a high, thin parapet which forms the outer margin of the jaw, and in which the outer sides of the teeth are imbedded for the height of 1^{cm} or more.

The coronoid is a small element at the anterior end of the supra-meckelian foramen. The main part of it forms the front margin of this foramen. The anterior part is slender and triangular, and is wedged in between the splenial and dentary.

The splenial extends from the prearticular to near the symphysis, but takes no part in the symphysis. It occupies the upper half of the inside of the mandible, and is very thin.

Below the splenial, and in front of the angular, an element that seems to be separate from the dentary is present. The suture between it and the dentary is not distinct, but at the symphysis the dentary seems to be separate from it. This seems to be a separate element in *Eryops* also, but the evidence is not conclusive in either case.

On the upper border of the mandible, just in front of the cotylus, there is an opening for Meckel's cartilage. For convenience in description, this is called the supra-meckelian foramen. Perhaps a name has been given to it previously, but, if so, the writer has failed to find it. It is subtriangular in shape, 85^{mm} long by about 40^{mm} in greatest width. On the inner side the articular projects farther forward than on the outer, making the posterior margin of the foramen diagonal to the long axis of the jaw. The apex of the foramen lies between the splenial and coronoid, while the inner and outer sides are formed by the prearticular and surangular.

The jaw is hollow throughout, the bones forming a mere shell, usually only a few millimeters in thickness. The cavity extends from the symphysis to the tip of the postcotyloid process with its greatest size in the region of the prearticular foramen.

The vertebræ.—As before stated, there are about forty vertebræ referred to *Anaschisma* in the collection, but none of them has the arch preserved. Among them are two imperfect atlases of an oval shape, about 70^{mm} broad by 50^{mm} high. Anteriorly they have two slightly concave faces for articulation with the condyles; posteriorly they are concave. A supposed axis is oval, and about the same size as the atlas. It is opisthocoelous. On each side at about the middle of the vertebræ there is a large, shallow facette for the articulation of a rib. The thoracic vertebræ are nearly circular in shape, varying from 40 to 65^{mm} in diameter. One of these shows that the ribs were borne on exogenous processes arising from both the arch and body. The caudals are smaller, proportionally longer, with the vertical diameter greater than the transverse. All of the vertebral articular surfaces are for the articulation of single-headed ribs.

Among the vertebræ present there are three others besides the axis that are opisthocoelous. Whether they belong to a different

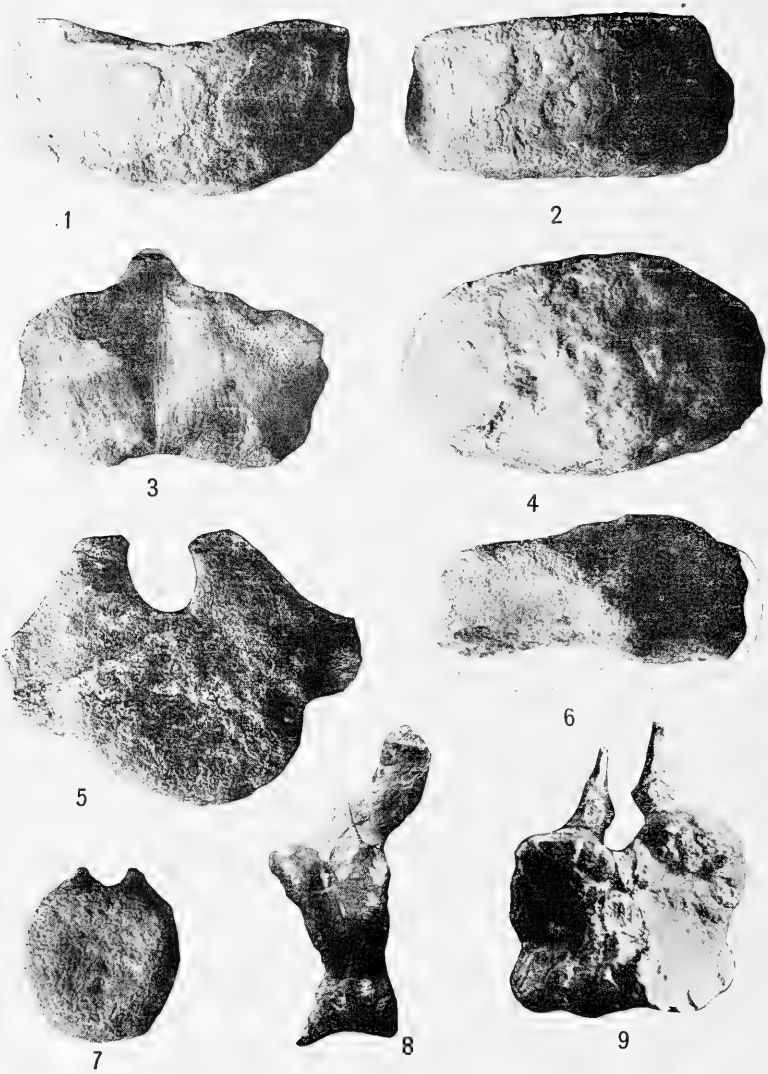


FIG. 5.—Vertebræ of *Anaschisma* and *Eryops*, two-thirds natural size.

1. Dorsal view of axis of *Anaschisma*.
2. Upper view of a dorsal vertebra of *Anaschisma*.
3. Upper view of atlas of *Anaschisma*,.
4. View of anterior end of axis of *Anaschisma*.
5. View of anterior end of a dorsal vertebra of *Anaschisma*.
6. View of anterior end of atlas of *Anaschisma*.
7. Caudal of *Anaschisma*.
8. Lateral view of atlas of *Eryops*.
9 View of anterior end of atlas of *Eryops*.

type of animal or to a particular region in the column of *Anaschisma* it is impossible to say. They agree in all respects with the others, save in being opisthocoelous. All of the others are slightly amphicoelous.

Pectoral girdle.—The clavicles and interclavicles collected from the Lander region were in such a poor state of preservation that nothing has been made out concerning their characters to add to what Mr. Lucas has published about *Metoposaurus fraasi.* One of the interclavicles evidently belongs to that species, but some of the others show very different types of sculpturing, and probably belong to different genera.

A cleithrum was found in position with one of the clavicles. It was complete when the writer removed it from the rock, but unfortunately part of the upper end was lost in transportation. In the figure this is restored. The bone is about 12^{cm} long, expanded at the base, and tapering to a point at the top. It projects upward and forward from the antero-outer end of the clavicle at an angle of about 45°. It is very different in shape from the cleithra that have been described from other Stegocephalians, but it can be homologized with no other element.

FIG. 6.—*Anaschisma;* cleithrum, natural size.

Anaschisma browni, *sp. nov.*

(Figs. 7, 8, and 10)

Skull broad posteriorly; proportion of greatest length to greatest width about 10 to 9. Bones of roof of skull coarsely sculptured, pitting predominating anteriorly, ridges and furrows posteriorly. Mucous canals of the lyra beginning in a deep depression just inside the postero-inner corner of the orbit. The main part of the posterior mucous canals begins on the postfrontals, and passes backward in a broad curve to a point in front of the middle of the postorbitals, where the part passing forward on the postorbitals meets it. It then turns at a sharp angle and passes outward and forward. Eyes large, subcircular, situated in anterior half of skull; nares large, approxi-

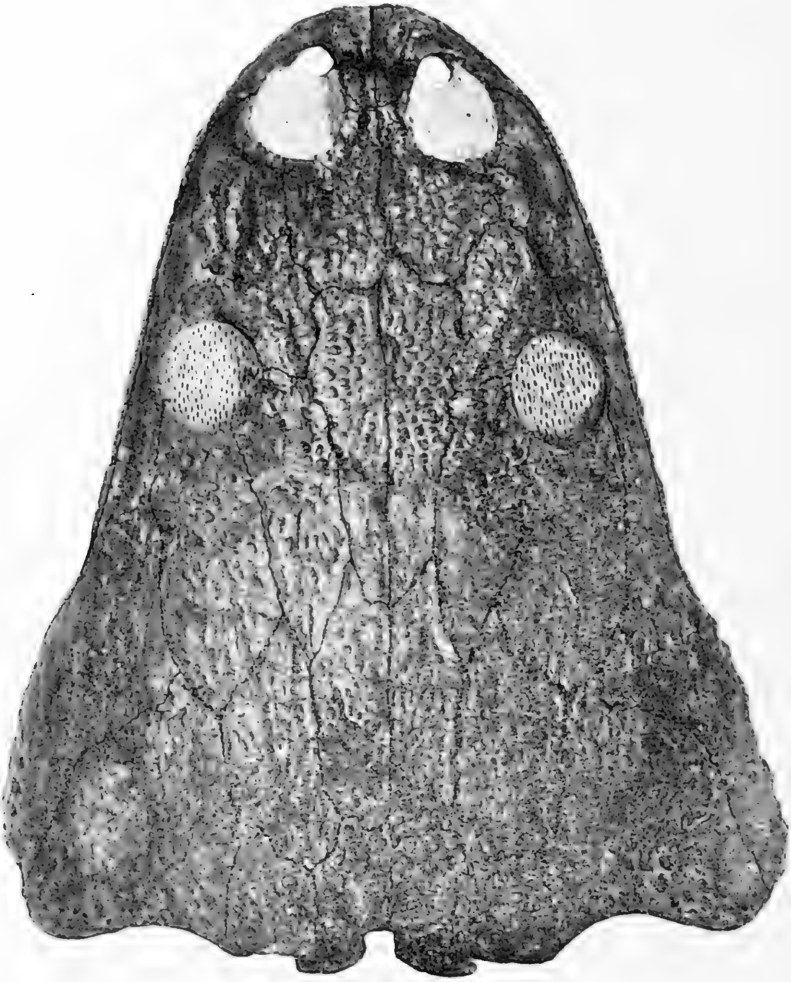


FIG. 7.—Upper view of skull of *Anaschisma browni*, one-third natural size.

mated; infratemporal foramina very broad; internal nares close to the palatine foramina. Maxillary and premaxillary teeth small; a few small teeth on the vomers in a row parallel to those on the premaxillæ; mandibular teeth compressed, with the long axis transverse to the long axis of the jaw; a very large tooth on each palatine a little in front of the internal nares; a few teeth on the transverse.

FIG. 8.—Palatal view of skull of *Anaschisma browni*, one-third natural size.

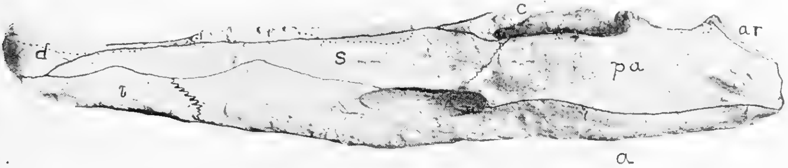
Anaschisma brachygnatha, *sp. nov.*

(Figs. 9 and 10)

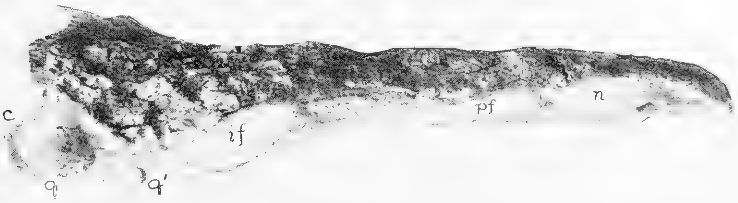
This species differs from *Anaschisma browni* as follows: Skull much narrower posteriorly in proportion to the length; proportion of length to breadth about 5 to 4. Eyes not as far forward; nares farther apart. Bones in roof of skull with finer pitting, and broader, more rounded ridges between the pits. Mucous canals of the lyra

FIG. 9.—Upper view of skull of *Anaschisma brachygnatha;* one-third natural size.

beginning farther back, and in a broader, shallower depression. The posterior canals beginning in a broad, shallow depression on the postorbitals, instead of on the postfrontals. Infratemporal foramina much narrower; internal nares much farther from the palatine foramina. Teeth as in *A. browni.*



1. Inner view of mandible of *Anaschisma brachygnatha;* one-fourth natural size.
a, angular; ar, articular; c, coronoid; d, dentary; ?, undetermined; pa, preartciular; s, splenial.



2. Lateral view of skull of *Anaschisma browni;* two-ninths natural size.
c, condyle; if, infratemporal foramen; n, internal nares; pf, palatine foramina; q, right quadrate; q¹, lower end of left quadrate.

FIG. 10

DESCRIPTIONS OF ALL OTHER LABYRINTHODONTIDÆ KNOWN FROM AMERICA

Metoposaurus fraasi Lucas

Original description:[1]

The species is characterized by the coarseness of the sculpturing of the episternum, and the fact that the markings of the center of the plate consist of irregular pits which, toward the margin, are transformed into radiating grooves. These grooves are most marked on the anterior portion of the bone. The portion of clavicles present also have the ornamentation in the shape of pits rather than grooves, and in this respect and in the greater coarseness of the sculpture the present species differs from the European *Metoposaurus diagnosticus* of von Meyer. It is, furthermore, characterized by the extent of the articulation of the clavicle with the episternum, the posterior end of the clavicle being well behind a line drawn through the center of the plate. The postero-inner angle of the

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[1] *Proceedings of the United States National Museum*, 1904, Vol. XXVII, p. 194.

clavicle is very much rounded, instead of being decidedly angular, as it is in *Metoposaurus diagnosticus.*

The episternum is 43^{cm} long and 30^{cm} wide.

The mandible is coarsely sculptured on the external face, and bears indications of two large teeth at the very front of the ramus, and behind these fifteen small teeth. These seem to have been largely attached to the external wall of the alveolus in a manner somewhat suggestive of the pleurodont dentition of an iguana.

Specimen from Trias five miles east of Tanners Crossing, Little Colorado River, Arizona.

This specimen is probably an *Anaschisma*, but only the finding of such interclavicles with a skull of *Anaschisma* will settle that point definitely.

Dictyocephalus Leidy

(No name) Emmons, 1856 (*Geological Report of the Midland Counties of North Carolina*, p. 347).

Dictyocephalus Leidy, 1856 ("Notice of Extinct Vertebrated Animals Discovered by Professor E. Emmons," *Proceedings of the Academy of Natural Sciences of Philadelphia*, p. 256; also *American Journal of Science*, 1857, Vol. XXIII, p. 272).

Dictyocephalus Emmons, 1857 (*American Geology*, Part VI, p. 59, Figs. 31 and 32).

Dictyocephalus Emmons, 1860 (*Manual of Geology*, 2d ed., p. 184, Fig. 182).

Dictyocephalus Cope, 1868 ("Synopsis of Extinct Batrachia of North America," *Proceedings of the Academy of Natural Sciences of Philadelphia*, p. 221).

Dictyocephalus Miall, 1875 ("On the Structure and Classification of the Labyrinthodonts," *Report of the British Association for the Advancement of Science*, p. 185).

Dictyocephalus Cope, 1875 ("Synopsis of the Vertebrata Whose Remains Have Been Preserved in the Formations of North Carolina," *Report of the Geological Survey of North Carolina*, Appendix, B p. 32).

Dictyocephalus Fritsch, 1879 (*Fauna der Gaskohle und der Kalksteine der Permformation Böhmens*, Vol. I, p. 61).

Dictyocephalus Zittel, 1890 (*Handbuch der Palaeontologie*, Vol. III, p. 408).

Dictyocephalus von Huene (*Uebersicht über der Reptilien der Trias*, p. 68).

Founded on the upper portion of a cranium discovered by Professor Emmons in the coal fields of Chatham County, North Carolina. Plates of the cranium covered with reticular ridges in a general radiant manner. Parietals comparatively short, broader in front than behind; parietal foramen near the center of the bones. Occipitals quadrate, a little longer than broad. Posterior outline of the cranium with a superficial transverse concavity on each side, and not with a deep sinus as in *Trematosaurus* and *Archegosaurus*. Breadth of occipital outline 28 lines; length of parietals 8½ lines; breadth anteriorly 3¾ lines, posteriorly 3 lines. Probable length of head, considering it to have nearly the proportions of *Trematosaurus*, 4 inches, breadth 2½ inches.[1]

Eupelor Cope

Mastodonsaurus Cope, 1866 ("Observations on Extinct Vertebrates of the Mesozoic Red Sandstone," *Proceedings of the Academy of Natural Sciences of Philadelphia*, p. 250).

Eupelor Cope, 1868 ("Synopsis of the Extinct Batrachia of North America," *ibid.*, p. 221).

Eupelor Cope, 1869 ("The Extinct Batrachia, Reptilia, and Aves of North America," *Transactions of the American Philosophical Society*, Vol. XIV, p. 25).

Eupelor Miall, 1874 ("On the Structure and Classification of the Labyrinthodonts," *Report of the British Association for the Advancement of Science*, p. 186).

Eupelor Fritsch, 1879 (*Fauna der Gaskohle und der Kalksteine der Permformation Böhmens*, Vol. I, p. 62).

Eupelor Cope, 1886 ("Note on the Fossils of the Mesozoic Rocks in York County, Pa,." *Proceedings of the American Philosophical Society*, p. 403).

Eupelor Cope, 1887 ("A Contribution to the History of the Vertebrata of the Trias of North America," *ibid.*. p. 209).

Eupelor Zittel, 1890 (*Handbuch der Palaeontologie*, Vol. III, p. 408).

Eupelor Cope, 1892 ("A Preliminary Report of the Llano Estacado," Geological Survey of Texas, *Fourth Annual Report*, pp. 12 and 17).

Eupelor von Huene, 1902 (*Uebersicht über der Reptilien der Trias*, pp. 68–82).

Postorbitals 11^{cm} long; parietals 7^{cm} wide behind and 10^{cm} between the postorbitals. On the posterior part of the interorbital region commence two smooth, shallow sulci 29^{mm} apart; between them the surface is pitted four or five to the inch. The parietal bones are longitudinally sulcate throughout. All other bones with a coarse honeycomb pattern of sculpture, the pits becoming confluent into radiating grooves near the margins. Base of mandibular teeth cylindric, with shallow grooves. An interclavicle measures 345^{mm} long by 140^{mm} broad.

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[1] *Proceedings of the Academy of Natural Sciences of Philadelphia*, Vol. VIII, p. 256.

The specimens that have been referred to this genus are the back part of a skull from Chester County, Pennsylvania, one ramus of a mandible, some teeth, an interclavicle, and some other fragments from York County, Pennsylvania, and some fragments from the Docum Beds of northwestern Texas. It is not at all certain that the specimens from York and Chester Counties belong to the same genus, and it seems very probable that the Texas specimens are generically distinct from those of Pennsylvania.

The data seem too meager to warrant a discussion of the relationship of this genus, but a few general conclusions may not be inappropriate. From the length of the postorbital it is evident that the part of the skull behind the orbits was shorter than in *Anaschisma*, but longer than in *Mastodonsaurus*. The breadth of the parietals posteriorly is about the same as in *Anaschisma*, but anteriorly they are much broader than in that genus. Since the mucous canals are only 3^{cm} apart between the orbits, it is probable that the orbits were approximated, though not so much so as in *Mastodonsaurus*. The interclavicle is proportionally narrower than in *Metoposaurus*. So far, then, as the characters that are known indicate, *Eupelor* is intermediate between *Mastodonsaurus* and *Anaschisma*.

In 1868 Cope referred[1] some teeth from Chester County, Pennsylvania, to this genus, but a year later he concluded[2] that they belonged to thecodont reptiles. Later he described teeth that he found *in situ*, in a mandible,[3] and suggested that those which he originally described were rightly determined. This is hardly probable, since these teeth are rarely found fossilized, except as stumps in the jaws, and his so-called thecodont reptiles teeth are not at all rare.

The known remains are all referred to one species, *Eupelor durus* Cope. No figures of the specimens have ever been published.

Pariostegus Cope

Pariostegus Cope, 1868 ("Synopsis of the Extinct Batrachia of North America," *Proceedings of the Academy of Natural Sciences of Philadelphia*, p. 221).

Pariostegus Cope, 1869 ("The Extinct Batrachia, Reptilia, and Aves of North America," *Transactions of the American Philosophical Society*, Vol. XIV, p. 10).

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[1] *Loc. cit.*, p. 221.

[2] *Loc. cit.*, p. 25.

[3] *Proceedings of the American Philosophical Society*, 1887, p. 209.

Pariostegus Cope, 1875 ("Synopsis of the Vertebrata Whose Remains Have Been Preserved in the Formations of North Carolina," *Report of the Geological Survey of North Carolina*, Appendix, p. 32).
Pariostegus Miall, 1875 ("On the Structure and Classification of the Labyrinthodonts," *Report of the British Association for the Advancement of Science*, 1874, p. 189).
Pariostegus Fritsch, 1879 (*Fauna der Gaskohle und der Kalksteine der Permformation Böhmens*, Vol. I, p. 64).
Pariostegus Zittel, 1890 (*Handbuch der Palaeontologie*, Vol. III, p. 488).
Pariostegus von Huene, 1902 (*Uebersicht über die Reptilien der Trias*, p. 68).

This genus is represented by a large part of the cranium of a batrachian from the Triassic coal-measures of Chatham County, North Carolina.

Contrary to what has been found the case in most genera of Stegocephalia, the maxillary appears to extend posteriorly to a free termination, as in modern Salamanders, and the supratemporal bone presents a very prominent, obtuse, arched margin. This margin extends from the margin on each side, and is inclined toward the posterior part of the cranium. There is therefore no quadratojugal piece.

The maxillary and mandibular pieces are slender, flat bones, as in *Menopoma;* the form of the posterior or articular portion of the latter cannot be ascertained from the specimen. The more or less exposed part of the median region of the latter exhibits a succession of shallow transverse notches, inclosing thirteen obtuse elevations. The former resemble rudimental lateral alveoli for minute pleurodont teeth. A few other similar minute ribs, and, perhaps, a minute curved cone without sculpture, are the only other indications of dentition.

A pair of narrow nasals, acuminate behind, penetrate between the frontals as far posteriorly as the posterior margin of the orbits. The suture between these is very distinct, and entirely straight. The preorbitals extend to above the orbit, and then appear to cease with a transverse suture. Between these and the nasals a broad triangular element enters on each side, not attaining the probable position of the nostrils. Each is divided by a longitudinal groove, which is probably a suture, and which would then divide the frontals from the parietals. The frontal would then divide the parietals entirely from the anterior half of their length. This would give the frontals a narrow form, acuminate in front, and bounded behind by a regular, coarse, zigzag transverse suture. The cranium behind this point is rugose, and the surface not well preserved, and it can only be said that two peculiar grooves converge to a point between the posterior extremities of the frontals, like the boundaries of the supraoccipitals. When the postorbital roof bone is raised up, the meeting of the two gular dermal bones, as I interpret them, is seen. One of these is a plate directed backward and outward, bearing minute radiating lines on its upper surface. It meets a similar flat plate directed forward and outward, with similar lines radiating to the circumference.

The orbits are remarkably small, and situated probably near the middle of the longitudinal measurement of the cranium. The external nares are not defined, but symmetrical depressions in the position they usually occupy in Salamanders are distinct.

Pariostegus myops Cope

The surface of the cranial bones is little sculptured; there are small tuberculiform elevations on the parietal, and more numerous ones on the preorbitals. The postorbitals show the strongest markings of elongated pits, which radiate to their circumference, leaving a smooth, obtuse border. The nasals present a series of small warts at a little distance on each side of their common suture and transverse to it. The surface of the maxillary is marked with longitudinal grooves and shallow pits.

No suture separating maxillaries and premaxillaries can be traced with certainty, though the bones of the jaw are interrupted at the usual place of suture, opposite the nostril.

Length of specimen (including mandible)	18.0 lines
Width between outer convexities postorbitals	17.0
Width between inner borders orbits	11.0
Width of same without preorbitals	8.0
Width of nasals at middle	2.5
Width of orbit	1.5
Length of frontal and nasal premaxillary	11.0
Length of supposed branchihyal	12.0[1]

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[1] *Proceedings of the Academy of Natural Sciences of Philadelphia*, 1868, p. 211.

Von Huene refers *Eupelor, Pariostegus*, and *Dictyocephalus* to the Temnospondyli, but their relationships, so far as can be made out from the fragmentary material known, are with the Stereospondyli.

In 1897 Dr. Williston described[1] a large labyrinthodont tooth from the upper part of the coal-measures near Louisville, Kansas. This tooth is as large and complex in structure as the large fangs of *Anaschisma*. The animal to which it belonged was probably one of the true Labyrinthodontidæ. The species was provisionally referred to *Mastodonsaurus*.

SOME NEW FACTS ABOUT ERYOPS

In the collection of vertebrate fossils of Walker Museum there is a specimen of *Eryops* of great interest from the Permian of Texas. It consists of an almost complete skull, a large number of vertebræ in association, the pectoral and pelvic girdles, and some limb bones. Most of the sutures in the roof of the skull are distinct; the under part and base of the skull are in a splendid state of preservation, and the characters of the sacral and presacral vertebræ are well displayed.

The writer has studied Cope's types of *Eryops*, and the present specimen is congeneric with them. It differs widely in three important characters from *Eryops* as restored by Broili:[2] the pterygoids do not meet in the median line; the prevomers are very large; the palatine foramina are small. Cope's types show these characters definitely, and the pterygoid region of twelve other skulls studied during the present investigation show that the pterygoids do not meet in the median line.

Skull.—The skull has been distorted by pressure, the right side being flattened, while the left side is pushed to the left at the top, and the lower margin crushed inward. A small part of the quadratojugal on each side, a part of the premaxillæ from the region of the maxillary foramen, some of the jugal, prosquamosal, postfrontal, and prefrontal of the left side, and a little of the squamosal and postorbital of the right side are missing.

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[1] *Kansas University Quarterly*, Vol. VI, No. 4 (1897), p. 209.

[2] *Paleontographica*, Vol. XLVI, Plate VIII, Fig. 1.

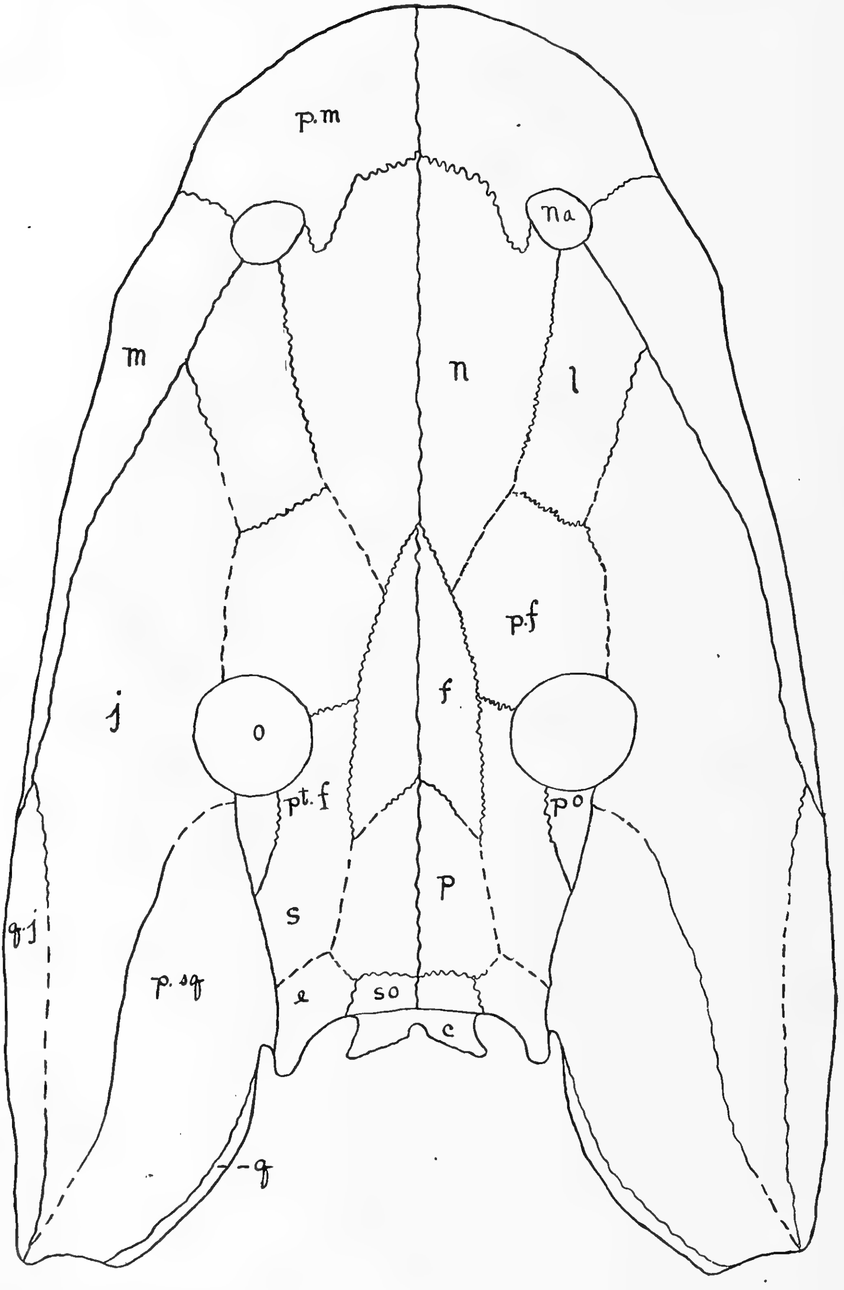

FIG. 11.—*Eryops* Cope; view of top of skull, four-thirteenths natural size.

c, condyle; e, epiotic; f, frontal; j, jugal; l, lachrymal; m, maxillary; n, nasal; na, nares; o, orbit; p, parietal; pf, prefrontal; pm, premaxillary; po, postorbital; ptf, postfrontal; qj, quadratojugal; s, squamosal; so, supraoccipital. Broken lines indicate that sutures have not been made out.

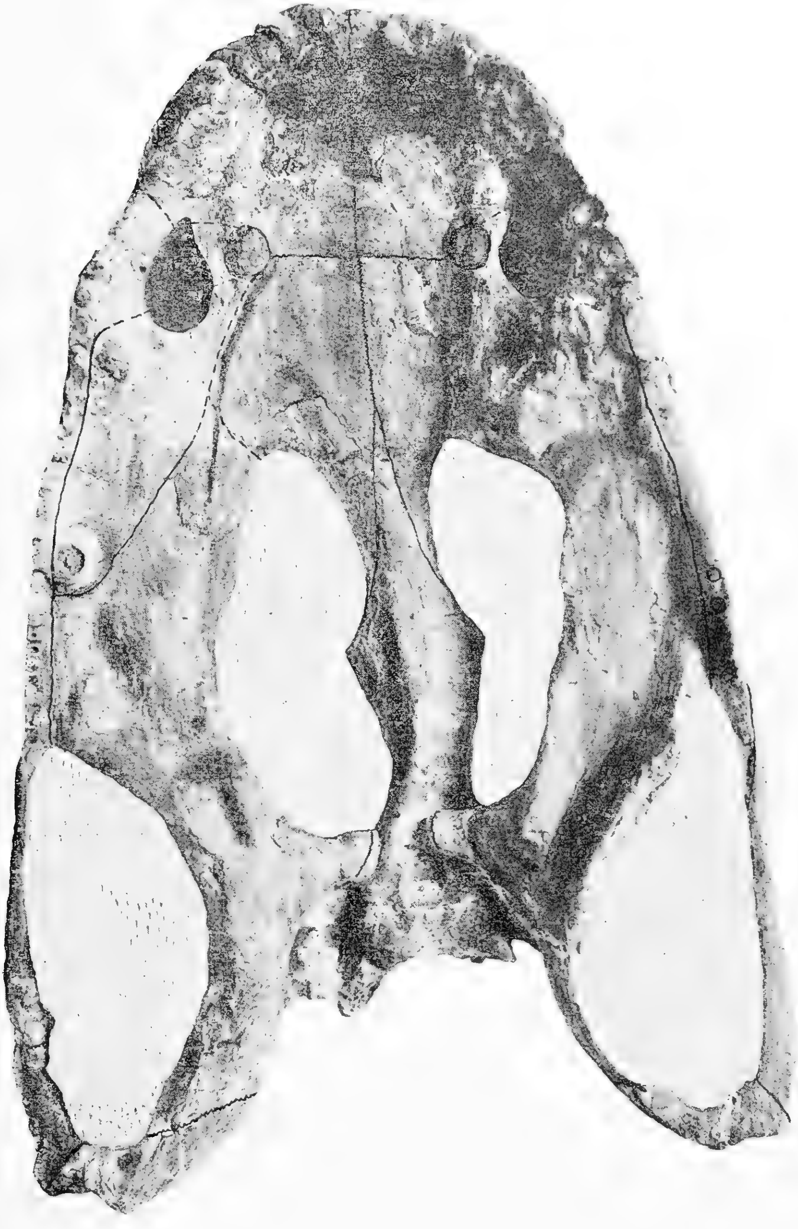

FIG. 11*a*.—Palatal view of skull.

The bones in the roof of the skull resemble those in *Actinodon* and *Mastodonsaurus*. The parietals, frontals, postfrontals, and supraoccipitals are small. The prosquamosal is elongate, reaching from just behind the orbit to the outer end of the quadrate. The quadratojugal is long and narrow. The jugals are the largest bones in the roof of the skull; they extend from a short distance behind the nares to just in front of the outer end of the quadrate. The maxillæ are long, narrow behind, expanded anteriorly. The prefrontal is pentagonal in outline. It unites with the postfrontal behind, excluding the frontal from the border of the orbits. The lachrymals are elongate, pentagonal, and reach to the nares in front. The premaxillæ are greatly expanded. The nasals are elongate and subtriangular.

The orbits are about the same size and in about the same position as in the type of *Eryops*, though they are slightly farther apart. The nares are ovate, situated at a considerable distance from the tip of the skull, and are slightly larger than in Broili's specimens, though smaller than in most other large Stegocephalians. The auditory slits are very short and narrow. No parietal foramen is present.

The anterior part of the roof is very finely sculptured with irregular elongate and subcircular pits, the ridges between the pits becoming tubercular near the median line of the skull. Toward the occiput the sculpture becomes coarser, and on the outer part of the prosquamosal the pits elongate to form radiating furrows.

From the posterior part of the epiotic a prominent ridge passes forward and outward to the back part of the orbit. A less prominent ridge passes forward from the antero-inner corner of the orbit, and gradually disappears about midway between the nares and orbits. Just in front of the antero-outer corner of the orbits there is a large, shallow depression, with a narrow furrow extending forward from it for a short distance. About 5^{cm} behind the nares there is another depression, but it is not so large as the one anterior to the orbits. Running straight forward from it on the nasals there is an indistinct narrow sulcus; passing outward from the posterior outer corner there is a broader, less well-defined, sulcus which meets the sulcus from the preorbital depression. Whether or not these canals are homologous with the slime canals of other forms it is impossible to say, but it seems probable that they are rudiments of such canals.

The dimensions of the skull and of the openings in the roof and floor are as follows:

Length along margin of jaw	580^{mm}
Length along median line from tip of snout to posterior end of quadrates	540
Length from supraoccipital to tip of snout	445
Greatest breadth	350
Breadth at posterior end of orbits	325
Breadth at posterior end of nares	233
Distance from back part of nares to fore part of orbit	185
Distance of orbit from supratemporal	120
Distance apart of nares	100
Distance apart of orbits	90
Length of nares	31
Breadth of nares	29
Length of orbits	53
Breadth of orbits	56
Length of palatine foramen	180
Breadth of palatine foramen	90
Distance from tip of skull	200
Distance from end of condyle	65
Distance from internal nares	65
Length of internal nares	45
Breadth of internal nares	27
Distance from tip of snout	110
Length of infratemporal foramen	175
Breadth of infratemporal foramen	80

Under side of skull.—The under side of the skull is not in one plane, but is arched upward very strongly along the median line posteriorly. This arching is caused by the inner wings of the pterygoids turning abruptly upward.

The parasphenoid is comparatively much shorter than in Broili's specimens. One of the skulls which he describes is about 38^{cm} long, and has a parasphenoid 26^{cm} in length, while the skull described in this paper is 45^{cm} long and has a parasphenoid only 22^{cm} in length. The parasphenoid is expanded in the middle and in front of the expansion tapers gradually to a point between the prevomers. Behind the expanded part it tapers gradually to near the posterior end, where it broadens slightly, separating the pterygoids and articulating with the exoccipitals. The parasphenoid does not separate the pterygoids or articulate with the exoccipitals in Broili's specimens. It has a broader median expansion than in this form, is narrower behind, and contracts more abruptly in front of this expansion, and has a much longer, slenderer cultriform process.

The prevomers are broad and thin. They articulate anteriorly with the premaxillæ in a straight line that runs at right angles to the main axis of the skull. On the outside they articulate with the pterygoids and palatines. They articulate with each other in the median line of the skull for the anterior half of their length, then pass backward on either side of the parasphenoid, and end just in front of the median expansion of that bone. They form the anterior inner boundary of the palatine foramina.

The palatines are long and slender, and extend from the middle of the outer margin of the skull to the anterior end of the internal nares. They are broadest immediately behind the nares, narrowest just inside their posterior end, and they form their entire inner and posterior borders. They bear three large teeth, one at the back end, one just behind the nares, and one immediately inside the anterior end of the nares.

The pterygoids have very long anterior and posterior wings, and a short, thick inner wing. The anterior wing is broad at the outer end between the maxillary and the palatine foramen, but becomes narrower anteriorly between this foramen and the palatine bones. It is narrower between the infratemporal and palatine foramina, and the part that forms the inner boundary of the former is turned upward at right angles to the main part of the bone. Just inside this upturned portion there is a deep depression that extends forward, becoming broader and shallower, until it finally disappears. The posterior wing is twisted on the main part of the bone until only the edge is seen from below. It articulates with the quadrate at the outer end and above, and projects outward nearly to the cotylus. The inner wings are present in six specimens preserved in Walker Museum, and in every specimen they are broadly separated by the parasphenoid, instead of meeting in the median line as in Broili's specimens.

The premaxillaries are greatly expanded, forming the anterior fifth of the floor of the skull.

The palatine foramina are much shorter than those shown in Broili's restoration of *Eryops*. They are separated by the parasphenoid and prevomers. The infratemporal foramina are long and narrow. The internal nares are large, rounded posteriorly and pointed anteriorly, and are widely sseparated from the palatine foramina. As the premaxillaries are somewhat imperfect anteriorily, the shape of the premaxillary foramina cannot be definitely determined. They do not penetrate the roof of the skull.

Base of skull.—The foramen magnum is remarkable because of its small size. In none of the specimens in the collection does its greatest diameter exceed 2^{cm}. As it is distorted by pressure, in all of the skulls, it is impossible to determine its exact shape, but it seems to have been oval, with its transverse diameter the greater.

The exoccipitals form the margins of the foramen, except above, where the supraoccipitals project downward between them. In the floor of the skull the exoccipitals are thick, and co-ossified with each other and with the parasphenoid. The condylar processes are short and strong, and the articular surfaces are concave. A short, strong upward projection from just in front of the condyles forms the lateral boundary of the foramen magnum and broadens to a head above, articulating firmly with the supraoccipitals. A long, slender lateral process, homologous with the opisthotic (paroccipital, Baur) of reptiles, passes outward to articulate with the epiotic (paroccipital plate, Baur) at its outer end. Between this process and the bones of the roof of the skull there is an elongate oval foramen, which is homologous with the posttemporal foramen of the Reptilia.

The posterior wing of the pterygoid, where it turns upward to articulate with the quadrate, forms a considerable part of the base of the skull. The quadrate extends from the cotylus to the auditory slit, showing as a long, narrow strip in the base of the skull. Along its entire upper edge it articulates firmly with the prosquamosal, along its lower edge with the pterygoid. The quadratojugal meets it at its lower outer corner. The surface for articulation with the mandible is somewhat saddle-shaped, and is formed entirely by the quadrate.

