JOURNAL OF GEOLOGY.

THE
JOURNAL OF GEOLOGY

A Semi-Quarterly Magazine of Geology and Related Sciences

VOLUME X

CHICAGO
The University of Chicago Press
1902

PRINTED BY
The University of Chicago Press
CHICAGO

CONTENTS OF VOLUME X.

NUMBER I.

NUMBER II.

NUMBER III.

NUMBER IV.

NUMBER V.

NUMBER VI.

NUMBER VII.

NUMBER VIII.

THE
JOURNAL OF GEOLOGY

JANUARY-FEBRUARY, 1902

DEVELOPMENT OF THE PROFILE OF EQUILIBRIUM OF THE SUBAQUEOUS SHORE TERRACE.

THE profile of a shore as seen at any one time is a compromise between two forms. One of these is the form which it possessed when the water assumed its present level; from this form it is continually departing. The other is the form which the water is striving to give to it; toward this form it is continually tending. There is a profile of equilibrium which the water would ultimately impart, if allowed to carry its work to completion. The continual change of shore line and the supply of new drift are everchanging conditions with which no *fixed* form can be in equilibrium. There are, however, certain adjustments of current, slope and load which, when once attained, are maintained with some constancy. The form involved in these adjustments is commonly known as the *profile of equilibrium.* When this profile has once been assumed the entire form may slowly shift its position toward or from the land, but its slope will change little or not at all. It may be compared to a stream channel which has reached grade but not base level.

The force which the water exerts is derived ultimately from the wind. The immediate agencies in the work are waves and currents. It will be convenient to consider these first as acting independently of the wind which caused them, and second, as acting under its continuous influence. It is also desirable to consider waves first in their free forms, while meeting no resistance and hence doing no external work. This condition is found in deep water. The various ways in which the bottom or shore may offer resistance and be subject to work may then be discussed.

WAVES IN WATER OF INFINITE DEPTH.

When wave agitation does not reach the bottom of a body of water it is customary to speak of the depth as infinite, because the wave is not influenced by the existence of a bottom.

PURE OSCILLATION.

Orbits.—In simple oscillatory waves each water particle moves in a circular and closed orbit. The water body itself, therefore, has no onward motion. These orbits diminish rapidly with depth, but so long as agitation does not reach the bottom, the orbits are circles at all depths.[1] The particles on the crest are moving in the direction in which the wave is traveling and particles in the trough are moving with the same velocity in the opposite direction.

Differential movement.—On a line in the direction of the wave movement (hence crossing the waves at right angles) each particle is subject to a gliding between its neighbors. The amount of this gliding is of molecular dimensions, hence not infinitely small. It will be spoken of here as the differential movement of particles. For diagrammatic purposes it is convenient to consider this differential as a considerable arc of the orbit, hence particles are chosen which are removed from one another by a considerable fraction of the length of the diameter.

General form of wave.—In a series of particles moving in equal orbits each particle is more advanced in its orbit (has a more advanced phase) than the one in front of it. If a series

---

[1] This principle was clearly elucidated by Gerstner in 1804. This and other fundamental principles of oscillatory wave motion are clearly set forth in the report of the brothers Weber on their experiments conducted in the early part of the last century. See "*Wellenlehre*, ERNST HEINRICH und WILHELM WEBER, Leipzic, 1825. This report also summarizes Gerstner's work and all other previous studies on waves from the time of Newton to 1820.

of orbits be drawn and the positions of the several particles be connected by a curved line, that line will show the wave form (Figs. 1 to 6). The curve is a trochoid.[1] It may be produced by rolling a circle on the under side of a straight horizontal line.

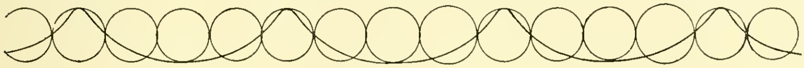


Fig 1

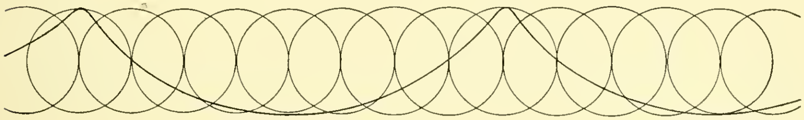


Fig 2.

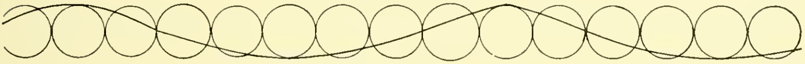


Fig 3

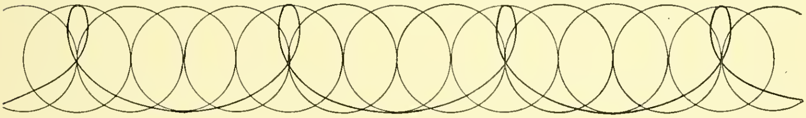


Fig 4.

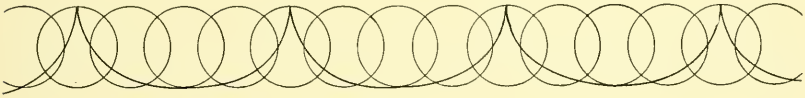


Fig 5

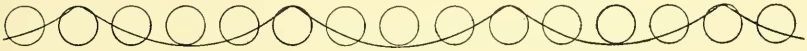


Fig 6

---

[1] First recognized by GERSTNER, *Theorie der Wellen*, Prague, 1804. See p. 343 of reprint in WEBER'S *Wellenlehre*. Discussed mathematically by W. J. M. RANKINE, "On the Exact Form and Motion of Waves at and near the Surface of Deep Water," *Philosophical Transactions*, 1863, page 127.

The path generated by any point within the circle is a trochoid. This line will be sharply curved or broadly curved, approaching straightness, according as the point which generates it is chosen near the circumference or near the center. The distance from the center to the generating point is called the tracing arm. When the point is at the circumference—that is, when the tracing arm equals the radius of the rolling circle—the curve is cusped at the top and is the common cycloid (see Fig. 8). This is the steepest and shortest form which a true wave can have. If the tracing arm be longer that the radius of the moving circle the curve is looped instead of cusped (*Fig. 4*). The failure of the water surface to assume these looped forms results in breakes.

Steepness dependent on differential movement.—If the same series of particles in their orbits be represented in several diagrams, assuming for each diagram a different amount of differential movement, the wave will be found to be long when the differential movement is small, and short when the differential movement is large (compare Figs. 1 and 2). If the size of the orbits be increased while the distance between the particles remains the same, and at the same time the differential movement continues to be a certain arc of the orbit, the wave-length remains the same, but its height and steepness increase (compare Figs. 1 and 3). If the size of the orbit be increased and the differential movement remain the same in absolute amount, instead of the same in arc, the shape of the wave will be preserved and its dimensions increased with the dimensions of the orbit (compare Figs. 2 and 3). If the differential movement exceeds a certain limit the curve will loop (see Fig. 4). This condition corresponds to that of breaking waves as noted above.

Movement of particles below the surface.—If a series of equidistant particles be considered which lie in a vertical line in still water, the movement of the topmost or surface particle is represented by any one of the orbits considered above. That of the second one is similar in every way except in size of orbit and hence in velocity. Its orbit is smaller and described in the same time. The two particles have always the *same phase* and hence their movements are parallel at a given instant. The same is true of the third particle and all below it, the orbits decreasing in a descending geometrical progression (Fig. 7).[1]

This fact is to be taken with one above stated, namely, that if orbits be decreased while the angular differential movement remains constant, the sharpness of the trochoid curve is reduced. It results from these properties that in a breaker where the curve of the surface would intersect itself, and is therefore impossible, the trochoids below the surface would show less of looping until a level is reached where normal wave motion is going on (compare Figs. 4, 5 and 6).

Lines of like phase.—If the orbits of a vertical series of particles be represented in diagram (see Fig. 7) and the corresponding points on the circles be connected with lines, then the line connecting the highest points and that connecting the lowest points of the several orbits are seen to be straight and vertical. The remaining lines are curved and inclined. In Fig. 8 these lines of like phase are shown in the positions where they occur in the wave. The particles ranged along any one of these lines would be in a vertical line if the water were at rest, just as all particles on one of the trochoid curves would lie in a horizontal line.[2]

Consequences of the trochoidal form and of decreasing orbits below.—If a horizontal plane be passed midway between the level of the crests and that of the troughs it will pass through the centers of the orbits described by the surface particles. All the water at the surface above this plane will then have a forward component, and all the water at the surface below this plane will have a backward component. An inspection of the diagrams will show that the crests are steeper and shorter than

---

[1] RANKINE, *loc. cit.* p. 131. RUSSELL, "Report on Waves made to the meeting of the British Association 1842–3," reprinted in *The Wave of Translation*, London, 1885, gives formulæ adapted from Gerstner for the rate of orbitical diminution with depth.

[2] RANKINE, *loc. cit.*, p. 129.

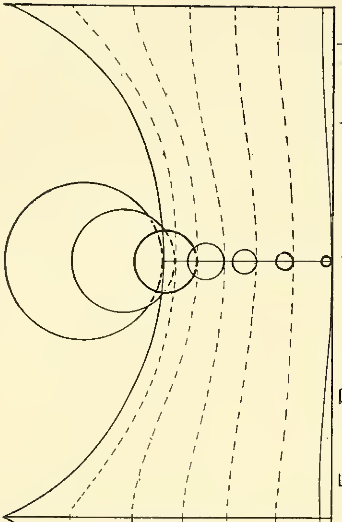


Fig. 7. Decrease of orbits with depth.

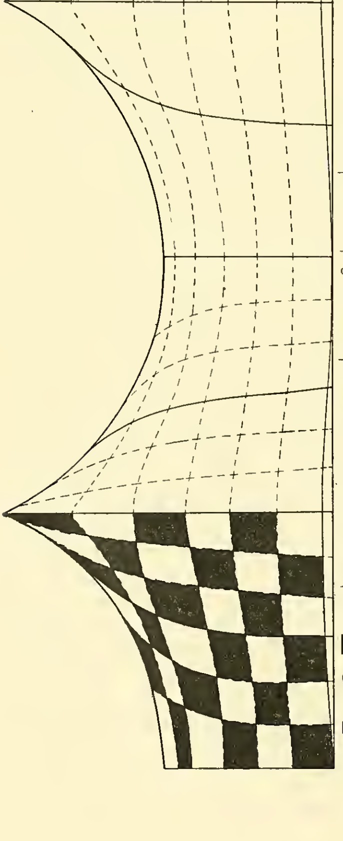


Fig. 8 Trochoid curves and lines of like phase.

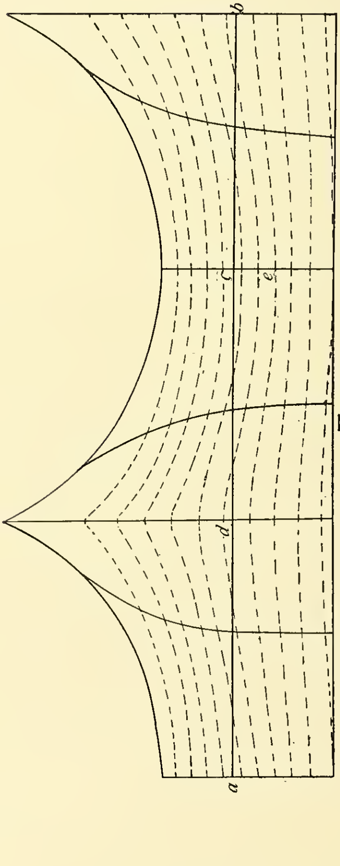


Fig. 9.