Mandible.—The sutures in the mandible of *Eryops* have never before been determined, but in all of the specimens in Walker Museum most of them are distinct. In Figs. 13 and 13*a* the sutures are indicated. The suture between the prearticular and the splenial has not been definitely located.

The articular is short and thick. It is covered on the outside by the angular and surangular, and on the inside by the angular and prearticular. The articular surface is convex, the convexity passing diagonally forward from the posterior inner corner. The coronoid is very small, and is situated in front of the supra-meckelian foramen, as in *Anaschisma.* The dentary is slender, sculptured anteriorly, and smooth posteriorly. The posterior end of it projects a little way behind the coronoid. There is a high, thin parapet on the upper side of the outer part of the bone, and the outer edges of the teeth are imbedded in it. The angular forms the greater part of the outside of the mandible in front of the supra-meckelian foramen. The suture between the angular and surangular has not been definitely determined. The splenial is slender and very thin. It projects above the inner edge of the dentary anteriorly, but gradually descends posteriorly. The portion in front of the angular (Fig. 13, ?) seems to be an element separate from the dentary. The suture between it and the dentary appears to be near the lower edge of the jaw on the outer side. As previously stated, this element seems to be distinct in *Anaschisma*, but the evidence in neither case is conclusive.

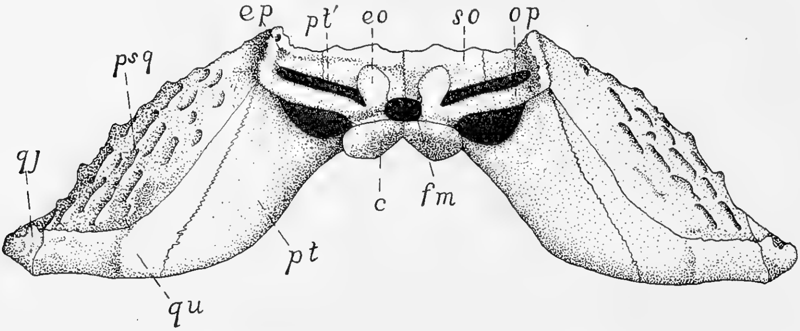

FIG. 12.—*Eryops* Cope; hinder view of occiput, one-third natural size.
c, condyle; eo, exoccipital; ep, epiotic; fm, foramen magnum; op, opisthotic; pt′, posttemporal foramen; pt, pterygoid; psq, prosquamosal; qj, quadratojugal; qu, quadrate.

The internal mandibular foramen is small, oval, situated between the angular and prearticular directly below the anterior end of the supra-meckelian foramen. The supra-meckelian foramen is elongate and narrow.

The sculpture on the outside of the mandible consists of longitudinal ridges and furrows above, but these become coarser and have more of the pitted character below.

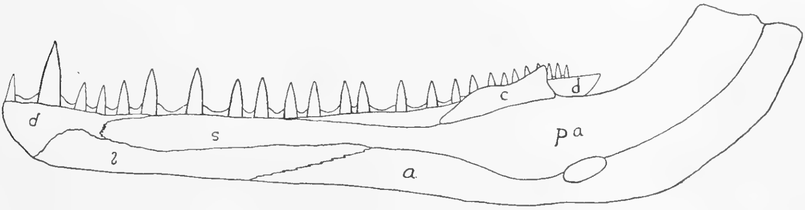

FIG. 13.—*Eryops* Cope; inner view of mandible, one-fourth natural size.
a, angular; d, dentary; c, coronoid; pa, prearticular; s, splenial; ?, probably a separate element.

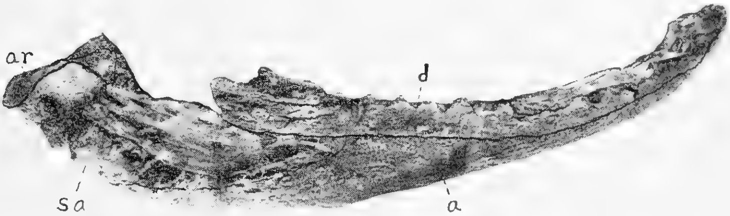

FIG. 13*a*.—*Eryops* Cope; outer view of mandible, one-third natural size.
a, angular; ar, articular; d, dentary; sa, surangular.

Vertebræ.—Belonging with the skull above described there are twenty vertebræ, five of which are caudals and the rest dorsals. A smaller specimen, probably of *Eryops megacephalus*, has twenty-four vertebræ preserved in a continuous series, beginning with the atlas. The number of presacral vertebræ can be pretty definitely determined from these two specimens, and seems to be twenty-five or twenty-six. There are two sacrals and about fifteen caudals. The number of caudals is estimated from the anterior and posterior ones figured by Cope. These specimens furnish some new and interesting facts about the vertebræ of *Eryops*.

The atlas is composed of the neurocentra and intercentrum, the neurocentra resting firmly on the intercentrum, but not co-ossified with it. The intercentrum is not divided on the middle, as Cope supposed.[1] The arch is small and bears no rib. The axis is composed of the same elements as the atlas, with possibly small pleurocentra in addition, but its arch is larger and bears a small rib. The rib seems not to have been attached to the intercentrum. The third cervical has small pleurocentra which support the arch. Posterior to the third the pleurocentra increase in size and push the intercentra far apart below. Toward the sacrum they again decrease in size and are pushed upward, finally resting on the intercentrum of the vertebra behind. The pleurocentra of the anterior caudals are reduced in size, and they gradually decrease caudad, until those of the distal caudals are very small. In the thoracic region the pleurocentra support the arch, but, as they become more and more reduced in size, the support is shifted more and more to the intercentrum, until in the caudals the latter forms the principal support. The intercentra are enlarged in the sacral and caudal regions, and those of the sacrum are opposed below.

The specimens that furnish these new facts are the ones from which Dr. Baur drew his conclusions, published in the November number of the *American Naturalist* of 1897. But Dr. Baur saw only three or four vertebræ free from the matrix. They were from the thoracic region, and his statements concerning them are accurate. The atlas was free from the matrix only on one side, and he says of it: "Only the first intercentrum is connected with the neural arches of the first vertebra, the atlas forming the atlas ring as in all Amniota."[2] The matrix still covered the vertebræ behind the atlas when the writer began work on them, and it was not then apparent that the second vertebra, like the first, has no pleurocentra in that specimen.

In the specimen figured by Cope the axis has no pleurocentra; but he does not mention this peculiarity in his description.[3] The intercentrum of the atlas was missing, and it was natural to suppose that the pleurocentra of both atlas and axis had been lost with it. But reference to his figure shows that there is little space for pleurocentra between the third intercentrum and the diapophysis of the axis arch. After examining Cope's specimen, the writer is not fully

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[1] *Proceedings of the American Philosophical Society*, 1880, Vol. XIX, pp. 52, 56.

[2] *American Naturalist*, 1897, p. 978.

[3] *Proceedings of the American Philosophical Society*, Vol. XIX, Plate III, Fig. 5.

decided that pleurocentra were not present in the axis. There is a possibility that they have been lost in the specimens examined. Cope's figure also shows that the pleurocentra of the third cervical are very small. He figures no caudals except five proximal ones, in which the pleurocentra are greatly reduced and the intercentrum bears the arch, and five at the end of the tail, in which the intercentra are large and the pleurocentra very small.

The absence of the pleurocentra in the atlas and axis, and their reduction in the caudals, force the following conclusions: *Eryops* is not near the direct ancestry of the Amniota, because in all primitive Amniota the pleurocentra are large in the atlas and axis. On the contrary, the tendency is toward the development of true stereospondylous vertebræ, as in the Labyrinthodontidæ. The atlas and axis are composed of the same elements as in that form, and the caudals are approaching that type by the reduction of the pleurocentra. This conclusion was reached independently before the writer had read Jaekel's paper on *Archegosaurus*,[1] in which he reaches a like conclusion concerning the vertebræ of that genus, because of the great reduction of the pleurocentra in the caudals.

The problem of the homologies of the elements in the temnospondylous stegocephalian vertebræ has been much confused by misapprehension on the part of some authors, and by a lack of full information concerning the structure of this part of the skeleton of some of the forms that have been discussed most. The status of opinion to date is about as follows:

All writers are agreed that the neurapophyses are homologous with the neurapophyses of the Amniota. Gaudry[2] and Fritsch[3] believed that the intercentrum (hypocentrum) is the true centrum (pleurocentra) of the Amniota, while Cope, Baur, Albrecht, Dollo, and others maintain that it is homologous with the intercentrum of the Amniota. The evidence is overwhelmingly in favor of the latter view, and it is the one now generally accepted. But the homologies of the elements called pleurocentra and hypocentra pleuralia are

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[1] *Zeitschrift der Deutschen geologischen Gesellschaft*, 1896.

[2] "Les enchainements du monde animal," *Fossiles primaires* (Paris, 1883).

[3] *Fauna der Gaskohle und der Kalksteine der Permformation Böhmens*, Vol. II (1889).

still in dispute. All are agreed that the posterior elements in the vertebræ of *Eryops* are homologous with the centrum of the Amniota, but Cope, Baur, and others believe that they are also homologous with the pleurocentra of *Archegosaurus*, *Actinodon*, and other temnospondylous stegocephalians; while Gadow holds that they are the hypocentra pleuralia of *Archegosaurus* and *Chelydosaurus*.[1]

> These elements of *Eryops* are ventralia, not dorsalia, consequently not pleurocentra. They are interventralia enlarged and extending upwards. Consequently they are homologous with Fritsch's hypocentra pleuralia of *Chelydosaurus*, of the tail of *Archegosaurus* and homologous with the centra of the Amniota.

Cope, Baur, Albrecht, Dollo, and others believe that the hypocentrum pleurale is united either to the intercentrum[2] in front, or to the pleurocentrum[3] above in *Eryops;* or, as Baur puts it, "Das Hypocentrum pleurale trägt zur Vervollständigung des Wirbelkörpers bei."[4]

Jaekel has clearly shown[5] that in the caudal region of *Archegosaurus* the pleurocentra elongate and each separates into two elements, one above and one below, the lower being the hypocentrum pleurale (interventralia of Gadow). Probably no separation of this kind takes place in *Eryops*, since in the anterior caudals the pleurocentra are reduced and pushed high up by the close approach of the intercentra. A comparison of Figs. 14 and 15, and 16 and 17, shows how closely the vertebræ of *Eryops* resemble those of *Archegosaurus*. In the thoracic region there can be no doubt about the homology of the pleurocentra of the two forms. In the caudal region the evolution has progressed along different lines. In *Eryops* the hypocentra pleuralia do not separate from the pleurocentra, but both are reduced together; but the difference is not sufficient to raise a doubt about the homologies of the parts.

Dr. Hans Gadow calls *Eryops* a reptile on account of the structure of its vertebræ, but his conception of the vertebræ of this animal was wrong in several particulars. He based his conclusions on the

[1] *Philosophical Transactions of the Royal Society of London*, Vol. CLXXXVII (1896), p. 22.

[2] *Proceedings of the American Philosophical Society*, Vol. XVI, p. 245.

[3] *American Naturalist*, 1886, pp. 76, 77.

[4] *Biologisches Centralblatt*, Vol. VI, p. 333.

[5] *Zeitschrift der Deutschen geologischen Gesellschaft*, 1896.

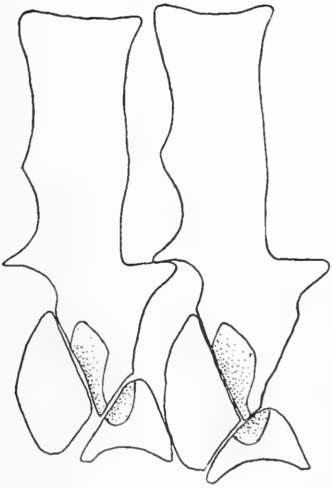

FIG. 14

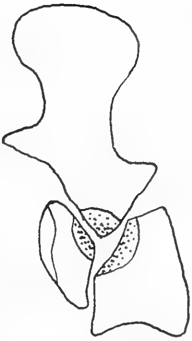

FIG. 15

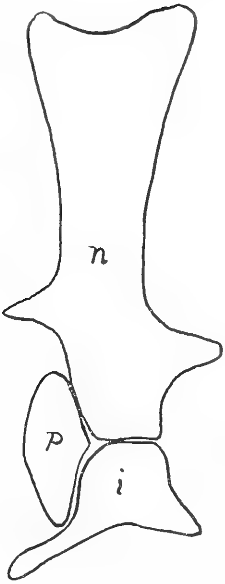

FIG. 16

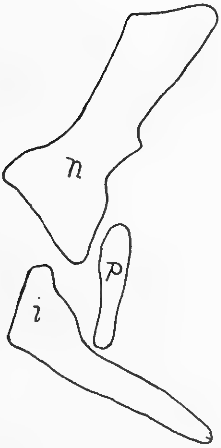

FIG. 17

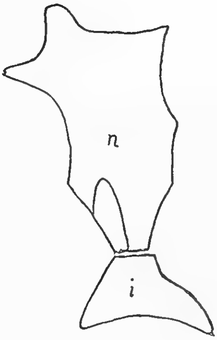

FIG. 18

FIG. 19

FIG. 14.—*Eryops* Cope; thoracic vertebræ; one-half natural size.

FIG. 15.—*Archegosaurus* Goldfuss; thoracic vertebra (after Jaekel).

FIG. 16.—*Eryops* Cope; anterior caudal vertebra; two-thirds natural size (after Cope).

FIG. 17.—*Archegosaurus* Goldfuss; caudal vertebra (after Jaekel).

FIGS. 18, 19.—*Eryops* Cope. Fig. 18, axis with top of arch missing; Fig. 19, atlas; one-half natural size.

i, intercentrum; n, neural arch.

literature on the subject, having examined very few specimens of the vertebræ themselves. He says: "The neural arches of the tail and thorax rest exclusively upon the posterior disk (pleurocentra of Cope)."[1] As already shown in the present article, the neural arches are gradually shifted on to the intercentra in the posterior part of the thoracic region, and in the caudals the intercentra furnish the greater part of the support. Dr. Gadow's figures[2] of two vertebræ in the British Museum shows that the neural arches rest against the intercentra in the dorsal region. Cope's figures[3] of the anterior caudals show that the intercentra form most of the support for the arches. (See Fig. 16.)

Dr. Gadow says:

> In the thoracic vertebræ the diapophyses of the neural arches alone carry the single-headed ribs. In the cervicals the articular facet extends downward and forms a shallow groove on the caudal portion of the intercentrum.[4]

In all of the thoracic vertebræ the rib is borne by both the arch and the intercentrum. The intercentra of the atlas and axis are the only ones anterior to the caudals that have no facet for rib articulation. The size of the rib facet on the intercentrum increases gradually posteriorly, and on the sacral vertebræ it is more than 2^{cm} in diameter. Furthermore the ribs are not all single-headed. As Cope has pointed out,[5] the sacral ribs are distinctly double-headed, though the capitulum and tuberculum are not widely separated. Five or six of the ribs just anterior to the sacrum have the capitulum and tuberculum separate, though not as distinctly as in the sacrals; and anterior to these the ribs are really double-headed, for they articulate with both the diapophysis and intercentrum.

Dr. Gadow says of the pleurocentra:

> They are, moreover, the pieces which, in *Eryops*, are attached to the caudal end of the cervical vertebræ, figured by Cope, and there actually and rightly called hypocentra pleuralia.[6]

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[1] *Loc. cit., infra*, p. 21.

[2] *Philosophical Transactions of the Royal Society of London*, Vol. CLXXXVII, p. 41, Fig. 41.

[3] *Transactions of the American Philosophical Society*, Vol. XVI, Plate 1, Fig. 1.

[4] *Loc. cit.*, pp. 21. 22.

[5] *Palaeontological Bulletin*, No. 32, p. 15.

[6] *Loc. cit.*, p. 22.

Cope says that in some specimens a groove crosses the inferior side of the intercentra of the cervical region, and that the anterior part is probably the hypocentrum pleurale, but he does not figure vertebræ that have the groove. The pleurocentra are present in all of the vertebræ excepting the atlas and axis, and possibly the posterior caudals, and an examination of the specimens will convince the most skeptical that they represent the same elements throughout the column. But in some of the cervicals the other element, called by Cope hypocentrum pleurale, are present in the same vertebræ with the pleurocentra. How, then, can the hypocentrum pleurale be the pleurocentrum, when the pleurocentra are already represented in those vertebræ by other elements? The conclusion is obvious. The pleurocentra of *Eryops* are the interdorsalia of Gadow, and not the interventralia (hypocentra pleuralia), as he believes.

Recent investigations furnish almost positive proof that the homologies of the parts of *Eryops* vertebræ proposed by Cope are correct.

The neurapophyses (basidorsalia of Gadow) are homologous with the neurapophyses of other temnospondylous Stegocephalians and of the Amniota.

The intercentra (hypocentra, basiventralia of Gadow) are homologous with the intercentra of other temnospondylous Stegocephalians and of the Amniota.

The pleurocentra (interventralia of Gadow) are homologous with the pleurocentra (interdorsalia of Gadow) of other temnospondylous Stegocephalians and of the Amniota.

The hypocentra pleuralia (interventralia of Gadow) are homologous with the hypocentra pleuralia of *Archegosaurus*, *Chelydosaurus*, and *Sphenosaurus*.

In *Archegosaurus*, according to Jaekel,[1] the hypocentra pleuralia are united with the pleurocentra in the thoracic and anterior caudal regions. The fate of these elements in other temnospondylous Stegocephalians and in the Amniota is not known. They may be united with the pleurocentra, which seems the most probable; they may be united with the intercentra; they may have entirely disappeared; or all three of these conditions may be represented.

[1] *Zeitschrift der Deutschen geologischen Gesellschaft*, 1896.

Eryops Cope

Skull long, comparatively narrow; proportion of length to breadth about 9 to 7. Roof bones coarsely sculptured posteriorly, finely sculptured anteriorly. Nasals and premaxillæ very large; frontals excluded from orbits by junction of pre- and postfrontals. Pterygoids not meeting in the median line; parasphenoid dagger-shaped, tapering gradually to a point just in front of the palatine foramina; prevomers large. Orbits subcircular, situated in the posterior half of the skull; nares subovate, remote, at a considerable distance from the tip of the skull. Many minute denticles on pterygoids, palatines, prevomers, and parasphenoid. Teeth circular in cross-section, strongly ribbed near base, dentine strongly infolded. Three large teeth on each palatine. Mandible without postcotyloid process. Vertebræ rhachitomous. Ribs double headed. Pelvic bones coalesced.

ACKNOWLEDGMENTS

The investigations of the writer on *Eryops* and the Labyrinthodontidæ were carried on under the direction of Professor S. W. Williston, head of the department of vertebrate paleontology of the University of Chicago. The writer's sincerest thanks are due Professor Williston for the privilege of studying the specimens in Walker Museum, and for his valuable advice and encouragement. Thanks are also due to those in charge for permission to examine the specimens of *Eryops* preserved in the American Museum of Natural History of New York City.

RECENT GEOLOGY OF SPITZBERGEN

JOHN J. STEVENSON
New York University, New York City

The Spitzbergen archipelago consists of many islands upon a submerged plateau. The largest, known as West Spitzbergen, is not far from 300 miles long from north to south, and its southern point, South Cape, is in N. L. 76° 20′, about 150 miles north from the outlying Bear or Cherry Island. The western coast is indented by bays extending inland 20–80 miles. The surface, as seen from the western side, is a succession of plateaux, 300–900 feet near the coast, and rising to 1,600 feet farther inland, with irregular peaks, 2,000–4,000 feet high, scattered over it.

The climate of the region in middle Tertiary times was not more severe than that of our latitude, and familiar types of tertiary deciduous trees, described by Heer and later by Nathorst, occur abundantly at a locality about 8 or 10 miles south from Icefiord. The rainfall up to a comparatively recent period must have been abundant to bring about the baseleveling of the area and afterward to cut the deep valleys, filled in later times by the glaciers. The rainfall now must be insignificant, as during the very brief summer the temperature seldom rises above 4° C.

In West Spitzbergen, glaciers begin at a few miles north from South Cape and, at Horn Bay, several come down to the water, some of which seem to reach back to the inland ice north from that bay. On Recherche Bay, a branch of Bell Sound, and about 90 miles from South Cape, two fine glaciers remain: one on the west side coming down from Bell Mountain, 4 or 5 miles away, and another on the southeast, which extends southward to the high inland ice. Between these is a deep valley, in whose lower portion no ice remains. Northward to Icefiord, 20 or 25 miles, ice is present in notable quantity on the upland, but reaches into few of the valleys, many of which are open from the sea almost to the plateau. On the northwesterly side of Icefiord, a vast glacier, beginning at 6 or 7 miles from the sea, extends almost unbroken along the coast from Safe Harbor to Cape

Bohemian, about 25 miles, and stretches back, 12 to 20 miles, to a high ridge, where it may be continuous with the névé basin beyond. This glacier appears to be without a name; it should be dedicated to Nathorst.

The climatic conditions of Spitzbergen have undergone such change since the glacial period that for a long time the waste has exceeded the snowfall; evidence of loss is distinct everywhere. Bear Island, 150 miles south from South Cape, while in some respects harsher in climate than is West Spitzbergen, now shows no trace of glacial ice, though a fine trough coming down to sea-level at the northwest corner proves its former existence. Both glaciers in Recherche Bay project into the water with an abrupt face, estimated to be about 150 feet high, and fully one mile long in one, two miles in the other; but each of them is retreating on one side, where the boundary curves back on the shore and the surface is gently rounded. This retreat is especially marked in the western glacier, whose lateral moraine on the northerly side extends far out into the bay, while the moraine on the southerly side, medial between it and the greatly diminished middle glacier, is the hook behind which whalers have their anchorage. Even in the ice-wall the loss is notable; for on the face of the western glacier a great recess appears. A similar story is told by the vast Nathorst Glacier on Icefiord, whose retreat is especially marked on the westerly side near Safe Harbor; while between Bell Sound and Icefiord one sees along the coast the long trough-like valleys, almost wholly devoid of ice, but owing their form to the passage of glaciers. The presence of such fiord valley on the sides of Icefiord, as well as dying glaciers at the heads of that bay's branches, indicate that, at one time, confluent glaciers filled Icefiord and extended seaward. It is equally clear that the same condition existed on Bell Sound. So that the extensive glaciers of West Spitzbergen, like the small glaciers of Norway, must be regarded merely as remnants of a great sheet covering the whole land and extending, finger-like, through gorges into the sea.

The valleys are not broad, with gently rounded outline, like very many of those along Storfiord north from Marok, but they have abrupt walls, resembling those of the deeper interior fiords along the Norway coast. In some of the Norwegian valleys, especially along Storfiord, the glaciers have changed the form of the valleys far beyond the usual trough, but such evidence of extended erosion is not distinct in those Spitzbergen valleys seen by the writer. Possibly the evidence is more satisfactory farther up those valleys where the floor becomes somewhat abrupt. On Advent Bay, just above a fragment of the terminal moraine forming the "hook" which protects the anchorage, there is a low wall of soft Jurassic rock rising sharply to about 20 feet above the water, and from its edge the floor reaches back to the bluff. This wall is somewhat higher than the marshy floor of Advent Dale, 3 miles away at the head of the bay. It seems strange that the ice did not remove this soft material. It is true that the movement could not have been rapid, as the slope of the floor is very gentle, and the place is less than a mile from the mouth of the bay where this glacier joined the main stream; but, unless the ice were heavily laden with débris, there should have been motion enough to cut away this petty obstruction.

There has been little erosion by water since the ice retreated, and the waste has been due to changes of temperature, which are superficial. The entry of the Spitzbergen Coal Company, about 200 feet long at the time of the writer's visit, was still in frozen coal. Summer heat thaws the ground to only a few inches, yet suffices to encourage growth of humble flowering plants, and an accumulation of peat, which makes tramping a matter of difficulty.

In the later Tertiary the surface of Spitzbergen must have been much nearer sea-level than now, to admit of the baseleveling which bears no relation to the position of the tilted, faulted, and contorted rocks, and which removed so much of the earlier Tertiary deposits. Comparatively rapid elevation must have succeeded, during which the deep valleys were digged out to be filled in later times by glaciers. Soundings reported on the English Admiralty Chart indicate that at one time the surface stood much higher than now. Possibly the later depression may be related in some way to the disappearance of the ice.

Northeast Land, a glaciated area of perhaps 20,000 square miles, forms with some outlying small islands the northern portion of the archipelago, and is separated at the southwest from West Spitzbergen by Hinlopen Strait. Westward from Northeast Land and its islands, the depth increases very slowly, the soundings showing 8–20 fathoms at 10–20 miles from the land; but the course of the valley of Hinlopen

Strait seems to be well marked, the depth increasing to 72, 90, and 200 fathoms, with 755 at 30 miles farther. As far as to the 200-fathom point high land is alongside, the depth being only 8–40 fathoms, while farther out toward the deepest sounding along the line of the strait the soundings eastward from that channel indicate a submerged dissected plateau.

Going westward 60 miles, one finds north from West Spitzbergen another area of soundings showing similar conditions. Wilde Bay extends southward from the north coast for 90 miles; forty miles up its depth is 30 fathoms; at 10 miles from the sea it is 90; but a submerged moraine reduces the depth at the mouth to 55–72 fathoms. Liefde Bay is just west, with, as its western boundary, a broad low area, about 100 square miles, apparently moraine stuff. At its mouth, where it adjoins Wilde, the depth is 93 fathoms. The course of the united bays can be followed northwestwardly until its depth becomes 150 fathoms, and at 15 miles farther 505. This is inclosed on the west by elevated land, covered by 42–70 fathoms and cut by valleys, some of which are tributary to the Wilde-Liefde, while others are tributary to a shallower valley at the west, which is but 360 fathoms deep at 10 miles west from the 505-fathom cast, and only 390 at 30 miles farther, or 120 miles northwest from Liefde Bay. Still farther west is a deeper valley with a depth of 235 at 27 miles, 300 at 40, and 730 at 115 miles from the northwest corner of the island.

Going southward along the west coast, one finds the long island known as Prince Charles Foreland, separated from West Spitzbergen by the narrow Foreland Sound, shallow and 8–10 miles wide. The depth of the sound at its mouth is 27 fathoms, but its course is clear, for the depth becomes 120 fathoms at 15 miles north. Westward from this the soundings are too few to be of much value, but the greatest depth at 75 miles from the coast is only 200 fathoms, though farther south the 300-fathom line is at 45 miles and the 500-fathom line at 51 miles from the coast. The abruptness of the change from 200 to 300 and then to 500 fathoms suggests that this line of soundings falls off into a valley.

Icefiord is much deeper than any of the bays at the north; it is 120 fathoms at 8 miles up, and 215 at its mouth, while at 60 miles west-southwest the soundings show 600 fathoms, though at a few miles north the depth is but 93–110 fathoms. At a few miles south, due west from Bell Sound, the depth increases very gradually for 40 miles to 100 fathoms, but the course of the Bell Sound channel is in southwest direction, 839 fathoms being reached in 70 miles, and only 15 miles west from a line of soundings showing 90–130; a sounding of 160 fathoms between this line and the shore suggests the existence of a tributary valley there. West from South Cape the depth becomes 118 at 45, 523 at 55, and 743 fathoms at 65 miles.

Farther south the 700-fathom limit is between 60 and 70 miles west from a line joining South Cape and Bear Island; eastward from this line the depth decreases within 10–15 miles to about 200 fathoms, which is the depth on a broad strip of 10–15 miles; thence eastwardly for nearly 200 miles the depth, except along well-defined lines, varies between 20 and 50 fathoms. In 225 miles northeast from Bear Island the depth exceeds 35 fathoms only three times; while between this broad strip and the larger islands at the northwest one can trace deep channel-ways marking the westward drainage. An elevation of 250 feet would unite all the great islands to each other and to Bear Island, now 150 miles from South Cape, the nearest point.

The long channel-ways at the north traceable between walls until they reach a depth of 390 in one case, 505 in another, that of Icefiord traceable to 600 fathoms, with only 100 fathoms at 15 miles away on each side, as well as the relation of the 700-fathom line to the direction of the coast, seem to leave little room for doubt that at one time the coast line lay not far from that marked by the depth of 700 fathoms. The details of soundings do not permit anything further at present. Icefiord, now only 8 miles wide at the mouth, was a broad valley beyond the present coast line, 20 miles wide at 70 miles away, with its bounding walls rising 2,000–3,000 feet above its floor; the valley of Hinlopen Strait as well as that of Wilde-Liefde Bays must have extended in like manner to more than 100 miles beyond the present coast line; and the Spitzbergen plateau was a triangular area extending from beyond N. L. 82° southward to an unknown distance beyond Bear Island, not less than 700 miles from north to south; the width in N. L. 81° much exceeded that of the area given on the Admiralty Chart, which is about 400 miles wide. The writer had no access, during the preparation of this note, to the results obtained by the several recent expeditions to Franz Josef Land; but Nansen's description of the fiord features of the inlets there, as well as the similarity in geological character between West Spitzbergen and a portion of Franz Josef Land, recognized by Nathorst, suggests that that area, now not more than 120 miles east from Northeast Land and extending northward to about 84°, may have been continuous with the Spitzbergen area, and may have reached as land far toward the North Pole.

Submerged moraines in many of the bays mark halts in recession of the ice. Where the branches of Red Bay on the north shore come together the depth decreases from 50 fathoms above to 6 and 7, with a narrow strip of 33 fathoms on one side; the depth increases to 78 farther down, but at the mouth of the bay is a bar with 8–23 fathoms. Near the head of Foul Bay the sounding is 61 fathoms, but at the mouth there is shallow water; Magdalena shows 50 fathoms near the head, but lower down it is blocked by shoals with about 30 fathoms on each side. Sassen Bay, the east branch of Icefiord, is 100 fathoms deep at 10 miles above its mouth, but is barred by a moraine with 49–63 fathoms. No such barring appears in Icefiord, which deepens steadily to 215 fathoms at its mouth; but the barring is distinct in Recherche Bay. Similar conditions exist at many other localities, and explain the absence of icebergs off the plateau. But in any case, the ice is not thick enough to give off imposing blocks, there being in all probability not more than 500 feet at any place where the wall comes down to the water.

That the great subsidence was succeeded by elevation—which may be going on—is proved by terraces in the moraine stuff on Icefiord and Recherche Bay, as well as at other localities along the coast. No opportunity was found for measuring these, but they are as characteristic as are those at Naes, Odda, and Marok as well as elsewhere in Norway. Sandy beaches were seen south from Icefiord.

The effect of wave-action is well shown on Bear Island, which has suffered severely on the east and west coasts. At one time a glacier had its origin on the southeasterly side and flowed to the northwest corner. The waves have cut away the névé area, and the trough is open at the east; as the coast on the westerly side is diagonal to the course of the trough, the bold rocky bluff at the southern point falls off northwardly until at the northwest corner the whole wall has been removed and the valley bottom is now the shore line.

THE NORTHERN AND SOUTHERN KINDERHOOK FAUNAS

STUART WELLER
The University of Chicago

The name "Kinderhook," as applied to a series of Paleozoic strata in the Mississippi Valley, was first used by Meek and Worthen[1] in 1861 for all those beds lying between the "Black Shale" below and the Burlington Limestone above. The name of this series of formations was taken from the village of Kinderhook, in Pike County, Illinois, where a good exposure of beds of this age occurs in the Mississippi River bluffs. Another typical section, designated by the authors of the name, included the beds exposed at Burlington, Iowa, lying below the Burlington Limestone and extending downward to beneath the river level. Besides these, the "Lithographic Limestone," "Vermicular Shales," and "Chouteau Limestone" in Missiouri, as defined by Swallow and his assistants, were considered as the equivalents of the Kinderhook beds of Illinois and Iowa, as was also the so-called "Goniatite Limestone" of Rockford, Indiana.

The typical exposure of the Kinderhook Group, from which it has received its name, "is at the point of the bluff, just above the village of Kinderhook." The section at this place, as given by Worthen[2] and confirmed by the writer, is as follows:

5.	Loess capping the bluff	20 feet
4.	Burlington limestone	15 "
3.	Thin-bedded, fine-grained limestone	6 "
2.	Thin-bedded sandstone and sandy shales . . .	36 "
1.	Argillaceous and sandy shales, partly hidden . .	40 "

In connection with his description of the section at this locality, Worthen states that "the thin-bedded sandstones (bed No. 2) . . . . abound in fossil shells, belonging to the genera *Aviculopecten*, *Spirifer*, *Orthis*, and *Productus*, mostly identical with those from the grit

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[1] *American Journal of Science*, Second Series, Vol. XXXII, p. 288.

[2] *Geological Survey of Illinois*, Vol. IV, p. 27.

stones at Burlington, which belong to the same horizon." Further than this, no description of the fauna of this typical Kinderhook section has ever been given.

The collection upon which the following list is based was made at the typical locality, the point of the bluff just above the village of Kinderhook. A few fossils were collected from the fine-grained limestone, bed No. 3, but they are so poorly preserved as to be scarcely identified with certainty. As indicated by Worthen in his original description of the section, the fossils occur most abundantly in the thin-bedded sandstones of bed No. 2. They do not, however, occur uniformly through this bed, but are restricted to a narrow horizon from 20 to 25 feet below the base of the fine-grained limestone, bed No. 3. The exact limits of this fossiliferous horizon have not been definitely determined because of the thickly covered talus slope, but it probably extends through not more than a foot or two of strata.

The fauna of this bed is of much interest, and the contained species will be briefly discussed in order.

1. **Orbiculoidea** sp. undet. A single specimen of this species has been observed. It is a brachial valve about 15^{mm} in diameter; the apex is excentric and is more than ordinarily sharp for members of this genus, the surface of the shell sloping away on all sides from the apex to the margin, with a concave curve.
2. **Crania**? sp. undet. This species is represented in the collection by a single depressed-convex internal cast of a subcircular shell about 12^{mm} in diameter. It is too imperfect to allow its relationships to be determined with accuracy, and its generic identification may be incorrect.
3. **Orthothetes chemungensis** Con. The species of *Orthothetes* which occur in the Kinderhook beds of the Mississippi Valley are so indefinitely characterized that it is exceedingly difficult to make satisfactory identifications. Several different species have been described by various authors, and some of them at least are doubtless good species. The species from Kinderhook are apparently identical with those from the Chonopectus fauna at Burlington, Iowa, which have been identified as *O. inaequalis* (Hall),[1] but all the specimens are probably distinct from the

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[1] Weller, *Transactions of the St. Louis Academy of Sciences,* Vol. X, p. 66, Plate 1, Fig. 18.

typical form of *O. inaequalis*, and approach more closely to the *O. chemungensis* of the middle and upper Devonian faunas.

4. **Chonetes geniculatus** White. Several specimens of a small, finely marked *Chonetes*, although imperfectly preserved, seem to represent this species, which is typically a member of the Louisiana Limestone fauna.
5. **Chonetes** cf. **C. ornatus** Shum. In the original description of *C. ornatus* the typical specimens were said to be from the Chouteau Limestone of central Missouri, and from what is now known as the Louisiana Limestone of northeastern Missouri. The figures of the species, published with the original description, do not adequately illustrate the specimens from either of these localities. Extensive collections of more recent date have shown that the Chouteau Limestone and Louisiana Limestone specimens belong to distinct species, although both are characterized by the peculiar concentric markings upon which the species, as originally described, was mainly established. The Chouteau Limestone specimens prove to be identical with the species from the Kinderhook Oolite of Burlington, Iowa, which was described by Norwood and Pratton as *C. logani*. The Louisiana Limestone shell attains a larger size at maturity, is marked with coarser and more angular plications, and is usually proportionately broader than *C. logani;* and the name *C. ornatus* may be restricted to this species. The specimens from Kinderhook are all internal casts and do not well preserve the specific characters, but they seem to agree more closely with the specimens of *C. ornatus* from the Louisiana Limestone than with any other species. The specimens somewhat resemble those from the Chonopectus fauna from Burlington, Iowa, identified as *Chonetes* sp. undet.,[1] and they may be identical.
6. **Chonetes** cf. **C. illinoisensis** Wor. A third species of *Chonetes* occurs rarely in the Kinderhook fauna. It is larger than either of the others and is marked by finer radiating costæ, there being about 100 around the margin of a shell 15.5^{mm} broad. This shell has been identified provisionally with *C. illinoisensis*, as it has the general form and proportions of that species, and agrees more closely with it in all respects than with any other.

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[1] Weller, *loc. cit.*. p. 69, Plate 1, Fig. 15.

7. **Productella** sp. undesc. This species is one of the more common members of the fauna, and is quite distinct from any heretofore described species of the genus from the Kinderhook faunas, from all of which it may be distinguished by its large size. It resembles some of the larger species from the Chemung beds of New York, but it is sufficiently distinct from any of them. Most of the specimens observed are more or less weathered, and in this condition some of the smaller individuals resemble weathered specimens of *Chonopectus fischeri*, the proportions of the two shells being much the same, but no authentic specimens of *Chonopectus* have been observed from this locality. The species has been named *P. sublaevis*, and a description with illustrations will be published elsewhere.

8. **Productus curtirostris** Win. This species, described from the Chonopectus fauna at Burlington, was, in a former paper,[1] referred to the brachial valve of *P. semireticulatus*. Additional specimens, however, studied since that paper was published, have demonstrated that the species was well founded, it being a remarkably depressed form of *Productus* of the *semireticulatus* type. The specimens from Kinderhook seem to be indistinguishable from those occurring at Burlington.

9. **Productus semireticulatus** Mart.? A species of *Productus* of the *semireticulatus* type, identical with the one so identified from the Chonopectus fauna at Burlington,[2] occurs in the fauna at Kinderhook. The only specimen representing the species is an external impression of the brachial valve which is scarcely different from similar specimens of *P. burlingtonensis* Hall, except that it is flatter. The pedicle valve also, as seen in specimens from Burlington, is not so strongly convex or ventricose as *P. burlingtonensis* from the Burlington Limestone.

10. **Productus** sp. undet. This species is represented by fragmentary specimens only, but, so far as can be determined, it is identical with the shells in the Chonopectus fauna at Burlington, formerly identified as *P. cooperensis* Swall.?[3] This identifica-

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[1] Weller, *loc. cit.*, p. 70, Plate 1, Figs. 7, 8.

[2] Weller, *loc. cit.*, p. 70, Plate 1, Figs. 5, 6.

[3] Weller, *loc. cit.*, p. 71, Plate 1, Figs. 3, 4.

tion, however, is incorrect, the original *P. cooperensis* being a much smaller shell from the Chouteau Limestone of central Missouri, and entirely distinct from this one.

11. **Paraphorhynchus transversum** Weller. This shell is identical with a species in the Chonopectus fauna at Burlington, which has been identified as *Pugnax striatocostata* M. & W. var.?[1] but the species is sufficiently distinct from the typical form of *striatocostata*, it being proportionately much broader than that species and attaining a larger size at maturity.[2]

12. **Spirifer subrotundatus** Hall. The specimens of this species from the beds at Kinderhook are indistinguishable from those in the Chonopectus fauna at Burlington.

13. **Spirifer marionensis** Shum. This is one of the more common species of the fauna, and is of especial interest because it is identical with the shell so common in the fauna of the Louisiana Limestone of Missouri, which may be assumed to be the typical form of the species. The shells from the Chouteau Limestone and other Kinderhook formations of Missouri, excepting the Louisiana Limestone, as well as those from the Kinderhook beds Nos. 5–7 at Burlington, which have usually been identified as *S. marionensis*, are distinct from the typical Louisiana Limestone representatives of the species. This typical form may be recognized by its less prominent umbo, and by the more nearly obsolete fold and sinus, and although the Louisiana Limestone and Chouteau Limestone species are much alike, they are doubtless specifically distinct.