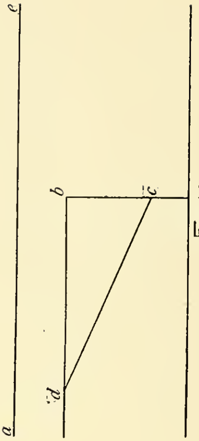


Fig. 10.

the troughs. This contrast increases as the wave shortens (compare Figs. 1, 2, and 5). The crests have not a sufficient volume of water to fill the troughs, and hence the level of the water at rest is lower than the level of the centers of the orbits which the surface particles describe. The lifting of the mean position of particles above their normal level gives a store of potential energy in the wave in addition to the kinetic energy of the motion of the water. It may be shown that this energy of position is exactly equal in amount to the energy of the water's motion.[1] This lifting and this store of potential energy are at a maximum when the wave has its greatest steepness (when it has the cycloid form).

The surface layer is thus divided into strips, in one-half of which the water is moving forward, while in the other half it is moving backward at the same rate. The peculiarity of the case lies in the fact that the backward moving strips are broader than those moving forward. Fig. 8 shows that the same is true in less degree of layers below the surface. Nevertheless, the amounts of water moving in the two directions are equal because of the greater thickness of the layers in the forward moving strips. The contrast of thickness and also of breadth disappears with depth.

MOVEMENTS DURING WIND.

Effect on size and form.—The immediate effect of wind in the direction of wave movement is to accelerate the movement of the particles on the crest. It also retards the backward motion of those in the trough, but this effect is smaller because these particles are largely protected from the wind. The result is (1) an increase in the size of the orbits; (2) an increase in the differential movement of the particles at the surface; (3) more rapid traveling of crest than trough, hence greater steepness in front. The first would result in increasing both height and length of wave in the same proportion. The second results in greater steepness, that is, a shortening in proportion to their height. The increased differential movement is accompanied by

---

[1] *Ibid.*, p. 132.

increased friction which comes at length to consume all the energy derived from the wind which cannot then further increase the height of the waves. The opposite effects are seen when the wind has ceased. Friction gradually diminishes the differential movement of particles and the size of the orbits. Waves then become lower and at the same time longer in proportion to their height.

Periodical large waves.—The change of wave-length must be propagated downward gradually. If such propagation were immediate, the wave-length at the surface would always be equal to that below. Not being immediate, there may be at times considerable differences in length. The periodical large waves always seen in a storm, may result from composition of lower and upper waves having different periods, as well as by composition of surface waves of different systems.

WAVES IN WATER OF FINITE DEPTH.

Wave base.—The extent of orbital movement decreases in geometrical progression with depth. A point is therefore reached where the force is too small to overcome the viscosity of the water. Before this point is reached and at comparatively small depths the movement is so slight that it cannot affect the smallest solid particles resting on the bottom. This level, below which the largest waves are inoperative, has been called wave-base. Its depth for any given lake or part of the ocean is a function of the height and length of the largest waves.

Behavior of water above wave-base in pure oscillation.— Before considering the action of water on a bottom which lies above wave-base it will be convenient to examine its behavior at any horizontal plane passed through a system of waves. Referring to Fig. 9, let *AB* be such an ideal plane. Being above wave-base it is in the region where the "planes of continuity" (planes including always the same particles which are in a horizontal plane when at rest) are in trochoid curves. The lines of like phase are inclined toward the crests; hence the layer of water included between two planes of continuity is not only thinner but broader under the troughs than under the crests. *In any one such layer* the water is moving forward under the crests (point *D*, Fig. 9) at the same velocity with which it moves backward under the troughs (point *E* of same layer). Of two adjacent layers the lower one is composed of slower-moving water. The line *AB*, drawn in a horizontal plane, traverses higher layers of water under troughs (at point *C*) and lower layers under crests (point *D*). Therefore the backward moving water along this plane has a more rapid motion than that moving forward. The area covered by it on the horizontal plane is also more than that covered by the forward moving water. This excess of backward movement below is the necessary correlative of the excess of forward movement above, for above the plane traversing the centers of the topmost orbits the movement on all planes is forward.

The same when waves are wind-driven.— If now the water be conceived to be driven by a wind, the current movement produced at any given depth must be added to the forward movement in the corresponding strips which lie below the crests, and subtracted from the backward movement in those under the troughs. The forward and backward velocities in any one layer between two trochoidal planes are now no longer equal. When a certain rate of current is reached, the forward movement in the lower layer traversed by the horizontal plane under the crests (point *D*, Fig. 9) will equal the backward movement in the upper layer which the plane traverses under the troughs (point *C*). A certain force of wind will therefore cause a balance of to-and-fro movements at a horizontal plane below the surface. Any greater force will cause an excess of forward motion.

Film representing surface of continuity.— If in one of the surfaces of continuity in a system of waves of pure oscillation, a film could be introduced which is perfectly flexible and frictionless, this film would show alternate depressions and elevations corresponding to those on the surface of the water, but less sharply curved. The curves would progress after the manner of surface waves. Any one point in the film would rise and fall vertically; any particle of water adjacent to it would continue to describe its normal circle, gliding to-and-fro on the frictionless film and tracing a straight line upon its surface. The diameter of this orbit is represented by the vertical distance through which any point in the film swings. If the water above the film be viewed in cross section, the area in which it is moving forward would equal that in which it moves backward.

Action on a solid horizontal plane surface.—If the film be supposed now to be stretched to a horizontal plane and to become a solid bottom of the ordinary kind, several changes become necessary in the behavior of the adjacent water particles. The up-and-down movement in their orbits becomes impossible, but the to-and-fro movement, tracing straight lines on the surface, can be continued. Observation shows that this does occur, that particles near a shallow bottom move back and forward in straight lines, and that vertical movement gradually appears in the paths of higher particles, these paths being at first very flat ovals, but becoming higher and more nearly circular as the surface is approached.[1]

The energy of the vertical movement thus interfered with is partly expended in friction on the bottom, though it is quite possible that a part of it may be used in an increased horizontal amplitude.[2] It is a matter of observation that this flattening of orbits affects the movements of surface particles as well as of those below.[3] This effect on the topmost orbits is in proportion to the degree of interference at the bottom. Very much elongated orbits indicate large friction, just as circular orbits indicate that there is no appreciable interference at the bottom.

Effect on wave-length, etc.— The immediate effect of retardation of particles in contact with the bottom must be an increased

---

[1] WEBER, *Wellenlehre*, p. 124.

[2] The observations of the brothers Weber, as recorded in the table given in *Wellenlehre*, p. 124, seem to show that the horizontal motion on a shallow bottom, while less than at the surface, is actually greater than a certain intermediate point.

[3] WEBER, *loc. cit.*

differential movement of adjacent water particles. The laws of fluids require that this differential movement be distributed throughout the series of particles reaching to the surface, though experienced to a less degree as the distance from the bottom increases. It has been shown that increased differential movement implies decreased wave-length. This shortening, accompanied by steepening, may or may not be sufficient to cause breaking. Since these effects are greater at the bottom than at the surface, the lines of like phase will incline forward. These effects — the increased differential movement, the shortening waves, and the forward inclination of lines of like phase — follow from friction on the bottom, but it is immaterial whether this friction be that of the forward-moving or that of the backward-moving water. The forward inclination of lines of like phase indicates nothing as to the movement of the water as a body. The inclination of these lines may be arrived at in another way. The retarded particles below may be thought of as having a decreased angular velocity, and hence a less advanced phase than the upper particles in the same vertical line. This would require that lines of like phase should connect them with upper particles in advance of them in the direction of wave movement.

Comparison of friction in forward and backward movement.— Looked at in cross-section, the area of the backward-moving water above the line *AB* (Fig. 9) is less than the area of forward-moving water. The areas are equal when bounded below by one of the trochoid curves. The area of backward-moving water is made smaller by the substitution of a rigid plane for the depressed part of the trochoid, and that of the forward-moving water is made larger by the substitution of a flat bottom for the curve bulging upward. This constriction and consequent greater friction of the backward-moving water makes itself felt in the form of the wave and in the bodily movement of the water.

Asymmetrical form.— The velocity of propagation of wave crests depends purely upon the behavior of particles in the upper halves of their orbits, while the propagation of troughs takes account of the lower halves only. It results from a greater orbital velocity in the upper halves that crests are propagated more rapidly than troughs.[1] The necessary accompaniment of this is the asymmetrical form, steeper in front than behind.

Resulting currents.—The constriction of backward-moving water mentioned above may be compensated either by greater velocity or by broadening the area of backward flow. Upon either of these assumptions, or upon the assumption of no compensation, certain conclusions follow from a geometrical inspection of the diagram, and these conclusions agree with observed phenomena.

Assume first that the deficiency in backward movement is uncompensated. This assumption involves an excess of forward movement which would be observed as a current, a well-known phenomenon where waves enter shallow water. On this same supposition of no compensation the area of the bottom covered by the backward-moving water is greater than that covered by the forward-moving water, and the velocity of that moving backward on the bottom is greater than of that moving forward at the same depth, because the former, being under the trough, is nearer to the surface. A current of this type would therefore be distinctly a surface feature which would not wash the bottom in the direction of its flow. It would, in fact, involve a certain amount of counter-current at the bottom, independent of any of the conditions which give rise to undertow.

Assume next that the deficiency of area of backward moving water is compensated in one of the ways above mentioned, either by greater velocity or by broadening the area. In either of these cases the backward movement on the bottom will be in excess, and will suffer more interference by friction than the forward movement will. This greater interference with the backward movement will favor, with each oscillation, a residual advance of the water as a whole, causing a progression in the

---

[1] Compare also C. S. Lyman, "A New Form of Wave Apparatus," *Journal of the Franklin Institute*, Vol. LXXXVI, p. 187.

direction of wave movement, by a process which has something in common with walking. In this way also, pure oscillation would give rise to a current.

It is evident then, that when a system of waves of pure oscillation advances over a shallow bottom, any supposition that may be made regarding the adjustment of internal movements will result in a forward flow of water above, and a dominance of movement in the opposite direction below. Owing to friction, the latter alone is never equal to the former. The resulting movement of water in the direction of wave propagation, whether it be viewed as a current or as an increase of the positive over the negative parts of ordinary waves, is not the same as waves of translation, technically so called.[1] These latter obey different laws and move with different velocities. They may be occasioned by breakers, or may perhaps grow out of oscillatory waves by gradual transition, but their movements are characterized by certain features to be mentioned later.

The return current.—As soon as a current is initiated a return of the water becomes necessary. If the process described above be supposed to take place on a shoal without shores this return may take place by another route. In this case the current may proceed as described for an indefinite time. If there is no return over another area by *horizontal circulation*, then the return must be over the same area by *vertical circulation;* that is, either above or below the original current. If the forward orbital movement above exceed the backward orbital movement below, as seems necessary, and no lateral escape is at hand, the pressure due to increased height of the water would cause a counter current which would appear below as undertow.

Action on bottom materials.—The essential value of the consideration of these currents, springing from waves of pure oscillation, is in the necessary conclusion that the *work of such waves is backward at the bottom, and not forward.* The advance of the water described is due to interference with its backward flow. The same friction which impedes the backward movement of the

---

[1] J. Scott Russell, *The Wave of Translation.*

water causes the motion which the water loses to be communicated to the materials of the bottom. The case is roughly analogous to the wheels of a locomotive, which in "flying the track" brush the sand on the track backward.

The case of wind-driven waves.—The above case is applicable only to waves of pure oscillation, which have of necessity been generated in deep water and are advancing over a shallow bottom. If the wind is blowing at the same time in the direction of wave movement, the result will be similar to that found in considering a mathematical plane above wave-base, provided, of course, that the return of the water is by horizontal circulation. The action of the wind increases the forward motion under crests and diminishes the backward motion under troughs. When the effect of this action reaches a certain amount, the influences named above, which give dominance to the backward movement at the bottom, will be counterbalanced, and any greater effect of the wind will give, at the bottom, an excess of forward movement. A moderate effect of the wind is probably usually sufficient to overcome the backward brushing due to oscillation alone. If the return is by vertical circulation, any increase in current above involves an increased reverse current below.

The case of breaking waves.—When waves generated in deep water advance over a bottom sufficiently shallow to cause breaking, a new factor is introduced. In this case there is a tendency to the formation of positive waves of translation, which may sometimes develop typically, though doubtless more often their motion enters in merely as a component. It is in the nature of these that all the particles in and under the wave form move forward and not backward, and the forward motion is the same at all depths.[1] To the extent that this factor enters, the effect on the bottom will of course be to urge material in the direction of wave movement.

---

[1] See RUSSELL, *The Wave of Translation*, p. 42; *Report on Waves*, p. 307; also D'AURIA, "A New Theory of the Propagation of Waves in Liquids," *Journal of the Franklin Institute*, 1890, p. 460. The last named is a mathematical discussion.

WAVES IN SHALLOWING WATER.

Tendency to enlargement of orbits.—When a system of waves generated in deep water reaches shallow water, certain forces operate to increase the sizes of the orbits, while others produce the opposite tendency. In general the increase of orbital motion is due to the transmittal of the motion of a larger amount of water to a smaller amount.[1]

If the shallow water be separated from the deep water by a vertical face (*BC* in Fig. 10), the change may operate in some manner similar to the following: The deep water on the right side of the figure is agitated to the depth of *C* by waves traveling toward the left. The motion of particles below the level of *B* is influenced by the vertical face *BC*, this influence being greater in proportion to their nearness. Those in contact with the surface must move in straight lines up and down, while those farther away describe ovals whose longer diameters are vertical, and whose shapes become more circular with distance from *BC*. The energy of the horizontal motion thus lost is, of necessity, partly expended in friction on the vertical face. That which remains must be devoted to increasing the vertical movement. By this means it is again communicated to the particles above the level of *B*.

If the change from deep to shallow water be gradual, the analysis of the process is essentially the same. In this case, however, the circular orbits below will give way to straight line movement, not vertical, but parallel to the sloping bottom *DC*. As before, friction will consume a part of the energy which orbital motion has lost, the remainder being expended in increased movement parallel to the sloping bottom. Of this movement the vertical component will go to increasing the vertical axis of the orbits above.

Tendency to diminishing orbits.—Along with the above tendency to increased orbits come two tendencies toward diminution. The first of these is the influence of the flatter orbits of the lower particles. It tends to diminish the vertical movement

---

[1] Compare C. S. Lyman, *loc. cit.*, p. 193.

above, but not the horizontal. The second influence toward diminution is the friction on the bottom which is shared by the particles above.

Opposite tendencies simultaneous.— On a sloping surface the opposing tendencies act at the same time. It is evident that in proportion as the slope is steep, sudden enlargement will be favored, and that slow shallowing favors reduction in size because of the long continued action of friction. Theoretically, there should be a grade on which an incoming wave should suffer no change of height, but since the form and internal movements would change, this ideal grade is not of importance in considering the work of water on the bottom.

Tendency to decreased wave-length.— If the supposed tendency toward orbital increase be balanced by the opposite tendency arising from friction, there will, of course, be no increase in the length or height. However, when waves do increase in height, showing that the orbits have enlarged, they are still very commonly diminished in length and of necessity increased in steepness. This is readily explained by the increased differential movement of particles, initiated by friction on the bottom.

Tendency to steepening due to wind.—The largest on-shore waves usually act in conjunction with the wind blowing in the approximate direction of their movement. The effect of wind on waves in deep water was seen to be similar to the effect of a shallow bottom, namely, (1) increase of orbits; (2) increase of steepness; (3) asymmetrical form. These effects may be carried to the point of breaking, even in water of infinite depth (white-caps). On a shallow bottom the effects are increased by the concurrent action of the two factors. Where there is no wind waves are commonly supposed to break in water whose depth is equal to or a little greater than the height of the waves above the level of repose.[1] When waves advancing on a shallow bottom are already strained by the wind, they may break with much regularity in much greater depths of water, equal to perhaps two, three, or four times the height of the wave. Thus while the

---

[1] RUSSELL, *Report on Waves*, p. 245.

breaker line for waves without wind is far up the slope from wave-base, it may move down indefinitely near to wave-base when the wind is active.

Tendency of wave to recover form.—Suppose a system of oscillatory waves to advance toward a shelving shore until the wave-base intersects the bottom. One effect must be produced here regardless of qualifying conditions. Bottom friction begins and that involves increased differential movement of particles, which is accompanied by shortening and steepening of waves. This implies increased internal friction, which in turn, operates to decrease the orbital motion and therefore wave dimensions. In so doing it would take away the conditions of bottom friction and its results. The wave would then return to its deep water form. Thus there is a chain of consequences from the original interference at the bottom, which involves at first the change of wave form, but later a restoration, the final result being reduction in dimensions only, suited to the diminished depth. Another decrease of depth must then be assumed if the wave be supposed to continue its contact with the bottom. *Thus there is a certain minimum slope for the bottom, upon which the waves may be propagated as a shallow-water wave.* In so far as the wave is affected by increase of orbit due to diminishing amount of water, the effect will be to hasten the deformation and to retard the recovery of form. If the wind is active it would retard the decrease of orbital movement and the minimum slope mentioned would be smaller.

Limit of tendency to recover form.—The greater the reduction of depth, the greater the increment of internal friction tending to reduce the wave size, and the greater this friction, the more rapidly does it operate to accommodate the wave dimensions to diminished depth. This corrective tendency has, however, a limit. This limit is marked by the breaking of the wave. *There is, therefore, a certain maximum slope for the bottom upon which the wave may be propagated without breaking;* at or beyond this maximum the wave breaks and other agencies come in. The effect of wind as before, is to diminish the maximum slope; hence true breakers (not whitecaps merely) may occur during a wind on a shore where waves of the same size would not break in a calm.

Effect of breaking on wave propagation.—Even when the distortion of wave form has been pressed beyond the breaking point, the effort to recover its form and habit does not cease. This effort is now favored by all the tendencies which existed before breaking and re-enforced by one more arising from the falling crests. As shown in the diagram (Fig. 4), breaking is an expression of conflicting orbits. The water above the node of the hypothetical surface does not continue the curve which it has been describing, but falls confusedly on the front of the wave. Here its downward motion is in direct opposition to the upward motion of the water in front of the crest. Thus, to the molecular resistance of friction, is added mass conflict, both of which operate to reduce wave motion. This reduction is therefore accomplished more rapidly than in the case of unbroken waves. It results from this, that waves often break at some distance from shore, and after traveling a short distance with foaming crests, recover their form and advance a long distance with crests entire. There is a certain slope on which waves will advance with nearly uniform shape and continuously foaming crests. On a gentler slope they will recover their unbroken form; on a steeper slope the first breaking occurs close to shore, and the wave form is speedily lost.

Waves of translation.—When waves of oscillation enter shallow water the habit of the water particles changes and becomes a compromise between orbital oscillation and movement of an entirely different nature, belonging to waves of translation.[1]

The essential features of the positive wave of translation, known also as the *wave of the first order* or the *solitary wave* are, (1) it is initiated by an elevation of the water surface above its normal level; (2) it is propagated without a corresponding trough and without companion crests, being entirely above the undisturbed level of repose; (3) its rate of travel is greater

---

[1] RUSSELL, *Report on Waves* and *Wave of Translation.*

than that of waves of oscillation, when like wave-lengths are assumed, the two rates having about the ratio of three to two;[1] (4) the water particles move forward and not backward, starting from rest as the wave approaches and coming to rest when the wave has passed; (5) the forward motion of particles at all depths is the same and equal to the volume of the wave divided by the depth of the water; (6) the paths of the particles are semi-ellipses in a vertical plane, the major axis being the distance through which the particle moves forward, and the minor axis varying from zero at the bottom to the height of the wave at the surface. This movement is in no sense the same as that of wind-driven waves or any other oscillatory wave motion compounded with current. It usually coexists with the latter on shallow bottoms, resulting in waves of a hybrid kind; but waves of nearly typical translatory character may sometimes be seen in nature. Whether the waves be of a pure or mixed type, the essential fact here is that a new *factor* has entered, whose action at the bottom is different from that of oscillatory waves and from that of currents.

The fact of this change to translatory character on a gently sloping beach may be seen in the behavior of floating chips which are seen to move forward on crests but not backward between crests. In place of the trough proper is a wide strip whose surface is almost flat and the water of which is standing still. The laws of translatory waves require that they move more rapidly than the oscillatory. This might be expected to reveal itself in broadening intervals between crests as waves take on the translatory character. It is probable that this *may* occur under suitable conditions. The tendency is usually more than counterbalanced by two factors. The first is the decreasing depth which is the main factor in controlling the velocity of waves of translation. The second is the increasing strength of undertow near shore which retards the translatory movement at the bottom.

As to the manner in which this new habit is developed, it may

---

[1] *Ibid.*, p. 288.

be cited that perfect waves of the first order are produced experimentally by the sudden addition of water at one end of a rectangular vessel, or by the immersion of a solid, or by a sudden pushing forward of the wall of the vessel, the effect in each case being the local raising of the water surface above the level of repose. A corresponding process in lakes or sea where the bottom becomes shallow may be found in the sudden delivery of the mass of water which falls upon the front of a breaking wave. Observation on the shores of large water bodies, such as the great lakes, would indicate that the area over which waves show a translatory element is somewhat definitely limited by the breaker line. It is probable, however, that there is also a more gradual change by which the waves become increasingly positive as the water shallows and the features of waves of the first order are thereby assumed.

If the modifications of oscillatory waves in shallowing water be reviewed while holding in mind the charactertistics of translatory waves as given above, it will be observed that these changes are all in the direction which would favor the conversion of oscillatory into translatory waves. This is seen in the increase of crests with corresponding disappearance of troughs; the growing excess of the forward movement of particles over backward movement and the increased horizontal amplitude of the lower orbits, approaching equality with that of the orbits above. For present purposes it may suffice to adopt the conception of Mr. Russell[1] who thought of the overgrown crest as

---

[1] The wave of the second order may disappear and a wave of the first order take its place. The conditions under which I have observed this phenomenon are as follows: one of the common sea waves, being of the second order, approaches the shore, consisting as usual of a negative or hollow part and of a positive part elevated above the level; and as formerly noted, this positive portion gradually increases in height and at length the wave breaks, and the positive part of the wave falls forward into the negative part, filling up the hollow. Now we readily enough conceive that if the positive and negative parts of the wave were precisely equal in height, volume, and velocity, they would by uniting, exactly neutralize each other's motion, and the volume of the one, falling into the hollow of the other, give rise to smooth water; but in approaching the shore the positive part increases in height and the result of this is to leave the positive portion of the wave much in excess above the negative. After a wave has first been made to break on the shore it does not cease to travel, but if the

falling forward into the diminished trough in the act of breaking; the trough is more than filled and the excess of water initiates a wave of translation exactly as in Mr. Russell's experiments.