14. **Syringothyrus extenuatus** Hall. Most of the specimens of this species from Kinderhook are separate brachial valves which are more or less imperfect. A single specimen, however, preserves both valves in such a manner that the angle between the plane of the brachial valve and the cardinal area of the pedicle valve can be approximately measured. This angle is 38°, a little larger than the average angle of the specimens in the Chonopectus fauna at Burlington, which vary but little from 30°. It is, however, much closer to these Burlington specimens than to

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[1] Weller, *loc. cit.*, p. 72, Plate 2, Figs. 16, 17.

[2] Weller, *Transactions of the St. Louis Academy of Sciences*, Vol. XV, p. 264.

the specimens of *S. hannibalensis* Swall., from the Louisiana Limestone, in which this angle does not vary much from 60.° In its flat cardinal area also the Kinderhook specimens agree with *S. extenuatus* rather than with *S. hannibalensis*, in which the area is usually more or less concave.

15. **Aviculopecten** sp. undet. A single imperfect specimen of a species of this genus has been observed. It is certainly distinct from any of the species in the Chonopectus fauna at Burlington, and may be an undescribed form.

16. **Pterinopecten** cf. **P. laetus** Hall. Several imperfect specimens of this shell have been observed, which are undoubtedly identical with those so identified from the Chonopectus fauna at Burlington,[1] although it is quite possible that they represent an undescribed species distinct from, but allied to, *P. laetus* Hall.

17. **Pernopecten cooperensis** Shum. This species has as yet not been recognized in the Chonopectus fauna at Burlington, but the Kinderhook specimens which have been observed are indistinguishable from specimens occurring in bed No. 5 in the Burlington section.

18. **Leiopteria undulata** M. & W. The type specimen of this species, described originally as *Pterinea? undulata*,[2] is said to have come from the Kinderhook at Burlington, Iowa. The authors of the species state, however, that they "have also seen some imperfect casts, very similar to this species, and possibly not distinct from it, from the same horizon, at Kinderhook, Ill. The latter are left valves, and seem to be a little more convex than in the typical examples." The specimens from Kinderhook mentioned by Meek and Worthen were undoubtedly the same as the specimens here under consideration. The species has not been seen by the writer from Burlington, but it doubtless occurs in the Chonopectus fauna at that locality. The figured type specimen is a very imperfect shell, showing parts of both valves; but, so far as it is preserved, it does not seem to differ in any marked degree from the specimens from Kinderhook.

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[1] Weller, *Transactions of the St. Louis Academy of Sciences*, Vol. X, p. 83, Plate 3, Figs. 1, 2.

[2] *Geological Survey of Illinois*, Vol. III, p. 456, Plate 14, Fig. 5.

19. **Avicula strigosa** White. The specimens of this species from Kinderhook are all imperfectly preserved, but they seem to show no essential differences from the typical members of the species in the Chonopectus fauna at Burlington.
20. **Pteronites whitei** Win. A single very perfect left valve of this species occurs in the collection, and is indistinguishable from the members of the species in the Chonopectus fauna at Burlington.
21. **Goniophora jennae** Win. This is another Chonopectus fauna species, but it seems to be more common at Kinderhook than at Burlington. The specimens exhibit some variation, but in general they correspond quite closely with the smaller of the two type specimens figured by Weller.[1]
22. *Undetermined pelecypod.* This species is represented by two specimens of a small *Allorisma-* or *Grammysia*-like shell, too imperfect for identification.
23. **Sphaerodoma pinguis** Win. A single specimen in the collection is apparently identical with this species which was originally described from the Chonopectus fauna at Burlington.
24. **Straparollus** sp. undet. A small specimen too imperfect for identification.
25. **Bellerophon** sp. undet.
26. **Patellostium scriptiferus** White. The specimens of this species from Kinderhook are identical, in all their essential characters, with the typical representatives of the species from the Chonopectus fauna at Burlington.
27. **Brachymetopus** sp. undet.

The most noticeable feature of this fauna is its striking similarity to the Chonopectus fauna at Burlington, although the total number of species recognized is much smaller, and the most characteristic species at Burlington, *Chonopectus fischeri*, has not been noticed at Kinderhook. In spite of the absence of this species, however, the fauna can be definitely stated to be equivalent to the fauna of the yellow sandstone at the summit of bed No. 2 at Burlington, and doubtless this yellow sandstone at Kinderhook and the yellow sandstone at Burlington would be found to be a continuous forma-

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[1] *Loc. cit.*, Plate 3, Fig. 14.

tion, if the outcrop could be traced through the intervening area. This correlation is of especial interest, because it assists in tying together the Kinderhook faunas at Burlington with those of northeastern Missouri, which are separated by the synclinal folding of the strata which carries the beds far beneath the surface in the area between.

The presence in the fauna of numerous specimens of *Spirifer marionensis*, of the typical form occurring so abundantly in the Louisiana Limestone, is another factor of great importance. This species is entirely absent from the Chonopectus fauna at Burlington, nor is it represented by any species at all closely allied to it. In the Burlington section no species of *Spirifer* likely to be confused with *S. marionensis* occurs except in the higher beds, Nos. 5 and 6, and this species, although it has usually been identified with *S. marionensis*, is believed to be a distinct form, which in Missouri occurs only in the Chouteau Limestone or its equivalents, and in beds lying above the Louisiana Limestone. Other species which are common to the Louisiana Limestone fauna and the one under consideration are *Chonetes geniculatus* and probably *Chonetes ornatus*, and of these one, *C. geniculatus*, and perhaps also the other, are recognized in the Chonopectus fauna at Burlington.

Although the relationships between this fauna from Kinderhook and the Louisiana Limestone fauna are far less striking than between the fauna at Kinderhook and the Chonopectus fauna at Burlington, yet it is believed that they are all but different facies of one fauna, the Louisiana Limestone expression being characteristically the limestone facies, while the Chonopectus fauna at Burlington represents the arenaceous facies. Another point bearing upon the correlation is the presence in the Louisiana Limestone of one of the commonest and most characteristic pelecypod species of the Chonopectus fauna, viz., *Grammysia plena* Hall.[1]

In the sections at both Kinderhook and Burlington there is a bed of fine-grained, more or less fragmental limestone, resembling in a marked degree the Louisiana Limestone of Missouri at Hannibal and Louisiana. On the Mississippi River the Louisiana Limestone

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[1] A specimen of this species has been seen by the writer in the collection of Professor R. R. Rowley, of Louisiana, Missouri.

attains a maximum thickness of 60 feet, but at Kinderhook the limestone layer above the yellow sandstone is but 6 feet in thickness, while at Burlington it has a maximum thickness of 18 feet. At Kinderhook this limestone is but sparsely fossiliferous, although one of the species recognized, *Productella pyxidata*, is one of the commonest members of the Louisiana Limestone fauna. At Burlington, Iowa, the fauna of the limestone (beds Nos. 3 and 4) above the yellow sandstone of bed No. 2 contains a modified facies of the Chonopectus fauna. *Chonopectus fischeri* is a common species, and associated with it is *Paraphorhynchus striatocostatum*, which sometimes occurs abundantly. This species was originally described from Kinderhook, and, judging from the lithologic characters of specimens from Pike County, Illinois, in the collection of Walker Museum, it occurs in the fine-grained limestone above the yellow sandstone. The same species, in its typical form, has been collected by Professor Rowley in the Louisiana Limestone.[1] Another species binding the fauna of the fine-grained limestone at Burlintgon to that of the Louisiana Limestone is *Syringothyris halli* Win., which is apparently but a small form of *S. hannibalensis* so characteristic of the Louisiana Limestone. Both of these species are distinct from, but closely allied to, the species of the same genus occurring in the yellow sandstone beds at both Burlington and Kinderhook, and known as *S. extenuatus* Hall.

The interrelationships of the various expressions of the Louisiana-Kinderhook-Burlington faunas under discussion are such as to make their correlation a matter of some certainty. It may be assumed that we have to deal here with one general contemporaneous formation, exhibiting at Louisiana and elsewhere on the Mississippi River a limestone facies throughout, while east and north, at Kinderhook and Burlington, the sediments were largely arenaceous, the conditions for the deposition of calcareous sediments not being introduced until near the close of the time epoch represented.

Another factor which adds to the strength of the correlation of

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[1] The writer has not seen a specimen from the Louisiana Limestone, but Professor Rowley states that he has collected a very perfect specimen, which is no longer in his collection. Hall and Clarke also illustrate a specimen of this species (*Paleontology of New York*, Vol. VIII, Part II, Plate 60, Figs. 33, 34.) from Pike County, Missouri, which doubtless came from the Louisiana Limestone.

the Louisiana Limestone with beds No. 2–4 at Burlington is afforded by the identity of the faunas of the superjacent beds in both regions. The fauna of beds Nos. 5 and 6 are modifications of one and the same organic assemblage, which exhibits characteristics totally different from those of the faunas below. This fauna of the upper beds of the Kinderhook section at Burlington is characterised by such genera of pelecypods as *Macrodon*, *Palaeoneilo*, *Promacrus*, and *Crenipecten*, and by the brachiopods *Chonetes logani*, *Lepaena rhomboidalis*, and *Spirifer* sp. allied to *S. marionensis*, but distinct from it. The whole expression of the fauna is entirely different from that of the beds below. In the vicinity of Louisiana this same fauna of the upper beds at Burlington is well exhibited in the yellow, vermicular, arenaceous beds near the summit of the Hannibal Shales, which overlie the Louisiana Limestone.

At Kinderhook the conditions are somewhat different, no evidence of the presence of the higher fauna having yet been found. At this locality the fine-grained limestone bed is apparently followed immediately by the typical Burlington Limestone, bearing the typical fauna of that horizon.

In tracing the further distribution of the fauna of the yellow sandstone of Kinderhook and Burlington, it is found to occur 60 miles northwest of Burlington, in Washington County, Iowa, at Maples' Mill on English River, near Wellman. At this locality a yellow sandstone similar to that at Burlington has been called the "English River Grit" by Bain.[1] The fauna of this bed is rather extensive, and contains the following species:

1. **Scalarituba missouriensis** Weller. Some portions of this Sandstone are perforated by meandering burrows with transverse concave ridges which are in every way similar to those in the Hannibal and Northview Sandstones of Missouri.
2. **Orthothetes** sp. The specimens of this genus from the English River Grit are larger and more numerous than those of the Chonopectus Sandstone at Burlington. They may perhaps be identified as *O. chemungensis* Hall; at least they are closely allied to that New York Devonian species.

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[1] *American Geologist*, Vol. XV, p. 322; *Iowa Geological Survey*, Vol. V, p. 134.

3. **Schizophoria** cf. **S. swallovi** Hall. This species is represented in the collection by a single specimen. It is specifically identical with the species in the Chonopectus Sandstone at Burlington, which has been referred to *S. swallovi.* The condition of preservation of neither the Burlington nor the English River specimens is sufficiently good to make such an identification absolutely certain, but they seem to agree more closely with that Burlington Limestone species than with any other.
4. **Chonopectus fischeri** (N. & P.). This species, which is so characteristic of the fauna at Burlington, is present in the English River Grits, but is much less common.
5. **Productus laevicostus** White. This *Productus* is one of the less common species of the fauna, but it differs in no essential respect from specimens occurring elsewhere.
6. **Productus curtirostris** Win.
7. **Productus** 2 or 3 undet. species.
8. **Productella concentrica** Hall. Several specimens of this species are present in the collection from English River, which are indistinguishable from examples occurring in the faunas of beds Nos. 5 and 6 at Burlington, but the species has not been observed at the latter locality in the Chonopectus Sandstone.
9. **Productella nummularis** (Win.). This is one of the common species in the English River fauna, while at Burlington it is rare. Individuals from the two localities agree closely in all essential respects.
10. **Paraphorhynchus transversum** Weller. This is a rare species in the English River fauna, but the specimens differ in no essential characters from those occurring at Burlington and Kinderhook.
11. **Rhynchonella**? sp. A single specimen too imperfectly preserved for recognition.
12. **Eumetria altirostris** White. In the English River fauna this species grows to a larger size and is much more abundant than in the Chonopectus Sandstone at Burlington.
13. **Athyris corpulenta** (Win.). This species is much more common in the English River fauna than at Burlington, but none of the specimens observed are perfectly enough preserved to admit of

the correct generic reference of the species. It undoubtedly is not an *Athyris*, but it may be allowed to remain in that genus until more definite knowledge of its characters can be gained.

14. **Spirifer** sp. undesc. This is a peculiar, elongate, narrow species, whose shell is plicated throughout. It has been named *S. maplensis*, and a description with illustrations will be published elsewhere.
15. **Spirifer biplicatus** Hall. This species is not uncommon in the fauna, the individuals not differing essentially from Burlington specimens. The species is remarkable because of its exceedingly elongate hinge-line, produced in long mucronate extensions.
16. **Syringothyris extenuatus** Hall. A single brachial valve, of rather large size, is the only representative of this species in the collection. It agrees perfectly with similar specimens from the Chonopectus Sandstone at Burlington.
17. **Aviculopecten** ? sp. undet. A single imperfect specimen of a very large Aviculopecten-like shell is preserved in the English River collection. When complete, its breadth must have been 100^{mm} or more, but its state of preservation is such as will not admit of definition.
18. **Pernopecten cooperensis** Shum. Several more or less imperfect specimens are present in the collection, which may be certainly identified with this species. The species has not been certainly recognized in the Chonopectus fauna at Burlington, but it occurs rarely at Kinderhook. It is especially characteristic of the Kinderhook faunas of central Missouri and of the higher Kinderhook faunas at Burlington.
19. **Leiopteria spinalata** (Win.). A single imperfect specimen of this species has been observed from English River. Its characters are not well shown, but it appears to be identical with the Burlington shells.
20. **Leiopteria** sp. undesc.
21. **Pteronites whitei** (Win.). A single small specimen from English River seems to belong to this species. Its extreme length is only 15^{mm}, but it agrees in all essential characters with the larger shells from Burlington and Kinderhook, and may be safely considered as an immature individual.

22. **Mytilarca occidentalis** W. & W. The specimens of this species in the English River fauna are similar to those of the Chonopectus fauna at Burlington.
23. **Goniophora jennae** (Win.). The English River specimens of this species are identical with the larger one illustrated from the Chonopectus fauna at Burlington. The smaller specimens from that locality should probably be separated from *G. jennae* as a distinct species, to which the Kinderhook, Illinois, shells should be referred.
24. **Macrodon cochlearis** Win. This is one of the common species of the fauna, and the specimens do not differ essentially from the Burlington examples.
25. **Grammysia plena** Hall. A single imperfect left valve of this species has been observed, but its identification with the Burlington specimens is entirely satisfactory.
26. **Sphenotus iowensis** (Win.). Specimens of this species from English River are similar to those from Burlington in all essential characters.
27. **Sphenotus** sp. undet.
28. **Murchisonia** sp. undet.
29. **Naticopsis depressa** Win. The "fine regular elongate nodes," mentioned in the original description of this species as marking the upper ends of the striæ of growth, could not be detected upon either of the two specimens marked as types in the University of Michigan collection, and no others from Burlington have been studied by the writer. Two specimens from English River, however, show this characteristic nicely, which leads to the supposition that all of the type specimens used by Winchell in the description of the species are not preserved in the collection at Ann Arbor.
30. **Straparollus** sp. undet. This is a rather common species in the fauna, but it is usually not well preserved. It resembles *S. angularis*, but does not have the angular revolving ridge of that species.
31. **Bellerophon bilabiatus** W. & W. This species, which is one of the commonest ones in the Chonopectus fauna at Burlington, is likewise a common species in the English River Grit.

32. **Bellerophon vinculatus** W. & W. This species is much more common at English River than at Burlington.

33. **Bellerophon** sp. undet. Two undetermined species of this genus are recognized in this fauna, one or both of which are probably undescribed.

34. **Euphemus** sp. undet. Two species of this genus occur in the English River fauna, both of which are probably undescribed. The genus has not been observed in the Chonopectus fauna at Burlington, and heretofore it has been described from the Kinderhook only in the faunas of central and southwestern Missouri.

35. **Porcellia obliquinoda** White. A single fragment of a shell of this species has been observed from English River, but, so far as it is preserved, it is essentially similar to specimens from the Chonopectus fauna at Burlington.

36. **Dentalium grandaevum** Win. This species, which is present in the Chonopectus fauna at Burlington, and also in the fauna of the upper yellow sandstone (bed No. 5) at the same locality, is represented by numerous fragments in the English River fauna.

37. **Orthoceras whitei** Win. A single imperfect fragment of this species has been observed, but it is sufficiently well preserved to make its identification certain.

38. **Orthoceras heterocinctum** Win. This species is somewhat more common than the last, but it is always preserved in a fragmentary condition.

39. **Phragmoceras expansum** Win.? A fragmentary specimen is identified with a query as this species, but too little of the specimen is preserved to make the identification certain.

40. Fish remains? Eastman[1] has called attention to some small, peculiar, bilobed bodies from Burlington, where they occur in the Chonopectus Sandstone, which are probably icthic in nature, but their systematic position cannot even be guessed. Similar specimens occur in the English River Grit, although they seem to be specifically distinct from the Burlington specimens. Occurring as they do in this fauna at distant localities, it becomes a matter

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[1] *Journal of Geology*, Vol. VIII, pp. 36, 40.

of convenience to be able to refer to them by name, and therefore I propose for them the generic name *Idiodus*. The Burlington species may be called *I. eastmani*, and the English River species *I. biloba*.

This fauna of the English River Grit is essentially that of the Chonopectus bed at Burlington, but with certain modifications. *Chonopectus fischeri*, although present in the fanua, is not one of the most abundant species; in fact, although most of the species at Maples' Mill can be identified with Burlington forms, many of those that are common at Burlington are rare on English River, and, *vice versa*, rare species at Burlington are in several instances more common on English River.

In Marshall and Tama Counties, Iowa, in the region of Le Grand, 120 miles northwest of Burlington, the entire Kinderhook section is not exposed. Several beds of limestone have been quarried extensively, and have afforded an abundance of fossils, the best-known of which are the famous Le Grand crinoids. The faunas of all these limestone beds are closely allied to that of the higher beds at both Burlington and Louisiana. Beneath these limestones, of which the lowest is a white oolite, there is a 20-foot bed of blue argillaceous sandstone[1] rarely exposed, which at Indiantown, about two miles east of Le Grand, is said to be very friable and of a yellowish tone due to weathering.[2] At this latter locality casts of fossils are said to occur, and although none of them have come under the observation of the writer, yet it seems quite possible that they may represent the Chonopectus fauna, and they should be carefully examined with that point in view.

The known distribution of the arenaceous facies of the Kinderhook fauna under discussion extends along a line having a general northwest-southeast direction, from Kinderhook, Illinois, to Burlington, Iowa, and thence to near Wellman, Iowa—a total distance of nearly 140 miles. If the fauna of the bluish or yellowish sandstone near Le Grand should prove to be the same, 60 miles more would be added to its northward distribution.

The outcrop of the limestone facies of the formation, with its

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[1] Beyer, *Iowa Geological Survey*, Vol. VII, p. 222.

[2] *Ibid.*, p. 223.

characteristic fauna, extends from near Hannibal, Missouri, nearly 60 miles to Hamburg, Illinois, where there are about four feet of strata referable to this formation, carrying the typical fauna as seen at Louisiana. The entire distribution, therefore, of both the arenaceous and calcareous facies of this Kinderhook fauna extends along a comparatively straight line for 200 or 250 miles.

The distribution of the beds carrying the fauna, which at Burlington and Louisiana is confined to the higher beds of the Kinderhook section, is quite different from the distribution of the beds just discussed. This fauna has its most characteristic expression in the Chouteau Limestone of central Missouri, especially in Pettis and Cooper Counties. At Pin Hook Bridge over Muddy Creek, 10 miles northeast of Sedalia in Pettis County, there are 60 feet or more of Chouteau Limestone, usually of a bluish-gray color, sometimes yellowish, and sometimes arenaceous or cherty. This limestone rests with apparent conformity upon limestones which are of Devonian age, as indicated by the fossils. Lying above the Chouteau Limestone is the Burlington Limestone, whose lower beds in this county contain a fauna identical with the lower beds of the same formation at Burlington, Iowa. At Sweney, 15 miles north of Sedalia on the Missouri, Kansas & Texas Railroad, a large quarry has been opened in the Chouteau Limestone, exposing about 60 feet, with probably the same Devonian limestone beneath it, and the Lower Burlington Limestone above it, as at the Pin Hook section. At neither of these sections have the details of the distribution of faunules been studied out, but the fauna as a whole bears the same expression as the fauna of the uppermost beds at Burlington and Louisiana, although at Burlington the beds bearing this fauna do not exceed 11 feet in thickness, more than half of which is a yellow sandstone,[1] and at Louisiana the fauna, so far as observed, is restricted to Keyes bed No. 8, 12 feet of brown sandy shale.[2] Furthermore, at no locality in central or southern Missouri has any trace of the Chonopectus fauna of the Burlington section been observed, nor of the fauna of the Louisiana Limestone.

In southwestern Missouri the same Chouteau fauna occurs that

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[1] Bed No. 7, the soft, buff, gritty limestone at Burlington, is not here included, as its fauna is much more closely related to that of the overlying Burlington Limestone.

[2] *Missouri Geological Survey*, Vol. IV, p. 47.

is present in central Missouri, but the beds containing it do not constitute one continuous limestone formation. Instead, three distinct formations are recognizable in Green County. The lowest of these is a limestone identical in lithologic characters with the lower beds of the Chouteau Limestone of Pettis County, and carries essentially the same fauna.[1] Its thickness may be estimated at about 10 feet, and it may be considered as the thinned edge of the Chouteau Limestone lens.[2] The second member occupying the Kinderhook interval in Green County has been called the Northview,[3] and corresponds with Shepard's Hannibal Shale, except that the limestone at the base is excluded as noted above. In its lithologic characters this formation is essentially identical with the Hannibal Shale and Sandstone lying above the Louisiana Limestone in northeastern Missouri, and the faunas of the two formations are related. However, the Northview and the Hannibal do not constitute one continuous formation, the entire interval in central Missouri being occupied by the Chouteau Limestone. The highest Kinderhook bed in Green County is the Pierson Limestone.[4]

In northern Arkansas all the Kinderhook beds, so far as they have been examined, are characterized by the faunas related to that of the Chouteau Limestone. In southeastern Missouri, Kinderhook beds are well exposed in the Mississippi River bluff near Sulphur Springs and Kimmswick, and elsewhere in Jefferson and St. Louis Counties. The most characteristic fauna in this region occurs in a red calcareous shale. The fauna is peculiar in some respects, but its affinities are with the Chouteau faunas of central and southwestern Missouri, and not at all with the Louisiana-Chonopectus fauna; this fauna is recognized as far north as southern Jersey County, Illinois.

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[1] In an earlier paper ("Correlation of the Kinderhook Formations of Southwestern Missouri," *Journal of Geology*, Vol. IX, pp. 130–48) this lowest bed of the Kinderhook section in Green County was taken to be identical with Shepard's Sac Limestone. This was an error, as further investigation has shown. The Sac Limestone lies beneath this Kinderhook limestone, the Phelps Sandstone with its *Ptyctodus* fauna being between. This lowest limestone of the Kinderhook interval was given but little mention by Shepard in his *Green County Report*, being included in his Hannibal Shales, On p. 87, he speaks of these lower harder beds being used for curbing, etc., and on p. 202 he mentions these beds as the Hannibal limestone.

[2] For the fauna of this bed see *Journal of Geology*, Vol. IX, pp. 136, 137.

[3] Weller, *Journal of Geology*, Vol. IX, p. 140.

[4] Weller, *loc. cit.*, p. 144.

At a distance from the Ozark region, the Chouteau fauna is recognized in the Goniatite Limestone of Rockford, Indiana, where the Cephalopod genus *Prodromites* occurs, the further distribution of this genus being in the Chouteau Limestone of Pettis County, Missouri, and in the higher beds at Burlington. In certain portions of the Waverly of Ohio, Kentucky, and Indiana characteristic elements of the same fauna may be recognized. In still another direction this fauna occurs in the limestones of the higher portion of the Kinderhook beds in Marshall County, Iowa, and in the Wassonville limestone of Washington County, Iowa.

From a detailed consideration, therefore, it is seen that the Kinderhook strata of the Mississippi Valley region contain two distinct faunal assemblages, each of which shows modifications into various facies. During earlier Kinderhook time these two faunas were restricted, one to the more northern, the other to the more southern region, and the two Kinderhook provinces were separated by some barrier, doubtless a land barrier. Near the close of the Kinderhook epoch, the barrier separating the two provinces was removed, and the fauna from the south migrated into the northern province. The northern fauna, however, probably continued to live in a more and more restricted area to the close of Kinderhook time, since at Kinderhook, Illinois, there is apparently no evidence of the presence of the southern fauna in any beds between those bearing the typical northern Kinderhook fauna and the base of the Burlington limestone. With the removal of the barrier, however, the northern fauna did not make any headway into the southern province.

THE DEVELOPMENT OF SCAPHITES

W. D. SMITH
Manila, Philippine Islands

CONTENTS

INTRODUCTION

The material used in this study is that of the Paleontological Collection of Leland Stanford Junior University, and includes material collected from two very different localities.

In 1900 Mr. Milnor Roberts collected, in the vicinity of Sand Springs, thirty miles north of Wibaux, Mont., a suite of fossils, the majority of which were *Scaphites*. The rock is a dark, very hard and compact limestone, and contains the following genera and species:

Scaphites nodosus
Scaphites nodosus var. brevis
Scaphites nodosus var. plenus
Scaphites nodosus var. quadrangularis
Scaphites mullananus

With these occurred:

Nautilus dekayi
Inoceramus barabini
Inoceramus sagensis
Antalis ———
Volsella meekii

Baculites ovatus
Pyrafsus (Neptunella) subturritus
Protocardia salinaensis (?)
Protocardia rara
Neæra ventricosa

All of these, and many more, are figured in the reports of the Hayden Survey of the Territories, and by Stanton,[1] and referred to the Fort Pierre horizon of the Upper Cretaceous.

Stanton records a similar fauna from the Cretaceous rocks of Nebraska, where the following species are contained in dark gray and bluish plastic clays:

Nautilus dekayi
Placenticeras placenta
Baculites ovatus
Scaphites nodosus
Inoceramus nebrascensis
Bones of *Mosasaurus missouriensis*
Dentalium graciale
Crassatella evansi
Cuculala nebrascensis
Inoceramus sagensis
Inoceramus vanuxemi

The beds also occur on Sage Creek, Cheyenne River, and on White River above the Mauvaises Terres in South Dakota. Mr. Stanton also states that these same beds are exposed in central Colorado and contain:

Nautilus dekayi
Baculites ovatus
Baculites compressus
Inoceramus cripsii
Inoceramus proximus
Placenticeras placenta
Avicula linguiformis
Sphenodiscus lenticulare
Scaphites nodosus
Ptychoceras mortoni
Heteroceras (several specimens)
Anisomyon
Lucina occidentalis
Avicula nebrascensis, etc.

Clearly, then, the suite from Montana belongs to the Fort Pierre horizon of the Upper Cretaceous, and is, as far as we know, confined to that horizon only. *Scaphites nodosus* certainly is characteristic of that horizon.

The other group of Scaphites is from the Pacific coast province and from the horizon known as the Lower Chico, Upper Cretaceous. The specimens I have used were collected and described by Mr. F. M. Anderson,[2] paleontologist for the California Academy of Sciences, from the '49 mine near Phœnix, Ore.

These occur in soft, yellowish sandstone, with the following characteristic fossils:

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[1] T. W. Stanton, *The Colorado Formation and its Invertebrate Fauna*, 1893, Bulletin No. 106, U. S. Geological Survey.

[2] F. M. Anderson, "Cretaceous Deposits of the Pacific Coast," *Proceedings of the California Academy of Sciences*, 3d series (1902), Vol. II, No. 1.

Desmoceras hoffmani
Desmoceras sugatum
Desmoceras ashlandicum
Baculites chicoënsis
Helicoceras breweri
Helicoceras declive
Ancyloceras lineatum
Lytoceras sacya
Lytoceras jackonense
Lytoceras jukesi
Placenticeras pacificum
Schœnbachia oregonensis
Arethusa californica
Nautilus sp. (?)
Scaphites inermis
Scaphites condoni
Scaphites gillesi
Scaphites perrini
Scaphites roguensis
Scaphites klamathensis

The first two in the list of *Scaphites*, *S. inermis* and *S. condoni*, have been selected for study principally for the reason that there was more material of these two species available for the work.

In connection with these the following have been studied:

Sonneratia stantoni
Desmoceras beudanti
Desmoceras hoffmani
Lytoceras alamedense }
Baculites chicoensis } chiefly from the papers by J. P. Smith.[1]
Pachydiscus

All drawings have been made with the camera lucida, either with or without the microscope.

The very young stages have in most cases been enlarged thirty diameters, and some of the larger adolescent stages only ten, while the adults are represented at natural size.

The writer wishes to express his appreciation of the valuable aid, in the matter of suggestions and in furnishing some excellent material to work on, rendered by Professor J. P. Smith. Acknowledgments are also due Professor Stuart Weller for valuable assistance and opportunity extended to the writer to examine material from the Upper Cretaceous of New Jersey.

DESCRIPTION OF SPECIES

The writer does not feel called upon to add to or repeat the description of these forms as found in Meek's or Anderson's works, more than to state just enough to aid the reader and save him the trouble of referring to these larger works.

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[1] J. P. Smith, "Development of Pytoceras and Phylloceras," *Proceedings of the California Academy of Sciences*, 3d series, Vol. I, No. 4; "Larval Coil of Baculites," *American Naturalist*, Vol. XXXV (1901), No. 409.

Scaphites nodosus Owen is by far the largest Scaphite of those mentioned in this paper. It is, like all of the *nodosus* group, coarse-ribbed in the neanic and ephebic stages, growing more smooth on the abnormal body chamber where the coil leaves the true spiral. It has strong nodes on the ventral shoulders, and sometimes also on the umbilical shoulders. The form is quite robust and is remarkable for its long, last body chamber which has left the whorl partly and turned back on itself somewhat as in the case of *Macroscaphites*, though not so pronounced.

Scaphites nodosus brevis is coarse-ribbed, but shows no nodes on the umbilical shoulders, and is a much smaller form, less gibbous, and just beginning to leave the coil. *S. nodosus plenus* is simply a very gibbous form, with about the same dimensions as *brevis*. Its suture in the adult is somewhat different, and the nodes are not so pronounced. *S. nodosus quadrangularis* can be distinguished from *brevis* only by its flattened dorsum and the very small nodes on the umbilical shoulders.

S. mullananus is slightly smaller than the others, and, as far as the writer can determine, does not leave the coil at all, and possesses no abnormal body chamber. Nodes are altogether lacking, the ribs coarse and passing from umbilicus to umbilicus.

The two Oregon species are very much smaller than those mentioned above, flatter, and almost devoid of ornamentation. At the very end of the last coil there is a slight departure from the coil and a constriction around the coil just back of the aperture. The largest of these would not be more than 15^{mm} in diameter. *Scaphites condoni* has a slight wrinkling or development of ribs on the side of the adult coil, but no nodes. *S. inermis*, on the other hand, possesses a row of very small nodes on the ventral shoulder or the last coil. They are both extremely thin forms.

S. nodosus Owen, which is not shown in the plate, measures about 3½ inches in diameter along its longest axis; *S. nodosus brevis* and the others, about 2 inches and less. They all have narrow umbilici. This is quite the opposite from what we find in the Oregon species.

DISTRIBUTION

The type of this comprehensive genus was first found in Dorsetshire, England, by Parkinson,[1] in the year 1811. *Scaphites*, however,

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[1] Parkinson, *Organic Remains*, Vol. III, p. 145, Pl. X, Fig. 10.

is well known from many parts of Europe and also India. Logan[1] thinks that all known *Scaphites* originated from one species in the Gault of Europe, the Gault being transitional from the Lower to the Upper Cretaceous, and have migrated from Europe to India and to America. At that time he thought *Scaphites* monophyletic, but the recent discovery by Mr. Anderson in the Upper Cretaceous of Oregon and California of some new scaphite forms with different ontogeny, and mingled with an entirely different fauna, makes it highly improbable that this is so.

According to Anderson,[2] there was probably a communication established between the Interior Sea of America and the Pacific province in Upper Cretaceous time, but none up to that time, unless we go back of the Jurassic. However, J. P. Smith[3] has shown that there was a connection between the Indian province and the west coast of America. An examination of the plates in the volume on the Cretaceous fauna of India reveals a striking similarity between the Indian *Scaphites* and those in the Pacific province.

On the other hand, the fauna of the western Interior Sea is known to be very similar to, if not identical with, faunas in just the other direction. The writer has seen some *Scaphites* from the Upper Cretaceous of New Jersey in Professor Stuart Weller's collection which appeared to be of the same type as those coming from Montana. Much the same fauna has been described from Texas and Alabama. This seems to make it quite conclusive that migration took place along the Cretaceous coast line from the eastern border around by the Mississippi embayment up into the interior. Having got as far as the Atlantic coast, we can explain the migration from western Europe in much the same way as the migration from the Indian province to western America.

As the writer will attempt to show, the ontogenetic study of the forms from the two regions, west coast and interior, simply corroborate these conclusions.

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[1] Field Col. Mus. Pub. 36, Geol. Ser., Vol. 1, No. 6.

[2] Anderson, *loc. cit.*, p. 67.

[3] J. P. Smith, "Periodic Migrations between the Asiatic and the American Coasts," *American Journal of Science*, Vol. XVII.

ONTOGENY AND PHYLOGENY

Scaphites nodosus var. **brevis**

Ontogeny.—This particular species or variety has been selected on account of its typical development, and because of the amount of material from which young stages could be worked out.

According to Logan,[1] *Scaphites nodosus* goes through the following stages in arriving at maturity:

1. Anarcestes.
2. Tornoceras.
3. Glyphioceras.
4. Gastrioceras.
5. Paralegoceras.
6. Pronorites.

In Fig. 3, the writer has placed, for purposes of comparison, some drawings of the sutures of typical species from the above-mentioned genera. Beyond a rather general similarity to *Glyphioceras*, the writer can see no reasons for correlations. It would be seen, too, from Branco's[2] excellent work on the young stages of ammonites, that many ammonites, and especially of the Jura and Cretaceous, have a Glyphioceran type of suture. It is thought by some that this does not mean kinship with Glyphioceras at all, but that it is a character acquired later, and pushed back by inheritance and acceleration until it is now found in the larva. In support of this, Professor J. P. Smith cites the development of *Pronorites* that possesses a Glyphioceran type of suture in its early stages of development, but which is clearly known not to have come through *Glyphioceras* at all.

In Logan's paper the suture is made the sole basis upon which relationships are based, and this lends itself to much criticism. As Professor Smith and the late Alpheus Hyatt have both respectively claimed, the suture cannot be taken as the sole criterion. Size of whorl, shape of whorl, ornamentation, etc., must be taken into account.

Numbers 9 to 11, Fig. 1, show the protoconch of this species. It is not, in essentials, very much unlike the protoconchs of many

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[1] Logan, *loc. cit.*, p. 210.

[2] Branco, *Entwickelungsgeschichte der fossilen Cephalapoden.*

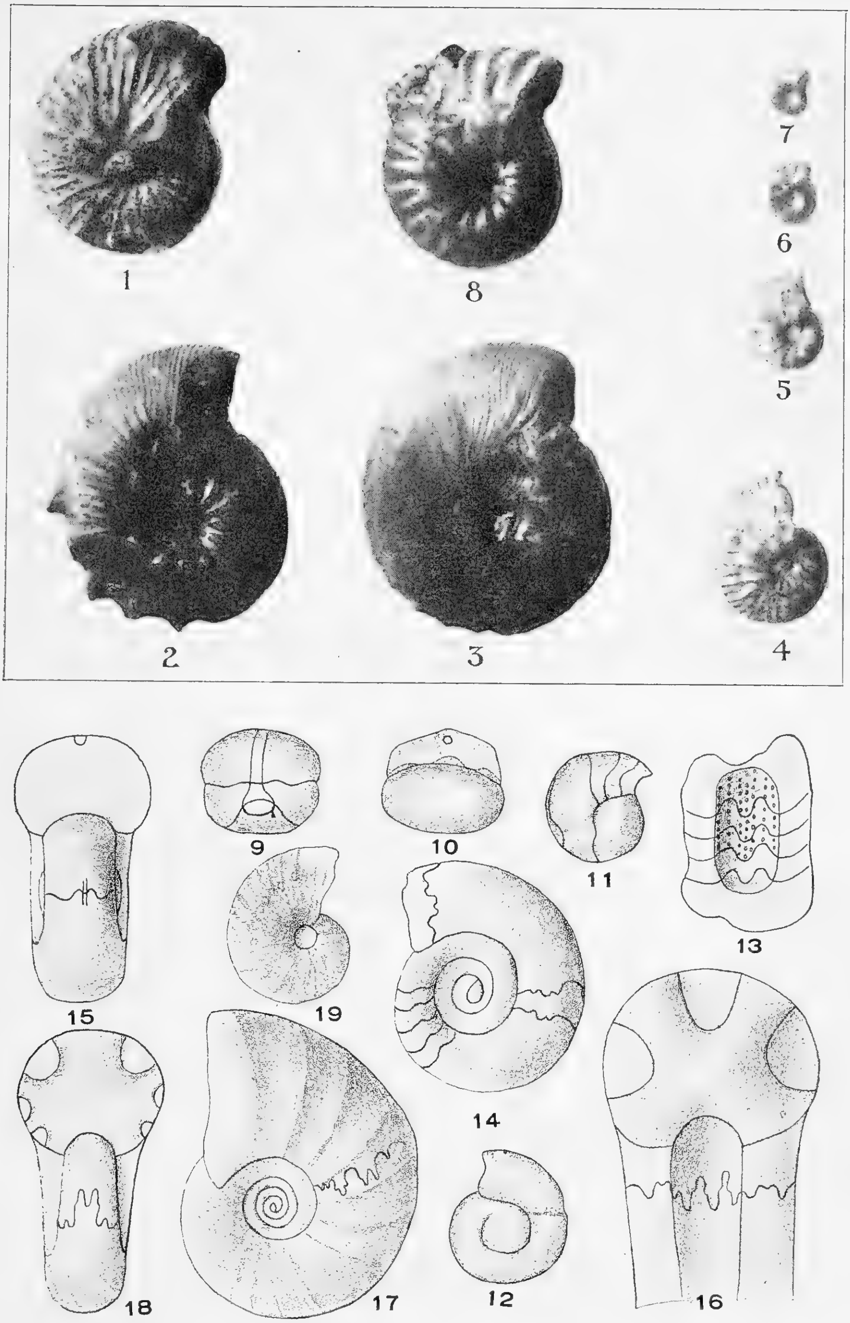

FIG. 1.—1, *Scaphites nodosus* var. *plenus;* natural size. 2, *S. nodosus* var. *brevis;* natural size. 3, *S. nodosus* var. *quadrangularis;* natural size. 4, *S. nodosus* var. *brevis* (Young); natural size. 5, *S. nodosus* var. *brevis* (Young); natural size. 6, *S. nodosus* var. *brevis* (Young); natural size. 7, *S. nodosus* var. *brevis* (Young); natural size. 8, *S. mullananuis.* 9–11, *S. nodosus* var. *brevis* (protoconch); ×30. 12, *S. nodosus* var. *brevis;* D = 1.14^{mm}. 13, *S. nodosus* var. *brevis;* inside of first whorl at D of 66^{mm}; ×30. 14, *S. nodosus* var. *brevis;* $2\frac{5}{6}$ whorls, D of shell = 2.26^{mm}; ×10. 15, *S. nodosus* var. *brevis;* $2\frac{3}{4}$ whorls, 1.76^{mm}; 20 D. 16, *S. nodosus* var. *brevis;* internal suture of the above. 17, *S. nodosus* var. *brevis;* 5^{mm}; ×9. 18, *S. nodosus* var. *brevis;* $3\frac{3}{4}$ whorls; ×4.

Mesozoic ammonites. It is about $\frac{1}{2}^{mm}$ wide and is calcareous, marked with regular rows of small pustules, as in *Lytoceras*, and shows very plainly the siphonal cæcum and siphonal collars pointing forward. What these pustules mean is a matter, more or less, of conjecture; however, it is quite possible that these may be traces of the ornamentation of some ancestor, either *Goniatites strictus*, which in the adult stage shows markings not greatly unlike these, or an ancestor of both. At any rate, they represent a character very remote which has been pushed back now into the embryonic stage. These pustules cease abruptly at a constriction in the shell which occurs at a diameter of 0.66^{mm}, or about one revolution. This is shown in Number 13, Fig. 1.

The protoconch is wider, invariably, than the first coil in all species of *Scaphites* studied during this work, and this is true also in the case of *Baculites* and *Lytoceras*, as will be seen from an examination of the plates in Professor Smith's papers.

The first septum is angustisellate. According to Hyatt, this is called the ananepionic stage, and shows that the animal has in its ontogeny a stage which in the history of the race is that of a nautiloid. (The sutures are shown in Fig. 3.)

With the second septum, which is marked by the development of a siphonal lobe, the animal becomes an Ammonoid. This stage is called the metanepionic or second larval period. Right here may be mentioned one thing that indicates the highly accelerated nature of some characters, and the unequal acceleration that may be found in these later Ammonites. In the *Orthoceratidæ* and *Nautilinidae* the siphuncle is central in the former, and just a little distance away from the center in the latter, migrating gradually in the later Nautiloids and Goniatites toward the margin of the coil, until in the ammonites it is marginal. But here, in the very early stages, which are nautilian and goniatitic, we find the siphuncle marginal, and also the collars prosiphonate (these characters could be made out on only the first four septa). In the early cephalopods the collars are retrosiphonate. So we have very great acceleration of some characters compared with others. This in itself makes it quite probable that the sutures are highly modified by acceleration of characters introduced late in the history of the race, and likewise lessens the prob-

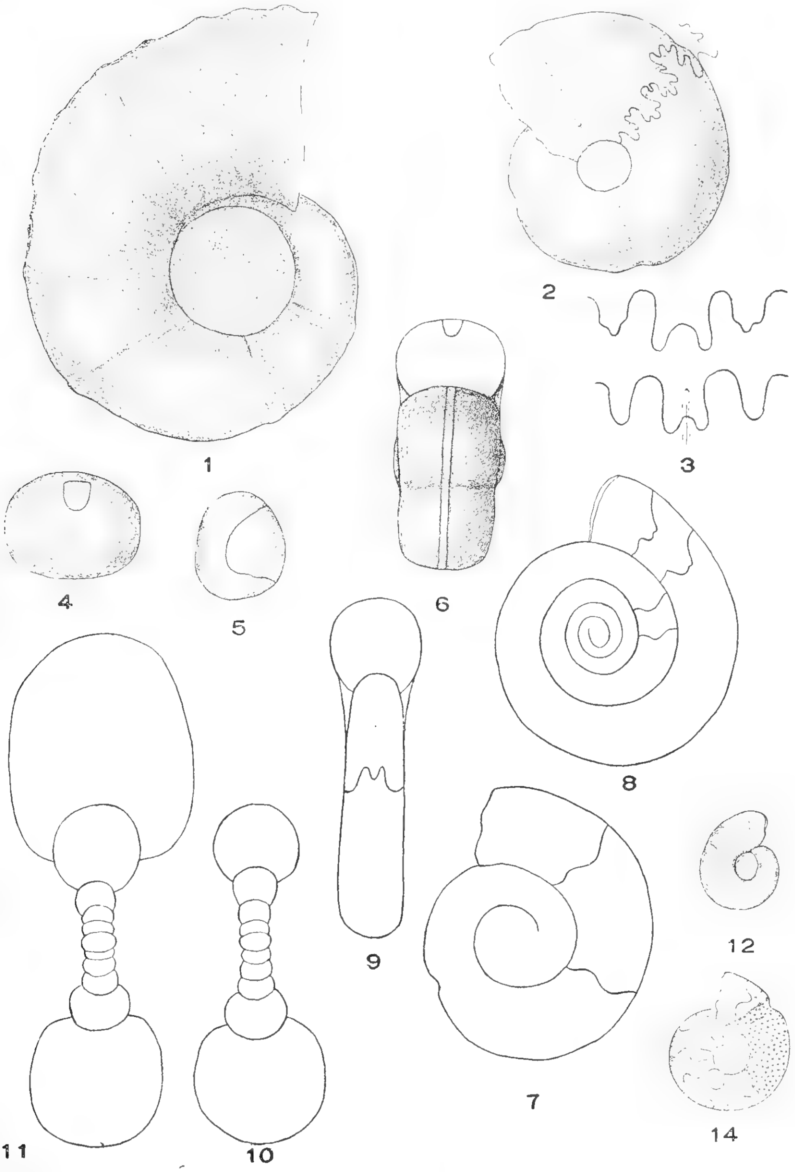

FIG. 2.—1, *Scaphites nodosus* var. *quadrangularis;* ×7. 2 and 3, *Desmoceras hoffmanii;* ×10; 4^{mm}; showing constrictions and development of sutures; 3 represents a much younger stage. 4, *S. condoni* and *inermis* protoconch showing cæcum. 5, Side view of protoconch; ×30. 6, Same at D. of 8^{mm}; ×30. 7, Same at 8^{mm}; ×30. 8, Same at 4^{mm}; ×8. 9, Same at end view; 4^{mm}; ×11. 10, Cross-section of *S. inermis* (half whorl missing). 11, Cross-section of *S. condoni;* ×7. 12, Adult of *S. condoni.* 14, Larval coil of *Baculites chicoënsis.*

ability of their being in close relationships with the ammonoids that Logan cites.

At 0.66^{mm} diameter a constriction was found on one individual (Number 12, Fig. 1), while again specimens were broken back to the protoconch and not a constriction seen. In others it was found recurring several times in the same individual. However, there is no constancy about this feature, as in *Baculites*, *Desmoceras*, and many others (Number 2, Fig. 2). In *Baculites* this is, according to J. P. Smith, a very constant feature, and comes always at the end of the larval coil, i. e., one revolution. In several specimens of *Scaphites condoni* and *S. inermis* this constriction has been noted by the writer at about three-quarters of a revolution from the protoconch.

In the Montana species this is taken by the wrier to be purelyt an individual character, and one likely to be found at almost any point in the development of a phylogerontic group. It means simply that there is a pause now and then in the growth of the animal, as should be expected in the members of a group that we know was then on the decline.

From this point on the shape of the aperture changes rapidly from a crescentic to a more roundish form, due to heightening of the walls, and when the adolescent period is reached, the aperture is almost circular (Number 16, Fig. 1). The adolescent period, in the species studied, has not been found to begin at any constant size. The notching of the first lateral lobe, when it becomes, to use a techincal term, bifid, is assumed to be the beginning of the adolescent period. In one specimen this stage began at a diameter of 1.87^{mm}, in another at 2^{mm}, in a third at 2.26^{mm}, while a fourth continues in a larval state up to 2.48^{mm}, or $2\frac{11}{12}$ revolutions.

Number 14, Fig. 1, shows a smooth shell of this form and the sutures. The umbilicus is quite wide still, and the shape of the aperture little changed. From this point on, however, the whorl increases rapidly in height and width, and the whole shell becomes thicker. In *S. nodosus* var. *plenus* this growth is very sudden and marked, as will be seen by referring to 7 and 8, Fig. 3.

Some measurements to show the relative growth at the different sizes will doubtless be more useful than a verbal description:

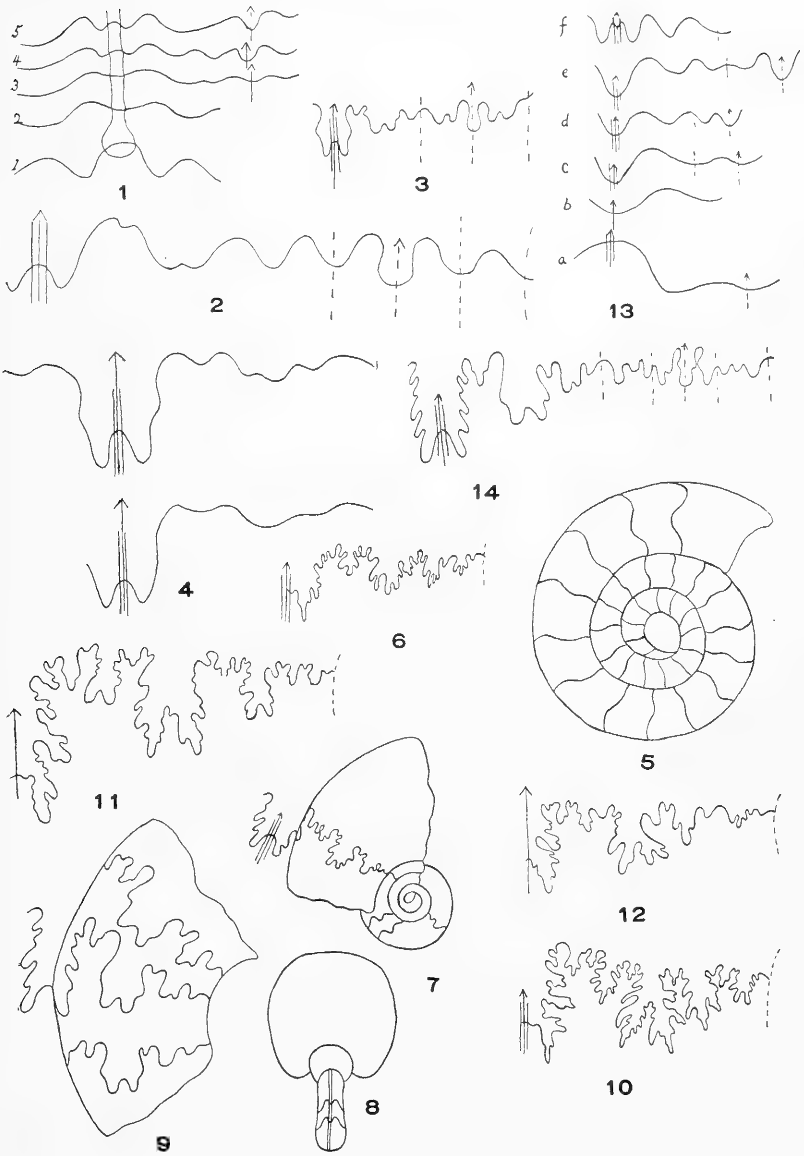

FIG. 3.—1, First five sutures of *S. nodosus* var. *brevis;* ×30. 2, Suture at 2.26^{mm}; ×30. 3, Suture at 4^{mm}; ×10. 4, Suture of *S. nodosus* var. *plenus* at 3^{mm}; 2⅞ whorls; ×30. 5, Side view of *S. nodosus brevis* showing sutures 1.76^{mm}; 2¾ whorls 20 D. 6, Adult suture of *S. nodosus brevis;* 28^{mm}; natural size. 7, *S. nodosus plenus* at 6^{mm}; ×7. 8, End view of same. 9, *S. nodosus brevis* at 5^{mm}; ×10. 10, *S. nodosus plenus* adult; natural size. 11, *S. mullananus* adult; ×3. 12, *S. condoni* and adult; ×5. 13, First six sutures of *Glyphioceras diadema* (Branco). 14—Internal suture of *S. nodosus* at same size as that shown in Number 9.

TABLE I[1]

S. nodosus var. *brevis*

	I Proto-conch mm	II ½ Whorl mm	III 1 Whorl mm	IV 1½ Whorls mm	V 2 mm	VI 2½ Whorls mm	VII mm	VIII Adult mm	IX mm
Diameter of shell...	0.40	0.56	0.78	1.04	1.50	2.18	5.00	20.0	5.00
Height of whorl...	0.40	0.26	0.30	0.46	0.60	0.90	2.40	12.0	2.20
Width of whorl....	0.46	0.48	0.50	0.60	0.76	1.12	2.50	13.0	....
Involution........	....	0.08	0.10	0.14	0.20	0.22	0.42	3.0	0.50
Width of umbilicus	....	....	....	....	0.86	1.22	....	6.0	2.00

From these figures we see that the protoconch is wider than the first coil, and consequently must bulge beyond it (see also Number 15, Fig. 1). The first few whorls, up to the third, are slender, and the umbilicus is correspondingly wider proportionally than in the case of the mature form. The involution in the larval and adolescent stages remains fairly constant, about 1 : 3, i. e., embraced part of the coil to the exposed portion; while in the adult it is 1 : 4 and 1 : 5, becoming less and less until in the old or senile stage the involution becomes negative, i. e., the outer coil begins to leave the inner coil. In both the Pacific province forms and those from the interior an impressed zone at the end of the last body chamber can be seen, which shows clearly that these animals were once coiled throughout, not these particular individuals, but the earlier members of the group.

At the beginning of the adolescent stage the following are the measurements:

	mm
Diameter of shell - - - - - -	2.26
Height of whorl - - - - - -	0.76
Width of whorl - - - - - -	0.84
Involution - - - - -	0.12

The shell at this stage is absolutely devoid of any marked sculpturing, save the presence of very fine lines of growth running around the coil, parallel to the outline of the aperture. The sutures continue developing gradually. The first change noticed is the development of marginals on the siphonal lobe. Then between the siphonal lobe and the first lateral lobe, and likewise between all the principal lobes, develop smaller secondary lobes. Fig. 3, Number 3, shows the suture at a diameter of 4^{mm}.

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[1] VII and IX different individuals.

At a diameter of 5^{mm} the shell is seen for the first time to be sculptured. A slight wrinkling of the surface is first noticed, and this soon becomes well defined costæ, and a little later nodes develop on the ventral shoulders. The costæ are seen to begin on the sides of the coil, running away from the nodes in one direction to the umbilicus, in the other across the venter. The sutures are in number of lobes, and in every way, save in minor, secondary digitations between the lobes, essentially adult. The internal lobes and saddles have changed very much from the types seen in the embryonic stage. These changes are shown in Fig. 3.

The way in which the ribs and nodes begin is interesting, and may be briefly outlined. First, there appears a slight wrinkling along the sides of the whorl; then there is to be seen a swelling along the ventral shoulder line. From these slight protuberances the costæ bifurcate in crossing the venter, but come together at the node on the opposite side. Between these, and later, a short rib develops on the venter, passing round on the sides afterward. In the adult stage more ribs are intercalated in the same manner. On the abnormal body chamber the ribs grow finer, and the nodes or tubercles cease abruptly (Numbers 2 and 3, Fig. 1). *S. nodosus quadrangularis* is the only one in all the forms studied to show nodes on the umbilical shoulders. They are never very prominent, however.

The abnormal body chamber or living-chamber, *anormaler Wohnkammer* of the Germans, marked not only by lack of sutures and diminuation of sculpturing, but in another characteristic, that of leaving the true spiral, is the last living-chamber. In the several species and varieties this is by no means constant. Here are some measurements, diameters at which this chamber begins:

	mm
S. nodosus var. *brevis* - - - -	29
S. nodosus var. - - - - -	30
S. nodosus var. - - - - - -	35
S. nodosus var. *quadrangularis* - -	37

S. nodosus Owen has a very long body chamber, and, having only one specimen, the writer could not break this off. It begins, though, at about the same diameter as the other varieties. *Scaphites nodosus* var. *plenus* differs in the adult from *brevis*, as will be readily seen in an examination of Numbers 1 and 2, Fig. 1, and Numbers 5 and 10, Fig. 3. The chief differences are the more gibbous form of *plenus*, and minor variations in the serrations and digitations of the suture. Up to the end of the larval stage, however, the two varieties are quite similar in every respect, but, as far as the writer has observed, *plenus* develops no nodes on the umbilicus. Number 8, Fig. 3, shows *plenus* at a diameter of $3\frac{1}{2}^{mm}$ where the great change in size of coil comes in. No specimens of the variety *plenus* were found showing a tendency to uncoil, and, furthermore, no crowding of the septa. It appears to be more normal and less degenerate than any of the forms studied. The young *Scaphites nodosus* Owen is very like, practically indistinguishable from, that of *brevis* and *plenus*. This variety has grown to its extraordinary size due, no doubt, to more favorable conditions. The variety known as *quadrangularis*, whose adult stage has been briefly described at the outset of this paper, differs in the larval stage not materially from the other varieties. In the adolescent and early ephebic stages there is, on the other hand, quite a difference in the ribs, every fifth or sixth one being much more pronounced.

Phylogeny.—In studying the shape of the whorl, number of lobes and saddle of the sutures, and the digitations in each, the umbilicus and sculptures, the writer has been led to the conclusion that the *Scaphites nodosus* group is to be considered as having come from some member of the *Stephanoceratidæ*, or "crown-shaped" ammonites. The writer has compared the young stages of the *Scaphites nodosus* with the young of *Desmoceras hoffmani* and *D. beudanti*, also with *Sonneratia stantoni*, both from the Lower Chico of California and found many general relationships. These similarities are found in (1) the shape of whorl; (2) deep, narrow umbilicus; (3) number and digitation of lobes and saddles in the sutures.

However, there is one marked difference, but one which may be easily accounted for in a way to be explained later, in the lobes of the sutures of *Scaphites* and the forms just mentioned. *Sonneratia* and *Desmoceras* have throughout their development triænidian lobes. The development of such lobes can be seen in Fig. 3, Numbers 2 and 3. This type of suture is the normal type according to Haug.[1]

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[1] Emile Haug, "Les Ammonites du Permian et du Trias," extract from the *Bulletin de la Société Géologique de France*, 3d series, Vol. XXII (1894), p. 385.

Sonneratia and *Desmoceras* both change very materially in the ephebic stages, becoming very much flattened through an unusual increase in the height of the whorl. It is found, too, that the same style of suture is characteristic of both *Scaphites* and of the *Stephanoceratidæ*. This can be seen by looking through Sarasin's[1] paper. It is to be noticed, too, that some species of *Desmoceras* have a greater number of lobes than other species, and more than are found in *Scaphites*. In one specimen of *Scaphites nodosus quadrangularis* the writer found one stage, diameter 8^{mm}, that resembled the adult of *Pachydiscus peramplus* Mantell, from the Lower Chalk of England. This is interpreted as being a reminiscence of characters belonging to some ancestor of both *Pachydiscus* and *Scaphites*. This was seen in no other specimen of any of the varieties. The sutures of neither form could be obtained for study, as the specimen of the *Scaphites* did not show it, and the original drawings of this species of *Pachydiscus* were not available.

Pachydiscus wittekindi Schlüter, from the Upper Chalk, also is not greatly unlike some of the early stages of *Scaphites*. Likewise there are reminiscences of *Macrocephalites*. These may be very superficial resemblances, but they are certainly suggestive.

Scaphites inermis and **S. condoni**

Ontogeny.—These two very small species from the Cretaceous of Oregon and California are both figured in Mr. F. M. Anderson's *Cretaceous Deposits of the Pacific Coast*, already cited above. Their young stages are so nearly alike, up to the very last whorl, that where a number of the two species are thrown into a vial together, it is almost impossible to separate the two. Numbers 10 and 11, Fig. 2, shows the remarkable similarity of the two.

It was extremely difficult to get drawings with the camera lucida of the sutures of most of these specimens, for they are for the most part only casts, and the sutures do not show. The protoconch is not so rounded in these smaller species as in the interior forms, but otherwise is very little different. The cæcal bulb was seen in one case only, and that was not perfectly shown (Number 4, Fig. 2). At

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[1] Ch. Sarasin, "Quelques considérations sur les Genres, Hoplites, Sonneratia, Desmoceras, et Puzosia," extract from the *Bulletin de la Société Géologique de la France*, 3d series, Vol. XXV (1897).

$.73^{\text{mm}}$, $\frac{1}{2}$ revolution, there is a constriction which is quite as marked, when seen, as in the young *Baculites* and *Lytoceras*. The presence of pustules could be detected only faintly, not nearly as well marked as in *Scaphites nodosus*. The first lateral saddle is notched at a diameter of 3.4^{mm}, or $3\frac{3}{4}$ revolutions. At this stage the lobe is bifid, and not trifid, just as in the *nodosus* group, with this difference, that the forms of the *nodosus* group are more accelerated in this respect. There is very little change in either of these species in the adolescent and early ephebic stages, not as much as there is between Meek's varieties of *nodosus*.

It does not appear to the writer, after a study of these forms, that Mr. Anderson found enough differences to warrant him in calling them distinct species. It seems that they differ only in late ephebic stages, and then in a little minor sculpturing. The two are flat, rather thin, with no sculpture until the last coil. It is probable, however, that if these forms had given rise to any progeny, the descendants would have shown that these slight differences had been pushed back and added to until there would be no mistaking even the young.

As these forms were all preserved as casts, the shell itself could not be studied. Whether there was anything distinctive about it or not, resembling any other group, of course remains to be settled.

For comparison the following table has been drawn up:

TABLE II

Scaphites inermis And.

	I Proto-conch mm	II $\frac{1}{2}$ Whorl mm	III 1 Whorl mm	IV $1\frac{1}{2}$ Whorls mm	V 2 Whorls mm	VI $2\frac{1}{2}$ Whorls mm	VII 3 Whorls mm	VIII $3\frac{1}{2}$ Whorls mm	IX 4 Whorls mm	X $4\frac{1}{2}$ Whorls mm	XI 5 Whorls mm
Diameter of shell	0.16	0.20	0.28	0.52	0.76	1.24	1.76	2.52	3.52	5.72	8.92
Height of whorl	0.16	0.04	0.08	0.24	0.24	0.48	0.52	0.76	1.00	2.20	3.20
Width of whorl	0.49	0.48	0.48	0.49	0.52	0.56	0.72	1.08	1.60	2.40	3.24
Involution	Too small to measure					0.6	0.14	0.28	0.48	0.20	....
Width of umbilicus	....	...	0.36	....	0.64	....	1.24	....	2.50	. ..	4.50

Ppylogeny.—From a study of the young stages of *Baculites* and *Lytoceras*, both from the material itself and J. P. Smith's[1] papers,

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[1] J. P. Smith, "Larval Coil of Baculites," *American Naturalist*, Vol. XXXV, No. 409; "Development of Lytoceras and Phylloceras," *Proceedings of the California Academy of Science*, 3d series, Vol. I, No. 4.

the writer has come to the conclusion that *Baculites* and *Lytoceras*, and these two species of *Scaphites*, had a common ancestor, or *Baculites* and *Scaphites* may have sprung from the *Lytoceratidæ*. Indeed, some are of the opinion that *Baculites* came from the *Lytoceratidæ*, and is a very degenerate descendant from this more normal and progressive family. The likeness of the young stages of *S. condoni* and *inermis* to the young of *Baculites* and *Lytoceras* is more in the general aspect of the shell rather than in any specific characters.

The interior forms of *Scaphites* soon change to forms with narrow, deep umbilici, and come to possess prominent ribs, while the two Pacific province forms do not develop in this manner at all, but remain thin and possessing wide umbilici. (See Numbers 8 and 9, Fig. 2.)

ACCELERATION AND RETARDATION

Logan, in the above-cited article, said that the *Scaphites* from the Interior Sea, *Scaphites nodosus* group, were progressive ammonites. The writer is forced to take issue with Logan on this point. He concludes that they are not progressive, but degenerate forms, and, moreover, forms exhibiting unequal acceleration of certain characters, and hence retarded in the sense that Cope[1] meant. J. P. Smith[2] gives a summary of the work of Hyatt, Cope, and others on the underlying philosophical principles of paleontogeny, and the two laws, the former of which was formulated by Hyatt, and the second by Cope, are explained, so that they will not be stated again in this paper.

In the first place, both of these groups of *Scaphites* are degenerate, and they are considered so on these grounds: (1) in the possession of an abnormal body chamber, they show degeneration or senility; (2) in the dicranidian lobes; (3) in the reduced number of lobes and saddles; (4) in the fact that they have, so far as we know, left no trace of a descendant.

Pompeckj[3] concludes that the possession of the abnormal body chamber marks that particular ammonite as senile, and when the

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[1] E. D. Cope, *Origin of the Fittest.*

[2] J. P. Smith, "Comparative Study of Paleontogeny and Phylogeny," *Journal of Geology*, Vol. V (1897), No. 5, p. 508.

[3] J. F. Pompeckj, "Die Ammonoideen mit anormaler Wohnkammer," *Jahreshefte des Vereins für Vaterlandische Naturkunde*, in Würtenberg, 50. Jahrgang (1894), pp. 220–90.

whole species possess it, then the term "phylogerontic" is used to describe the stage. Pompeckj does not agree with Hyatt in saying that this abnormal chamber may appear several times during the growth of the individual, and afterward be absorbed. On the other hand, he asserts that this chamber is always the last chamber.

In one individual only did the writer see anything that looked like a resorption phenomenon, but he is of the opinion that the peculiar swelling around the coil was due to some distortion of the shell. Cases where the individual paused in its growth, forming constrictions and building sutures close together, are quite common in *Scaphites*, but further than these nothing pointing to an abnormal chamber in the young stages similar to that found in the adult or senile stages was found.

All the normal, close-coiled, progressive ammonites, as far as the writer knows, have lobes triænidian. This also is the opinion of Haug, as stated above. On the other hand, *Baculites*, one species of *Lytoceras*, *L. alamedense*, and all the species of *Scaphites* studied show dicranidian lobes. In the matter of number of lobes it will be found, on examination, that many species of *Desmoceras* and many ammonites of the Trias and Jura possess more lobes than are found in the *Scaphites*. This is taken to be another sign of degeneracy.

It seems to the writer that the reduced number of lobes and saddles, and the lessening of the degree of digitation, in many of the varieties of the *Scaphites* may be satisfactorily explained by retardation, i. e., failure to reach the highly developed condition of their ancestors. In the fact, too, that we find simplified sutures and the normal whorls together, and the presence of nodes in the young stages along with other characters that are not signs of senility, we have evidence of retardation. The reminiscenses of *Pachydiscus* and *Macrocephalites*, also, in the young of *S. nodosus quadrangularis* point to unequal acceleration or retardation. From Beecher's[1] work on spines we know that these belong to the gerontic condition, and to find them appearing in the young stages at all shows the working of the law of retardation.

In Number 9, Fig. 3, is illustrated a very interesting point in this

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[1] C. A. Beecher, "Origin and Significance of Spines," *American Journal of Science*, Vol. VI (1898).

connection. If retardation be assumed to take place, it is clear that it will be noted first in the case of the lobes and saddles nearest the ventral lobe, for these are the oldest. In this figure the first auxiliary lobe is seen to develop normally into a triænidian lobe, while the first lateral develops in a dicranidian lobe. In time it is quite possible that through unequal acceleration all the lobes will become dicranidian.

VARIATION

In all the varieties and species of *Scaphites* studied the variation is seen to be very pronounced. In the variety *brevis* we find nodes away down in the young stages long before they appear in similar stages of *plenus* and *quadrangularis*. In the Oregon and California species we do not find them until the very last. In the ribs, too, there is seen to be a great diversity. We evidently have to deal with modifications, some of which have been acquired and pushed back in the ontogeny to earlier stages, and others that have been lately assumed. If we could find the progeny of some of these varieties, we might be able to see differences enough to warrant calling them species; for varieties, if given time enough, will undoubtedly produce species.

CONCLUSION

We are of the opinion, then, from this study, that the genus *Scaphites* is in need of revision; that a number of "morphological equivalents," to use Hyatt's expression, have been grouped together as species of one genus; that this genus is polyphyletic, and not monophyletic, as it has been treated heretofore; that both groups of *Scaphites* are degenerate, phylogerontic forms; that the *nodosus* group, from Montana, sprang from some member of the *Sephanoceratidæ*, while the Oregon species probably originated from the *Lytoceratidæ*, or the ancestor of this group.

In the *nodosus* group we have a number of varieties that are on the road to becoming species. In the two so-called species from Oregon and California it is our opinion that we have varieties merely.

Scaphites perrini, found with *S. inermis* and *cononi* by Mr. Anderson, may have come, not from the *Lytoceratidæ*, but from *Stephanoceratidæ*. This is based on the aspect of the whorl, the young stages not being available for study.

These forms, then, sprang from the normal, close-coiled ancestors, but are themselves degenerate, partially uncoiling forms. They may be on the road to a state of complete abnormality, as *Baculites*, *Hamites*, etc., but at present have not gone very far in that direction.

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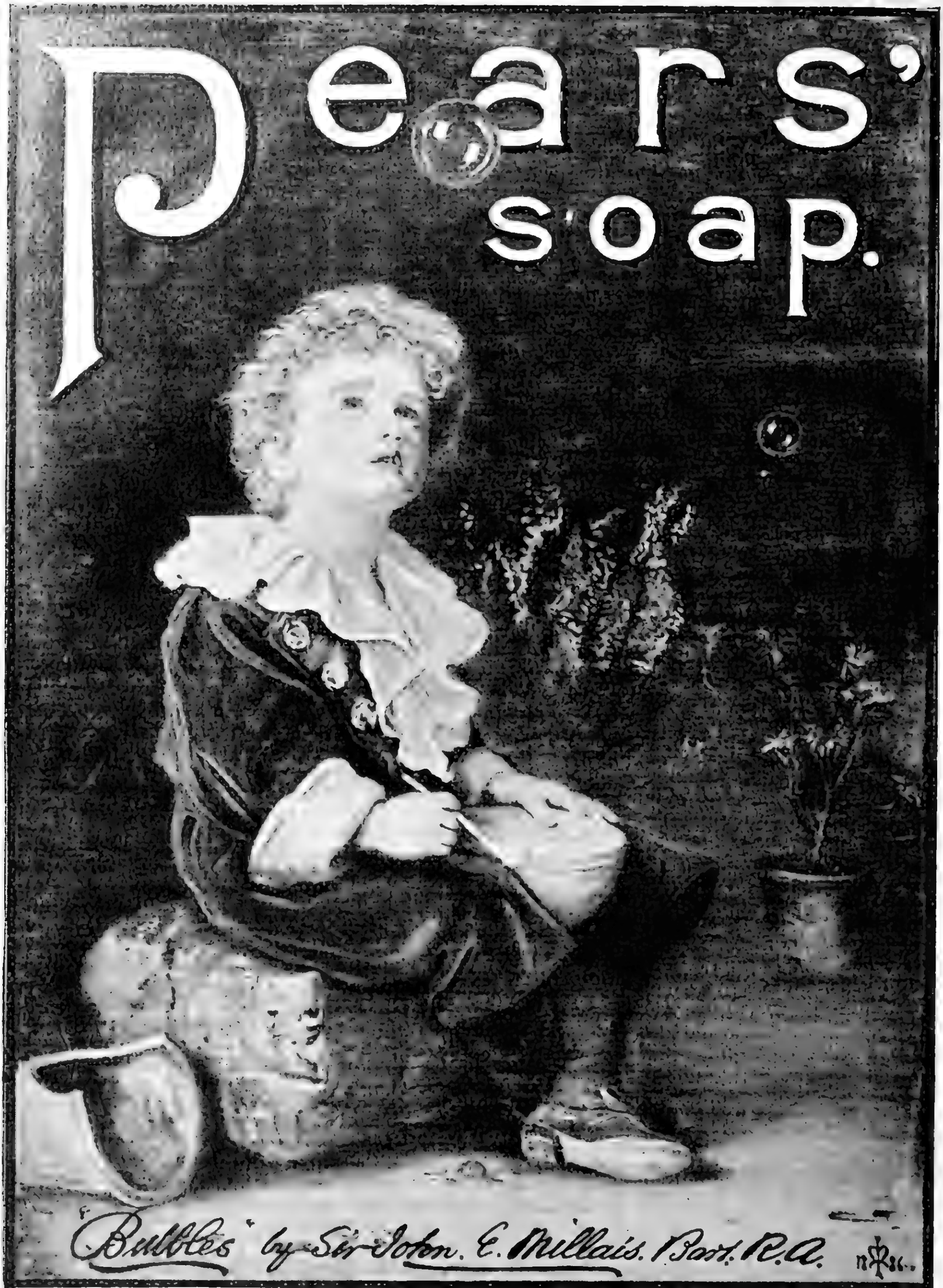
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THE MORRISON FORMATION AND ITS RELATIONS WITH THE COMANCHE SERIES AND THE DAKOTA FORMATION[1]

T. W. STANTON

The beds now generally designated on U. S. Geological Survey maps as the Morrison formation have been a subject of interest and discussion since 1877, when abundant remains of dinosaurs were found in them. The first extensive collections of the vertebrate fauna were obtained in the neighborhood of Morrison near Denver, in Garden Park, near Canyon City, Colorado, and at Como, or Aurora, Wyoming. Since then the formation has been recognized by means of its fossils, its lithologic features, and its stratigraphic relations in the Black Hills, on the Laramie Plains, and elsewhere in Wyoming, in Montana, in western Colorado, in southeastern Colorado, and in adjacent parts of Oklahoma and New Mexico.

Of the various names that have been applied to the formation Atlantosaurus beds is, perhaps, most frequently seen in the literature, but Como stage, Beulah shales, Morrison formation, and Gunnison formation have been locally applied. In recent publications Darton has used the term "Morrison formation" in all the areas mentioned.

The formation is non-marine throughout, so far as known, and consists of variegated marls and shales with irregular beds of sandstone and sometimes thinner layers and lenses of siliceous limestone.

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

The colors of the shales and marls are greenish-gray, purplish, maroon and red, very irregularly distributed, while the sandstones are usually gray, sometimes weathering brown or with small brown spots. The limestones are gray, in some cases weathering with a reddish tinge. The general appearance of the formation is remarkably uniform over large areas, and yet the individual elements are so variable that no two detailed sections are exact duplicates of each other. The total thickness is seldom more than 200 feet, though it is possibly more than 400 feet at Canyon City.

Stratigraphically the Morrison is always rather closely associated with the Dakota formation. When the huge Morrison dinosaur bones were first discovered it was announced that they came from the Dakota, and after it was learned that they really came from a lower horizon it was generally believed for many years that there was no unconformity nor visible stratigraphic break between the two formations. Through the work of Ward, Jenney, and Darton in the area north of Colorado the Lakota and Fuson formations have been recognized between the true Dakota and the Morrison and referred to the Lower Cretaceous. I shall presently show that in southern Colorado, New Mexico, and Oklahoma the so-called Dakota should also be divided because it includes a marine Lower Cretaceous horizon. It is nevertheless true that the base of the Dakota is usually not more than 100 to 200 feet above the top of the Morrison, and it is often less than that. Darton has recognized a general unconformity at the top of the Morrison in Colorado and eastern Wyoming, but he believes that the interval represented by it is unimportant. The base of the restricted Dakota also rests on an uneven surface wherever the actual contact has been seen.

While the Morrison formation is thus almost invariably accompanied by the Dakota, the converse is not true; for the Dakota has a much wider distribution to the east and southeast, and, in the typical Dakota area extending southwesterly from the Missouri River in eastern Nebraska to the Arkansas in Kansas, the Morrison formation does not occur. The Dakota is fairly well recognized in northern Texas near Denison, where it rests on the Comanche series, here developed to a thickness of several hundred feet. This area was doubtless originally continuous with the Cretaceous in southern Kansas (Kiowa, Comanche, Barber, and Clark Counties), where the Dakota sandstone is separated from the Red Beds by 100 to 150 feet of Comanche shales and sandstones, representing not the whole series but probably only its upper, or Washita, group. The attenuated margin of late Comanche deposits has been recognized by means of marine invertebrates as far north as Salina, Kansas, where it rests directly on the Permian and beneath the Dakota. Its occurrence at several points in Oklahoma, and eastern New Mexico, especially at Mesa Tucumcari, has long been known, but until recently there was no evidence that Comanche sediments with their marine fauna approached the dinosaur-bearing Morrison formation more closely than several hundred miles.

In 1901 Lee announced the discovery of the Morrison formation[1] in southeastern Colorado on the Purgatoire River, and its probable occurrence as far south as the Cimarron in New Mexico. It had previously not been known east of the Rocky Mountain foothills. The following year Lee continued[2] his explorations south and east and found the Morrison on Canadian River[3] in New Mexico, as well as on the Cimarron. He also suggested its correlation with the Comanche series in the following words:

> In Mr. Hill's folio of the *Texas region* he gives a section showing the geology of the Texas region. This region embraces the exposures which I studied along the Canadian, and extends to within a few miles of the Rio Cimarron. According to Mr. Hill's section the Lower Cretaceous, consisting of the Trinity, Fredericksburg, and Washita, lies between the Red Beds and the Dakota. If Mr. Hill's section represents correctly the age of the formations in the Canadian valley, then the shales and possibly the Exeter sandstone, must be of Lower Cretaceous age. But the shales, as I have already shown, are probably the same as the dinosaur-bearing shales of the Purgatory. There is some probability, therefore, that the Morrison formation may be identical with some part of the Lower Cretaceous of the Texan region.

This suggestion and the argument supporting it would have force if Hill's generalized Texas section were applicable to the Canadian valley, and if sedimentation had been continuous from the Red Beds to the Dakota inclusive. Several years earlier Hill suggested the possible equivalence of the Atlantosaurus beds with the basal or Trinity group of the Comanche series.

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[1] *Journal of Geology*, Vol. IX, pp. 343–52.

[2] *Journal of Geology*, Vol. X, pp. 36–58.

[3] Pp. 56, 57.

The next step in the attempted correlation of the Morrison formation with the Comanche series was the announcement by Lee, at the Washington meeting of the Geological Society of America in 1902, that he had discovered *Gryphaea corrugata* Say, a characteristic Comanche fossil, in the Morrison shales on the Cimarron near Garrett, Oklahoma. Only brief abstracts of his paper, entitled "Age of the Atlantosaurus Beds," have been published.[1] His conclusion was that the non-marine Morrison formation is traceable laterally into marine shales of the Comanche series containing fossils that indicate a horizon within the Washita group, and that therefore the Morrison is of that age. Darton stated that he had observed similar relations on Butte Creek, southeastern Colorado, and he accepted Lee's interpretation. As Darton's current field-work covers the entire area from the Missouri River to the Wasatch Mountains, the immediate effect of the new correlation on the mapping and classification was far-reaching. In two published folios[2] of the *Geologic Atlas of the United States*, and in *Professional Paper No. 32*, "Geology and Underground Water Resources of the Central Great Plains,"[3] the Morrison formation is classified as Cretaceous and the chief reason assigned in every case is essentially that it "appears to be equivalent to a portion of the Comanche series in northwestern Oklahoma and southeastern Colorado."

Last June, through the courtesy of Mr. Darton, I was enabled to join Mr. Lee in the field and visit with him the exposures on the Purgatoire, the Cimarron, and the Canadian that he had previously studied. We were accompanied by Mr. C. W. Gilmore, of the U. S. National Museum, who is familiar with the dinosaurs of the Morrison. We also visited Mr. Darton's locality on Butte Creek, and later extended our observations as far south as Tucumcari, New Mexico.

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[1] *Science*, New Series, Vol. XVII (1903), pp. 292, 293; Geological Society of America, *Bulletin*, Vol. XIV (1904), pp. 531, 532. *Science* gives a very brief account of the discussion that followed the reading of the paper but the reporter completely missed the point of Stanton's argument in opposition.

[2] "New Castle (Wyoming-South Dakota)," and "Edgemont (South Dakota-Nebraska)."