Volume of undertow.— It is not necessary to suppose that the loss of velocity of the undertow is as rapid as the increase of its cross-section. This would be the case if all the upper water moving shoreward should reach the shore before turning back. The volume of the undertow would then also be constant throughout its course and its velocity would be inversely as its cross-section. But even if the loss of motion due to friction and interference of the bottom be ignored, not all the shoreward moving water reaches the shore. The on-shore motion causes elevation of level over a belt of considerable width. This broad elevation constitutes a *head* which is the cause of outward flow below. It may be shown that the average position at which incoming particles turn back and join the undertow, is at the center of mass of the head. This head is greatest at the edge of the water, hence more water turns back at that point than at any other, but the undertow which has its beginning here is constantly being augmented by that which returns toward deeper water without reaching the shore.

slope be gentle, the beach shallow and very extended (as it sometimes is for a mile inward from the breaking point, if the wave be large) the whole inner portion of the beach is covered with positive waves of the first order, from among which all waves of the second order have disappeared. This accounts for the phenomenon of breakers transporting shingle and wreck and other substances shoreward after a certain point; at a great distance from shore or where the shores are steep and abrupt the wave is of the second order, and a body floating near the surface is alternately carried forward and backward by the waves, neither is the water affected to a great depth; whereas, near the shore the whole action of the wave is inwards, and the force extends to the bottom of the water and stirs the shingle shoreward; hence the abruptness also of the shingle and sand near the margin of the shore where the breakers generally run. . . . . The residuary waves given off after breaking are wide asunder from each other, are wholly positive, and the spaces between them, several times greater than the amplitude of the waves, are perfectly flat and in this condition they extend over wide areas and travel to great distances. These residuary positive waves evidently prove the existence, and represent the amount, of the excess of the positive above the negative forces in the wind wave of the second order.—*Report on Waves*, p. 292.

Relation of the phenomena above to agitation on the bottom.—It is to be inferred from what precedes that symmetrical wave form indicates freedom from interference at the bottom, that friction below is great in proportion as crowding, steepening, and asymmetrical form above are prominent, and that where an off-shore breaker line is seen it indicates a maximum of bottom interference. It is understood in all cases that the surface effect will lag a little behind the cause below, and therefore appear a little to shoreward.

PROFILES RESULTING FROM FORCES DISCUSSED ABOVE.

In the actual operation of the forces discussed above, the resulting action on a sloping bottom may be outward at all places, or inward at all places, or outward over one part and inward over another. Forces in either direction may be gradually augmented or diminished. The different forces are capable of different combinations. Each set of conditions will lead to certain features of profile. If there be no change of condition, a permanent profile of equilibrium may be reached. The constant supply of load constitutes an ever shifting condition. Equilibrium as commonly realized depends on the uniformity of this supply.

Factors in profile-making.—The agencies which shape the marginal bottom may be treated in three groups, (1) oscillatory wave action and undertow, carrying material from shore; (2) on-shore currents and translatory wave action, carrying the material toward the shore; (3) currents alongshore. The tendency of the first group is to steepen the slope from the water's edge to the line at which its erosive power ceases, and deposition begins and to reduce the slope beyond that line. There is also for the second group a line of maximum power on the bottom, within which their effect is to steepen the profile by accumulation at the water's edge, and beyond which the slope is reduced by cutting down. Currents alongshore will be introduced later.

Conflict between on-shore and off-shore action.—The first two pairs of agencies are in conflict as to the direction in which bottom materials are to be moved. If all the water which moves shoreward must return over the same area and as a bottom current, this current would seem to have greater efficiency than the one above, moving in the opposite direction. This is certainly the case where translatory waves are not favored, as where the off-shore slope is steep. Where slope is gentle and translatory waves are well developed, they have one decided advantage. They are short as compared with the distance from wave to wave, hence all the shoreward movement of the water is concentrated into a small portion of the entire time. Divers are said to feel the passing of one of these waves as a sudden jerk between intervals of quiet. The undertow, on the other hand, has a steady flow except as interrupted by these sudden reverses.[1] The laws of energy give to these concentrated movements a much greater efficiency than to the same amount of motion more evenly distributed in time. On many shores of gentle slope, sand is worked landward, and in this process the agency just mentioned is doubtless important. The effect here referred to is that of waves of translation and is therefore inside the breaker line. It might accumulate sand on-shore but not in off-shore barriers. The dominance of shoreward action is essentially temporary (omitting currents alongshore from consideration). Its effect is to steepen by narrowing the slope. This steepening, in turn, is adverse to waves of translation.

Laws of equilibrium; eroding currents.—Ignoring the presence of a bank and the load derived from it, a current of uniform power tends to reduce the bottom to a level surface, that is, to require equal depth throughout. Equilibrium cannot exist on a level bottom where the power of the current is unequal at different places. In such cases, the depth must suffer a corresponding change until the power of water on the bottom is

---

[1] HENRY MITCHELL, "On the Reclamation of Tide-Lands and its Relation to Navigation," *Report of the U. S. Coast and Geodetic Survey, 1869*, Appendix 5, p. 85. In this paper Mr. Mitchell takes the extreme view that the sea restores to the continent "all the material washed from its bluffs and headlands." Certain exceptions are made for islands.

everywhere the same. A current of uniformly increasing power requires a uniformly increasing depth, that is, a plane slope. The opposite is true for a current of uniformly diminishing power. A current whose power is augmented at an *increasing rate*, as, for example, in geometrical ratio, requires a descent to deep water on a curve which is convex upward. Increase of power at a diminishing rate requires concavity. Loss of power at increasing rates, and loss at diminishing rates, require concavity and convexity respectively.

Uniform cutting or building.—If a uniform current on a level bottom has eroding power, the whole will be cut down at the same time, and the bottom will remain level while depth increases. In this case the load is furnished at all points equally, and is all carried forward at the same rate. If load be furnished in excess of carrying power, and at all points uniformly (as from top or sides), then the level surface of the bottom would be preserved while depth would decrease.

Load derived from the shore.—To make the case applicable to undertow, the excessive load must be supposed to be furnished at the end where the current enters upon the bottom in question. In this case deposition will first reduce the load at the end upon which it enters and at the same time reduce the depth and thus constrict the current, increasing its power. The latter influence will determine a higher level to which the bottom will be built; a level at which the power of the water is sufficient to carry the load which before was excessive. Filling will then advance forward over the bottom, the filled and unfilled portions both being level, the former growing while the latter diminishes, and the two being separated by a slope, mentioned below. It is evident that the depth at which this slope begins is determined jointly by the power of the water, the amount of the load, and the size of the fragments which make up the load.

The front.—The shape of the slope which intervenes between the area which has been filled and the bottom beyond, will be determined by the rate at which the power of the current decreases. If the loss of power were instantaneous, the slope would be simply the subaqueous earth slope. If it be in any arithmetical progression, the slope will be a plane whose steepness will vary with the rate of decrease, the slope being steeper when the rate is higher. If the loss of power be in some other manner than by arithmetical difference, the slope will show a curve which will be convex or concave according as the rate of decrease is augumented or diminished. In actual deposition by a current advancing into deep water, the decrease of power is at an increasing rate, as may be seen from the following. If a plane slope be assumed, so that depth increases in arithmetical ratio, then the velocity of the current will decrease in similar ratio, but transporting power varies as the square of the velocity, hence its rate of decrease is progressively augmented. This will require convexity of slope, a feature generally observed at the edge of embankments and subaqueous terraces. The general law of equilibrium, as given above for an eroding current still applies; current power is uniform over all parts of the bottom, if by the term *current power* is understood *power with reference to load* and the current considered is the *resultant of all conflicting currents.* In this case, while the current is acually losing power, the loss is balanced by the coincident loss of load, and the uniformity of power in comparison with load is maintained.

Presence of a bank; equilibrîum on a slope.—The presence of a bank fixes not only a horizontal limit to the bottom in question, but determines that at this limit the depth shall be zero. This involves a slope. If equilibrium is to exist on this slope in harmony with the general law stated above, the advantage in power due to shallower water on one side must be balanced in one of four ways, (1) the equality of transporting power in deep and shallow water may be partially maintained by the participation of more water where the depth is great than where it is small. In the case of undertow this has been shown to be true; (2) currents in both directions may be stronger, so that the resultant motion in one direction may be more in shallow water than in deep water, it may even be zero or it may be in the opposite direction. The factors of translatory wave motion and on-shore currents may occasion this condition; (3) the excessive power of the water on the shallow bottom may be employed in the transporting of a greater load or even in erosion. This is quite generally true; (4) the material may be heterogeneous, the larger stones coming to rest in the shallower water because of their ability to withstand the greater agitation at a higher level. Of all these reasons, it will be seen that only the first can provide for a permanent slope: the others depend upon a continual supply of fresh drift.

Necessity of a continuous supply of load.—Suppose now that a short section of coast line be enclosed between perfectly resistant walls or piers perpendicular to the shore line, and extending out to deep water. The transportation of material alongshore will thus be prevented. If the shore also be supposed to be perfectly resistant, so that no new drift can be furnished to the waves, then the profile of equilibrium, toward which the bottom will tend, is a steep descent from the water line to the depth at which undertow becomes ineffective, and then a low slope outward, following the base of effective undertow. This base is necessarily on a slope because of the increasing volume of undertow with distance from shore.

Effect of a supply of drift.—If now, drift be supplied at the shore line at a given rate, filling will occur at the foot of the steep descent leading down from the water line, until the bottom has risen to a level at which the power of the water is sufficient to transport the material at the rate at which it is furnished, and this filling will advance off-shore, ending in a convex front as shown above.

At the shoreward boundary of this filling area is an angle made by the plane of deposition, with the steeper descent leading down from the water's edge to the line at which deposition becomes possible. In an actual case, where the material of the shore yields to erosion, the water's edge is carried landward, and the first descent is not only far from vertical, but in weak material, is very gentle; probably always steeper, however, than the slope made by deposition farther out. This may be observed on almost any of the coastal charts of the United States Coast and Geodetic Survey. The east coast of Florida furnishes typical illustrations.

Normal profile; cutting coast.—The normal profile then, of a shore where the resultant of transporting power is outward, is a compound curve, which is concave near the shore, passing through a line of little or no curvature, to a convex front. Where this front rests upon the bottom below the reach of currents, the descent merges into the more level bottom by another concave curve, due to deposition from suspension. If the supply of material from the shore be cut off, the entire shelf will be cut down and its slope reduced and it will necessarily be separated from the shore by a steeper slope than before. If, on the other hand, the supply of material be suddenly increased, a smaller shelf will grow from shore on the surface of the older, for the reason that the new load, being greater, is in equilibrium with the currents at a higher level than before. The greater the load, the nearer will the surface of deposition approach that of the water. On the Atlantic coast of the United States, the depth at which the concave curve merges into the plane of deposition varies from three fathoms near the mouths of some rivers, to ten or twelve fathoms where the lead is smaller. On some parts of the Pacific coast, where the lead is small, the concave curve descends to twenty or thirty fathoms.