[3] See pp. 34, 96, 102, 141, and 164.

The general features of the whole region traversed have been well described by Lee[1] and the description need not be repeated except to say that it is a portion of the Great Plains region through which the principal streams have cut canyons several hundred feet deep, thus exposing good sections of the nearly horizontal strata. The Dakota sandstone always forms prominent cliffs near the top of the canyon walls and in some part of the course of each large stream the cutting extends as low as the Red Beds. The conditions are thus especially favorable for studying the strata immediately below the Dakota, as the Dakota itself, and many of the other hard beds are often continuously exposed for many miles, and furnish convenient, easily-recognized reference planes.

Purgatoire River.—Our first examinations were made on Purgatoire River at Higbee Plaza, about twenty miles south of La Junta, Colorado, where some marine invertebrate fossils, seen in the talus by Mr. Lee, gave us an important clue to the solution of our chief stratigraphic problem. At the top of the canyon wall is a cliff-forming gray and brown, mostly massive, cross-bedded sandstone, here fifty feet thick, but the upper part has been removed by modern erosion. Back from the river, where it passes under the Benton shales, its total thickness is not far from one hundred feet. This is unquestionably Dakota, as is attested by its stratigraphic position, its lithologic character and its flora, of which a few specimens, collected here and at other localities in the region, have been identified by Dr. Knowlton. Separated from this upper sandstone by about fifty feet of dark shales and thin-bedded sandstones, usually in large part covered by talus, is another lithologically similar coarse gray sandstone, varying in thickness from fifteen feet, or less, to sixty feet. This has also been referred to the Dakota by Lee, and probably by every geologist who has worked in southern Colorado, the intermediate more shaly portion being correlated with the "fire-clay band" of the earlier reports.

It was soon found that this intermediate shaly portion of the "Dakota" was the source of the fossils found in the talus below, and the fossils themselves were recognized as belonging to the

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[1] *Journal of Geology*, Vol. IX, pp. 343–52; Vol. X, pp. 36–58; *Journal of Geography*, Vol. I, pp. 357–70; Vol. II, pp. 63–82.

Comanche fauna, although some of them belong to unnamed species and others are not well enough preserved to justify positive specific determination. Among those collected at this locality are:

Inoceramus comancheanus Cragin
Trigonia emoryi Conrad?
Cardium kansasense Meek
Cyprimeria sp.
Pholadomya sancti-sabae Roemer?

Farther up the Purgatoire, in the neighborhood of Chaquaqua Creek, where the underlying formations are better exposed, this fossiliferous horizon was easily recognized and fossils were collected from it in Browns Canyon, on the ridge east of Chaquaqua Creek, and in Iron Canyon. These localities added to the list of species *Protocardia texana* Conrad, *Leptosolen conradi* Meek and an unnamed species of *Tapes* (?) which also occurs in the Kiowa shales of Kansas. No specimens of *Gryphaea corrugata* were found on the Purgatoire, but the forms listed are elsewhere associates of that species and there is no doubt that the horizon is the equivalent of some part of the Washita group, and should be directly correlated with the Kiowa shales of southern Kansas. It must certainly be removed from the Dakota. The underlying sandstone, which has been called Lower Dakota, probably goes with the shales in the Comanche series, though the evidence on this point is not conclusive. Its variation in thickness and its absence from some sections would suggest a possible erosion interval after its deposition.

The variegated shales and the sandstones and limestones, of the Morrison with an average thickness of about 200 feet are partly exposed in the neighborhood of Higbee, but they may be better seen farther up the river especially near Chaquaqua Creek, about fifteen miles southwest of Higbee.

Here Mr. Lee had previously announced the occurrence of large dinosaurs, and Mr. Gilmore was able to recognize Brontosaurus and other dinosaur genera of the Morrison fauna. At the locality where the bones were seen in the greatest abundance, near the southeast corner of the Timpas quadrangle, the dinosaur horizon is about 200 feet below the marine Comanche fossils.

Beneath the Morrison formation, or possibly forming a member of it, there are gypsiferous shales and gypsum varying greatly in thickness in different exposures, the maximum observed being 125 feet.

Immediately underlying the gypsum and forming the lowest exposures of the region are the Red Beds of which 200 or 300 feet are exposed over a considerable area, where the overlying formations have been removed from a broad, domelike uplift. They consist mainly of coarse, dark-red sandstones with some red and purplish shales and a few thin bands of white calcareous sandstone, which are conspicuous where they form the surface of low mesas. In the upper layers of the Red Beds, below the mouth of Chaquaqua Creek, Mr. Darton has collected a bone that has been identified as Belodon, indicating Triassic age.

The Purgatoire section may be summarized as follows:

1.	Benton shales, thickness probably not more than	200	feet
2.	Dakota sandstone	100	“
3.	Dark shales and shaly sandstones with Comanche fauna	50 to 100	“
4.	Coarse gray, cross-bedded sandstone	15 to 60	“
5.	Variegated shales, marls, sandstones and limestones of the Morrison formation, with Brontosaurus, etc.	200	“
6.	Gypsum and gypsiferous shales	70 to 125	“
7.	Red Beds with Belodon near top, exposed	200 to 300	“

With some variations in thickness and, in a few cases, the disappearance of one or more members, this section is essentially repeated throughout the area we examined in Oklahoma and New Mexico as far south as Tucumcari.

Two Buttes uplift.—On the way south from Lamar, Colorado, to the Cimarron in Oklahoma, the exposures were examined near Two Buttes, where Mr. Darton[1] had found the Comanche *Gryphaea corrugata.* Here the so-called Lower Dakota, beneath the fossiliferous Comanche shales and sandstones, appears to rest directly on the eroded surface of the Red Beds. Several additional Comanche species were collected, including *Pachydiscus brazoensis* (Shumard), and incidentally it was determined that the oyster bed reported by Darton as occurring in the Dakota of this region is probably beneath the true Dakota and in the Comanche.

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[1] *Science*, New Series Vol. XXII, July 28, 1905, p. 120.

Rio Cimarron.—East of Garrett P. O. on the Cimarron in western Oklahoma, the Red Beds are exposed with a slight westerly dip which carries them below the surface near Garrett, and in that neighborhood the section extends up to the top of the Dakota.

The section generalized from observations covering a few square miles is as follows:

1. Massive, coarse, cross-bedded gray and brown sandstone of the Dakota	150 feet
2. Dark shales with layers of brown flaggy sandstone and bands of somewhat calcareous yellow sandstone with Comanche fauna	50 to 60 "
3. Coarse, brown or gray cross-bedded sandstone with irregular bands of pebbles, apparently unconformable on the underlying stratum	4 to 15 "
4. Variegated shales, gray sandstones and bands of siliceous limestone, referred to the Morrison, not well exposed. Thickness probably less than	100 "
5. Red Beds.	

The Comanche horizon has yielded a varied fauna which is clearly the same as the Washita fauna that has long been known at Mesa Tucumcari, New Mexico, in northern Texas, and in the Kiowa shales of southern Kansas. The following species have been identified:

Gryphaea corrugata Say
Ostrea subovata Shumard
Ostrea quadriplicata Shumard
Plicatula incongrua Conrad
Inoceramus comancheanus Cragin
Gervilliopsis invaginata White
Trigonia emoryi Conrad
Protocardia multilineata Shumard
Pholadomya sancti-sabae Roemer?
Anchura kiowana Cragin?
Turritella seriatim-granulata Roemer
Hamites fremonti Marcou?
Pachydiscus brazoensis (Shumard).

This horizon was traced with practical continuity westward up the Cimarron to Folsom, New Mexico, a distance of about seventy-five miles across the strike. Its lithologic features show little variation and its thickness is never less than fifty feet nor more than one hundred feet. Fossils gradually become less abundant in both species and individuals toward the west, until near Folsom only a small mactroid shell was found in considerable numbers. The most western point at which *Gryphaea corrugata* was collected is about thirty miles east of Folsom.

Along this line the coarse sandstone beneath the Comanche fossils is from fifteen to forty feet in thickness, and the variegated shales, sandstones, etc., of the Morrison increase to about 200 feet. Lithologically and stratigraphically this is identical with the Morrison beds seen on the Purgatoire where characteristic dinosaurs were collected. Fragmentary, undetermined, dinosaur remains were seen in it on the Cimarron near Exter, New Mexico.

Beneath the recognized Morrison some localities show forty to fifty feet of gypsum and gypsiferous shales resting on a massive white or pinkish sandstone which Mr. Lee has described as the Exter sandstone. It varies greatly in thickness, the maximum observed being eighty feet. The Exter is separated from the Red Beds by a striking angular unconformity, wherever the Red Beds are folded in local uplifts. The Red Beds show the usual character and at Tod's ranch, fifteen miles east of Folsom, they yielded fragmentary Triassic vertebrates.

From Folsom we traveled by rail to Tucumcari and from that place by wagon to Las Vegas.

Tucumcari region.—At Mesa Tucumcari the Dakota sandstone, eighty feet in thickness is underlain by sixty feet of fossiliferous Comanche shales and yellowish sandstones containing the same fauna as at Garrett, Oklahoma, with a few additions. The Morrison formation was not recognized but its place in the section is occupied by a talus slope with no exposures. The lower part of the section is composed of Red Beds of the ordinary character, overlain by friable, light-colored sandstone that is suggestive of the Exter.

At Mesa Redondo, a few miles south of Tucumcari, the space between the Comanche zone and the Red Beds is filled by 300 feet of heavy bedded gray and buff sandstones with intercalated thinner beds of red shales.

About ten miles northwest of Tucumcari station the section shows

[1] *Journal of Geology*, Vol. X (1902), p. 45.

considerable change. The Comanche fossiliferous zone, here only twenty-five feet thick, rests on 100 feet of coarse gray cross-bedded sandstone which in turn is underlain by 300 feet of variegated shales and sandstones very similar to those of the Morrison on the Cimarron and the Purgatoire. Fragmentary bones of large dinosaurs are common in these shales but none of those collected was sufficiently characteristic to be identified.

On the north side of Canadian River, fifteen miles northwest of Tucumcari, a similar section is exposed with only twenty feet of fossiliferous Comanche, and this is the last point in this direction at which Comanche fossils were found in place. Farther north and west in the neighborhood of Sanchez and on the upper course of the Rio Concha, the stratigraphic place of the Comanche is occupied by an inconspicuous shaly band in which no fossils were found. The other members of the section remain practically unchanged.

An occurrence of Unio previously discovered by Mr. Lee about 500 feet below the top of the Red Beds on Rio Concha is worthy of mention as indicating the post-Paleozoic age of that much of the Red Beds.

Canyon City.—At the end of the field season I visited the well-known Morrison locality in Garden Park, eight or nine miles north of Canyon City, Colorado. On Oil Creek, below Garden Park and about a mile south of the "Marsh quarry," which has yielded so many dinosaurs, the Dakota sandstone and associated strata are well exposed with a dip of 17° S. E. Guided by the experience gained on the Purgatoire and the Cimarron a brief search in the shaly strata beneath the upper cliff of Dakota sandstone was rewarded by the discovery of plentiful marine fossils that belong to the Comanche fauna. Those collected include *Pholadomya sancti-sabae* Roemer, a *Tapes* (?), a *Lingula* and a small mactroid shell, all of which occur in the Kiowa shales of Kansas. The cliffs at this point show the following section:

1.	Rather massive gray Dakota sandstone overlain by Benton shale	100 feet
2.	Dark gray shales alternating with thin-bedded sandstones. Marine Comanche fossils at 35 feet from top	85 "
3.	Massive gray sandstone with bands of fine conglomerate near top	35 "

4. Chocolate, reddish, and variegated shales and variable sandstones of the Morrison. Only upper part here exposed. Total thickness probably . . . . 300 or 400 "

The general section of the region includes the entire Upper Cretaceous and a considerable thickness of Red Beds and Paleozoic.

Under the guidance of Mr. Edward Felch, who has had personal knowledge of all the vertebrate collecting that has been done in the neighborhood, I visited the various quarries that were worked by Marsh, Cope, and Hatcher, and determined that they are all on horizons below the Comanche fossiliferous bed and below the sandstone immediately underlying it. It is evident therefore that the Morrison formation is no more closely related to the Dakota near Canyon City than it is at other localities.

Extent of the Comanche Sea.—It has now been shown that the Comanche sea extended as far northwest as Canyon City, Colorado, and that its sediments overlie the Morrison in an area more than 100 miles wide. How much farther it extended in that direction is not known, as no special search for paleontologic evidence has yet been made, though the recent discovery by Prof. S. W. Williston[1] of Comanche species of fish teeth in the "upper part of the Atlantosaurus beds" near Lander, Wyoming, suggests the possibility of much greater extension.

This leads to the question whether the Fuson and Lakota formations, which have been differentiated from the Dakota in the Black Hills, should be identified respectively with the Comanche shaly beds and the underlying sandstone which hold the same stratigraphic positions in southern Colorado and New Mexico. Such an identification is plausible, and yet it seems to me that it is not warranted by the evidence now in hand. The Fuson formation is apparently non-marine, and, judging from the descriptions, its lithologic character is different from that of the Comanche shales and sandstones. It contains a flora which is comparable with that of the lower Potomac, and has nothing in common with the Dakota flora, which is of much later type. On the other hand, the Comanche[2] of Colorado

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[1] *Journal of Geology*, Vol. XIII (1905), p. 347.

[2] The term Comanche throughout this paper is used as a general term of correlation—not as a formation name.

and New Mexico is the equivalent, in part at least, of the Kiowa and Mentor beds of Kansas which are very intimately connected with the Dakota, as Gould[1] has pointed out. This connection is shown by the flora as well as by apparent stratigraphic continuity. The Cheyenne sandstone which underlies the Kiowa in southern Kansas contains a flora not yet fully studied which is of the same type as the Dakota flora and includes some identical species.

In the neighborhood of Marquette, central Kansas, there are sandstone bands with Dakota species of plants intercalated in the marine beds with characteristic Comanche fauna. The paleobotanic evidence therefore tends to place the Fuson formation considerably lower in the general geologic column than the shaly Comanche beds beneath the Dakota in Colorado and Kansas.

Age of the Morrison.—The question whether the Morrison formation is Jurassic or Cretaceous is still to be answered, and if a satisfactory answer is ever received it will doubtless be from vertebrate paleontology, aided by careful stratigraphic methods. If the Morrison is Cretaceous, the proof that it is so will not be by tracing it directly into marine Cretaceous strata. It has been shown that the beds supposed to be thus connected with it overlie it for more than 100 miles across the strike. But these overlying beds are by no means the earliest Cretaceous, and there is still room for the Morrison within that system if the fauna requires such a reference. On the other hand, there is ample space for it in the Jurassic[2] not otherwise represented in the region by sediments, and before the final decision is made the character of the flora in the Fuson formation of the Black Hills and in the Kootanie of Montana should be given due weight, and these formations should be closely studied and searched for other evidence.

In this connection I may quote from the late Clarence King who, in speaking of paleontologists as "these scientific autocrats," says:[3]

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[1] *American Journal of Science*, 4th series, Vol. V (1898), pp. 169–75; *American Geologist*, Vol. XXV, pp. 10–40.

[2] The marine Jurassic Sundance formation, characterized by *Cardioceras cordiforme* M & H, etc., on which the Morrison rests in the northern area, does not represent the latest Jurassic according to European standards

[3] *Report Chief of Engineers*, U. S. Army, 1875, p. 919.

It is the misfortune of geology to be more or less dependent on this branch of specialists. Without their specific determinations the geological maps, even, cannot receive their ultimate color designations, nor can reports, which, like ours, involve a wide range of stratigraphy, be safely written.

It may seem autocratic, but in these days the paleontologist insists, not only that his specific determinations must be used, but that he must be consulted as to the interpretation that is placed upon his lists, and especially he insists that the geologist must know what horizon yielded the fossils under discussion before he uses them in stratigraphy and correlation.

TERTIARY FORMATIONS OF OLTENIA WITH REGARD TO SALT, PETROLEUM, AND MINERAL SPRINGS

G. M. MURGOCI, PH.D.
University of Bucharest

CONTENTS

INTRODUCTION

In Oltenia, the western part of Roumania, there are three geological regions:

1. The mountains to the north, a part of the Carpathian chain,

formed by eruptive rocks, metamorphosed schists, and sedimentary deposits, the uppermost being the Lower Cretaceous, with a Flysch basin in the Olt valley, the basin Brezoi-Titesti.

2. The high plateau of Mehedinti to the west, constituted by the same formation, but with small tertiary Neogene fjords and basins.

3. The Tertiary foothills, with a characteristic depression near the mountains, the so-called Subcarpathian depression.

The researches on Tertiary formations in Roumania have usually touched only casually the region west of the Olt River, and still less the Subcarpathian region between the Olt and Jiu Rivers. The valuable work by Fuchs, Foetterle, Tournouëri, Porumbaru, Fontannes, Toula, etc., refers in general only to the highest layers, Pontic and Levantine, of Oltenia; and even the extensive study by Sabba Stefanescu, on the whole Roumanian Tertiary, gives us very few facts about the northern part of this region, which appears as uniform and without interest. In this respect, however, we must remember the scattered observations by Gr. Stefanescu, and the study by K. Redlich, exhaustive on some points, which permit us to see how interesting a detailed study of this region might be.

In this paper I propose to present the stratigraphical results of my researches, extending over five years in the complicated petroleum and salt region, and over several years more in the mountains of Oltenia. The paleontological determinations, which throw light on and confirm my field observations, were made by Professors A. Koch, N. Andrussow, and W. Lascareff, to whom I here present my heartiest acknowledgments.

THE NORTH ZONE OF THE TERTIARY OF OLTENIA
BREZOI-TITESTI BASIN

The earliest studies, especially by Grégoire[1] and Sabba Stefanescu,[2] have presented the region west of Olt and south of the boundary of the crystalline formations, as constituted in its whole extent, right up to the Danube, by tertiary deposits only. Later Dr. K.

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[1] Grégoire Stefanescu, *Annuaire du Bureau géologique*, année 1882–83; *Carte géologique de la Roumanie; Cours de géologie*, 1891, etc.

[2] Sabba Stefanescu, *Etude sur les terrains tertiaires de Roumanie*, 1897; "Mém. sur la géol. du Jud. Arges," *Ann. d. Bur. Géol. Roum.*, 1882–83; several notes in the *Bull. de la Soc. géol. de France*, 1894, etc.

Redlich[1] has shown that the marls, sandstones, and conglomerates of the Brezoi Basin, which on Gr. Stefanescu's map were figured with the color for Eocene with a point of interrogation, belong to the Senonian, the horizon with *Inoceramus Cripsii;* he suggested that similar formations lower than Eocene strata, in the neighboring Titesti Basin, might belong also to this horizon.

1. It may be that the conglomerates above the Brezoi breccia,[2] mica sandstones and marls, which form the mountains to the northwest of the Cozia Monastery and Sturii Olanestilor up to the Piatra Stogului, can be ascribed to the upper Cretaceous (Cenomanian upward).[3] I can adduce as evidence the topographic continuity of these deposits with the Senonian strata from the Brezoi Basin through the Stan valley, and the identical facies and composition of the rocks from these two places. These are: coarse conglomerates, shingle, and sandstones with crystalline rock elements at the contact with the crystalline foundation; finer sandstones and marls farther off from this contact.

Stratigraphical and tectonical considerations speak even more for the synchronism of these deposits (see below). L. Mrazec, in a communication to the Society of Science (Bucharest, February, 1904), expresses the same hypothesis for the Brezoi breccia from the Arges valley (Capatineni) which underlie the Eocene strata (described by Sabba Stefanescu); K. Redlich makes also the same suggestion for representatives of the same breccia and conglomerates in the west of Salatrucu. The strata about which I am writing are lower than the horizon to which Redlich and Mrazec refer.

I may add that many years ago I found at Vf. Candoaia on the mica schists transgressive siliceous mica sandstone like that from

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[1] K. Redlich, "Geologische Studien um Gebiete des Olt- und Oltetzthales in Rumänien," *Jahrbuch der k. k. geolog. Reichsanstalt,* 1899. Three notes in *Verhandlungen,* etc.

[2] A (Liassic ?) breccia which forms the foundation of the Brezoi Basin and the limestone, also the higher deposits on the Narutu, Sida, Foarfeca, Folia Mountains and the foundation of the sedimentary formations at the skirt of the mountains. G. M. Murgoci, "Calcare si fenomene de erosiune in Carpati merid." *Bull. Soc. Sciences Bucharest,* 1898.

[3] Suggested already by L. Mrazec and myself in "Muntii Lotrului," *Bull. Soc. Ing. mine,* 1898.

the Vasilatu valley (west of Brezoi), which has here and there traces of undeterminable fossils, but where *Inoceramus* can be distinguished.

2. On the other hand, I do not think that the whole deposits from the Brezoi Basin are Senonian, but that the upper strata belong to the Eocene, corresponding to the Eocene strata from the opposite Titesti Basin. Dr. Redlich tells us that in the strata with *Orbitoides* (upon the sandstones and marls with *Inoceramus*), he has found a section similar to one of *Nummulites;* still more important evidence is revealed to us by the stratigraphy and facies of the deposits (Figs. 1 and 4).

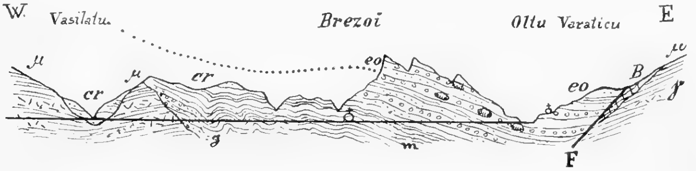

FIG. 1.—Profile of the Lotru valley at Brezoi; 1 : 100,000.

μ=Mica schist with p=pegmatite veins; B=Brezoi breccia; cr=Upper Cretaceous; g=sandstone and grit; m=marls and sandstone with *Inoceramus Cripsii;* eo=coarse conglomerates with *Hippurites* limestone blocks; F=fault.

Omitting the consideration of the Brezoi breccia, we find that the coarse conglomerates, shingle, and sandstones with an intercalation, in the lower horizon, of a thick bank of marls and fine silicious sandstones, bend themselves into small undulations, with an anticline more pronounced on the side of the Calimanesti valley. Between Brezoi and Valea lui Stan I can confirm a small syncline with many folds in the marls. The whole formation is inclined toward the southeast (angle variable from 30°–60°), and it lies in obvious unconformability on the mica-schists and Brezoi breccia, which form klippes at the bottom of these deposits. A fault along the right bank of the Lotru has been confirmed by Dr. Redlich and myself at the same time.[1]

The marls, contrary to the interpretation of K. Redlich, constitute a horizon intermediate between the conglomerates and sandstones from the Vasilatu valley, which are rich in Senonian fossils, and the coarse conglomerates in the east of Brezoi, rich in huge blocks of limestone, with Senonian fauna.

[1] *Loc. cit.* (footnote 1, p. 672).

From the marly-sandy layers of the Stupinita ravine Dr. Redlich cited:

Inoceramus Cripsii.
Orbitoides Faujasi Brown.
Orbitoides secans Leym.
Astrocoenia sp.
Serpula filiformia Sow.
Pecten inversum Nils.
Actinacis Haueri Rs.
Avellana sp.
Baculites anceps Lam.
Anisoceras cf. subeonopresum Forb.

He found in the blocks of a white, grayish, or reddish limestone, with red veins, a numerous fauna, among which are:

Hippurites Lapeirousei Goldf.
Hippurites colliciatus Woodw. var. *romanica.*
Orbitoides gensacica Leym.
Orbitoides secans Leym.
Lithothamnium cf. turonicum Roth.
Terebratula carnea Sow.
Terebratula biplicata Brocc.
Lima tecta D'Orb.
Lima divaricata Duj.
Lima inversum Nils.
Gryphaea vesicularis Lamk.
Exogyra sp.
etc., etc., etc.
And two new species:
Terebratella Mrazeki.
Waldheimia Pascuensis.

Dr. Redlich, considering that the conglomerates which contain these certainly Senonian limestone blocks underlie the above-mentioned Senonian marls and sandstones, expresses his opinion that these blocks are destruction products of a bank of *Hippurites* limestone which was formed within the conglomerates. But the conglomerate layers with these interesting blocks overlie the marls and sandstones with *Inoceramus Cripsii,*[1] and I think I am making no mistake in saying that they are an Eocene formation.

Besides the *Nummulites* indicated by Redlich in the lower strata, with *Orbitoides*, of this complex, I adduce the identity in constitution and the continuity with the strata from the Titesti Basin, where in layers immediately on those banks of conglomerates Sabba Stefanescu and K. Redlich have collected abundant Middle Eocene fossils.

Such blocks of *Hippurites* and *Coral* limestone are very frequent, not only in the Brezoi-Titesti Basin, but also in the Eocene conglomerates, which form a zone from Arifu (Arges valley) at Salatrucu, Calimanesti, up to Cheia (Valcea). In the coarse conglomerates Sabba and Gr. Stefanescu have found also numerous Middle Eocene fossils. At Calimanesti-Salatrucu the conglomerates are overlain by

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[1] *Loc. cit.* (footnotes 2 and 3, p. 672).

marls and sandstones similar as to facies and fauna to the upper marly layers from the Titesti Basin; Redlich indicates, further, on his sketch an anticline between the Titesti Basin and Salatrucu Dangesti; this suggests to me that the marls from Titesti may be the same horizon as those from Salatrucu-Calimanesti, and then the correspondence between the conglomerates from Brezoi Basin and the similar ones from Arifu-Cheia would be even more obvious and unassailable. In this case the Flysch of Brezoi-Titesti presents the same character of facies which is described for the whole Carpathian Flysch; Cenomanian = coarse conglomerates; Senonian = marls and sandstones; Middle Eocene = very coarse conglomerates with huge *Hippurites* limestone blocks, etc.[1]

From these speculations it follows that the lower Flysch has made an anticline above the Narutu and Cozia Massif, which has been in parts sunk along the Lotru valley, eroded up the ridge, but traces of it were still left in the Valea lui Stan, the small basin at the Turnu monastery and between Baesti and Dangesti.

TERTIARY OF THE SUBCARPATHIAN REGION

In the foothills of Oltenia the Tertiary is represented in the whole of its development from the Eocene to the Pleistocene beds. Its general character here is a continuity of deposits, chiefly in the Olt region, from the Cretaceous up to the Levantine; but only a critical and detailed study of the strata, now violently dislocated, can reveal to us the early partially conformable succession. In the western part there may be observed the uninterrupted succession of deposits only from the Mediterranean Sea to the Levantine lake, and also a persistence of facies along the skirt of the mountains, the persistent strand of the sea.

A. THE FLYSCH OF THE UPPER PALEOGENE

On the geological map by Grégoire Stefanescu the Eocene formations are drawn correctly in their extension toward the south; their edge passes near Suici (Topologu V.), enters into the Oltu valley at Daesti, and runs with small undulations toward the west, reaching

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[1] See about this question the masterly researches by V. Uhlig. A clear résumé is: "Ueber die Klippen der Karpathen," *Comptes Rendus, IX^e Congrès Géol.*, 1903 Vienne.

Mirlesti-Petreni, where the deposits overlie the Jurassic massif of Bistrita. Between Cozia and the south boundary of the Paleogene formations I can distinguish three horizons.

1. *Lower*, lying to the north of the line Dangesti-Calimanesti-Olanesti-bai-Cheia, a zone of sandstone with hieroglyphs and Strzalca structure, conglomerates, and a few marls with fucoids. In their highest beds the silicious conglomerates and grits contain, as mentioned above, huge blocks of *Hippurites* limestone, which are to be found in every valley from Arifu up to Cheia. *Orbitoides* and *Nummulites* (*Nummulites Lucassana*, *N. perforata*, etc.) have been found here, proving it to be the Middle Eocene. Last summer Gr. Stefanescu found at Calimanesti, in these conglomerates, *Cerithium giganteum* Lam., which was found also by Sabba Stefanescu at the prolongation of these beds at Salatrucu in the Topologa valley.

2. *Middle.*—There now comes a zone of marls with a few sandstone and sand beds, which give their character to a region of meadows between Jiblea and Cheia (the meadows of Jiblea, Calimanesti, Muereasca, Olanesti, Tisa, and Cheia).

In repeated sandstone beds in the Puturosita ravine (Calimanesti) in the Purdoi bank and the Olanesti village, I have found[1] the following fossils, which are identified by Professor A. Koch of Budapest:

Nummulites Bucheri De la Harpe
Nummulites Tournouëri De la Harpe
Nummulites Budensis Hant.
Nummulites aff. Madariszi Hant.
Orbitoides papiracea Boubée
Orbitoides aspera Güm.
Orbitoides applanata Güm.
Operculina cf. ammonea Leym.
Alveolina cf. Bosci D'Orb.
Nodosaria latijugata Gumb.
Nodosaria baccillum Defr.
Heterostegina sp.
Cidaris cf. subularis D'Arch.
Maeandroseris (?)
Bourgueticrinus elipticus D'Orb.
Bourgueticrinus Thorenti D'Arch.
Bryozoa, Cidaris, Cerithium
Cardium, Cardita, Ostrea, etc.

From this fauna Professor A. Koch concludes that we have here to do with the Upper Eocene, but the presence of *Operculina ammonea* gives us a transition to the Middle Eocene, and that of *Nodosaria latijugata* and other fossils a transition to the Lower Oligocene. Sabba Stefanescu, who studied this horizon in the Topologu and Argesu valleys is similarly of opinion that this marly facies began to

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[1] I have described these localities in *Gisements du Succin de Roumanie. Assoc. p. In. si Resp, Sciintelor*, 1903, *Mém. Congrès* Iasi.

be deposited at the end of the Middle Eocene and continued until the Oligocene. In this horizon there occurs the fossil resin of Olanesti (malul Purdoi) and Cheia.[1]

3. *Upper.*—We find in the southern region of Muereasca another zone of sand and shingle and limestone blocks with, at rare intervals, bands of conglomerates and sandstones. At Müereasca de jos I have found Nummulites and Orbitoides, which are indications of Oligocene, but characteristic of no particular horizon; probably we have here beds also of the Lower Oligocene. All these formations have in the Olt valley a direction southeast by east to northeast by east, and dip south-southeast at a quite variable angle of about 40°. In the west of Cheia we find them running from east to west, and in the east of Dangesti also K. Redlich and Sabba Stefanescu report an east-to-west direction for these beds. Obviously the Paleogenic Flysch must make an interesting horizontal inflection in the Olt region. Insignificant undulations, but not folds, are also to be seen here and there (at Olanesti below the spas, etc.).

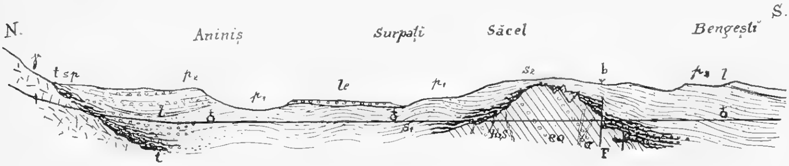

FIG. 2.—Profile of the Blahnita valley.

g=granite; *eo*=Eocene conglomerate and grit with (H_2S) sulphur and (σ) salt springs; *t*=Tortonian conglomerate and *Lithothamnium* limestone; s_1=Lower Sarmatian; s_2=Middle Sarmatian; p_1=Lower Pontic with *Valenciennesia;* p_2=Upper Pontic with *Vivipara bifarcinata;* *l*=Lignite seams; *le*=Levantine shingle.

We meet, further, with the Paleogenic formations in close relation with the mountains only in the high plateau of Mehedinti, where they form a narrow zone westward from Baia de Arama up to Batta.

B. THE PALEOGENIC KLIPPES OF SACEL AND SLATIOARA

When we leave the Olt region, we find the Eocene appearing as a small but interesting klippe in the Blahnita valley at Sacel (Gorj.). It includes conglomerates, grits, and sandstones identical with those from Calimanesti (Valcea), inclined at an angle of 50°–60° toward the south-southeast, and constituting the bottom and walls of the valley, about 600^{m} (Fig. 2). This cliff has been the subject of much discussion between Gr. and Sabba Stefanescu.

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[1] G. M. Murgoci, *Gisements du Succin de Roumanie. Assoc. p. In-Sciintelor,* 1903.

The former geologist, although he did not find any fossils, considered it, judging from the facies and occurrence, to be Eocene, and figured it as such on his map; the latter at first described it as Sarmatian,[1] but after the publication of Gr. Stefanescu's reply[2] changed his views and assumed the conglomerates to be Tortonian like those from the skirt of the mountains.[3] Some three years ago, however, I was fortunate enough to find here in the grit stratum below the Villa Speranta many imperfectly preserved *Nummulites* and *Orbitoides* (*Orbitoides papiracea* Boub.), and last summer I collected in the northern beds a large number of *Nummulites*, *Orbitoides*, *Corals*, *Operculina* (*ammonea*), *Cidaris*, etc., which would indicate the same horizon as at Olanesti-Calimanesti, the Middle Eocene in transition to the upper Eocene. But we must be wary, because these Eocene conglomerates are covered by transgressive beds of Tortonian and Sarmatian conglomerates (see below).

Gr. Stefanescu figures on his map another still larger Eocene klippe at Slatioara, about which Sabba Stefanescu says nothing; on the several occasions of my visits to this point I have not been successful in finding fossils. However, I am inclined to believe that only the shingle beds and loose conglomerates which constitute the Maguricea and both walls of the Cerna valley are Oligocene. Like the Sacel Cliff, these beds retain the same direction and inclination, and have the same constitution—crystalline schists, granite, white and reddish limestone, conglomerates, etc.—as the corresponding beds of the Olanesti-Muereasca. The Slatioara klippe is covered transgressively by the more recent strata of the salt formation and Pontic. (Fig. 3.)

Mineral springs and natural gas.—The Middle Eocene conglomerates are characterized by many mineral springs, salt and sulphur springs occurring in the bottom of almost every valley, and the foot of the klippes, the chief being Jiblea, Calimanesti (spa), Muereasca de sus, Olanesti (spa), Cheia, Dobriceni; Slatioara, Sacel (spa).

Another line of springs is farther to the north at the contact of the

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[1] "L'âge géologique des conglomérats de Muntenia," *Bullet. d. l. Soc. géol. de France*, Vol. XXII, p. 229.

[2] "L'âge géologique des conglomérats de Sacel," *ibid.*, p. 502.

[3] Sabba Stefanescu, *Etudes des terrains tertiaires de Roumanie* (1897), p. 112.

Cretaceous conglomerates with the crystalline rocks: Bivolari (hot springs), Puturoasa, Posta, Lacul Doamnei, etc.

Between these two series of springs there is the widely known alkaline spring of Caciulata, on the bank of the Olt River. Most of these springs are very rich in emanations of gaseous hydrocarbons, there being up to 97 per cent.[1] methane, but only 2 per cent. H_2S. While the origin of H_2S can readily be explained from the occurrence of partly altered pyrites in the mica schists,[2] which are among the constituents of the conglomerates, the large percentage of methane is not easy to understand; though probably the springs are in relation with petroleum-containing layers. The salt springs (Calimanesti, Slatiora, Sacel, etc.) indicate a salt deposit in connection with the petroleum, such as is usual in all petroleum regions.

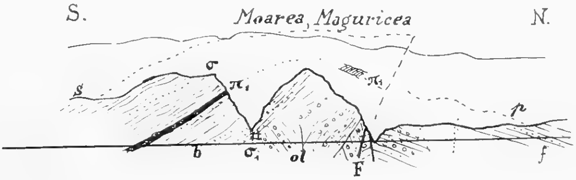

FIG. 3.—Profile of the Cerna valley at Slatioara.

ol=coarse Oligocene conglomerate and shingle; σ^1=lower salt formation (Burdigalian); π_1=*Palla* (Dacite tuff); σ=upper salt formation; *s*=Sarmatian; *p*=Mœotic and Lower Pontic marl and sandstone with (*f*) *Helix* and *Lymnea;* *F*=fault.

C. NEOGENE FORMATIONS, MIOCENE SERIES

The lowest stage of the Neogene, the Burdigalian, was studied in the south Carpathians by Stur, Hoffmann, Koch, etc., at Petrosani, in Transylvania; by Gr. Stefanescu, Draghiceanu, Fuchs, and Sabba Stefanescu, at Bahna, Balta, Fantanele, etc., in Jud Mehedinti, where the *I* Mediterranean Sea deposits form smaller or larger basins in the crystalline zone. I have mentioned these deposits as occurring at the south of the Carpathians at Gura Vai on the Oltu River.[3]

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[1] Analysis by Gr. Pfeifer, "On the Olanesti Springs" (in manuscript); about Caciulata spring he has published his results in *Bul. Soc. Sciinte Bucharest,* Vol. III (1904).

[2] A sulphur spring occurs in the crystalline region of Puturoasa sub Pleasa in the bottom of the Romani valley; the mineral water comes from the red and brown altered, pyrites-bearing mica schists. Dr. Redlich cites a similar spring from the conglomerates of Brezoi (*loc. cit.*).

[3] Communication to the Society of Science (Bucharest, May 6, 1902); description in *Gisements du Succin de Roumanie,* 1903, *loc. cit.*

They consist of sands and loose sandstones, with large crystals of gypsum, and of a few sandy marls and conglomerates, and they lie conformably on the similar formations of the Oligocene. In a valley in the west part of the village of Gura Vai, I have found in these beds *Cerithium plicatum* Brug (?) var. *papillatum* Sabba), *Cerithium margaritaceum* Brocc., etc.

I may add, as a result of my last summer's study, that the Burdigalian layers of Fântânele, Ponoare, and Balta form a narrow continuous zone, a Mediterranean fjord, in the high plateau of Mehedinti, The Bahna basin is of course the continuation of this zone, though separated by a strong later erosion. The layers of Ponoare, with some thin lignite seams, very often show a strong efflorescence of salt, etc., like those from Gura Vai.

Bearing in mind the presence of *Cerithium plicatum* in the other basins, and of bituminous coal at Gura Vai, just as in Bahna, and the Balta, etc., Basin, and more especially noticing some nuances of *Cerithium margaritaceum* (to use Professor Laskaroff's expression), we have reason to consider these beds to belong to the *I* Mediterranean layers. They reach westward to Cheia, and on the east they cross the Olt and extend to Daesti, etc. Some salt efflorescences may be mentioned as occurring in the sand marls at the Bogdanesti bridge, etc.

D. SALT FORMATION

There follows on the *Cerithium plicatum* strata in the Olt valley and westward a complex of marly, sandy formation which often lies unconformably on the Oligocene, and which is characterized throughout its whole extent by a well-marked saline efflorescence, by salt springs, and by a dacite tuff, the *palla* of the Hungarian geologists. In the true salt formation I found no fossils, but some found in higher strata indicate either Tortonian or the lowest Sarmatian strata, so that the salt formation would be intercalated between the Burdigalian and the Sarmatian. It has two petrographical features of great importance—the repeated palla beds, and the great salt massif of Ocnele Mari. In his sketch Sabba Stefanescu figures the salt as Helvetian (Subcarpathian salt formation), but without further description. However, on considering facies, tectonic, presence of palla, and indications given by the salt, I came to the conclusion that the whole formation was Schlier, and as such it was figured in the sketch of the salt formation by Mrazec and Teisseyre.

Where the salt formations rest on the strata with *Cerithium plicatum* we cannot distinguish the exact limit of each, because, as mentioned above, they are in continuity; from Cacova up to Petreni the Schlier lies unconformably on the Oligocene, and at Bistrita on the Jura limestone. The prolongation southward is easier to define, because there the Sarmatian layers are rich in fossils.

In the Subcarpathian salt formation of Oltenia we can distinguish two horizons very well characterized by two facies, which, contrary to received opinion,[1] are very similar to, if not identical with, those of the bend of the Carpathians, and especially of the Slanic basin and Trotusu valley.