Normal profile; building coast.—If the resultant of shore action be to carry material landward, the general character of the resulting curve cannot be very different, since this process also produces steepening near shore. In general the velocity of shoreward motion increases with nearness to land. If the effectiveness of this motion increases with its velocity, there is no accumulation until the shore is reached. The shore is then progressively steepened by accumulation, until the force which acts shoreward can no longer carry material up against the growing component of gravity. This landward urging of sediments is commonly thought to be one of the factors in the production of off-shore barriers. It is plain, however, that unless the power of inward transportation is decreased before reaching the shore, no barrier can form. This decrease may, at times occur, for carrying power will depend not only on the velocity, but on the agitation of waves at the bottom. It has been seen that waves are rapidly reduced in size and vigor in the act of breaking. It is possible, therefore, that when the slope is so gentle that waves recover their form after breaking, thereby showing that oscillatory wave motion has been much reduced, deposition may take place along the line of wave reduction, which is essentially the breaker line. With these conditions alone, however, the growth of this feature would probably be confined to narrow limits by the undertow. It would, moreover, be a very transient feature, a mere incident in the process of shoreward transportation. The steepening of the shore, to which this process is incidental, would rapidly remove the conditions of the incident.

Variations of the compound curve.—The compound curve will be more marked in proportion as the surface of deposition is broad and its slope is gentle. Where it is narrow its significance may not appear from a profile drawn from widely spaced soundings.[1] If all the waste from the land be carried alongshore, the marginal terrace is of the cut type purely, in which the compound curve is not noticeable, the only prominent angle being that where the surface of cutting intersects the original steeper bottom.

Currents alongshore.—If the effect of currents alongshore were the same at all distances from land, they might be ignored as a factor in profile making. Their variation in strength at different distances from shore produces important results. It has been stated above that *for any one current* the power at the bottom with respect to the load must remain constant. It may also be shown that of *two currents*, each of which is furnished with load to its full capacity, the stronger, which may be supposed to dissipate gradually, will be in equilibrium with its load at the smaller depth. Hence if transportation alongshore be

---

[1] This is illustrated at many places on the Pacific coast of the United States.

distinctly greater in a zone adjacent to the land, a smaller terrace will rest upon the larger. If transportation parallel to the shore line be distinctly greater in a zone off-shore, and the supply of drift be at hand, a ridge will be built along the line of this more effective current.

Barriers.—It has been shown above that when the off-shore slope is too low for equilibrium, and there are no currents alongshore, steepening is effected, in the main, by accumulation at the water's edge, though there may be some small tendency to accumulation at or just within the breaker line. When currents are flowing, they have a zone of greater efficiency along this same line or just outside. This is because the material which they transport is more agitated by wave action, and is to some extent lifted into the current. Excessive transportation along this zone initiates the ridge which may continue to grow until it assumes the functions of the beach. It this then called a barrier.

The essential function of the barrier is to steepen the bottom slope by carrying the shore line farther out. If the slope is not abnormally low, the barrier is not needed; nor are the conditions present which make its formation possible, one of these conditions being that the agitation on the bottom at the breaker line should exceed that nearer shore. It was seen above that this condition is present, only on a deficient slope.

The slope may become deficient in several ways. The currents themselves might be the cause; or it may result from the sediments delivered by streams, as at many places on our Atlantic coast; or the gentle slope may have belonged to the original bottom over which the waters rose, as seems to have been the case with Lake Michigan in its former extension in the vicinity of Chicago. Doubtless far the most frequent occasion of deficient slope is the falling of the water level or the rising of the shore. That the immediate off-shore slope should in this case be too low, is the necessary consequence of the concavity of the normal slope near shore. The slope from the Atlantic shore line, where well removed from rivers, as on the east coast of Florida, is perhaps ten fathoms in the first two miles, but if the sea level should fall ten fathoms, or the land should rise by that amount, the new ten-fathom line would lie many miles off-shore, and new barriers might be expected. On some of the small lakes of Wisconsin, especially those without outlet, as Silver Lake of the Oconomowoc group, the falling level has found a deficient slope and barriers are constructed.

The front of the marginal shelf.—If the marginal shelf be a pure wave-cut terrace with no addition by deposit, its limit will be marked by an angle where the plane of the shelf meets the original bottom. The depth of the shelf at this edge will constantly approach wave-base, for it may be safely assumed that wherever waves can agitate, there will be sufficient current to transport. If there are currents strong enough to erode below wave-base, the shelf may be cut still lower. The hardness of the rock can make no permanent difference. This is well illustrated even in so young and small a body as Lake Mendota at Madison, Wis., where the sandstone shelves southwest of Governor's Island and Maple Bluff are cut to the same depth as the clay shelves west of Picnic Point and Second Point.[1]

If the shelf is being broadened at the same time by materials carried across and deposited on its front, there will be, between its upper surface and its steep front, a curve convex to the sky as shown above. This steeper slope begins, not at the depth where the power of the water ends, but at the depth at which the power of the water becomes insufficient to carry the entire load. From this depth the slope becomes progressively steeper to the depth at which the movement of the water is ineffective. Off the Atlantic coast of the United States, the depth at which the slope begins to steepen is usually fifty or sixty fathoms, but the maximum of steepness is not attained until a much greater depth is reached. The depth familiarly assigned to wave-base along this coast is one hundred fathoms, and this figure expresses fairly well the horizon at which the maximum steep-

---

[1] See hydrographic map issued by the Wisconsin Geological and Natural History Survey.

ness is reached. This would mean that currents become unable to carry the *whole load* at fifty or sixty fathoms, and at one hundred fathoms or less, become unable to transport anything except in suspension. If the factor of transportation in suspension did not enter, the front of such a shelf should show the subaqueous earth-slope.

It is commonly assumed as above, that undertow and wave agitation lose their efficiency at the same point, the limit of the former being determined by that of the latter. Probably this is very generally true; moreover, since wave oscillation decreases with depth in geometrical ratio at a high rate, and the decrease of its agitating power is at a rate measured by the square of this same ratio, it may readily be seen that there is a somewhat definite horizon below which wave action is ineffective. Such a condition is signalized by a somewhat definite limit to the sedimentary shelf.

Transportation beyond wave-base.—The undertow may, however, be constricted laterally and preserved from dissipation, as when the water drifts into a re-entrant curve of the shore; or deep currents may result from a system of rebounds. By either of these means the power of the lower water may be increased, so that at depths greater than that of wave-base sand or even gravel may be transported.[1] In such cases no break in the profile may be seen at wave-base. Broad sheets or streaks of sand may cover the bottom to depths far beyond this line. Such troughs as those of the great lakes, in which all the surface water may be drifted simultaneously in one direction, should especially favor vertical circulation with vigorous movements below. Wave-base of Lake Michigan, where revealed by a sharp angle at the edge of a marginal terrace, is sixty or seventy feet below the surface; yet around much of its margin, a sand covered or gravel covered bottom, concave upward, extends outward to several times this depth with little or no evidence of change of slope at wave-base.[2] This is to be expected from the

---

[1] See H. C. KINAHAN, "The Beaufort's Dyke off the coast of the Mull of Galloway," *Proceedings of the Royal Irish Academy*, Third Series, Vol. VI, No. 1.

[2] Charts of Lake Michigan, War Department.

necessarily powerful undertow. In Lake Mendota, where wave-base is not lower than twenty feet, sands and even heavy gravels are irregularly distributed over the bottom at depths frequently approaching fifty feet. Some lie at the bases of steep slopes which gravity may have helped them to descend, but others are far from slopes and plainly illustrate the erosive power of currents resulting from a concentration of movement along certain lines.

N. M. FENNEMAN.

THE UNIVERSITY OF CHICAGO.

A NEW COMBINATION WEDGE FOR USE WITH THE PETROGRAPHICAL MICROSCOPE.

Three different methods are at present in general use for determining the optical character of a mineral with the petrographical microscope. The first of these employs a quarter-mica undulation mica-plate, the second a selenite plate showing the interference color, red of the first order, and the third a quartz wedge whose interference colors run from gray of the first order to red of the third (Newton's color scale).

The underlying principle of these three methods is the same. For the examination of the optical interference figures in convergent light they answer their purpose well, but for the determination of the optical character of minerals in parallel polarized light they all exhibit one common failing. On inserting any one of them into the tube of the microscope the interference color of the mineral in the slide rises or falls abruptly to some other interference color of the color scale. This jump of the interference color, due to the sudden change of the distance between the two rays passing through the crystal, and caused by the insertion of the plate or thin edge of the quartz wedge, which in itself is so thick that it alone shows gray of the first order, is often sufficient to render the determination uncertain. In deeply colored minerals (in certain amphiboles and pyroxenes) this is particularly noticeable, for there the natural color of the mineral hides the interference color to a great extent. On inserting the plate or wedge, one observes a change of color in the mineral, but is often unable to distinguish whether the color has risen or fallen.

This fault is easily remedied by combining a quartz (or selenite) wedge which shows gray first order to red third order, and in which the ray vibrating parallel to the long direction of the wedge has the greater velocity ($\mathfrak{a}$) with a selenite plate showing green of the second order, in which, however, the ray vibrating parallel to the long direction has the lesser velocity ($\mathfrak{c}$). These two plates are cemented one above the other between glass plates (Fig. 1, cross section. Vertical scale exaggerated.)

With this arrangement the central part of the wedge (Fig. 1, A) appears dark between crossed Nicols as the effect of the quartz wedge on the light passing through at that point is exactly compensated by the selenite plate. To the right and left of A, however, the interference colors rise from dark to blue of the second order at the two ends. This wedge has therefore no noticeable effect on the rays passing through it at the center (Fig. 1, A). The interference color of the mineral seen through the wedge at this point will be the same as though no wedge were there. If, however, the wedge is pulled out or pushed in, the interference color of the mineral either rises or falls, but with a gradual transition from one color to another without an abrupt rise or fall of the color at the start.

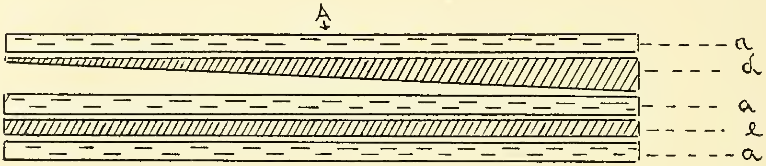


Fig. 1.

Near the center of the wedge is a point for which the difference between the two rays is $\frac{1}{4}\lambda$. This part of the wedge can therefore take the place of the quarter undulation plate.

To make the combination wedge as useful as possible, it was fitted in a metal frame of the same outer dimensions as the ordinary wedge, and with it in the same frame a short selenite plate, red first order, is placed at one end. A space is left free, and is thrown into the field when the wedge is not in use. To steady the motion of the wedge, and also to mark the position of the open space, a small steel spring is screwed onto the tube above the objective. The small rounded tip at the end of the spring presses up against the metallic rim of the wedge, and at the point where the space is in the center of the field snaps into a small pit made in the rim for the purpose.

The weak point of the ordinary wedges, that the interference colors rise or fall abruptly on their insertion, is thus remedied, and the three plates, quarter-undulation plate, red first order, and wedge are united to one wedge which remains in its place on the microscope, and which it is not necessary to remove after each determination.[1]

FRED EUGENE WRIGHT.

MICHIGAN COLLEGE OF MINES,
Houghton, November, 1901.

---

[1] The above wedge was first described in a footnote, p. 275, of "Die foyaitisch-theralitischen Eruptivgesteine der Insel Cabo Frio, Rio de Janeiro, Brasilien," von Fred Eugene Wright," TSCHERMAK'S *Minerolog. petrogr. Mittheilungen.* Bd. XX, pp. 233–306. The combination wedge is made by Voigt & Hochgesang, Göttingen, Germany. Price, 21 M. (*ca.* $5 if quartz be used. [The wedge can also be obtained from Bausch & Lomb.] The price is still less if selenite be substituted for quartz). In ordering, the dimensions of the aperture into which the wedge is to be inserted should be given, also whether the wedge is inserted into the microscope tube parallel to the horizontal cross hair, or at an angle of 45° with same.

THE MORRISON SHALES OF SOUTHERN COLORADO AND NORTHERN NEW MEXICO.

OUTLINE.

- I. Introduction.
  - 1. General statement.
  - 2. Work previously done, areas examined, etc.
  - 3. General structure of the region discussed.
- II. Places examined.
  - 1. Rio Cimarron Canyon.
    - *a*. Detailed sections.
    - *b*. Discussion of formations.
    - *c*. Exeter sandstone.
    - *d*. Unconformity at the base of the shales.
  - 2. Canadian canyon.
    - *a*. Detailed section.
    - *b*. Discussion of formations.
  - 3. Apishapa Canyon
  - 4. Foothills region.
- III. Summary and conclusions.
  - 1. The shales of the whole region form a stratigraphical unit.
  - 2. The shales belong to neither the Dakota nor the Red Beds.
  - 3. The relation of the shales to other formations.
  - 4. The possible connection between the Morrison and the Lower Cretaceous.
  - 5. Correlation of the shales with the Morrison.

THE Morrison formation is known as the Atlantosaurus beds, the Como, and the non-marine Jura. It is a persistent formation composed of colored clay-shales which contain varying amounts of impure sandstones and limestones. Its maximum thickness, so far as known, is about 400 feet, but the average thickness seems to be between 200 and 300 feet. It has an extensive distribution, but the limits are unknown. It occurs in the Black Hills, and has been reported from various parts of Wyoming. It is found over a large part of western Colorado, where it is known as the Gunnison, and outcrops east of the

Rocky Mountains throughout Colorado. Until recently the formation has not been known east of the foothills region of the Rockies, although it was supposed to extend for some distance underneath the younger formations of the plains.

During the past year, 1901, I have been interested in pushing an investigation of this formation as far as possible to the east and south in the hope of finding its limits in these directions; and in the hope also that some light might be thrown upon the age of this formation, which remains a subject of some dispute. In a recent number of the JOURNAL OF GEOLOGY (Vol. IX, No. 4, May–June, 1901) I described certain shales found in the canyons of southern Colorado, and gave reasons for considering them as the probable equivalent of the Morrison formation. Since the publication of that article, these shales have been examined by Mr. Barnum Brown, of the American Museum of Natural History, with a view to opening bone quarries in them. After an examination of several days, Mr. Brown confirmed the opinion that the shales are of Morrison age, and stated furthermore that Dinosaur bones occur from a horizon fifty feet from the base to the top of the formation. He says in a private letter:

> I identified *Morosaurus* and *Diplodocus* vertebræ, and the lithological character of the beds is identical with those (Morrison) extending along the eastern side of the Rocky Mountains.

My present purpose is to report progress in tracing this formation still further to the east and south, where it is exposed in the canyons of southern Colorado and Northern New Mexico.

Over a large part of southeastern Colorado and northeastern New Mexico occurs an extensive uplift, which, roughly speaking, seems to be in the form of an oblong dome, whose axis lies near the Colorado-New Mexico line in the vicinity of Mesa de Maya. From the center, the strata dip more or less in all directions, unless perhaps in a southwesterly direction, where data are wanting. (It is possible that more detailed work will show that the slight southwest dip shown by Mr. Hills in his map of the El Mora and Spanish Peaks regions[1] is only local,

---

[1] *U. S. Geol. Surv.*, El Moro and Spanish Peaks Folios.

and that the uplift may prove to be an anticline extending eastward from the mountains, rather than a dome.) The dome, if such it be, is in general terms bounded on the north by the Arkansas River; on the west by the Rocky Mountains; on the south by the eastward flowing part of the Canadian River, New Mexico; to the east the dip continues at least to Beaver county, Oklahoma.

The Dakota sandstone occurs throughout this region. It is an easily recognized formation, and conspicuous wherever exposed at the surface. It is, therefore, a convenient reference horizon. Over a large part of this elevated region — perhaps the eastern four-fifths — the Dakota is either the surface formation or lies so near the surface that it is exposed in the numerous canyons. Over the western fifth, the Dakota is buried beneath the younger formations to reappear along the mountain front in a nearly perpendicular reef known as "stonewall." The greatest elevation at which I have identified the Dakota is 6,300 feet,[1] at the point where I crossed the Mesa de Maya. Over a considerable area in the vicinity of Mesa de Maya, the elevation of the Dakota is practically the same. From this region northward there is a gradual descent until the Dakota drops beneath the younger formations near the Arkansas River.[2]

The westward dip of the strata is indicated by Mr. R. C. Hills in the geological maps of the folios just referred to. A study of these maps shows that the Dakota lies about 2,200 feet beneath the surface at Trinidad, Colo., *i. e.*, it lies 3,800 feet above sea level, while twenty-five miles to the east it lies at an elevation of 5,300 feet, and sixty miles east of Trinidad, where I crossed the Mesa de Maya, it lies at an elevation of 6,300 feet. There is then a westward dip of the strata in this region of 2,500 feet in sixty miles, or about forty-one feet per mile on the average. The dip of the strata in the southern, eastern, and

[1] See *U. S. Geol. Surv.*, Mesa de Maya Sheet.

[2] G. K. GILBERT, *U. S. Geol. Surv.*, *Seventeenth Annual Report*, Pt. II, "Underground Waters of the Arkansas Valley in Eastern Colorado," sections following p. 574.

FIG. 1.—Sketch map of Southern Colorado and Northern New Mexico.

northern limbs of the uplift is practically the slope of the surface, and is indicated by the contour lines[1] of the accompanying sketch map. On these three sides, the uplift has been

---

[1] The contours are taken from the maps published by the U. S. Geol. Surv.

trenched by numerous streams to a sufficient depth to expose the shales which are the subject of this paper.

There is no claim advanced that this vast region has been exhaustively studied. My purpose has been to trace the shales which underlie the Dakota sandstone, over as wide an area as possible. In so doing I have visited the canyons of the Apishapa, the Purgatory, the Rio Cimarron, the Canadian, and their tributary canyons, as well as the foothills of the mountains where the sedimentary formations are sharply upturned. The itinerary is indicated by the dotted lines on the accompanying sketch map.

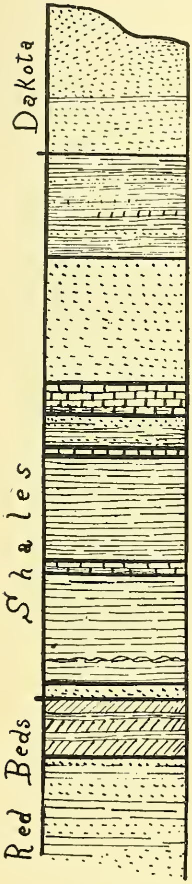
Dakota.	Sandstone, massive and quartzitic, somewhat conglomeratic in places.
Shales.	200 feet of varicolored shales with local beds of brittle limestone and lime concretions. A coarse, loose-textured, cross bedded sandstone occurs near the top·
Red Beds.	Deep red sandstone.

FIG. 2 (Sec. I). Taken in the Rio Cimarron, 14 miles east of Folsom, N. M.

Rio Cimarron Canyon.[1]—There are two Cimarron rivers in New Mexico. The one referred to here, which for distinction I shall call the Rio Cimarron, flows eastward near the northern border of the territory, and finds its way through Oklahoma and Kansas to the Arkansas River. A few miles east of Folsom, N. M., the Rio Cimarron cuts through the Dakota sandstone and into the Red Beds beneath. The thickness of the Dakota was estimated at 200 feet at this point. Below this sandstone occurs twenty-five to fifty feet of soft variegated clay-shales, underneath which is a series of gypsum layers inter-stratified

[1] I am greatly indebted to Mr. T. A. Pierce for assistance in this work. He has taken an active interest in furthering the investigation.

with clay. This series in turn rests upon red sandstones of typical Red Beds type. The shales thicken from this point toward the east. In a section fourteen miles east of Folsom, the shales are about 200 feet thick. The gypsum becomes less important eastward and is absent in places, as shown in the detailed sections on opposite page.



250 feet sandstone, massive, quartzitic, cross-bedded, slightly conglomeratic in places. A thin seam of blue clay 100 feet from the base.

40 feet colored shale containing layers of argillaceous sandstone and limestone.

50 feet coarse grained loose textured sandstone.

10 feet conchoidal limestone with clay and coarse sand at the base.

10 feet arenaceous shale.

1 to 3 feet conchoidal limestone.

40 feet variegated shale.

3 feet argillaceous limestone.

40 feet shale containing irregular seams and masses of agate-like concretions, colored in varying shades of blue and pink.

5 feet sandstone.

20 feet gypsum interbedded with clay.

—— red to purple sandstones and shales.

Fig. 3.—Section 2, in the canyon of the Rio Cimarron east of Long Canyon.

Still further to the east, below the junction of Long Canyon and the Rio Cimarron, an isolated mesa stands in the midst of the canyon. The sides of the mesa are well exposed and the out-cropping edges of the formations easily accessible. The upper member of the Red Beds at this point is gypsum. Between this and the Dakota which caps the mesa, occurs about 200 feet of variegated shales containing a subordinate amount of sandstone and impure limestone, as shown in the accompanying detailed section, Sec. 2.

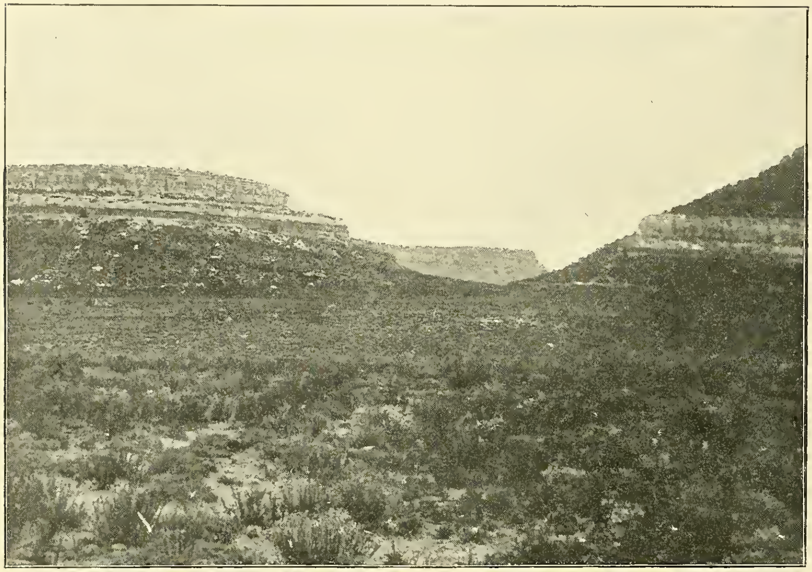


FIG. 4.—Photograph taken near Exeter post-office, N. M., showing the Exeter sandstone at the top of the butte, lying unconformably upon red beds.