1. *The lower horizon of the salt formation.*—The lower horizon is of a sandy facies, with small intercalations of conglomerates, and bluish or reddish sandy marls corresponding with the reddish facies of the salt formation in the east. The colored bands of those deposits can be seen from afar in the walls of the valley and the river beds, viz., at Gura-Vai-Daesti; along the Olt River between Bujoreni, north and south Fedelesoaia-Cetatuia, at Bujoreni, in the Trantu valley, Runcu, etc.; then at Govora Spa, Tomsani, Maldaresti, etc. Two small bands of palla of a fine grain, and with scales of hexagonal biotite, occur on the banks of the Olt, under the salt wells from Olteni. Between Bujoreni and Vladesti the salt formation is covered by the marly facies of the Sarmatic layers, and can then be seen only in the beds of the valleys. At Runcu, at the head of the Trantu valley, this facies appears again very well marked, and with a large and characteristic palla bed. Here may be seen a variety of palla with very many foreign sedimentary elements, of the size of a hazelnut. The water-worn constituents are of quartzites, sandstones, limestones, schists, etc. In the Olt valley the banks fall south-southeast, almost 30°, and in the west we find this formation much

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[1] Messrs. Mrazec and Teisseyre, in their valuable research on salt formations in Roumania (*Moniteur du Pétrole roumain*, 1902), dwelt just a little on this basin. It must not be forgotten that at that time neither the existence of the two horizons nor the extent of the salt formations was known. Palla also was not identified, but confused, as was the case with all earlier geologists, with the silicious calcareous marl or sandstone.

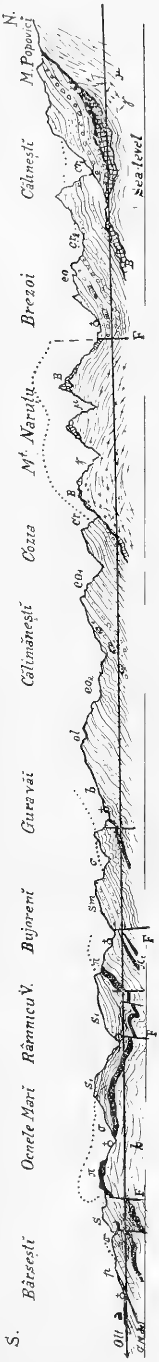

FIG. 4.—Profile of the Olt valley in the Subcarpathian region.

L. = 1 : 200,000; H. = 1 : 75,000; μ = mica schists; (γ) = pegmatites and granite and Cozia gneiss; B = Brezoi-breccia; cr_1 = Cenomanian conglomerates; cr_2 = Senonian marls and sandstone with *Inoceramus Cripsii*; eo_1 = Lower and Middle Eocene marl with fucoids and strzalca structure and coarse conglomerates with *Hippurites* and *Coral* limestone; eo_2 = Upper Eocene marls and sandstone; ol = Oligocene sandstone and conglomerate; b = lower salt formation. (Burdigalian) sandstone, sand, and marl, with *Cerithium plicatum*; π_1 = palla; π_2 = levigated palla; σ = upper salt formation Tortonian marl and sand; s_1 = Lower Sarmatian with *Ervilia podolica*; s_2 = Middle Sarmatian sandstone and conglomerate; Sm = Upper Sarmatian and Mœotic conglomerate and limestone with *Dosinia exoleta*; p = Upper Pontic with lignite seams and *Vivipara bifarcinata*; a = Alluvian; F = fault.

dislocated and folded, following the core of the two chief anticlines. (Fig. 4.)

Some faults at Bujoreni-Fedelesoaia bring the upper formations (Sarmatian) in contact with the banded salt formation. In the southern region, at Ocnele Mari-Govora, this horizon is constituted almost exclusively of sand with shingle and small banks of sandstone or conglomerates; the deposits present here the character of a delta with violently rushing arms.

A very interesting point of this horizon is at Casa Arendasului (Govora), where we find an intercalation of marls and more or less dissolved gypsum beds between the uniform sand and shingle strata. This horizon occurs in the middle of an eroded anticline, and has often a lenticular form; it is limited here and there by faults. Northward from Govora Spa it touches and passes into the banded facies; at Aninoasa, south of Slatiora, it reappears with the delta or torrential facies.

In the ravines of Ocnele Mari quantities of fossil débris may be seen, and I have found very many small *Nummulites* and *Orbitoides*, all somewhat eroded.

Nummulites was collected also from a conglomerate bank north of Govora Spa, also in secondary beds. In the ravines below Titireciu I found in the same torrential strata fossil débris in quantity, where *Cerithium plicatum* Brug., *Cerithium lignitarum* Eichw., and *Corbula* sp., could be determined.

These fossils show us that the lower horizon of the salt formation, with its sandy conglomerate facies, is the continuation of the strata of Gura Vai, and accordingly is to be classified under the *I* Mediterranean Sea deposits. To the west of Govora Spa, at Folesti-Tomsani and Maldaresti, the layer with the banded facies is very thick, and though fossils are not found, it is not impossible that the lowest beds should belong to the Oligocene; the same arrangement is to be observed at Barbatesti, where the beds seem to be a continuation of the Oligocene strata like those from Gura Vai (Olt). In the Slanic and Trotusu Basins, and also in the north Carpathians (Galicia, etc.), this horizon of the Subcarpathian Miocene salt formation occurs, according to the description of Mrazec and Teisseyre,[1] Zuber,[2] etc., similarly to the Oltenian one.

The salt formations of the Olt region, and indeed the whole Subcarpathian salt formation, have accordingly come down in the world as far as and including the Burdigalian.

The occurrence of eroded *Nummulites* near Ocnele Mari-Govora is evidence that in *I* Mediterranean times a redeposition of Paleogenic material took place; this view is supported also by the topographical and stratigraphical relations of the two formations in contact. The conclusion from these facts is, as proved for other localities in the Carpathians, that *at the end of the Oligocene, and beginning of the Burdigalian age there was an important dislocation in this region, more pronounced in the west at the contact with the skirt of the Carpathians.*

a) *Petroleum and salt.*—This formation is important, because in it we find: petroleum at Gavora Spa, and Ferbea; natural gas at Ocnele Mari, Teiusu, Gatejesti,[3] Pausesti, Barlog, Valeni, etc.; mineral wells, containing iodine, etc., at Gavora, Bunesti, etc.; and salt wells at Olteni, Govora Spa, Pausesti (de Otasau), Slatiora, etc.; and many localities with salt efflorescences. The petroleum

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[1] *Loc. cit.;* Ueber die oligocen. Klippe bei Bacau," *Verhandlungen d. geol. Reichsanstalt*, 1902. W. Teisseyre, "Die Geologie der Bacauer Karpathen," *Jahrbuch der Reichsanstalt*, 1897.

[2] Zuber, *Geologie der Erdölablagerungen in den galizischen Karpathen*, 1899.

[3] Some of these localities are mentioned by Gr. Stefanescu, *Annuaire du Bureau géol. de Roum.*, I, p., 73 etc. (1882–83); and V. Tacit, "Regiunea petrolifera din Valcea," *Moniteur du Pétrol. Roum.*, 1901.

and natural gas occur here along an anticline dislocated by a fault which extends from Govora Spa to Otasani.

That fault explains why at Govora Spa we have two wells, at a distance of a few meters only, with totally different mineral waters; one well is bored in the lower salt formation, the other in the higher.

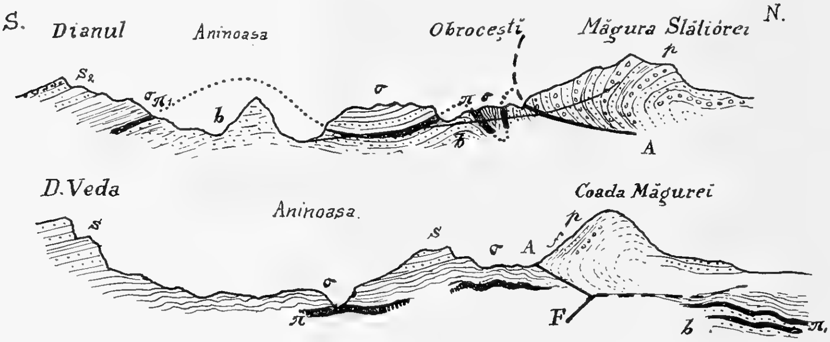

FIG. 5 and 6.—Sections through the Magura Slatioarei. The letters represent the same formations as in Fig. 4.
A = thrust plane; *F* = fault; *f* = Mœotic (or Pontic) layers with *Helix*.

b) *The Slatioara anticline.*—We have stated that the shingle and sand with conglomerates was considered by Gr. Stefanescu to be Eocene, but from the tectonic and the facies it seems to me that the western part, at least, at Maguricea in the Cerna valley must be Oligocene. (Fig. 3.) The adjoining Sections (Figs. 5 and 6) summarize the stratigraphical and tectonical facts. At Maguricea, in the Moarea valley (Fig. 3), the lower banded facies of the conglomerates of the salt formation rests unconformably on the Oligocene shingle. While some sulphur springs with hydrocarbons originate in the Oligocene shingle beds, other ones, as well as the salt springs, come from the salt formations, which in the higher horizon contain an intercalation of palla. The continuation of palla on the north side of Maguricea and Coada Magurei indicates an old anticline. While at Maguricea the banded salt formation rests undisturbed above the Oligocene beds, in the east we find the whole salt formation folded and thrust southward, and a very obvious overlapping of the Pontic strata above the salt formation. This is well seen at Coada Magurei and eastward (Figs. 5 and 6): there, over the folded marls with intercalations of palla covered by Sarmatian strata, come the Mœotic (or Pontic?)

conglomerates, sands and sandy marls, with *Helicidae,* inclined at 70°, and resting apparently with their end above the Miocene basis. Between Cerna valley and Coada Magurei there are very many ravines with beautifully exposed sections; in one the folding of the salt formation may be shown; in another, the overlapping of the Pontic folded strata over the salt formation. The Pontic strata are evidence here of a redeposition of the Oligocene, perhaps also of the Burdigalian beds (see general considerations).

2. *The upper horizon of the salt formation.*—The upper horizon of the salt formation is formed by deep banks of green or gray marls and clays with *Globigerina* (Mrazec and Teisseyre), and repeated beds of palla, sand, and sandstone. The sand is better represented, but the conglomerates all but wanting. It would correspond to the gray marly facies of the east and north salt formation. The depth of this formation is variable: At Ocnele Mari (Fig. 7), where a salt massif is intercalated, it is of considerable thickness; at Slatioara, however, it is not 50^{m} thick. This horizon is very well defined; as substratum we find often large quantities of palla, which here has, very rarely, an eruptive or crystalline facies. This palla is very fine, like pumice or chalk; in one place it is compact with conchoidal fracture, without stratification, but with fluidal zones, and of a white, yellow, or bluish color, and it is very similar to *Trass;* in another it is porous, friable, sandy, like tripoli, and not wanting in diatomaceous débris. All transitions can be found between true vulcanic dacite tuff or ash, and marl or sandstone, according to the percentage of foreign sedimentary elements which it may contain. That it was transported and deposited by sea waves is obvious. The calcareous variety is very rare (at Vladesti, Valcea); the sandy is the most developed. In its macroscopical and microscopical characters it is

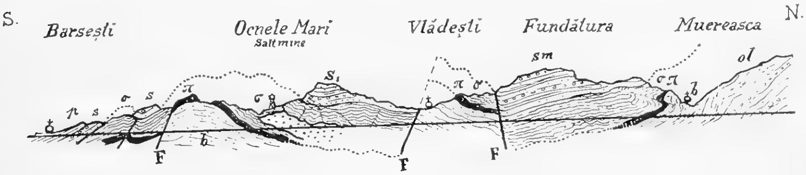

FIG. 7.—Section through the Ocnele Mari salt basin. The letters represent the same formations as in Fig. 4.

similar to the Slanic and the Transylvanian palla. About the origin of this palla see below under "Pontic tuff."

In Oltenia palla is a bed characteristic of the lower limit of this facies; I have followed it eastward over the Olt valley, and westward up to Slatioara.

As hanging, the salt formation has thick banks of marls and sandy clays very finely banded, the gray or bluish *Tegel* of Austria-Hungary; the bands, which are sometimes as thin as a sheet of paper, arise owing to difference in composition, as well as difference of subsequent alteration. This complex, the upper strata of which have intercalations of sandstone or sand beds, belong partly to the lower Sarmatian (Buglowian) with *Syndosmya apelina* and *Ervilia pusilla.*

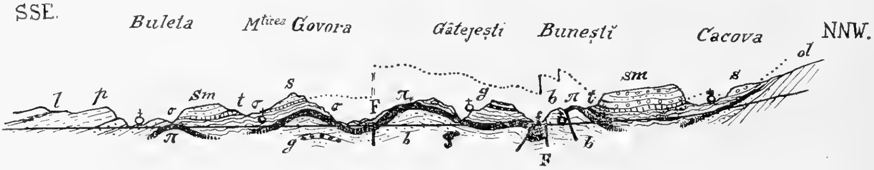

FIG. 8.—Profile of the Govora valley. The letters represent the same formations as in Fig. 4.

g=gypsum bed; F=sand and grit with *Cerithium plicatum; f*=sand with *Ervilia pusilla; L*=lignite layers.

Near to the coast and to the old cliff there took place in these marls some intercalations of sandstone and conglomerates with vegetable detritus, and dark porous limestone or gray-bluish calcareous marls, smelling strongly of petroleum. *We may consider all these latter formations as deposits from the II Mediterranean Sea.*

I have found no fossils in this horizon, but the deposits here are similar, as regards stratigraphy and facies, to the Tortonian deposits from the west, which are, according to their fossils, classified as *II* Mediterranean.

Gypsum, which is very frequent in the other parts of the Subcarpathian salt formation, is sporadic in the Oltenian one, and plays a secondary part. It comes in the higher part of this horizon of salt formation: at Licura (Stoenesti), Pausesti (Otasau), Barbatesti (Figs. 8 and 9) and Lacul Buha, and occurs as repeated layers between the marls and clays in relation with the bituminous limestones and marls. It everywhere undergoes changes, being dissolved or decomposed and forming sulphur. At Pucioasa[1] (Pausesti de Otasau), however, I believe that some small and beautiful gypsum crystals occurring in intercalated marls, soaked with SO_2 and water, have been formed recently. The gypsum from this horizon in Galicia, Podolia, etc., was classified by the Polish, Austrian, and Russian geologists[2] as belonging to the deposits from the *II* Mediterranean Sea. At Barbatesti I found blocks of *Leithakalk* in the neighborhood of the gypsum bed, and although the limestone does not occur as a bed, I think that the two formations belong together, the Leithakalk being immediately above the gypsum.

Salt and Petroleum.—The salt formation of Oltenia contains one salt massif only, but a very large one, 7^{km} long, from Teiusu up to Ocnele Mari. It is not possible to see the width, because the formation is inclined, the depth being more than 300^{m}. It is the only salt massif in Roumania which shows the *Jahresringe* of anhydrite. It very often contains charred wood and nuts (walnut). A piece of amber is mentioned also as occurring here. The composition of the best quality of salt is up to 99.8 per cent. NaCl, the second quality contains up to 2 per cent. impurities, viz., $CaCO_3$, 0.8 per cent.; calcium sulphate, 0.9 per cent.; and water, 0.35 per cent., according to the analysis by Dr. Istrati, Popovici Max.[3] Salt wells occur

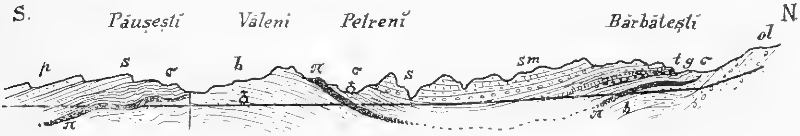

FIG. 9.—Profile of the Otasau valley. (The letters represent the same formations as in Fig. 4.)
g=gypsum bed.

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[1] See my description of that locality in *Zacamantul de Sulf de la Varbilau*, by L. Mrazec, Mem. Assoc. de Sc. II. Roum., 1904, and Analele Acad. rom. 1905.

[2] Besides the interesting discussions about gypsum, and the Mediterranean deposits in general, by Teisseyre, "Bakauer Karpathen," *Jahr. d. k. k. geol. Reichsanstalt*, 1897; *Atlas géologique de Galicie*, VIII, 1900, etc.; by I. Simionescu, "Tarmul Prutului; Geologia Moldovei intre Siret si Prut," "La Géologie de Moldavie" (*Annales scient. de l'Univ. Iassy*, 1903). I mention the valuable description and general review of this stage and gypsum in general by G. Mikhailowsky, "Die Mediterran-Ablagerungen von Tomakowka," *Mémoires du Comité géolog.*, XXII, 4, 1903.

[3] See the description of Mrazec and Teisseyre, *loc. cit.*

frequently in Oltenia as in the eastern salt region; they are arranged along three lines: (1) Daesti-Bogdanesti-Cacova-Dobriceni; (2) Ocnele Mari, Mt. Slatiora, Pausesti (de Otasau), Folesti, Otasani Aninoasa; (3) Teiusu, Petreni, Tomsani.

They are accompanied by emanations of hydrocarbons. At Cacova we see a *Ferbe* (boiling) of natural gas, but no mud volcanoes. These emanations of petroleum gas come probably from the next oil-bearing strata, the greater number from the Burdigalian formation, the lower salt formation which shows an indication of liquid petroleum. Although the upper salt formation is both eroded, folded and faulted, and the anticlines are eroded down to the lower horizon, no trace of liquid petroleum is to be seen. At Pausesti (Otasau) many wells, and two borings of 327^{m} and 87^{m}, were made; there was considerable escape of natural gas from below (from Burdigalian), but no petroleum; however, the work was neither good nor careful, otherwise petroleum would have been found; just as at Govora Spa the administration extracts quantities of petroleum from an iodiferous well bored in the lower horizon (Burdigalian) of the salt formation. The upper horizon of the salt formation in the Pausesti boring was 181^{m} thick; gypsum was met with at 56^{m}.

E. THE TORTONIAN STAGE

Sabba Stefanescu and K. Redlich[1] have studied Tortonian deposits from the skirt of the mountains, but they did not mention them as occurring in the salt region. In the above description I have considered as *II* Mediterranean deposits some sandstone conglomerates, dark or bluish, porous limestones, and marls, which alternate with the argillaceous marls in the uppermost horizon of the salt formation. Everywhere, where they occur, they smell very strongly of hydrocarbons. On the hill between Bunesti and Stoenesti they can be well observed; they alternate with marls and thin strata of palla, and contain a small quantity of the elements of palla in their composition (Fig. 8). At Govora (spa and monastery), Pausesti (Otasau), Lacul Buha, and Bistrita they contain gypsum, or come into closer relation with beds of it. These bituminous marls and limestones correspond to the *Nullipora* limestone strata which accompany the gypsum of the

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[1] *Loc. cit.*

II Mediterranean deposits in the east of the Carpathians (Galicia, Podolia, Bessarabia, and Moldavia).[1] K. Redlich has described the Tortonian deposits of Cernadia and Polovragi at the skirt of the mountains. He found at Cernadia two horizons: (1) Tegels with a rich fauna: *Ostrea cochlear* Polli, *Pecten*, cf. *Reussi* Hörn, *Nucula nucleus* L., *N. Mayeri* Hörn, *Corbula gibba* Olivi, *Turritella bicarinata* Eichw., *T. turris* Bast., cf. *terebralis* Lam., *Trochus* sp., *Natica helicina* Brocc., *Risoa Lachesis* Bast., *Ringula buccinea* Desh., *Mitra recticostata* Belt., *M. striatula* Brocc., etc. (2) Above these tegels come conglomerates and limestone banks with a Leithakalk fauna: *Lithothamnium ramosissimum*, *Alveolina melo* d'Orb, *Cerithium rubiginosum* Eichw., *Monodonta angulata* Eichw. *Pectunculus pilosus* Linn., *Conus ventricosus* Bronn., *Vermetus intortus* Lam., *Rissoina pusilla* Brocc., *Cypraea* sp., etc., etc.

Both horizons belong to the Upper *II* Mediterranean deposits, equivalent to the Leithakalk of the Vienna basin, or to the deposits of Steinabrunn. Representatives of one or the other horizons I have found at Baia de fer, Racovita, Barbatesti, eastward from Cernadia, and in the Scarita ravine, Radosi, Carpinis, Crasna,[2] etc., westward from Cernadia, always along the skirt of the mountains. The Leithakalk facies is, however, better represented and developed. The blocks which I have found above the gypsum at Barbatesti contain a numerous fauna and are identical with those of Cernadia:

Vermetus intortus Lam.
Trochus cf. patulus Brocc.
Pecten sp.
Pholas sp.
Nucula nucleus L.
Chama sp.
Lithothamnium ramosissimum, etc., etc.

The Leithakalk and conglomerates do not, however, seem to form a horizon separate from the marly facies, but only a local phenomenon occasioned by the conditions of the sea and the coast. Westward from Jiu valley the *II* Mediterranean deposits were studied and figured by Sabba Stefanescu (Sketch 1). Dobrita and Suseni are points favorable for studying it. At Suseni especially above this complex of conglomerates and Leithakalk there comes a bank of

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[1] See footnote 2 above, and L. Mrazec and Teisseyre, "Salzvorkommen in Rumänien," *Zeitschrift für Berg. and Hüttenwesen*, 1903, p. 17.

[2] Some of these localities are described by L. Mrazec in "I Partea de E a Muntilor Vulcan," *Bul. Soc. Ing. de mine*, 1898.

Sarmatian conglomerates with a rich fauna, and above that an oölitic limestone with *Congeriæ* and *Neritina,* perhaps Mœotic strata.

In general, along the skirt of the mountains from Barbatesti up to Baia de Arama we meet with a thick, persistent bed of conglomerates, shingles, and sand, in which we can determine Tortonian strata in some parts; in others, higher up, Sarmatian; and in others still, strata probably Pliocenic containing *Unionidae* and lignite layers. We must admit, then, that these conglomerates at the skirt of the mountains, with the character of cones of dejection, took their rise in the Tortonian and ended in the Pontic age.[1] I have mentioned that the Leithakalk does not form a separate horizon in the Tortonian deposits, but has been formed whenever the character of the sea beach of the *II* Mediterranean Sea has been favorable. The Tortonian and Sarmatian conglomerates contain very many bones of large vertebrates, which perhaps have been brought down by water from the continent.

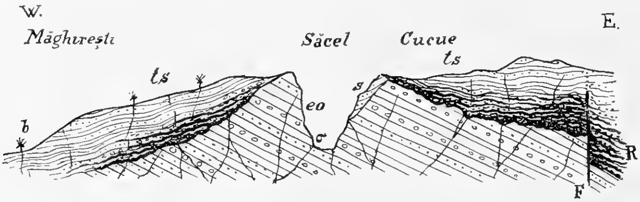

FIG. 10.—Section of Eocene island of Sacel.

eo=Eocene conglomerate and grit; *σ*=salt spring; *ts*=conglomerate and limestone from Tortonian into Sarmatian age; *R*=*Lithothamnium* and *Serpula* reef; *s*=unconformable sand and conglomerate in the lagoon of the Sarmatian Atoll; *b*=(boiling) hydrocarbon emanations; *F*=fault.

The most interesting point of the *II* Mediterranean Sea is at Sacel (Fig. 10).

We have noticed above that in the Blahnita valley there arose an Eocene island; the Blahnita, a small river, cuts this island right through the middle, and through the part which is at present the broadest and highest, thus exposing a very instructive geological section. We see to the north of the spas, and also to the south of the island in Valea Dracoaia, *Lithothamnium* limestone and conglomerates which are like those from the skirt of the mountains, and which cover

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[1] F. Toula has emphasized their resemblance to "Belvedere Schotter," of Pontic age. *Jahrbuch für M. & G.* 1897.

the Eocene conglomerates unconformably. Around the Eocene island we see the Lithothamnium formations in the ravines which cut through the Sarmatian deposits down to the Eocene beds. On the summit of the Eocene island I found sandy limestone and conglomerates with casts and moulds of fossils, indeterminable, probably *Tapes*. The beds which cover the island are certainly Sarmatian, because they are the prolongation of conglomerates, sandy and marly beds, in which Sabba Stefanescu[1] and myself have found many Sarmatian fossils. Besides the fossils obtained by Sabba Stefanescu, Professor Laskareff has determined, from my collection, *Tapes gregaria* Pt., and *Mactra fragilis* Lask., and concludes that we are dealing with the lower Sarmatian. These fossiliferous beds at the bottom of the valley do not lie directly on the Eocene conglomerates, so that the inferior marls, conglomerates, and dark *Lithothamnium* limestone may be Tortonian, as indicated by the facies. The structure and arrangement of the formations around the Eocene island are the same as those described both for old and recent coral reefs,[2] corresponding in particular with the formations "Miodobaren" of Galicia, "Toltry" of Podolia, and Stanca of north Moldavia.[3] We have, in short, around the Eocene cliff of Sacel a coral reef which began, like "Miodobaren," to form in the *II* Mediterranean Sea, and continued to grow in the Sarmatic. The lower layers, where they can be seen, are inclined quaquaversally: the higher strata, viz., sandstone, conchiliferous limestone, marls, with leaves of trees and bones of vertebrates, form an anticline, the core of which is composed of Eocene conglomerates. Northward we find, as shown by Grégoire Stefanescu[4] a syncline, followed by an inconsiderable anticline (Fig. 2). If we take into account the great amount of erosion of the Eocene beds before the Sarmatian deposits, and the very complicated outline of the Paleogenic island, which is covered

[1] "Sur l'âge des conglomérats de Roumanie," *loc. cit.*

[2] I mention here the valuable recent work by Saville Kent (Barrier Reef of Australia, 1893); Grabau (Paleozoic coral reef, 1903); Agassiz (Pacific c. coral reef, 1903). Branner (stone reef of northeastern Brazil, 1904); Funafuti (atoll, 1904); Skeats (dolomites of Tyrol, 1905).

[3] The extensive literature about these formations is summarized by Simionescu on the occasion of his study of Stanca, "Sur la géologie de la Moldavie," *Annales de l'Université de Jassy*, 1903.

[4] *Loc. cit.*, Bull. de la Soc. géol. de France.

by limestones and conglomerates, and more particularly by a deposit occurring in some small old valleys, and consisting of sand and conglomerate, quite unconformable both to the Eocene strata, and also to the Tortonian and Sarmatian beds, we come to the conclusion that there was at this point a little *atoll of Sarmatian age.*

This enables us to explain why the Blahnita, a small river with little water, was able to cut its way right through the widest part of the very hard silicious sandstone and conglomerates of Eocene age. Other geographical facts can be similarly explained.

The coral reef extends toward the east, where it is covered by later deposits, but at Bircei-Ciocadia it stands up from the eroded sandstones and marls as a high rock 4^{km} in length, consisting of a cavernous limestone with pockets and lenticular intercalations of sands and sandy marls, and seldom showing any organic structure such as *Lithothamnium.* At Ciocadia, however, the whole rock is filled with tubes of *Serpula gregalis;* the limestone banks have here a lenticular form, and at some points end abruptly, limited by the undisturbed Sarmatian layers. We notice that the rock is identical with that of Toltry and Stanca in the north of Moldavia. The overlying sandstones and marls contain a middle Sarmatic fauna; underneath all this, in a ravine, hard, bluish, sandy marls were found, which alternated with bituminous marls, and in which I collected many tubes of *Serpula* and two petroleum-blackened fossils, probably *Ervilia.* We should thus have here the lowest horizon of the Sarmatian strata, and, if so, the beds underlying the coral reef would be Tortonian, as in the similar reefs in Podolia and Galicia.

The *petroleum* which comes out here from under the coral reef, the emanation of natural gas (at Bircei, Valea Dracoaia, Maghiresti, etc.), and the mineral springs come probably from the Paleogenic island from which the Tortonian conglomerates, and also the cavernous limestone, have imbibed the hydrocarbons. The occurrence of petroleum at Bircei is one of the most interesting in Oltenia.

F. THE SARMATIAN STAGE

The formations belonging to this stage are well developed, and are considered by Gr. Stefanescu (with determination of fossils by Fontannes), by Sabba Stefanescu, apropos of the discussion about Sacel, and also by K. Redlich. I have found these deposits extending over a large surface in the Olt region, and also as lumps or patches on the salt formation of that region, and as a belt along the skirt of the mountains, where it can be seen in the valley wall of the rivers which have eroded the upper strata. Its occurrence around Sacel, with characters of great interest, has been mentioned above.

In several places organic remains have been found, and from the fossils in my collection Professor Laskareff has been able to distinguish three horizons, as in the south Russian Sarmatic:

1. The lower horizon begins as a continuation of the marly facies of the salt formation; there are: bluish or grayish marls and clays, banded or compact, forming thick beds with small intercalations of sandstones. In the highest beds sandstone with sand and calcareous banks, and a few conglomerates, prevail. Here and there (Ramnic-Valcea-Pausesti, Suseni) there are bands of yellowish oölitic limestone. In the Olanesti valley, Sacel, and Voitesti we find round sandstone concretions, as described in the Sarmatian of Moldavia, Bessarabia, etc.

a) The lowest layers in which I have found fossils are a thin sandstone stratum intercalated between the green marls from the northeast of Ramnicu Valcea, and overlying the levigated palla on the Oltu bank.

Cardium lithopodolicum Dub.
Trochus sp.
Hydrobia Frauenfeldi Hörn
etc., etc.

In the green, banded marls which contain *Lithothamnium* nodules and veins, and which overlie the salt marls from Dobriceni in the Drogu ravine, and underlie the sand and sandstone banks from Smeuretu-Stoenesti, there occurs *Syndesmya*, cf. *apelina* Ren.

At Titireciu, in a ravine cutting the folded salt marls and sand which have a well-marked salt efflorescence, and which lie immediately above a bed of levigated palla (Fig. 8), I found in an intercalation of sand: *Ervilia* cf. *pusilla* Phil., *Congeria* cf. *Sanbergeri* Andr., etc.

Ervilia pusilla denotes the lowest Sarmatian strata, the transition from Tortonian to Sarmatian—a stratum described exhaustively by Professor Laskareff at Buglowo[1] (southern Russia). Accordingly,

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[1] W. Laskareff, "Die Fauna der Buglowka Schichten in Volhynien," *Mémoires du comité géologique*, Nouv. Série 5, 1903. Perhaps the limestone with *Tapes vitaliana* from Lacul Buha belongs also to this horizon.

the levigated palla would be Tortonian, as would appear also from the evidence given above; and, what is still more interesting, the *salt facies of the Oltenian Tertiary extends upward to the lower Sarmatian.* Sarmatian layers with salt facies were mentioned also by Mrazec and Teisseyre in Distr. Prahova, Ramnicul sarat, Bacau, etc.

b) Besides the above localities, the lower Sarmatian was identified in the sandstone facies at Buda, Inotesti, Pausesti de Olanesti,[1] Negoesti-Petrari, Viezure, Tomsani, Govora, Sacel, etc.; it is a horizon (Volhynian according to Simionescu) well characterized in Volhynia, Moldavia, and Bessarabia, etc., by *Ervilia podolica* Eichw. At various localities in this horizon I collected the following fossils:

Mactra fragilis Lask.
Modiola marginata Eichw.
Modiola volhynica Eichw.
Cardium protractum Eichw.
Cardium obsoletum Eichw.
Cardium plicatum Eichw.
Cardium lithopodolicum Dub.
Cerithium disjunctum Sow.
Cerithium rubiginossum Eichw.
Cerithium mitrale Eichw.
Corbula sp.
Spirorbis sp.
Ervilia podolica Eichw.
Buccinum duplicatum Sow.
Trochus sp.
Melanopsis impresa Kraus.
Serpula spiralis Eichw.
Hydrobia sp.
Dentolina
Modiolae (Small)
Gastropods (Small)
etc.

The stratum which contains these fossils is always higher than that described under *a*).

2. The middle Sarmatian (Bessarabian Sim.) is represented by beds of sandstone, sand, and conglomerates with shales, at Stoenesti, Buleta, Dianul (S. de Slatioara), at Marita determined by Redlich, Racovita, Polovraci, Ursani, Baia de fer, Novaci, Sacel, Surpati, and at Ciuperceni (in Oltetu valley), determined by Fontannes,[2] and is characterized by *Mactra Fabreana* d'Orb., *Tapes gregaria* Partsch, etc. I may here mention the conglomerates from Crasna, Suseni, Dobrita, at the skirt of the mountains which contain:

Cardium protractum Eichw.
Cardium lithopodolicum Eichw.
Modiola marginata Eichw.
Syndosmya reflexa Eichw.

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[1] Fontannes mentions some Sarmatian fossils from Ramnicul Valcei, Episcopia, Cetatuia, Glimboaca, etc.: "Faune malacologique tertiaire de Roumanie," *Archives du Muséum d'Histoire naturelle*, Lyon, 1886. From Episcopia (Roumicu Valcei) he described *Tapes gregaria* var. *Ramnicensis.*

[2] From here comes *Mactra Stefanescui.*

Mactra Fabreana d'Orb.
Mactra fragilis Lask.
Mactra Neritina sp.
Morenstermia inflata Andr.
Serpula gregalis,
etc.

This horizon of the Sarmatian penetrates also into the Mehedenti Plateau at Tismana, Sohoholu, Baia de Arama, etc. At Tarnita (Baia de Arama) I found *Cerith. mitrale*, which demonstrates that the upper beds of the conglomerates, considered by Sabba Stefanescu to be Tortonian, must in part be classified as Sarmatian.

3. The upper horizon (Kersonian Sim.) consists of sands, sandstone and argillaceous marls; it is not rich in fossils. At Buleta, in calcareous conglomerates and conchiliferous limestone, I have found: *Mactra caspia* Eichw., *M. bulgarica* Toula, *Cerithium disjunctum* Sow. cf. *Constantiae* Sabba, *Cardium* sp., *Hydrobriae*, and *Dosinia exoleta* L.

It is interesting to note that in the conglomerates and conchiliferous limestone at Titireciu there occur also *Dosinia exoleta* and *Modiola Volhynica* Eichw., *var. minor* Andr., etc., etc., which would indicate the first appearance of the Mœotic stage in this country.

Toward the west I have found no evidence for the extension of the Mœotic assise in that direction. Possibly the beds with *Helicidæ* between the strata with brackish and subbrackish fossils, and the strata with *Valenciennesia* and *Limnea*, belong to the Mœotic stage; in Mehedinti similar marls with *Globigerinae* and *Orbulinae* were classified by S. Stefanescu and Fuchs as Sarmatian.

In the middle and upper horizons of the Sarmatian (Aninis, Sacel, Buzesti, Surpati, etc.) many plant remains[1] and bones of vertebrates have been found.

The mineral springs which appear in the Sarmatian at Pausesti, Costesti, Ramnic, Polovraci, Novaci, Maghiresti, Balanesti, etc., owe their salts and H_2S to the pyrites and other minerals which occur among the shingle of the Sarmatian conglomerates and sand, just as is the case in the Eocene conglomerates. The emanations of natural gas in the Dracoaia valley, Maghiresti, etc., are very probably derived from the oil-bearing Eocene or Tortonian substratum.

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[1] Some remains of plants collected by Gr. Stefanescu in this region were described by A. Marion and L. Laurent (*Annuaire du Musée de Géologie et Paléontologie*, 1895).

G. THE PONTIC STAGE

While we find Pontic formations with a well-marked fauna, northward from the Slatioara anticline, it would appear that they do not exist northward from the Ocnele mari anticline. At Fundatura, Smeuretu and Cacova we meet with some thick shingle beds without fossils and with a torrential character. They lie on top of the conglomerates with shales and conchiliferous limestone of Titireciu, in which I found *Dosinia exoleta* and *Modiola volhynica* var. *minor*, indicating the uppermost Sarmatian, perhaps the Mœotic, so that, at all events, the highest shingle may be Mœotic or perhaps Pontic, but without certainty. To the west of the salt region the Pontic beds, after forming a bend around the Magura Slatioara island, are prolonged eastward as a gulf extending up to Bistrita Massif and the Carpathian Mountains. As to facies, the Pontic deposits are very variable. Along the skirt of the mountains and at Magura Slatioara they retain the facies of the cones of dejection, as did the Tortonian and Sarmatian deposits. It is of interest that in the lower strata of the Pontic, at Coada Magura, in the sandy marls intercalated between conglomerates and shingle, I have found *Helicidae*, which would indicate the presence of dry land in the vicinity. Teisseyre and others consider the *Helix* layers as Mœotic.

Southward from Slatioara we have a uniform zone of yellow sand, with greenish or bluish marls and clays, and a seam of lignite, etc., which comes from the east, from Arges, and runs westward parallel to the skirt of the mountains, right up to the Danube in Mehedinti. In the Subcarpathian region, from Horezu westward up to Baia de Arama and even farther, the facies of marls, with small sand beds as bands, is the predominant one. At Novaci, Aninis, Porceni, etc., along the skirt of the mountain, we can convince ourselves that this facies is the somewhat distant continuation of the sand and shingle conglomerates of the cones of dejection. This is an important fact which explains to us the orographical and hydrographical conditions under which these formations, and the similar ones in the Sarmatian salt formation and even Burdigalian strata, have been deposited.

The thickness of this facies is enormous, and constant in the Jiu valley and west of it. All the rivers—Gilortu, Jiu, Bistrita, and their affluents—have cut their beds deep into this formation. At

Targu Jiu a well was bored 250^{m} deep, and only fine banded marls were found, without any other rock, lower layers not being reached. Through the whole of its extent this facies contains very many *Cypris* and small *Hydrobiae*, and traces of plants, especially algæ. In such deposits, or in their representatives among the conglomerates, I have found *Unionidae* and *Congeriae* in several localities, where Sabba Stefanescu and Redlich and I have also found *Mactrae* and *Modiolæ*, etc. Sabba Stefanescu has emphasized the fact of the mixture of the Sarmatian marine fossils with fresh-water species;[1] and I agree with Andrussow and Laskareff in thinking that also in Oltenia the transition from the Sarmatian beds to the conformable Pontic ones is through the Mœotic layers.

Westward from Oltetu I have found, in the lower marls and sand, the following characteristic Pontic fossils: *Valenciennesiae*, *Limneae*, and transition forms; then *Congeriae*, *Zagrabica*, *Dreissensidae*, *Cardii*, etc. (at Piticu, Pociovalistea, Huluba, Balcesti, Turbati, Targu Jiu, Dealul Targului, Barzesti, etc.). Among the marls there is a small bed or lenticular pocket of sand containing pyrites, which becomes changed, forming sulphates (gypsum, melanterite, epsomite, etc.) and iron oxides, etc.

Iodine and mineral water also come from these beds. In the highest horizon of the marls we find *Cardium Riegeli* Hörn., *Prosodacnae*, etc. (Bengesti-Scoarta-Zorlesti, etc.).

Eastward of Bengesti, up to Oltetu (Zorlesti, Sitoaia, Igoiu, etc.), the Pontic layers form a very flat anticline; there are deep banks of sand and shingle, sandstone and grit with *Congeriae* and *Planorbis*. Above this complex we have a bank of oölitic limestone full of *Neritinae*, *Unionidae*, *Congeriae* (and *Dreissensidae?*), etc. A similar oölitic limestone with *Neritinae* can be seen at Suseni above the Sarmatian conglomerates.[2] Above the oölitic limestone we find sand and marl beds at Negoesti-Rosia-Igoi, etc.; and then comes the lignitiferous zone with *Vivipara bifarcinata*, studied by Fontannes at Cucesti and Turcesti, Genuneni, Folestidejos, Berbesti, and by

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[1] *Palæontologie*, Vol. II.