The next section taken was a few miles east of Exeter post-office. Numerous buttes and mesas, varying in size from small mounds to table lands many acres in extent, have been left standing in the midst of the canyon in this vicinity. They rise abruptly from the broad, well graded bottom which is several miles wide at this point. The larger mesas are capped by the Dakota sandstone, while the smaller ones have lost their protecting caps. On the butte, shown in the photograph, Fig. 4, the Dakota and the underlying shales, have been removed. They appear however in the point shown at the right in the photograph, where the third detailed section was taken. The cap rock of the butte is the Exeter formation, to be described beyond. In this region it immediately underlies the shales in place of the gypsum which is absent. No detailed section was taken east of this point, but the outcropping edges of the formations were seen continuously in the canyon sides to a point about seven miles east of the eastern boundary of New Mexico, where the eastward dip of the strata carries the shales beneath the canyon bottom.

In the section east of Exeter, the Dakota rests upon a series of variegated clay shales which contain layers of sandstone and impure limestone, and at this point the limestone attains greater importance than at other places examined in the Rio Cimarron. The brown limestone near the base resists erosion to such an extent that a shelf often several rods wide is produced in the canyon side. In the concretionary limestone near the top was found the only invertebrate fossil obtained from the shale formation of the Rio Cimarron. It is a fragment of a pelecypod too poorly preserved to identify.

The formations represented in the detailed sections, with the exception of the Exeter formation, to be described later, were traced continuously from Folsom eastward to a point seven miles beyond the boundary of New Mexico. The canyon sides are steep and well exposed throughout this distance and no difficulty is encountered in following the outcrops. Throughout this distance the Dakota sandstone forms the protecting rim of the canyon walls, while the middle portions of the walls are as uniformly occupied by the shale formation. This middle formation consists mainly of clay shales of various colors, and friable sandstones, varying from nearly pure silica to various admixtures of clay and sand. In certain places, however, the sandstones are hard, coarse, and slightly cross-bedded. The character of the formation varies laterally within short distances. The limestone which forms a subordinate amount of the formation, may occur at any horizon. The layers are generally less than one foot thick, and never, so far as observed, attain a thickness of more than a few feet. They vary in character from brittle masses often of a reddish-brown color, to seams of tough admixtures of clay, lime, and sand. All of the members of this formation vary laterally in character and thickness. No two sections exhibit the same order of succession nor the same relative proportion of materials.

There is, however, one feature which is remarkably persistent, and which may deserve special mention. Near the base of the formation occurs a curious nodular seam of silica resembling imperfectly formed agates. These are sometimes loosely held together, with clay filling the internodular spaces, and sometimes gathered into a compact mass. Calcite is also found imbedded in the silica. The silica is obviously a deposit from solution. In many instances it shows a concentric structure with bands of different colors. The color varies from deep red to light blue. The seams bearing this agate-like material are usually only a few inches thick. Either the seams themselves or "float" from them were noted at nearly every point examined in the canyon of the Rio Cimarron, as well as at other localities to be described.

Throughout the extent of the Rio Cimarron, Red Beds occur underneath the shale formation. These Red Beds are composed principally of deep red to purple sandstones, although more or less red shale is interstratified with them. In the upper twenty-five miles of the canyon the upper member of the Red Beds series is gypsum. In the lower or eastward part the Exeter formation, to be described later, takes the place of the gypsum between the Red Beds and the shale formation, and lies unconformably upon the Red Beds.

I have previously shown[1] that the Dakota sandstone extends from the Purgatory and its tributary canyons to the Rio Cimarron and that a shale formation similar to the Dinosaur-bearing beds of the Purgatory was found beneath the Dakota. It is obvious, therefore, that the protecting sandstone of the Rio Cimarron is Dakota. No vertebrate fossils have been found in

---

[1] Jour. Geol., Vol. IX, May-June, 1901.

the shales of the Rio Cimarron, although ranchmen from that vicinity report having seen large petrified bones. A comparison of this formation, however, with the shale formation of the Purgatory, indicates that the two are identical in composition and stratigraphic position, and leaves little room for doubt that they are parts of one and the same formation.

In the vicinity of Exeter post-office the shales are separated from the underlying Red Beds by a well-marked unconformity. The Red Beds were thrown into gentle undulations and these undulations eroded previous to the deposition of the younger sediments upon them. Several miles west of Exeter post-office the shales rest upon the eroded edges of a local arch, from the top of which about sixty feet of the Red Beds had been removed previous to the deposition of the shales. The gypsum, which is here considered as the top of the Red Beds, appears in the flanks of the truncated arch. From this point eastward for several miles angular unconformities were noted at the top of the Red Beds. In the vicinity of Exeter, the thickness removed by erosion is considerable, but no attempt was made to estimate it. The dip of the truncated Red Beds may be estimated from the accompanying photograph (Fig. 4).

Near Exeter post-office a sandstone formation appears between the Red Beds and the shales. It lies unconformably upon the Red Beds as shown in the illustration (Fig. 4). The cap rock of the butte at the left is this new formation, which I shall for the present call the *Exeter sandstone*. It is a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color. The lower strata are pink, while those above grow progressively lighter colored. It has the appearance of being composed of the coarser material from the eroded Red Beds, and may be a basal sandstone formed by the encroaching waters from the east or south, which cut away the Red Beds. The sandstone has a maximum thickness of seventy-five feet, and extends from a point several miles west of Exeter, where it thins out, eastward to the New Mexico line where it drops beneath the canyon bottom. No fossils of any kind were found in this sandstone. Wherever it occurs it forms a series of nearly perpendicular cliffs, thus making a broad conspicuous band along the canyon sides.

It is evident, then, that the shale formation rests in turn (1) upon the gypsum conformably; (2) upon the gypsum and the underlying Red Beds unconformably; (3) upon the Exeter sand-

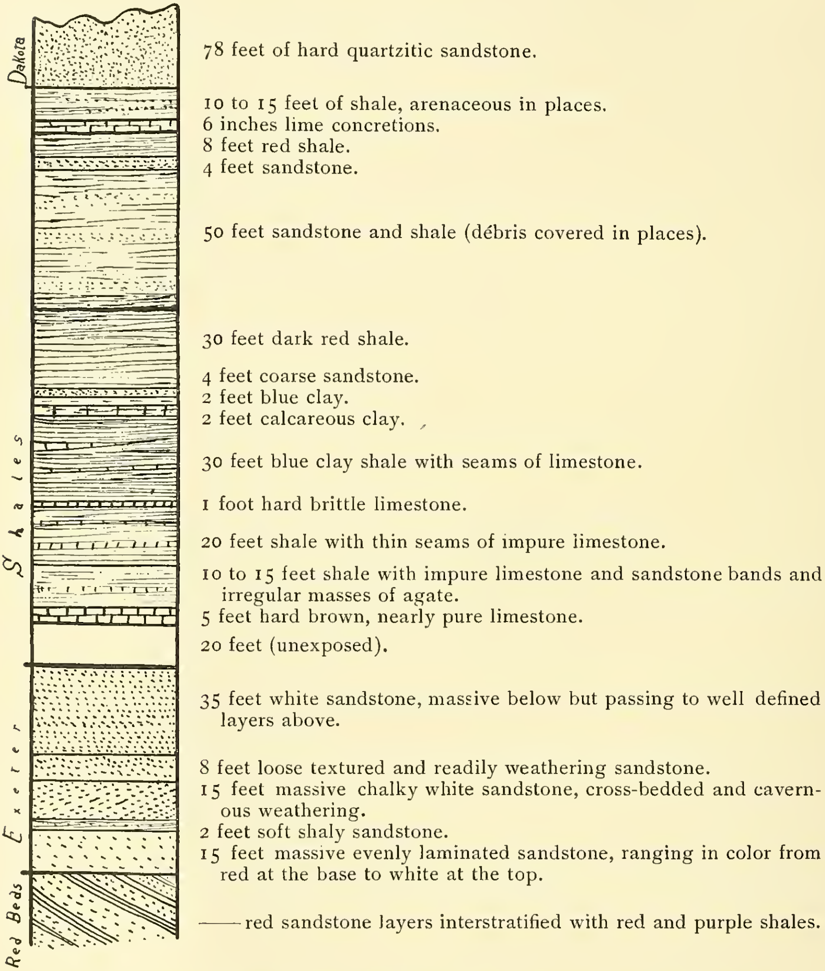


FIG. 5.— Section 3, near Exeter post-office in the canyon of the Rio Cimarron.

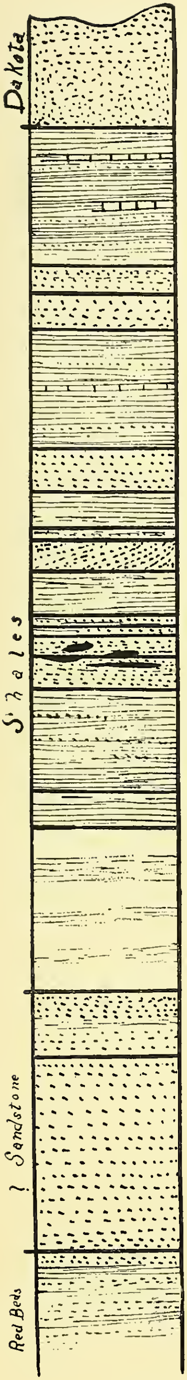
stone conformably. It is noted, furthermore, that the shales, as a formation, do not vary in any marked degree either in character or thickness. Whatever may have been the physical conditions prior to the deposition of the shales, it is evident that the shales were deposited over a well-graded surface. It follows also that there was a somewhat notable time-interval between the Red Beds and the shales. A part at least of this time-interval is represented by the unconformity between the Red Beds and the Exeter sandstone. It is uncertain whether there is a time break between the Exeter sandstone and the overlying shales. However this may be, the seeming conformity which exists in many places between the Red Beds and the shales is deceptive. The contact really represents the whole time indicated by the unconformity between the Red Beds and the Exeter sandstone and the time required to form the Exeter sandstone, besides the possible period between the deposition of the Exeter and that of the shales.

The region south of the Rio Cimarron.—In the course of the journey from the Rio Cimarron to Clayton and thence westward to Springer, no stream was found which had cut entirely through the Dakota sandstone until the Canadian River was reached. There is, therefore, a space of about sixty miles — the space by which the nearest points of the Rio Cimarron and Canadian canyons are separated—in which the shale formation was not seen. It has been penetrated, however, by wells. One well several miles northeast of the Don Carlos hills—nearly due south of Folsom—was drilling at the time I visited the region. The drill had penetrated the Dakota sandstone and was then cutting through a series of soft shales. The engineer in charge of the work described the formation as "a soft clay of different colors containing a few sand layers and thin seams of a *smooth whetrock without any grit.*" The "whetrock without any grit" was probably one of the argillaceous limestones of the shale formation.

Canadian Canyon.—The canyon of the Canadian begins where the river penetrates the Dakota sandstone a few miles south of Springer, N. M. For about fifty miles it is a narrow gorge several hundred feet deep, but further to the south and east it widens to a broad gently inclined plain, bordered by escarpments 500 to 1,000 feet or more in height. The preservation of the escarpments is due principally to their capping of Dakota sandstone, but in some places extrusive sheets of lava form the surface rock. The canyon walls were examined at intervals as far south as Bell Ranch. From Canyon Largo, eastward, I followed along the base of the northern escarpment continuously for about thirty miles. Sections were studied, in more or less detail, at Mill's Ranch and at the toll road crossing, and at several points east of Canyon Largo. A detailed section taken at the edge of the escarpment north of Bell Ranch (Sec. 4) may be taken to represent the structure of this region. The thickness of the capping sandstone was not taken. It is the surface rock, and its thickness varies, due to surface erosion. Its original thickness does not seem to differ materially from that of the Dakota as described for the plains region in general. It was estimated at something over 300 feet. Its character differs in no obvious way from that of the Dakota described in other places. It was traced with little interruption from the Rio Cimarron to the Canadian and throughout the region examined. It is massive, quartzitic, slightly conglomeratic, and being so much more resistant than the shales and softer sandstones beneath, always forms escarpments in the regions where it has been trenched by the streams.