[2] This horizon resembles closely, as facies and fauna, that described as Mœotic by W. Teisseyre in the Buzeu district, *Verhandlungen d. k. k. geol. Reichsanstalt*, 1897. I am awaiting the determination of Professor Laskareff, which will solve the question.

S. Stefanescu at Seciurile, etc. At Cucesti and Slatiora I collected a fauna which was investigated by Professor N. Andrussow, who was good enough to communicate his results to me. He found:

Dreissensia tenuissima Sinz
Dreissensia Berbestiensis Font.
Prosodacra littoralis Eichw.
Vivipara bifarcinata Biettz.
Vivipara Woodwardi Brus.
Vivipara Sadleri Partz
Cardidae sp.
Neritinae sp.
Prosodacua Munieri Sabba.
Didacua placida Sabba.
Limnocardium aff. ochetophorum.
Pyrgula aff. Siuzowi Andr.
Hydrobiae sp.
Pisidium sp.

According to the determination by Professor Andrussow, as he himself expresses it, this horizon contains a fauna with species characteristic of the blue clay facies from Odessa, and also species belonging to the upper layers between the Pontic and *Psilodon* assise. This horizon corresponds to the *II* horizon of the Pontic stage, according to the classification of Professor Andrussow.[1] Fontannes[2] and Sabba Stefanescu[3] classify the zone Cucesti-Berbesti among the highest layers of the Pontic (s. s.) stage, which is in accordance with my observations. Professor Andrussow adds, however:

> I have noted in several places (see in particular the synoptic tables in the Monograph of *Dreissensidae*) that the Roumanian Pontic stage does not quite correspond to the layers which are understood under this name in southern Russia, Austria, Austria-Hungary, and even in Italy. The lowest limit of the Roumanian Pontic—the *Congeria* layers—does, indeed, coincide with that of the south Russian Pontic, but the upper limit in Roumania is much higher than that between the Pontic and Levantine stages in Hungary and the southern Slavonic countries. Accordingly, the upper part of the Roumanian *Congeria*, or better *Cardium* layers, which are called Pontic by many authors, correspond to the deposits which in other districts are classified as Levantine.

Southwest from Slatioara, on the highroad near Cerna, and at Cristanesti (north of Cucesti), I found in the marls an intercalation of sandstone and sand which, like the horizon from Bengesti, contains many fossils: *Cardidae*, *Prosodacnae*, *Dreissensidae*, *Hydrobiae*, etc.

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[1] N. Andrussow, "Excursions dans la presqu'île de Kertch," *Guide géol. du VIIe congrès géol.*, St. Pétersbourg, 1897, Fas. XXX; *Die Neogen-Ablagerungen S. Russlands*, 1901 and 1903.

[2] Fontannes, "Contrib. à la faune malacologique des terrains tertiaires de la Roumanie," *Arch. du Muséum d'Histoire naturelle de Lyon*, Tome IV (1886).

[3] S. Stefanescu, *loc. cit.*, "Etage pontic."

In the Cerna, under the bottom of the river, the complex of marls and sandstones, many banks of alternating sandstone and marls may be seen which contain beautiful leaves of trees and *Helicidae* and *Planorbis*. I may add that these strata are very probably the continuation of the sandstone and oölitic limestone with rich mentioned fauna of the Sitoia anticline. These banks would correspond either to the *Valenciennesia* strata, or, according to Andrussow and Teisseyre,[1] to a formation which in other localities lies on, or is in continuity with, the Upper Mœotic assise. These *Helicidae*, and those from Coada Magurei, would indicate a former dry land in this region.

The corresponding strata at Slatioara and Cucesti were bent into an anticline above the Slatiora island (Figs. 3, 5, 6); a part of the Pontic strata were thrust over the folds of the salt formation. The anticline produced toward the southwest can be made out in the Oltetu valley at Nicoresti-Cursoru, etc.

1. *Andesitic tuff of Gantulesti.*—Of great importance for the Pontic petrography of Roumania is the occurrence of a lenticular bank of andesitic tuff at Gantulesti, between Madulari and Armasesti. The rock is porous, fine-grained, with sedimentary Schlieren, and with pseudo-Kaolinitic patches like the pseudomorphs of an unknown vanished mineral. Prismatic crystals of basaltic hornblende are scattered throughout the whole mass of the rock, while the glittering crystals of bytownite occur only in the white patches. The groundmass is constituted by microscopical glass lapilli, and small crystals of hornblende, bytownite, augite, olivine, etc., show shining crystal faces (110, 100, 101, 111, etc.), and form twins; and while the crystals of both are much cracked, we can still separate perfect ones up to 2^{mm} in length.

By mixture with sedimentary elements, the tuff receives a water sediment facies, and becomes sandy or marly.

The bank of tuff, about 1^{m} broad, runs eastward from the highroad some 100^{m} before it terminates; westward it crosses the river Cernazioara, and then is lost to sight because of the wood. Immediately above it we find marls and sands with *Neritinae*, large *Hydrobiae, Vivipara Woodwardi, Unionidae, Cardidae*, etc., which corre-

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[1] W. Teisseyre, "Die Helixschichten aus Buzau Distr.," *Verhandlungen d. k. k. geol. Reichsantalt*, 1899.

spond to the horizon from Bengesti-Cristanesti, underneath the lignite zone of Cucesti-Berbesti-Seciuri.

2. *The origin of palla and andesitic tuff.*—The same question arises here as in the consideration of the occurrence of palla. The structure of the tuff, unchanged for the most part, and the fact that the very fragile crystals are still perfect and undisturbed, are proofs that these rocks could not have been carried by water. It must have appeared at its present site, and undergone a redeposition at its upper surface only. Accordingly, there must have been volcanic activity in this region at the end of the Pontic age, just as we find in Transylvania, where andesites appear in the upper Sarmatic and Pontic strata. It is curious, however, that no other sign of volcanic activity can be found here, except possibly the hot spring at Bivolari, and some SO_2 emanations at Pausesti, Maghiresti, etc. Probably the volcanic region was more to the south, so that its products and remains were covered by later depositions from the Pontic and Levantine lakes. If we admit the existence of a volcanic activity in Oltenia, as in Transylvania, in the Tertiary period, we can explain the occurrence of the palla which occurs in such quantities at the convexity of the bend of the south Carpathians.[1] Professor Mrazec has described a well-preserved andestic tuff from the Bacau district, not, however, found in situ, but very interesting from our point of view. Professor Laskareff states that in my specimens containing fossils which come from Sacel, Buleta, etc., in the lower and upper Sarmatian, there are constituents of the material thrown out by a volcano. Accordingly, it is possible that in the concavity of this west bend of the Carpathians, Tertiary eruptions could have taken place, just as in Transylvania and in east Servia (Timoc valley).

3. It may be of interest to mention some other geological phenomena in relation to the Pontic deposits, particularly the marls:

a) Mineral springs at Balanesti, Pociovalistea, Ciocadia, Putul Balanescu, etc., whose origin from mineral containing sands I have mentioned above.

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[1] To explain this palla, Professor Mrazec assumes a possible connection between the salt formation from Transylvania and Moldavia through the Oituzu valley, but he observes exactly in this region that palla is wanting. A connection between Transylvania and Oltenia in the Pliocene age is less possible; but I must add that in east Servia, in the Timoc valley, dacite tuffs in the Mediterranean deposits were described by Zujovic (*Annales géolog. de la péninsule Balcanique*, 1900), etc.

b) Some mud volcanoes, the largest being at Serbesti, Basnesti Novaci, Tetila, etc. The numerous *gloduri* ("muds"), mud volcanoes in miniature, are phenomena related to those of natural gas; they occur along three lines: (1) Cernadia-Carpenis-Tetila; (2) Pitic-Pociovaliste-Turbati-Lazaresti-Tetila-Arcani, Bala, etc.; (3) Zorlesti-Balanesti-Preajba-T. Jiu, etc.

c) Natural gas at Balanesti, T. Jiu, Barsesti, Lazeresti, etc.

d) The occurrence of many beds of a red shale, natural brick or quite black or brown, porous hard stone like artificial basalt. They come in the immediate vicinity of the lignite seams, and are produced by the spontaneous burning of the lignite.

e) Petroleum occurring in the highest layers at Balteni (Gorj) in the strata with *Vivipara bifarcinata* (*loc. cit.*).[1]

The petroleum emerges from sand and gravel beds in the Valea Pacurei ("Tar Valley") and at Lacul Sarat ("Salt Lake"), and has been worked many years ago. These oil layers are quite isolated from any other oil-bearing deposits or older formations: They have as underlying, thick banks of sand and marls, and also the lower marl horizon with *Valenciennesia* more than 250^{m} thick. They are inclined at 15° toward the south-southeast, and prolonged eastward and westward over the whole of Oltenia. Neither a fault nor an important fold was observed in this horizon.

There are two ways of explaining the occurrence of Balteni oil:

(1) An underground infiltration from Paleogene or lower Miocene oil-yielding layers. Petroleum was found in the strata with *Vivipara bifarcinata* elsewhere also, and, for example, the Baicoi-Tintea-Gura Ocnitei zone (with a production of 7 per cent. of the whole production of Roumania). There petroleum was explained by L. Mrazec and Teisseyre as being in a secondary bed; it may be possible there, because that region is very folded and faulted, and the underlying Mœotic assise is very rich in petroleum (87 per cent. of the production).[2] The Pontic region of Gorjiu is, however, undisturbed. An infiltration could be only through the southern end of the Pontic assise; in this case, why should not petroleum occur also in the

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[1] Described by Gr. Stefanescu, together with some of the mineral springs of this region.

[2] Les travaux de la commission du pétrole, I, 1905.

lower strata of the Pontic stage? Balenescu at Targu Jiu, and Daniilescu at Barzesti, have made two borings (250^{m} and 80^{m}) into the Lower Pontic; strong emanations of hydrocarbons were observed, but no petroleum.

(2) This petroleum may be in relation to the repeated underlying seams of lignite and the beds which are very rich in molluscan fauna. The lignite often burns spontaneously; at Turcesti, Rosia (Valcea), Rosia Amaradia (Jiu), Negoesti, etc., it is continually burning. Some seams of this lignite are very bituminous; when they burn, they increase from seven to ten times in volume, and they smell of bitumen from afar; through their heat the adjoining shale and sandy marls, etc., are burned and metamorphosed.

In general, the phenomena are similar to those described from the Californian oil region (Santa Barbara), but the metamorphism of the red shales, brown and black stones (like basalt or jasper), etc., of Oltenia is obviously due to the burning of lignite.

I hope that the vegetable theory accepted and developed by Zuber[1] for the north Carpathian oil regions will receive a contribution by means of these facts of Oltenia. The gaseous hydrocarbon from the Lower Pontic could have their origins in the large quantity of algæ, plant, and fish remains which are abundant in the *Valenciennesia* strata. The oil from the upper strata arose, very probably, from the distillation of organic substance of the molluscan beds and lignite seams, by the burning of lignite.

H. THE LEVANTINE STAGE

The Levantine formations which occur to the south of the Subcarpathian region have been studied exhaustively by Fontannes, Fuchs, Tournouëri, Porumbaru, Sabba Stefanescu,[2] etc.; accordingly I did not presume to repeat their observations. L. Mrazec[3] has described a Levantine terrace along the skirt of the mountains westward from Jiu; east of this valley it is not well marked. According to the orography (terraces and peneplanes) in the high mountains

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[1] R. Zuber, "Kritische Bemerkungen über die modernen Petroleum-Entstehungs-Hypothesen," *Zeitsch. f. prakt. Geologie*, 1897, 6.

[2] See the discussion of this stage by Sabba Stefanescu (*loc. cit.*).

[3] L. Mrazec, "Les schistes cristallines des Carpathes méridionales," *Comptes Rendus du Congrès géol., IX*, Vienne, 1903.

and high plateau of Mehedinti, it appears that this terrace may be older than Levantine, and may very probably be Pontic. Further it is possible that here, as in the whole Subcarpathian depression, the shingle which covers the highest river terrace, and the eroded ridge of the hills, may be Levantine.

THE TECTONIC OF THE SUBCARPATHIAN REGION OF OLTENIA

1. *General consideration of the Tertiary formations.*—A comparison of the Tertiary formations of Oltenia with those from the east and north sides of the Carpathian Mountains[1] will give us a clear idea of the past of this region.

The Cretaceous and Lower Eocene Flysch shows here almost the same facies and the same relation to older klippes as in the north and east of the Carpathians: a torrential period (Cenomanian and Turonian), with deposits of coarse conglomerates, and coarse shingle consisting of crystalline rocks; a period of comparative rest (Senonian to Middle Eocene), with the deposition of layers of marls and sandstones with *Inoceramus*, corresponding to a period of upheaval of the region; and then another torrential period (end of the Middle Eocene), with deposition of conglomerates and shingle with large blocks of coral limestone with *Hippurites*. The facies of all these formations are similar around the Carpathian bend,[2] the lower horizon corresponding to the Bucegi conglomerates.

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[1] I take into consideration this region of the Carpathians, because our region is its natural continuation. The Transylvanian Basin, which is very similar to, and synchronous with the formations of Oltenia, was separated, however, from them by the south Carpathians, Although in the Mehedinti plateau, and in the Carpathians of Banat, Miocene basins are frequent, I believe that an open communication in this direction between the Miocene sea of Banat and Oltenia did not exist; the geologists of Servia (Radovanovic, Pavlovic, etc.) have shown that the Neogene fauna of northern and western Servia, like that of Banat, bears a relationship with the Panonian Neogene one, while the Neogene fauna of eastern Servia (Timoc valley) and Bulgaria is very similar to that of the south Russian Tertiary. The Oltenian Tertiary region is the northward continuation of the Servian, and its similarity with that of Russia has already been mentioned several times in this description.

[2] The explanation of the klippes and Flysch in the north and east Carpathians was given by V. Uhlig. His very appropriate hypothesis has received many confirmations through the researches of the study by L. Mrazec, Teisseyre, Sava Atanasius, Simionescu, etc., in the Carpathians of Moldavia and Muntenia. It is pleasant for me to be able to confirm the fact that the theory of the Carpathian savant is applicable in Oltenia also.

The upper deposits of the Flysch no longer show the same facies as in the east. While the lower strata still show some similarity of fauna, neither the green conglomerates (a local facies in the east) nor the characteristic menilitic schists, or the Kliwa sandstone is seen. I have shown elsewhere[1] that the upper deposits of Muereasca-Olanesti correspond to the Targu-Ocna strata; another point of similarity would exist if my suggestion, that the Eocene layers of Oltenia should have salt and petroleum, should hold.

As for the Miocene salt formation of Oltenia, its similarity with the east and west salt formations, and more especially with the Slanic and Trotus Basins, may be clearly seen from the above. I have shown that the Oltenian salt formations consist of two horizons:

a) Conglomerates, shingles, and sand, with less important colored marls, gypsum, and palla, belonging to the *I* Mediterranean Sea (Burdigalian and perhaps Helvetian in parts). Its constitution shows a coast and lagoon facies, and its relation to the Oligocene layers—in some localities conformable, but in others unconformable—and more particularly the occurrence of water-worn *Nummulites*, etc., are evidence for *the regression of the Flysch Sea, and the beginning of the Mediterranean Sea, at the end of the Oligocene, with other shores.*

The reddish facies of this horizon, with its gypsum and marls, represents a deposition at some distance from land; both facies correspond, as regards position and stratigraphy, with the similar formations of the Slanic Basin.

b) The upper horizon, gray-bluish marls with *Globigerinae*, lies above the Burdigalian in the Oltu valley, and, like the deposits of the Slanicu and Trotus Basins, is a deposition far from the Flysch shore. The palla characteristic for the Subcarpathian Miocene salt formation is represented, perhaps even more abundantly, to the west of the Olt River. It appears with the banded facies of the Burdigalian, and continues up to the upper Tortonian, like that of Transylvania. There are two kinds of palla; a genuine tuff with an eruptive crystalline facies predominant, and a levigated palla, like Trass, with a sedimentary facies predominant, just as was observed in the Slanic Basin.

Gypsum is also represented in Oltenia, and comes in the upper

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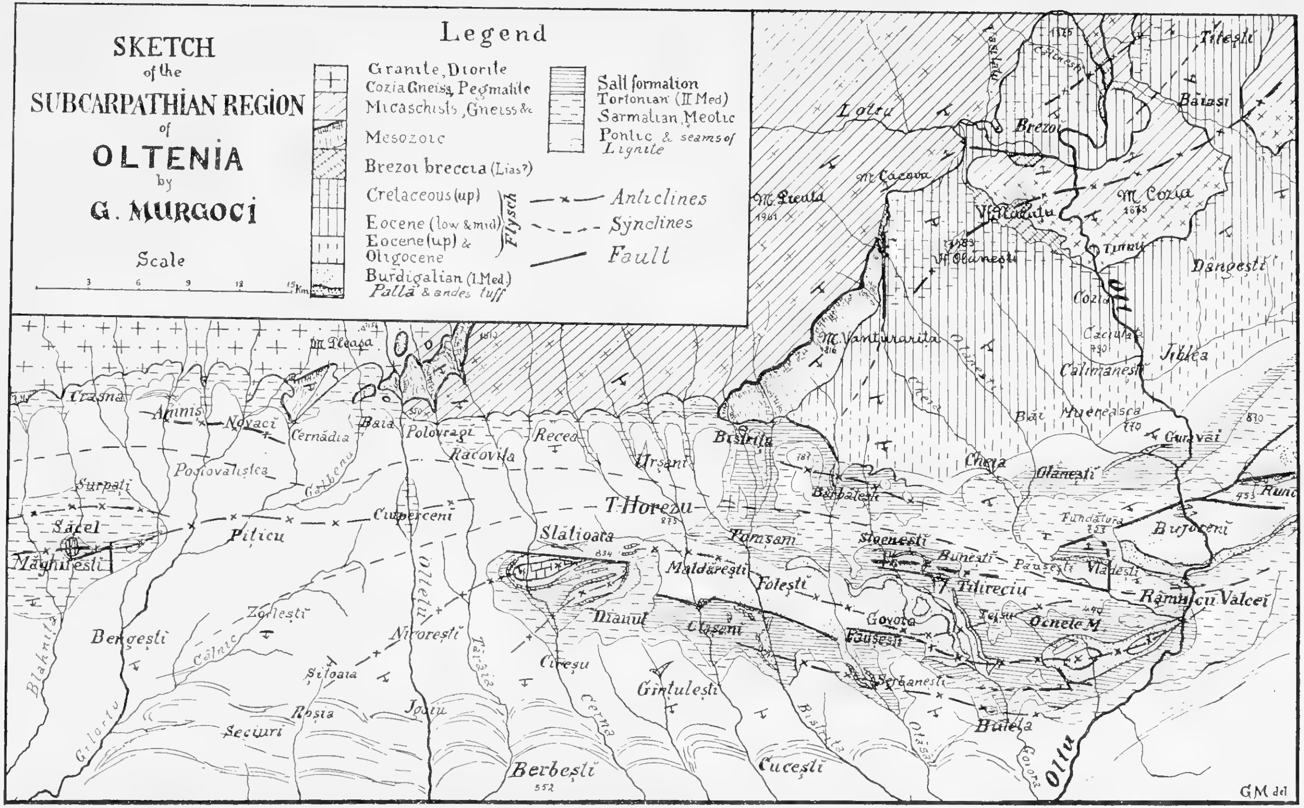
[1] *Gisements du Succin de Roum.*, 1902.


SKETCH
of the
SUBCARPATHIAN REGION
of
OLTENIA
by
G. MURGOCI
Scale
3
6
9
12
15 Km
Legend
Granite, Diorite
Cozia Gneiss, Pegmatite
Micaschists, Gneiss &c
Mesozoic
Brezoi breccia (Lias?)
Cretaceous (up)
Eocene (low & mid)
Eocene (up) & Oligocene
Flysch
Burdigalian (I Med.)
Pallă & andes tuff
Salt formation
Tortonian (II Med)
Sarmatian, Meotic
Pontic & seams of Lignite
Anticlines
Synclines
Fault
Titești
Băiași
Lotru
Brezoi
M. Cacova
M. Preuța
1961
Vf. Mălăița
M. Cozia
1675
Vf. Olănești
Turnu
Olt
Dangești
Cozia
Căciulata
Jiblea
Călimănești
M. Vânturarița
Băi Mănăstirea
Curvai
Runc
Bujoreni
Olănești
Cheia
Fundătura
Bistrița
Barbătești
Stoenești
Bunești
Păușești
Vlădești
Râmnicu Vâlcei
Tilireciu
Ocnele M.
Govora
Păușești
Șerbănești
Buleta
Oltu
M. Pleașa
Crasna
Aninis
Novaci
Cernădia
Baia
Polovragi
Racovița
Recea
Urșani
T. Horezu
Slătioara
Romani
Măldărești
Folești
Diănul
Olășeni
Surpați
Săcel
Măghirești
Poșcovalistea
Galbenu
Pitîcu
Cuperceni
Oltețu
Zorlești
Bengești
Călnic
Niorești
Sitoara
Roșia
Seciuri
Jaleu
Țărăia
Cireșu
Cerna
Gîrtulești
Berbești
552
Bistrița
Cucești
Otăsău
Govora
Blahnița
Gilortu
GM del

layers of the salt formation, very probably constituting a deposit from the *II* Mediterranean Sea, as in Moldavia, Bucovina, and Galicia, etc.

The alternation of the salt marls and palla beds with bluish marls and black cavernous bituminous limestone, perhaps containing *nullipora*, bituminous sandstone, and gypsum, is evidence that the Schlier facies includes the deposits from the *II* Mediterranean Sea, as was suggested by Hilber, and more recently by Mrazec and Teisseyre. On the other hand, the occurrence of salt marls and sand which, near Titireciu, lie immediately on the levigated palla, and which contain *Ervilia pussila*, *Syndosmya apelina*, etc., demonstrates to us the *continuity of the Mediterranean lagunar facies, in Oltenia at any rate, with the lower Sarmatian, the Buglowian assise belonging also to the salt formation.*

But while in the center of this region the marly facies predominates, at the skirt of the mountains we find a very gradual transition to the Sarmatian through the Tortonian, with its alternating layers of limestone and calcareous conglomerates. An important confirmation of this continuity is the retardation of the facies westward. Even the middle Eocene conglomerates and grit of Salatrucu have at Sacel an Upper Eocene fauna, like that of the marl facies of Olanesti. The banded facies of the salt formation is apparently deposited at Barbàtesti, Titireciu, Tomsani, and Otasani well into the Tortonian age, and the marl facies appears as part of the lower Sarmatian. Mrazec and Teisseyre have mentioned Sarmatian layers with salt facies (Prahova R. Sarat Bacau), and Ion Simionescu noticed the same behavior for the marly facies which comes under the Moldavian Sarmatian.

There is an obvious conformity between the two salt facies, although there are intercalated beds of palla. At Dianul and Otasani there follows on the salt marl a complex of marls, sands, sandstones, and calcareous marls, and above them all, conglomerates with *Mactra Fabreana.*

If we assume the same geological conditions for the Ocnele Mari Basin as for the Slanic one, the question would arise: What formed the south shore of the lagoon? It could not have been the line between Slatioara and Sacel, because the salt formation occurs also to the south of the Slatioara anticline. The torrential shingle and conglomerates, however, which near Ocnele Mari-Govora contain eroded and waterworn *Nummulites*, *Cerithium plicatum*, etc., and which are separated from the mountain deposits by a zone of the banded facies 20^{km} broad, could not have been brought from the north; they must have been carried from the south, where, accordingly, there must have been a broad dry land. The reduction in size of the salt formation southward from Slatioara, the occurrence of conglomerates, limestone (with *Lithothamnium*) at Govora, Otasani, and more particularly the coral reef (barrier reef) of Bircei-Sacel, indicate the proximity of the seashore at this point; the presence of *Helicidae* and *Planorbis* at Slatioara in the Mœotic (or Lower Pontic) is further evidence that dry land had again appeared at this time. The absence of the lower Pontic in the Olt region, and the occurrence of the andesitic tuff in the Upper Pontic, show that this dry land extended eastward from Slatioara. At Marculesti (on Baragan) in a deep boring, the Sarmatian has been found resting directly on the Cretaceous. The paleogeographical conditions of this region are represented in Fig. 11.

Accordingly, the Mediterranean Sea must have sent a gulf along the Carpathian Mountains, and later the country to the south of them was covered by brackish and fresh water from the Sarmatian and Pontic to the Levantine age. Slatioara and Sacel formed islands, and east from Sacel various organisms built up a barrier reef, as a prolongation of the Podolian-Moldavian Toltry.

From the Tortonian age on, the Oltenian

FIG. 11.—Section through the Tertiary region of Oltenia.

L=1 : 1500,000; H=1 : 100,000; L : H=1 : 15. The letters represent the same formations as in Fig. 4. *k*=Jurassic and Lower Cretaceous limestone; *Lev.*= Levantine assise; *V*=igneous rocks.

deposits are almost identical with those from the north Moldova, Bessarabia, and Volhynia. The Buglowian strata, intermediate between the Tortonian and Sarmatian, are, also represented in the Olt region, but with a degenerate salt facies.

The Oltenian Sarmatian is more complete than that from Moldavia; we can distinguish the three horizons which are described in Bessarabia, and Volhynia. The upper Sarmatian is not well developed, and is perhaps continuous with the Mœotic strata (at Buleta there is Kertch limestone). It is of interest to note that where the Mœotic appears, we do not find the Lower Pontic layers, while in the west it runs to a considerable thickness. I may further add that below Baragan only the Upper Pontic is well marked.

I now summarize the above results in the following synoptic table.

2. *Dislocations.*—A consideration of the above geological sections, and an inspection of the adjoining sketch, will give a good idea of the structure and tectonic of the Subcarpathian salt region of Oltenia. We have there a characteristic layer, the palla, which is easy to recognize and to trace, which appears in almost every valley, and which I have attempted duly to emphasize in my sections. Accordingly, a detailed description will be unnecessary. The epochs of movements coincide with those sketched by Sabba Stefanescu in his monograph on the Tertiary of Roumania, and confirmed by L. Mrazec and Teisseyre in subsequent researches.

Between the Upper and the Lower Cretaceous a series of movements and dislocations, similar to that described for the northeastern Carpathians, occurred in the Carpathians of Oltenia. It would seem as if in the southern Carpathians the movements had been more violent and intense; there is evidence to show that that part of the crystalline mountain region north and eastward from Polovragi was thrust over onto the western portion, just as the scales of a fish move one over the other.[1]

The edge of the upper scale would coincide now, after much erosion and dislocation, with the southern skirt of the mountains, the contour of the Mesozoic formations of the mountain region. Magmas coming from below have cemented together the two sur-

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[1] See on this question: G. Murgoci "La grande mappe de charriage dans les Carpathes méridionales." *Comptes Rendus de l'Académie des Sciences.* Paris, 1905.

GROUP	SYSTEM	SERIES	STAGES & SUBS.		FACIES	FOSSILS	ROCKS	OLTENIA REGIONS	ELSEWHERE
TERTIARY	NEOGENE	PLIOCENE	Levantine						
			PONTIC	Upp.	Large Basin	*Viv. bifarcinata, V. Abichi, V. Woodwardi*, etc.	Sand, clays, and marls. **Tuff** (andes.), **Lignite Petroleum.**	Lignite zone Tigveni-Cucesti-Berbesti-Rosia-Olteni.	Below Baragan, etc.
				Mid.		*Unionidae, Congeriae, Prosodacnae* without *Vipip.*	Oölitic limestone; sandstone, sand, marls.	Voitesti-Bengesti-Sitoaia-Jgoi-Cristanesti.	Prahova Buzau East Servia (Timoc Valley)
				Low.	Deep Basin	*Valenciennesia, Limnea, Pontalmira*, etc. *Fishes*, etc.	Marls, little sand and sandstone. Pyrites.	Vaidei-Slatioara-Poenau-T. Jiu-Tismana-Mehedinti.	Istrita (Kertch)
		MIOCENE	Mœotic						
			SARMATIAN	Upp.	Coast and Lagoon	*Dosinia exoleta, Modiola volhynica, Mactra caspia, Helicidae*, etc.	Conchiliferous limestone (Kertch), conglomerates, coarse sandstones.	Titireciu-Fundatura, Buleta Negoesti-Tomsani.	Podolia Volhynia Bessarabia
				Mid.	Near the Coast	*Mactra podolica, M. Fabreana, Tapes gregaria.*	Sandstones, conglomerates, limestone, marls.	Stoenesti-Negoesti-Dianu, Surpati-Oltet-Skirt of Mt.	
					Deep and Calm Sea	*Ervilia podolica, Mactra fragilis*, etc.	Sandstone with concretions, limestone.	Olanesti Valley, Sacel Rimnicu V.	Moldova
				Low.	Far from Land	*Syndosmya apelina Ervilia pusila.*	Marls, little sandstone (Tegels).	Titireciu-Dobriceni.	Buglowo Bucovina
			TORTONIAN (II Mediter. Sea)		Dejection cones, stone reef, and sea marl.	*Ostrea cochlear, Alveolina melo, Vermetus intortus, Lithothamnium ramosissimum, Pecten*, etc.	Conglomerates, Leithakalk, Gypsum, **Petroleum**? Tegels. **Palla.**	Skirt of the Mountains Sacel. Barloz-Petresti-Govora-Buha-Barbatesti.	Slanic Basin Trotosu Valley E. Galicia Podolia
			HELVETIAN?		**Subcarpathian Salt Formation.** In closed lagoon.		**Salt.** Marls, Sands, **Palla.**	Bogdanesti-Bunesti-Tomsani-Otasau, Ocnele Mari Teisu-Govora-Pausesti.	W. Galicia Transylvania Bahna Petrosani
			BURDIGALIAN (I Mediter. Sea)		Coast and torrent. delta. and far from land.	*Cerithium plicatum, Cerithium margaritaceum*	Conglomerates and shingle. **Palla, gypsum, petrol.** Sand, sandy marls, lignite.	Gua Vai-Olanesti, Bujoreni-Runcu, Ocnele M. Govora-Statiora.	
	PALEOGENE	CARPATHIAN FLYSCH	OLIGOCENE		Coast and torrential	*Nodosaria latejugata, Cerithium umpulosum.*	Sands, sandstones, and conglomerates.	Muereasca de jos. olanesti.	N. and E. Carpathians Basins B. of Glodu, Stamisoara, etc. Tirgu Ocna assise
			EOCENE	Upp.	Deep, far from the coast	*Nummulites Boucheri, N. Tournouëri, N. Budensis.*	Marls and sandstones, **amber, petroleum, salt?**	Northward from Daesti-Mueraesca Cheia.	
				Mid.	Very torrential	*Operculina ammonea, Num. Lucasana, N. perforata.*	Conglomerates, grits, etc. (Blocks of Hippurites limestone.)		
				Low?		?	Marls and silicious sandstones.		
SECONDARY	CRETACEOUS		DANIAN SENONIAN		Calm and Open Sea	? *Inoceramus Cripsii*, etc.	Sandstones with fucoids, etc.	Westward from Brezoi.	Puchow marls
			TURONIAN CENOMANIAN		Very torrential	?	Coarse conglomerates and shingle.	Northward from Vf. Olanesti and Brezoi.	Conglomerates with *Exogyra Columba.*

faces of contact, so that now only an inspection which is at once exhaustive and carried out throughout a large area can reveal the true position of the Cretaceous formations in the Carpathians. After these movements, the sea, which had deposited the Carpathian Flysch, penetrated into the heart of the crystalline region, and took possession of the Brezoi and Titesti Basin. The movements which agitated this region between Tortonian and Eocene times reappear with more intensity at the end of the Oligocene period. At this time probably there arose the Narutu-Cozia anticline, a subsidence with a fault along the north side of the Narutu-Cozia Klippe, also many undulations in the deposits of the Brezoi-Titesti Basin. At the margin of the Carpathian bend the phenomena were more intense; along the present skirt of the mountain an extensive subsidence occurred, forming a geosyncline between Bistrita-Polovragi-Novaci-Bumbesti-Baia de Arama, and Slatioara-Sacel, etc., and also a depression in the Arges-Muscel region. The retreating Flysch sea takes on the character of a Mediterranean Sea in the Olt region, and we have here the same geological and chemical phenomena as in Galicia, Muntenia, and Transylvania, viz., deposition of salt, gypsum, etc.

It would not surprise us if at the south coast of the sea there could have been found the open vents of volcanoes, as is also the case in Transylvania and Servia. These volcanoes could have furnished the ashes and tuffs of the Subcarpathian salt region.

It is noticeable that we have here a bend of the Carpathians just like the one found in eastern Transylvania, which was characterized by volcanic eruptions in this age at the south part of this bend. In the Timoc valley (eastern Servia) dacite and andesite lavas appeared also in that age.

At that time the orographic outlines of the high Carpathians were already fixed. As for the rest of the Roumanian hills and plains region, it probably formed the continuation of the Dobrogean and Bulgarian plateau. The present skirt of the mountains had been uninterruptedly a seashore from the first Mediterranean Sea until the end of Pontic times.

As the southern margin of the sea, we know only that eastward from Sacel a barrier reef developed, identical with that from northern Moldavia and Galicia.

Both at the beginning of and during the Sarmatian age some changes took place in the Olt region; here we find the Lower Sarmatian wanting, there the Upper, and in the higher deposits of the Sarmatian and Mœotic we find gypsum and blocks of palla. The sea also becomes of different character in different parts; in the Olt region subbrackish water, with *Dosinia exoleta* and *Modiola* var. *minora*, predominates; in the west the water becomes fresh, and *Valenciennesia* and *Limnea* appear.

These dislocations are contemporaneous with the large Danube fault; subsequently Pontic waters invaded the hollowed-out ground, forming a lake and depositing layers several hundred meters thick. At this time some volcanic activity made itself felt. The epoch of the most dislocations and folds which are figured in the adjoining map is posterior to the time of *Vivipara bifarcinata.*

After the deposition of the lignite seams, the syncline Rimnicu-Horezu-Piticu became accentuated,[1] between the anticlines Fundatura and Ocnele Mari. In the anticlines many fissures and land-slips have formed. The chief faults are: (1) Dosul-Fundatura-Bujoreni-Runcu; (2) Govora-Maldaresti; (3) Stoenesti-Titireciu-Vladesti-Ramnic; (4) Slatioara with a thrust of the Pontic layers over the folds of the salt formation. As secondary anticline I may note the Buleta-Serbanesti one.

At the same time, the Sacel region became faulted and corrugated, intercalating the anticlines between the mountains and the Slatioara anticline, of which the most important is the southern one. Small the faults can also be recognized (Bircei). The movements, violent in Olt region, are quite reduced in the west, so that, while the Slatioara island is transformed into an unrecognizable "pienine," the Sacel island still retains the character of a true Miocene klippe.

As a long-delayed result of the Mediterranean geosyncline, a stream chose its bed in the Levantine age alongside the skirt of the Carpathians, Gilortu westward, Matru eastward, the deposits from

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[1] L. Mrazec (*Bull. Soc. Sc.*, 1900, 1904, etc.) and E. de Martonne (*Comptes Rendus de l'Acad. Sc. Paris*, 1901 and 1904) have described this depression, and especially E. de Martonne first adduced many facts for the tectonic origin of the Subcarpathian depression; my observations, in these adjoining figures and sketch, confirm their suggestion.

which stream can be seen on the eroded hills in the Subcarpathian depression. After this, there occurred in this region small dislocations only, which changed the hydrographic lines,[1] and from this time we have the rivers of Oltenia and the south Carpathian region as we know them at present. This last phenomenon is very important for the orography and hydrography of Oltenia; to this question of paleogeography I intend soon to return.

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[1] E. de Martonne has studied this depression exhaustively, and has brought out clearly the last movements of this region and of the whole of Oltenia (*C. R. Ac. Paris,* 1904, etc.).

THE PLEISTOCENE FORMATIONS OF SANKATY HEAD, NANTUCKET[1]

J. HOWARD WILSON
Columbia University

HISTORICAL

The fossiliferous beds at Sankaty Head have been a subject of interest since first reported by Messrs. Desor and Cabot in 1849. The section has been referred to by Professor Shaler[2] as "one of the most important on the New England coast." The beds have been visited and studied by a number of well-known scientists, among whom were Professor A. Hyatt, Mr. C. H. Merriam, and Mr. Sanderson Smith, in 1875; Mr. S. H. Scudder and Mr. Richard Rathbun, a short time afterward; and, still later, Dr. F. J. H. Merrill and Dr. Arthur Hollick. While these investigators have added to the number of species reported from these beds by Messrs Desor and Cabot, they have differed somewhat in their descriptions of the beds, and in their interpretations of the phenomena presented.

The section, when first seen by Messrs. Desor and Cabot, seems, from their description, to have presented very much the appearance shown in Fig. 1, the lower clay forming twenty feet of the lower part of the section and being overlain, apparently unconformably, by the lower sands and gravels. The section at this time was freshly exposed by the cutting of the waves, but for a considerable period of years this cutting has been prevented by the northward extension of the Siasconset apron beach. The face of the bluff at Sankaty Head is now thickly covered with talus, composed of the drift material above the fossiliferous beds, and is in places overgrown with bunches of beech grass (Fig. 2).

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[1] Presented to the Faculty of Pure Science in Columbia University as a Thesis for the Degree of A.M.

[2] *Bulletin No. 53,* U. S. Geological Survey, p. 30.

RECENT WORK

During the summer of 1904 the writer made extensive excavations at this point, and exposed a section from the small dunes at the foot of the bluff, to a point several feet above the fossiliferous beds. This work revealed features differing somewhat from those previously recorded, and resulted in the discovery of a number of species which have not heretofore been reported from this point. This paper presents the results of this work, and an interpretation of the phenomena observed.

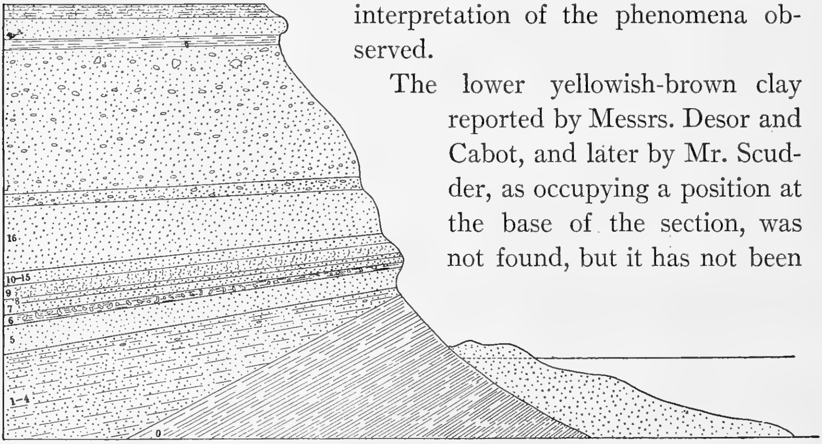

Fig. 1

The lower yellowish-brown clay reported by Messrs. Desor and Cabot, and later by Mr. Scudder, as occupying a position at the base of the section, was not found, but it has not been noticed by any observer since Mr. Scudder's investigations, and its disappearance is no doubt due to its high dip to the southwest, which, joined with the cutting back of the bluff, has caused it to sink below the level of the dune and beach sands, and thus be beyond reach of the ordinary means of excavation. Fig. 3 shows the effect of the cutting on the position of this lower clay. The dotted lines indicate the eroded portion with the clay occupying the position as first reported, while the solid lines represent the bluff approximately as it is today, with the clay hypothetically many feet beneath the dune sands, and perhaps even below sea-level.

No attempt was made to expose the section above the fossiliferous beds which constitute two-thirds or more of the bluff; but as previous investigators have found this to consist of the stratified sands and gravels normal to drift deposits, study was concentrated on the beds from the base of the bluff to the top of the fossiliferous deposits, and especially on the latter.

LOCATIONS

These Sankaty Head deposits have often proved somewhat difficult to locate on account of the depth of talus which now covers the face of the bluff. Professor F. J. H. Merrill[1] reports them as occurring "at a point about three hundred yards south of the lighthouse," and Dr. Arthur Hollick[2] refers to their position as "about a quarter of a mile south" of that structure. It is possible that they extend for some distance along the bluff, appearing at lower and lower levels toward the south, on account of the dip.

FIG. 2

The section[3] exposed by the writer was found to be roughly 375 yards south of the lighthouse tower, measured along the top of the bluff. The section is shown in Fig. 4, and described below.

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[1] *Transactions of the New York Academy of Science*, Vol. XV (1895–96), p. 11.

[2] *Ibid.*, p. 8.

[3] The fossiliferous beds were located in advance by Miss Elizabeth S. Kite.

DESCRIPTION OF BEDS

No. 1.—Light-gray sand; coarse and fine, more or less stratified and sorted, with light-colored, clayey seams ½ inch thick, which are somewhat ferruginous and hard. The coarse sand grains are rounded, the smaller are more angular and appear fresher. Small pebbles occur, mostly quartz, up to 10^{mm} (rarely 20^{mm}), which are sometimes incrusted with sand grains cemented by iron oxide.

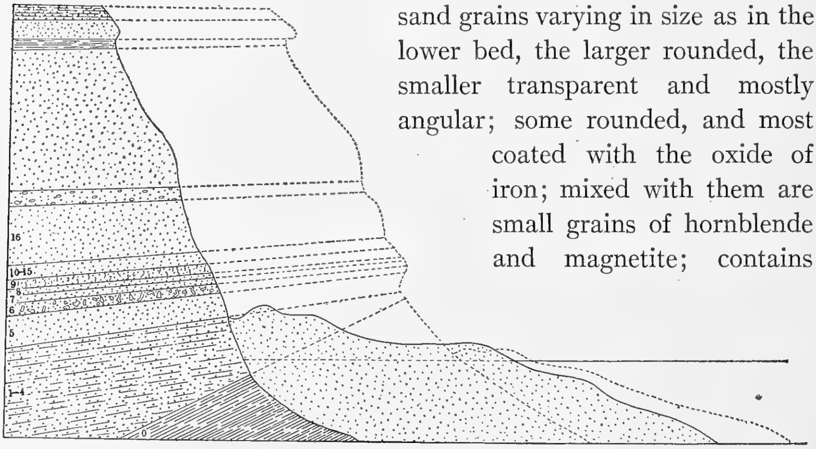

FIG. 3

No. 2.—Ferruginous gravel; sand grains varying in size as in the lower bed, the larger rounded, the smaller transparent and mostly angular; some rounded, and most coated with the oxide of iron; mixed with them are small grains of hornblende and magnetite; contains coarse rounded quartz and other pebbles up to 8^{cm}. In an excavation which was made through the talus 3 or 4 feet south from this point, this 3-inch bed was found to be 1 foot thick, with a base of hard, clayey sand, streaked with reddish-brown and blue clay.

No. 3.—Size of quartz grains uniform with minute grains of hornblende and magnetite. Quartz grains mostly angular, and transparent, ranging up to 3^{mm}; no pebbles; color slightly yellowish.

No. 4.—Ferruginous gravel; coarse and fine sand, and pebbles of quartz and other material up to 25^{mm}, rarely larger; sand and pebbles frequently cemented by iron oxide; pebbles and coarse sand grains well rounded; finest grains of sand angular and transparent; streaks of sand without iron ore are common throughout the bed; grains moderately worn, and quite transparent; larger grains show considerable grinding; black specks throughout, and small pebbles

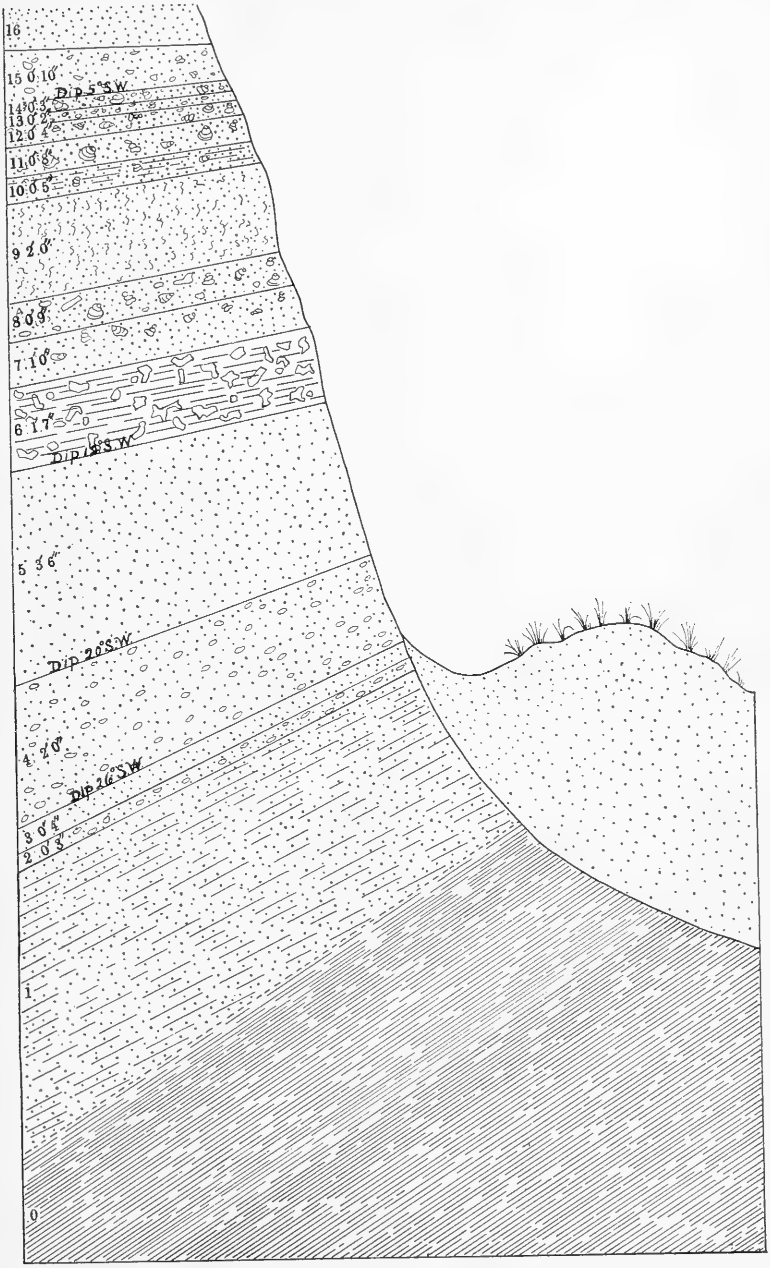
16
15 0' 10"
Dip 5° S.W.
14 0' 3"
13 0' 2"
12 0' 4"
11 0' 8"
10 0' 5"
9 2' 0"
8 0' 9"
7 1' 10"
6 1' 7"
Dip 18° S.W.
5 3' 6"
Dip 20° S.W.
4 2' 0"
Dip 26° S.W.
3 0' 4"
2 0' 3"
1
0

FIG. 4

up to 15^{mm} occasionally; light-gray and pink grains, the latter garnets, the former probably epidote; material evidently derived from disintegrated granite; minute fragments of shells found?

No. 5.—Almost pure quartz sand, grains varying moderately in size, the smaller angular and transparent, the larger rounded and ground; occasional grains up to 8^{mm}; small black grains, and also dark-green grains of glauconite; occasional garnet fragments, but no pebbles; a few streaks are ferruginated; top of bed, sand fine and angular with numerous black specks. The upper surface shows giant ripple marks in places. Lignite was found in the upper part, some in fine laminæ; one stem-like piece, 20^{mm} in diameter.

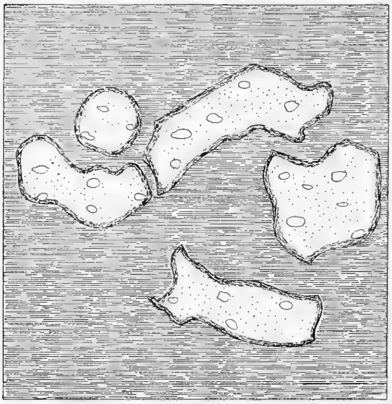

FIG. 5

No. 6.—Begins with a very fine, lutaceous sand, with mica scales and quartz grains, a rock flour with no clay odor. Higher up is blue clay, not very sticky, with faint clay odor, containing much quartz flour; pockets of ferruginous sand, which suggest decayed ferruginous concretions; one concretion found, consisting of a hard, reddish-brown shell, containing coarse ferruginous sand, and small pebbles. This structure is shown in Fig. 5.

No. 7.—Highly ferruginous quartz sand, occasional pebbles, and irregular fragments from the underlying bed. Quartz grains small, mostly rounded, and opaque by iron deposit; minute shell fragments.

No. 8.—Sand of beach type, coarse and fine, the coarse rounded and opaque, the fine angular and transparent, rounded quartz and other pebbles up to 25^{mm}. *Ostrea* extremely abundant, commonly with the valves still together, unworn and unbroken, and with barnacles still adhering to them; *Petricola pholadiformis*, with valves together and erect; *Venus mercenaria*, with valves in contact and held together by the ligament; *Mya arenaria*, with valves together and erect; *Ilyanassa*, minute *Odostomia*, and other delicate shells occur, none showing wear. Pebbles not numerous, commonly rounded, rarely angular; no clay. This is the so-called "oyster bed."

No. 9.—Quartz sand, with ground-up shell material, and often solid masses of *Serpula dianthus;* fine material, largely fine sand, common among the talus; pebbles, except small ones, not common; no clay or glauconite noticed, but bed hardens on exposure to air. Speciments of *Arca* and *Venus*, with perfectly preserved surface markings occur, many of the latter with valves together, and ligament in place. *Solen*, *Mya*, *Cummingia*, and *Ceronia* also occur with valves together, the two former noticed in their natural upright position. A number of other species occur, and some fine shell fragments. Some shells are perforated by borings and the serpulæ sometimes occur in bunches. This bed is generally referred to as the "serpula bed."

No. 10.—Coarse quartz sand, much water-worn and rounded, many of the grains coated with iron oxide. Pebbles up to 8 ^{cm} common, generally well rounded and largely of quartz; also some fine material of lutaceous character. Shell fragments, and occasionally whole shells, mostly *Venus*, found throughout.

No. 11.—Coarse and fine sand, not well assorted. Pebbles angular or sub-angular, 5–6^{cm}, and even up to 20^{cm}; quartz-porphyry quite common. Shells entire and fragmentary, with *Ostrea* and *Venus* very abundant, the latter of the var. *antiqua.*

No. 12.—Quartz sand of varying grain, full of shell fragments and rounded pebbles, generally small, but some up to 15^{cm}; shells generally fragmentary, but many delicate ones are perfect. Large *Venus*, and well-preserved *Buccinum undatum* fairly common; shell of Mactra removed, leaving a large bunch of barnacles in the bed in the position in which they had been attached to it; bed gray, from fragments of Mytilus.

No. 13.—Reddish, highly oxidized, ferruginous sand with rounded and sub-angular pebbles up to 8 ^{cm}. This is hardly a distinct bed, but is rather a more pebbly and ferruginous layer in Nos. 12 and 14 taken as one bed.

No. 14.—Like No. 12, but more shelly; resembles an uncemented coquina, full of barnacles, in places almost entirely made up of them

(*Balanus portalus*); numerous perfect, small shells and sub-angular pebbles.

No. 15.—Mussel bed; normal beach sand, in places crowded with fragments of *Modiola*, and containing complete small shells of other genera. The mussel shell fragments are generally worn; *Balanus* fragments also common; perfect *Astarte* found, and more or less fragmentary *Lunatia heros*, and *Venus* shells; fossils like those found in Nos. 12, 13, 14, but not so numerous. The upper layer is marked by rounded pebbles, generally small, but occasionally 8^{cm} in diameter; pebbles sometimes occur in the mussel layer of lower part of bed. Some of the purer layers of sand are pink, rarely yellow.

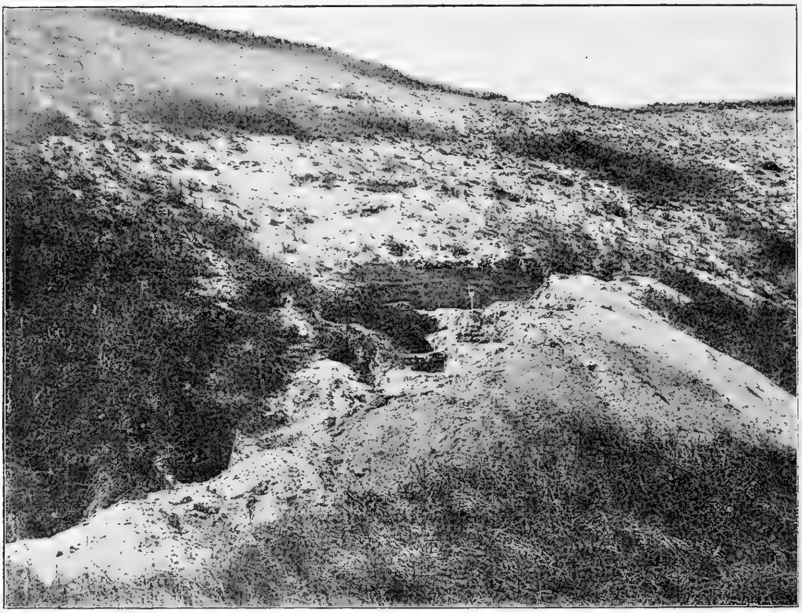

Fig. 6

No. 16.—Pure quartz sand, of varying grain, stratified and well assorted; grains all rounded and opaque, as if sand had been wind-blown before deposition; some fine streaks, almost like rock-flour, which show as very fine sand grains under microscope, and contain mica scales; occasional small pebbles up to 6^{mm}; black specks numerous in the finer streaks; rarely a small shell fragment.

The general appearance of the section toward the latter part of the work is presented in Figs. 6 and 7. A close view of the fossiliferous beds is shown in Figs. 8 and 9. No. 8, with the serpula bed above, is shown in Fig. 8, while the beds above, including the lower part of the white drift sands, appear in Fig. 9.

FIG. 7

The upper beds will be referred to now somewhat more collectively, and their more general features described.

No. 10 seems to present some transitorial features from the serpula bed below, while Nos. 11, 12, 13, 14, and 15 have frequently been classed together as the "upper shell bed," although the last has received the special name of the "fragment bed."

In the section exposed, No. 15 seems hardly to be separated as a distinct bed from the bed below, there being no sudden change of character. The shells and shell fragments of No. 14 were found to extend upward into this so-called "fragment bed," in the form of streaks and pockets, appearing less and less in the upper part.

The proportion of shell material to sand in No. 15, as compared with Nos. 12, 13, and 14, taken as one bed, was found to be considerably less. This would be expected in the resorting of material, the lighter and more soluble shell material being dissolved and borne away, leaving a greater proportion of sand. No. 15, then, has all the appearance of being a disturbed and partially assorted portion of the "upper shell bed."

FIG. 8

In exposing these beds northward along the bluff, it was found that at a distance of 25 or 30 feet from the section, No. 15 pinches out, while the three beds below have become indistinguishable and their combined thickness is only 9 inches. No. 11 also appeared finer and less shelly, and had increased in thickness to 1 foot, 6 inches. The most noteworthy fact, however, and that which is responsible for the thinning out of these upper beds, is the unconformity of

No. 16, which seems to be the lowermost member of the drift deposits, or its base. So far as the writer knows, this unconformity between the fossiliferous beds and the overlying drift deposits has never before been noticed.

The general phenomena presented by these upper beds are shown in Fig. 10, in which the vertical scale is about three times the horizontal. The thinning of the fragment bed and the unconformity between it and the overlying white sands, are also shown in Fig. 9.

FIG. 9

FOSSILS

Of the total number of species heretofore reported, only eleven were not found, and are given separately in the following list:[1]

Bryozoa
- *Membranipora tenuis Desor.*
- *M. catenularia Smett.*
- *Eschara verrucosa Esper.*
- *Celleporaria incrassata Smith* (?)

Gastropoda.
- *Scala greenlandica Perry.*
- *Eupleura caudata Say.*
- *Cerithiopsis greenii. C. B. Adams.*

---

[1] A *Panopens* has been reported from these beds, but its species not identified.

Pelecypoda.
  Arca pexata Say.
  Gouldia mactracea Linsley.
  Gemma gemma Totten.

Crustacea.
  Eupagarus pollicaris Say.

A complete list of the fossils found is given below. A number of species not heretofore reported from this locality were found. It was noticed also that a number of species were not found in the beds in which they have been reported as occurring or are more common in some other bed. The writer is of the opinion that many fossils have formerly been collected from the talus, and referred to the wrong bed; for the irregular face of the section, covered with talus, was found at first to be very confusing, and it was not until considerable work had been done that the real nature of the beds, with their sequence and characteristic fossils, was established. Many of the fossils were collected before the work had proceeded far enough to make it possible to say with certainty what beds they came from, but, as far as possible, these will be indicated by their corresponding numbers. The species not before reported from these deposits are indicated by an asterisk.

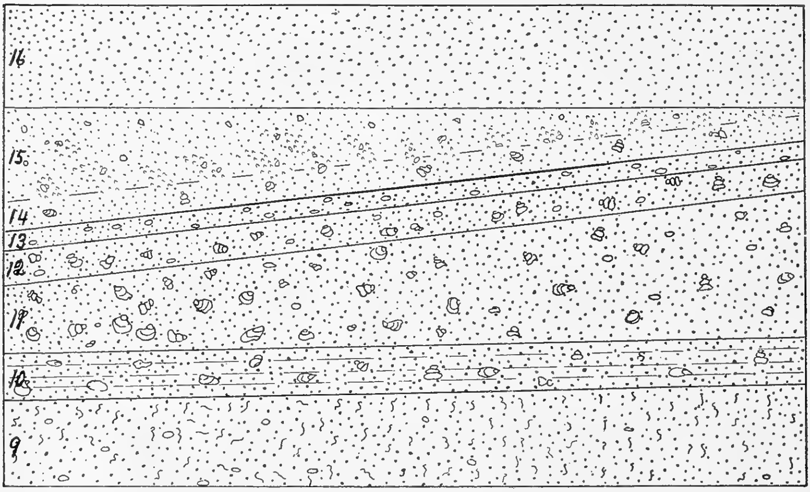

Fig. 10

In the table: x=occurs, a=abundant, c=common, r=rare.

	NUMBER OF BED				
	8	9	10	11	12–15
Porifera.					
Cliona sulphurea Desor	*a*	*x*	*x*	*x*	
Echinodermata.					
Strongylocentrotus drobachiensis Müll				*x*	spines *a*
Annelida.					
Serpula dianthus Verrill		*a*	*a*		
Bryozoa.					
Hippothoa variabilis Leidy	?	*a*	*x*	?	*x*
Pelecypoda.					
Arca ponderosa Say			?		
A. transversa Say	*a*	*a*	*a*	*a*	
Venus mercenaria Linn	*a*	*a*	*x*	*x*	*x*
V. mercenaria var. antiqua Verrill		*x*	*x*	*a*	
Ostrea virginiana Lister	*a*	*c*	*a*	*a*	*a*
Anomia aculeata Gmelin					*a*
A. simplex D'Orb					*c*
Mya arenaria Linn	*c*	*c*	*c*	*c*	*x*
M. truncata Linn					few
Mactra solidissima Chemn			one		few
**Serripes laperousii* Deshayes					one
**Pecten magellanicus* Conrad					one
Ensis directus Conrad	*c*	*c*	*c*	*c*	
Corbula contracta Say			*c*		
Mytilus edulus Linn	*x*	*c*	*x*	*x*	*c*
**M. exustus* Linn	few	?			
**Modiola plicatula* Lamk	?	?	?		
M. modiolus Linn					*c*
M. hamatus Verrill	*c*	*x*	*x*		
Crenella glandula Totten					*c*
Macoma fusca Say					few
**M. fusca var. fragilis* Say					one
**M. incongrua von* Martens					? one
Cummingia tellinoides Conrad	*c*	*c*	*c*	?	
Petricola pholadiformis Linn	*r*	*r*	*r*		
**Pholas truncata* Say			one		
**Zirfaea crispata* Linn					one
Panopea arctica (Lamk.) Gould (=*Saxicava norvegica* Linn.)					frag.
Saxicava arctica Linn					*c*
Pandora gouldiana Dall					*r*
**P. crassidens* Conrad					two valves
Astarte quadrans Gould					*a*
Astarte undata Gould					*r*
A. castanea Say					*a*
**A. crebricostata* Forbes					*r*
Ceronia deaurata Turton (=*Mesodesma*)					few
C. arctata Adams					*c*

	Number of Bed				
	8	9	10	11	12–15
Venericardia (*Cyclocardia*) *borealis* Conrad					few
V. novangliae Morse					*c*
Thracia truncata Migh. and Adams					few
Gastropoda.					
Odostomia impressa Say	*a*	*x*	?	?	
O. trifida Gould	*a*	*x*	few	few	
Turbonilla interrupta Totten	*r*				
Ilyanassa obsoleta Say		*x*	few		
I. trivittata Say					*c*
Urosalpinx cinerea (Say)	*r*	*c*	*r*	*r*	*r*
**Bittium negrum* Totten	*r*				
Cingula (*Rissoa*) *aculeus* Gould					*r*
**C. latior* Migh. and Adams					one
**Cerithiopsis terebralis* Adams					one
Skenea planorbis Forbes and Hanley					*r*
Margarita (*Solaricella*) *obscura* Couth					frag.
**M. undulata* Sowerby					one
**Fasciolaria ligata* Migh. and Adams					one
Tritonofusus stimpsoni Mörch					*c*
**Fusus tonatus* Gould					frag.
**Chrysodomus stonei* Pilsby					one
Buccinum undatum Linn					*c*
**Sipho islandicus?* Linn					frag.
Trophon scalariformis? Gould					*r*
Lunatia heros Say					*c*
L. triseriata Say					*c*
Neverita duplicata Say					one
**Littorina palliata* Gould					one
Astyris lunata Dall				*c*	
Caecum pulchellum Stimpson					*r*
Diodora noachina Gray					*r*
Crucibulum striatum Say					*r*
Crepidula fornicata Lamk	*c*	*a*	*c*	*c*	
Crepidula convexa Say	*c*	*c*	*c*	*x*	
C. plana Say	*c*	*c*	*c*	?	?
Crustacea.					
Balanus crenatus Brug					*c*
B. eburneus Gould	*c*	*c*	*c*		
B. porcatus Da Costa					*a*
**Eupanopeus herbsti* Milne-Edwards		*a*			one worn claw
**Neopanope texana sayi* Smith		*c*			
**Callinectes sapidus* Rathbun		one claw			

It will be noticed that twenty-one species new to this locality were collected. Of these a number were identified by Dr. W. H. Dall. The crab fragments were identified by Miss Mary J. Rathbun. The identification of *Serripes laperousii* Deshayes, *Macoma incongrua* von

Martens, and *Pandora crassidens* Conrad, was a surprise, as the first two belong to the arctic fauna of the Pacific coast and, according to Dall, have not heretofore been found east of Point Barrow, while the last is common in the Miocene of Maryland, and, according to the same authority, has not previously been found above that horizon. It does not seem possible that the *Pandora* could have been derived from an older bed, as all the other species are distinctly Pleistocene; and in case the material from an older bed had been disturbed and redeposited, we should expect to find a number of associated species. Moreover, the two left valves found were entirely free from any trace of an old matrix, were no more worn than the other fossils from the same bed, and were of the same color and general appearance. It would seem, then, that *Pandora crassidens* Conrad has in some localities continued on into Pleistocene times. The two Pacific species would seem to indicate that in Pleistocene times the "Northwest Passage" was more open than at present, and perhaps also that in the interglacial period in which these beds were deposited the ice had entirely disappeared from even the northern part of the continent, so as to leave the channels along the coasts of that region free from ground ice.

A single specimen of the rare species *Chrysodomus stonei* Pilsbry was found, which was first reported and described from specimens washed ashore from supposed Pleistocene beds under the sea, off the southern coast of New Jersey. This, and the Miocene *Pandora*, are the only species yet found occurring in these beds which are now extinct.

It has been a matter of comment, that not a single *Pecten* has heretofore been found at this locality in beds furnishing in abundance such species as *Ostrea virginica*, *Venus mercenaria*, and *Mya arenaria*. In looking over a quantity of material from the "upper shell bed," a two-inch shell fragment was found which seems to be clearly identified as from near the ventral margin of a specimen of our northern species, *Pecten magellanicus* Conrad.

Modiola hamatus Verrill is mentioned in former reports as common in the "lower shell bed," and was found in association with *Mytilus exustus* Linn, from which at times it is difficult to distinguish. It is probable that the latter species has been mistaken for *Modiola* *hamatus* by collectors from this locality, and all listed under the latter name.

In regard to the position in the section of *Venus mercenaria* var. *antiqua* Verrill, previous reports mention it as abundant in the "lower shell bed," but not found above this horizon. The writer found, on the contrary, that the most typical forms occurred only above the serpula bed, in No. 11, while forms less typical, and more intermediate between it and the common species, were found in the serpula bed. In this case, the name *antiqua* would be somewhat of a misnomer, as the variety would seem to represent simply a short lived mutation from the common species.

The *Astartes* as a group are very variable, presenting some puzzling differences within what may be considered a single species. Several species occur in the Sankaty deposits, and a small form which occurs very abundantly in the upper beds (over two hundred being collected), seems to have been identified in the past as *Astarte quadrans* Gould; but of the great number collected, the one which approaches nearest to *A. quadrans* of Gould seems to be identical with the variety *portlandica* of Mighels, the others differing from *A. quadrans* in a line of development far beyond even *A. portlandica.*

A number of the Sankaty Head forms are shown in Fig. 11, Nos. 6–15, while several *A. castanea* from the same locality are figured in Nos. 1–5 for comparison. The whole series of *A. quadrans* differs from *A. castanea* in their small size, excentric position of the beaks, the nearly straight anterio-dorsal margin, the absence of the broad, slightly elevated bands of growth sometimes found in *A. castanea*, and the fact that the latter has a much heavier shell, with very much higher hinge area and stronger teeth.

In the figures shown, No. 14 is almost identical with Gould's figure of *A. portlandica*, and is considered here as representing the type of that species. Most of the other forms figured, however, seem to show specific differences, being much higher and having the beaks much more excentrically situated, and should perhaps be separated as a distinct species, for which the name *sankatyensis* is proposed.

Nos. 7–12 exhibit very well this great divergence from the type of *A. portlandica*, while Nos. 6, 13, and 15 are intermediate types.

A. portlandica at the present time is more limited in its range than *A. quadrans*, and is somewhat rare.

From the fact that *A. sankatyensis* occurs only in the "upper shell bed," where it is quite common and associated with arctic species, it seems probable that it has a very northern range, or is a form which has died out, and is not represented among recent shells.

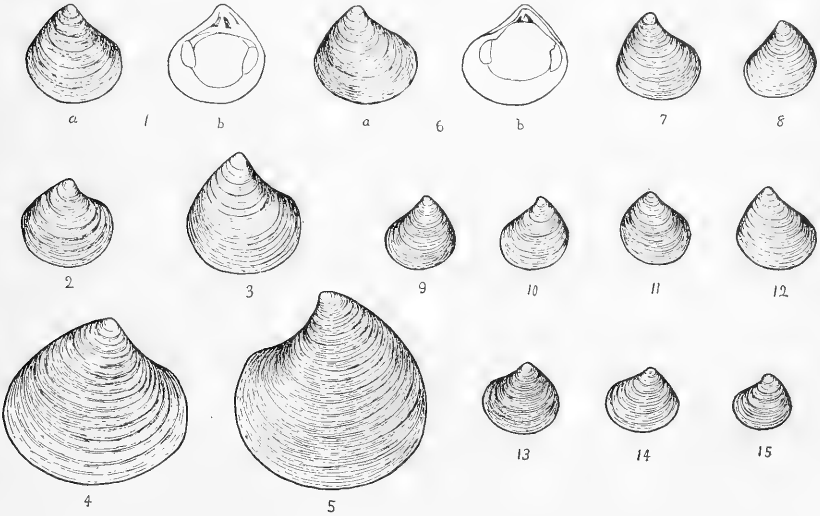

FIG. 11

INTERPRETATION

It has been thought that these fossiliferous beds at Sankaty Head were made up of old material redeposited; that the last or Wisconsin ice-sheet, moving across the sea-floor, had torn up and transported a quantity of material from old beds lying beneath the sea, and redeposited it in the present position near the ice margin. A notable case of this kind is found in the deposits containing marine fossils which are found on the flanks of Mount Snowdon in Wales, and which owe their elevated situation to the movement of the great Irish Sea glacier over the bed of that sea, and the crowding of its front with its morainal accumulations up onto the highlands of northwestern Wales.

It may be mentioned in this connection that the line of kame hills of which Sankaty Head is the eastern extension do not represent the southern limit of the ice-sheet at this point. It was found that the ice maintained a quite stationary front some three miles farther to the south, forming the well-developed contact slope which runs in a northwesterly direction from Tom Never's Head.

The writer held the same opinion in regard to these Sankaty Head deposits at the beginning of the work, the beds at that time presenting a very confused appearance, which was found later to be due to a superficial disturbance with a mingling of talus. When the disturbed portion was finally removed, however, the beds were found to present very characteristic and constant characters. That these beds could not owe their origin to glacial action, but are normal marine deposits, seems to be certain for the following reasons: (1) Numerous delicate, perfect, and unworn shells occur. (2) Numerous bivalves, already mentioned in the description of the beds, were found in the natural position in which they lived, with both valves together, and, in the case of *Venus*, with even the ligament in place. (3) There is no mixture of faunas, as would be the case in the redeposition of material from different beds. The three lower beds contain fossils which have a distinctly southern range, and are of a shallow water type; while the upper beds contain a decidedly northern fauna, many species being characteristic of arctic seas, and of considerably deeper water. Such conditions can hardly be explained except by supposing these beds to be in their original positions.

In view of the phenomena observed, and the facts ascertained in regard to these deposits, it would seem that an attempt might be made toward an explanation of their history. The lower clay noticed by early observers is probably identical with the yellowish-brown clay found elsewhere on the island, generally more or less covered by the glacial drift. This clay is apparently an old till of pre-Wisconsin age, and which, modified by erosion, formed the land surface of hills and valleys in this region before the advance of the last ice-sheet, which buried it under a heterogeneous mass of drift. At this time shallow inlets probably occupied some of the low areas between the higher land surfaces, or lagoon-like bays were to be found at points along this old shore, protected from the open sea by bars or low barrier beaches.

The Sankaty Head deposits seem to be best accounted for as having accumulated in one of these inlets or lagoons. The lower beds were undoubtedly deposited in a shallow body of water connected with, but well protected from, the open sea. This is well shown by the prevalence of such species as *Ostrea*, *Venus*, and *Mya*, and especially numerous specimens of mud crabs, and the presence of our edible crab, *Callinectes sapidus* Rathbun, which is found today in some of the little creeks connected with the harbor on the north side of the island.

Although the total thickness of the fossiliferous beds is but 8 feet a great difference is found between the lower and upper beds, showing changes in the physical conditions. At the time of deposition of the upper beds, the waters had become much colder, probably due to the return of glacial conditions, the fossils being chiefly of the northern fauna driven southward in front of the advancing ice-sheet. The fossils, besides being more northern, and in some instances even arctic, in their range, are also of species which are generally found in somewhat deeper water.

A noticeable unconformity is found between the fossiliferous beds and the overlying 10 feet of white sand (No. 16) at the point where the section was exposed, as shown in Fig. 10. These sands are very pure, and are finely stratified and assorted, the bedding being nearly horizontal. The sand grains are mostly well-rounded and worn, and at rare intervals, minute fragments of shells occur. In fact this bed, to all appearances, seems to consist of wind-blown sand derived from dunes which have been destroyed and redeposited.

It will be noticed also from the general section, Fig. 4, that there has been a gradual decrease of dip from the lowest of the beds exposed, to the uppermost of the fossiliferous beds, above which the unconformity occurs.

The upper fossiliferous beds, with their change of fauna, the apparent unconformity above, and the overlying white sands, show changes in the physical conditions which require special explanation.

There seem to be but two hypotheses which are at all applicable to the facts, and while the phenomena can hardly be reconciled to one, it will be given first, and the points wherein it fails to satisfy the conditions will be explained. The first hypothesis may be stated as follows:

After the lower beds were deposited, and the Wisconsin ice-sheet had attained considerable extension, the land began to subside as the ice advanced, while a deeper water fauna, of arctic type, driven southward by the advancing ice, lived in the region, and its shells were imbedded in the upper beds. As the ice reached Nantucket, the pressure of its front against obstructing surfaces produced a crumpling or folding of the strata, as has been observed in other regions, such as shown in Fig. 12. This folding would account for the gradual increase of dip from the top to the bottom of the section at the point indicated by the diagonal line *AB*, representing the face of the bluff in Fig. 12. After the folding had taken place, the barrier beach brought below sea-level by the subsidence of the region, was destroyed by wave-action and redeposited as the upper white sands. As the Wisconsin ice-sheet reached and passed beyond this point, it is likely that a portion of these sands was removed; but soon deposition of glacial material began to take place, and these beds were buried under the vast amount of kame sands and gravel which form the upper part of the bluff.

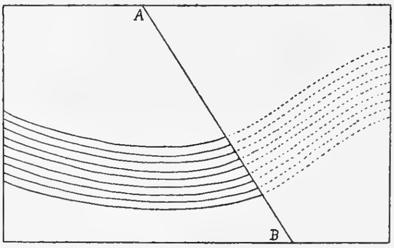

FIG. 12

This hypothesis seems to fail in the following particulars: (1) It seems improbable that the difference in dip can be accounted for in the way mentioned, because (*a*) the earliest reports on the dip of the various beds agree almost exactly with present observations, while a cutting back of the bluff, such as has taken place since the locality was first visited, should show a very different dip for the same beds as will be seen from a study of Fig. 12; and (*b*) the lateral pressure sufficient to produce this folding would be indicated by minor crumplings of the tough upper clay (No. 6), but, so far as observed, these crumplings do not occur. (2) In order to produce the folding, we must assume the ice-front to have been in the immediate vicinity, which assumption cannot be reconciled with the deposition of the upper white sands, which are of seaward origin, very pure and unmixed with any such heterogeneous material as could not fail to be present in proximity to the ice-front.

This theory, then, in its entirety, cannot be reconciled to the facts, and must be modified in some particulars.

The following hypothesis is presented as being in accord with all the phenomena observed, and probably coming nearest to the truth in an exposition of the history of these deposits:

At the beginning of this deposition, a precipitous shore probably stood to the north of the lagoon, or the lagoon itself may have been in the nature of a basin-shaped inlet, open to the south, and surrounded by steep shores of which the deeply dipping lower clay formed the portion below sea-level. A variety of material derived from this old shore by the encroaching sea before the outer bar was formed, was spread over the bottom of the basin, assuming nearly the dip of the surface upon which it was deposited, the dip becoming less and less as the basin became filled. This agrees with the coarse nature of the lower deposits, and the irregular bedding noticed. One of the lower ferruginous gravels (No. 2) was found to increase from 3 inches to 1 foot in thickness within a distance of 3 or 4 feet to the south. The dip is in the nature of a false dip, the deposits resembling very much in structure those fan-like non-marine accumulations in which the dip decreases in passing upward through the successive layers. We may consider then that the dip is an initial one, and not caused by a subsequent folding of the strata.

The lower white sands (No. 5) probably represent the washing in of some seaward material, and giant ripple marks, such as would be made by ocean waves, were found on the upper part. The lignite found in this bed is no doubt derived from seaweed and driftwood.

The lagoon or inlet now became well protected from the open sea by the development of the outer bar or barrier beach, and the upper clay of No. 6 became deposited from landward washings, on the floor of the lagoon. This now became the home of shoal water animals, as evidenced by the species which have already been enumerated. How long these conditions lasted it is of course impossible to tell, but they were brought to an end before the deposition of the upper beds. As these upper beds were formed, a subsidence of the land in this region was taking place, and no doubt connected with the advance of the huge mass of the Wisconsin ice-sheet. The water became colder, the southern fauna was driven out, and deeper-water northern, and even arctic species were present, and included in the deposits. As the subsidence continued, the barrier beach, unable to hold its own, allowed the seas to break into the lagoon, causing a disturbance of the upper deposits, the formation of the fragment bed, and the unconformity. Finally this outer bar became destroyed, and the material of which it was composed was washed into the lagoon, forming the upper white sand (No. 16).

The next event which took place was the advance of the Wisconsin ice-sheet over and beyond this region, eventually burying the deposits under 50 feet or more of drift. This last advance of the great continental glacier may have pushed its front some distance to the south of Nantucket, during which time, and during its retreat to the position in which the Nantucket terminal moraine was formed, or during the first part of this Nantucket stage, a re-elevation of the land to its present position must have taken place.

At any rate, from evidence gathered all over the island we know that the land stood not far from its present level when the ice-front occupied the Nantucket position. There is absolutely no evidence to show that the Nantucket moraine, with its apron plain and other characters, was formed below sea-level, or at any elevation essentially different from that which it occupies at the present day.

EDITORIAL.

The growing importance of economic geology finds a fitting expression in the establishment of a journal of high grade devoted especially to its interests, under the editorial direction of John Duer Irving, with Waldemar Lindgren, James Furman Kemp, Frederick Leslie Ransome, Heinrich Ries, Marius R. Campbell, and Charles Kenneth Leith as associate editors—a staff that is at once a guarantee of the new journal's high purposes and of its complete scientific control. It takes the title *Economic Geology*, and is to be a semi-quarterly. It pays this *Journal* the compliment, for which we bow our acknowledgments, of taking a similar form as well as a like period of publication. It starts with an October-November number containing a very attractive table of contents, consisting of "The Present Standing of Applied Geology," by Frederick Leslie Ransome; "Secondary Enrichment in Ore-Deposits of Copper," by James Furman Kemp; "Hypothesis to Account for the Transformation of Vegetable Matter into the Different Varieties of Coal," by Marius R. Campbell; "Ore-Deposition and Deep Mining," by Waldemar Lindgren; "Genesis of the Lake Superior Iron Ores," by Charles Kenneth Leith; and "The Chemistry of Ore-Deposition—Precipitation of Copper by Natural Silicates," by Eugene C. Sullivan; with an editorial by Irving, and Discussions, Reviews, Recent Literature on Economic Geology, Scientific Notes, and News.

It will be noted that the initial papers, chiefly by members of the editorial staff, treat of subjects of the higher order of importance, and this may doubtless be taken to foreshadow future lines of editorial endeavor. There is a notable tendency to strike at radical facts, or at underlying principles and hypotheses—a welcome feature. No less than in other fields of geology is there present need for radical treatment of economic problems. This is true not more on the economic side, in the narrow sense of the term, than on the scientific and philosophic side. Probably the greatest contribution that can now be made to applied geology is the development of the underlying principles of that portion of scientific and philosophic geology that is applicable to formations of industrial value. Contributions to this may be sought, as has been the endeavor of this *Journal*, through attempts to develop the basal science and philosophy upon which all formations depend, or it may be sought by a more selective effort, such as the new journal essays.

We extend cordial greetings to our new colleagues and wish them the success we are sure they will merit. There is a peculiar personal pleasure in extending a managing editor's welcome to the son of Roland Duer Irving, our most intimate geological friend and colleague during the years of youthful endeavor to find a place among geological workers.

T. C. C.

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