The lower parts of the canyon walls are made up of Red Beds. No attempt was made to study these further than to determine their relation to the overlying shales. A thickness of several hundred feet of the Red Beds is exposed where the canyon is deepest. They are deep red to purple, easily disintegrated sandstones and shales except the upper 50 to 100 feet or more in thickness. This upper series is composed of sandstones which differ so materially from the strata beneath that they may be considered as possibly representing a separate formation. They are massive, red to light pink sandstones, and form a conspicuous cliff throughout the length of the region examined.

Between the Red Beds and the Dakota occurs a shale and



250 feet sandstone, coarse, massive and quartzitic.

50 feet variegated shale containing numerous thin bands of limestone and sandstone.

10 feet argillaceous fissile sandstone.

13 feet coarse sandstone.

45 feet bluish-green shale with a few bands of sandstone and impure limestone.

15 feet coarse massive sandstone.

12 feet variegated clay shale.

5 feet white sandy shale.

13 feet coarse white sandstone, cross-bedded in places.

15 feet colored sandy shale.

6 feet argillaceous sandstone.

15 feet coarse sandstone containing lime concretions in places.

36 feet variegated shale containing thin layers of sandstone.

12 feet red and green shales.

65 feet poorly exposed. Shale seen at intervals.

10 to 50 feet rusty brown to red sandstone with bands of red clay.

50 to 100 feet massive pink to white sandstone. Forms a persistent cliff.

——Friable sandstones and shales in thin layers, red to deep purple in color.

FIG. 6.—Section 4, taken at the escarpment north of Bell Ranch.

sandstone formation approximately 300 feet thick and composed principally of variegated clay-shales and friable sandstones. Limestones of varying degrees of impurity occur with more or less frequency according to location. At the point represented in the detailed section (Sec. 4) the limestone layers are nearly all at the top. A few miles from this point a well exposed section exhibited no limestone near the top, but a stratum of bluish-green limestone several feet thick occurs near the middle. In no two sections studied do the limestones occur at the same horizon. The sandstones of this formation in the Canadian Canyon compose a notable part of the thickness (about one third to one half). The various layers differ in character from firm, well-cemented masses to beds of loose-textured sandstones which disintegrate with the greatest ease. They vary from masses of nearly pure silica through various admixtures of sand and clay to nearly pure clay. Near the middle of the formation occurs a slightly cross-bedded layer of sandstone which seems to be more persistent than the others, although this cannot be confidently stated. The shales are soft and weather readily except where they are intermingled with sand or lime in sufficient quantities to render them resistant. They are colored in various shades of red, brown, and green. In short, they differ in no obvious manner from the shales which I have already described from the canyons of the Rio Cimarron and the Purgatory.

The transition from the massive sandstone (Dakota) at the top to the shale formation is abrupt, but no definite evidence of unconformity was seen. The base of the shales is not marked here by gypsum as in the canyons of the Rio Cimarron and the Purgatory. In its place occurs the coarse, massive pink sandstone shown in the section and in the photograph (Fig. 7). No evidence of unconformity was found at the base of the shales, and the line of delimitation is drawn at the top of the heavy sandstone because of the marked change in character and composition at this horizon. No fossils were obtained from the shale formation of the Canadian, and its correlation must rest, for the present, entirely upon stratigraphic and lithologic grounds. There is little doubt that the upper sandstone belongs to the Dakota. It is possible, however, that there may be some question regarding the lower limit of the Dakota. In the canyon of the Purgatory, the Dakota sandstone rests upon variegated shales which are in places full of Dinosaur bones. There can be no doubt in this case as to where the line of separation should be drawn. The same change of character in passing from the Dakota to the shales obtains in the canyons of the Rio Cimarron and the Canadian. It is therefore probable that the lower limit of the Dakota is properly placed at the lower limit of the massive sandstone, and that the shale formation beneath is separate and distinct from the Dakota, although conformable with it. It is

FIG. 7.—The Canadian escarpment west of La Centa Canyon, N. M. The summit is Dakota. The gentle shape near the top is occupied by the shales, with heavy sandstone at the base. The massive "columnar" layer—100 feet thick—is the upper part of the Red Beds—the possible Trias. The lower portion is occupied by the Red Beds (Permian).

furthermore probable that this shale formation of the Canadian is identical with that of the Rio Cimarron and the Purgatory.

Apishapa Canyon.— East of Walsenburg, Colorado, the Apishapa River cuts through the Dakota sandstone, making a sharp, narrow canyon several miles long and something more than 300 feet deep at the deepest place.[1] The greater part of the thickness exposed is sandstone. This occurs in two series separated by about 30 feet of dark colored clay-shale. The upper series forms the protecting rim of the canyon. It is about 100 feet thick, hard and quartzitic, and contains an occasional leaf impression. It weathers to a rusty brown color which seems to be characteristic of the upper part of the Dakota in this region. The lower series is massive, white, and less strongly quartzitic. In places the uneven induration permits cavernous weathering. The dark clay-shale between the two series is probably the layer of fire clay which usually occurs about the middle of the Dakota. Near Thatcher, Colorado, a few miles east of the Apishapa Canyon, fire clay is mined to some extent at a horizon which is evidently the same as that occupied by the dark shales of the Apishapa. The fire clay of Thatcher and the dark shales of the Apishapa are similar in color, character, and position, and are probably parts of one and the same deposit. Below the lower sandstone about 50 feet of somewhat highly colored shale occurs. In composition and character this shale is similar to the shales found in the Red Rocks Canyon, several miles to the east, underlying the Dakota sandstone, and are probably identical with them.[2] On the other hand a similar shale formation, and similarly placed, occurs in the canyon of the Huerfano River a few miles west of the Apishapa. The shales of the Huerfano are described by Mr. R. C. Hills in the Walsenburg Folio of the U. S. Geological Survey, and referred to the Morrison. There is little doubt, therefore, that the shales exposed in the bottom of the Apishapa Canyon belong to the Morrison.

Extension along the mountains.—Along the mountain front

---

[1] See *U. S. Geol. Surv.*, Apishapa Sheet.

[2] See Sec. 2, p. 347, JOUR. GEOL., Vol. IX, No. 4, May–June, 1901.

west of Trinidad, Colorado, the sedimentary formations are strongly upturned. In some places they are even overturned to such an extent that the apparent dip to the west is something like 30 degrees. A sharp "hog-back" in this region is locally known as the "stonewall." The name is derived from a quartzitic sandstone which, on account of its resistance to erosion, forms a ridge parallel to the mountain front. The serrate edge of this sandstone, which rises in places several hundred feet as a sheer wall, forms the crest of this ridge. This sandstone contains fossil tree trunks and branches. Stratigraphically above the sandstone lies a series of shales and limestones which yield fossils of Colorado-Cretaceous type. Beneath the sandstone lies a series of shales, sandstones, and limestones, which in turn is underlain by an extensive series of red sandstones—the Red Beds of the mountain front. Stratigraphically and lithologically the "stonewall" is identical with the Dakota sandstone as described from various places along the mountain front. This stonewall was traced from La Veta, Colo., southward to Gold Creek, N. M., a distance of about 40 miles.

The shale series lying between the Dakota and the Red Beds is composed principally of variegated clay-shales, with varying amounts of friable sandstones and a few thin seams of impure limestone. The best exposed section found is near the town of Stonewall, Colo., but no satisfactory place was found for making a detailed section, owing to the growth of underbrush and to the surface débris. The total thickness, where upper and lower contacts could be located, was estimated at 300 feet. The shales, sandstones, and limestones of this formation are stratigraphically and lithologically identical with those described from the canyons to the east and south. They are also identical with those described by Mr. Hills from the Walsenburg area a few miles to the north. They were identified on the north fork of the Purgatory, at the town of Stonewall, and at Gold Creek, N. M. There are strong indications that the shale underlies the Dakota continuously throughout the length of the region examined along the mountains.

Summary and conclusions.—It seems evident from the foregoing data that the shales lying beneath the Dakota sandstone in this region are found, with little variation in thickness or character, from the foot of the Rocky Mountains eastward to Oklahoma and southward to the Canadian River wherever streams have cut deep enough to expose them. This persistency in thickness and general character exhibited by the shales wherever exposed, forces the conclusion that the formation was originally continuous, at least over the area represented by the accompanying map, and leads naturally to the inference that it extends far beyond these limits. The absence of paleontological data from the New Mexico areas leads to doubt concerning the integrity of the formation over the whole area. In the absence of such data, we must resort to stratigraphic and lithologic proofs. Since the shales lie between the Dakota above and the Red Beds beneath with apparent conformity except in the canyon of the Rio Cimarron, it may not be evident to those unfamiliar with the field relations that they compose a formation distinct from the Dakota on the one hand and the Red Beds on the other. In the Purgatory Canyon the contact is sharp between the Dakota sandstone and the Dinosaur bearing shales. In the Rio Cimarron and Canadian canyons there are equally sharp contacts between the upper sandstone and the underlying shales, and these are lithologically identical with the Dakota and the shales of the Purgatory. There is, therefore, little probability that the shales belong to the Dakota.

There is even better evidence that they do not belong to the underlying formations. In the Purgatory and Rio Cimarron canyons they are separated from the Red Beds formation by a gypsum series which is here considered as representing the closing stage of the Red Beds period. As already stated, there is in the Rio Cimarron an angular unconformity between the shales and the Red Beds where the shales are seen resting upon the truncated edges of the upturned gypsum and underlying red strata. Where the Exeter formation occurs, the shales overlie it conformably, but the marked contrast between the two series leaves little room for doubt that they are two distinct formations. A similar contrast is apparent in the canyon of the Canadian and the exposures along the mountain front. There is little doubt, therefore, that the shales are separate and distinct from the Red Beds.

Wherever the shale formation was found in this region its character is the same. Minor variations occur constantly within the formation, which in themselves constitute one of its most persistent features. The clay-shales vary laterally, as well as vertically, through arenaceous shales to sandstone on the one hand and through calcareous shales to pure limestone on the other. The members of the formation, however, are in general easily distinguished from the Dakota above and from the Red Beds beneath. There are wide areas within the region in which the shales are not exposed. But their lithological character wherever seen leads to the inference that throughout the region examined the shale series is one and the same formation.

The age of the formations underlying the shales is not definitely known. The Red Beds along the base of the mountains have been called Triassic by many geologists, while some portions at least have been referred to the Carboniferous by others. The Red Beds of the Purgatory Canyon seem to differ in no essential manner from those near the mountains, unless it be in the greater massiveness of the upper series — the upper 100 to 200 feet of the Purgatory Red Beds being massive sandstone. The Red Beds of the upper Rio Cimarron seem to be indentical with those of the Purgatory and the mountain front. Those of the lower Rio Cimarron are less massive, and composed of thin seams of red sandstone interstratified with red to purple shales. In this respect they resemble the lower series of the Red Beds exposed in the Purgatory.[1] The unconformity at the summit of this series indicates that the upper portion of the Red Beds has been removed. The Exeter sandstone entering from the east or south and thinning towards the west lies unconformably upon the Red Beds. The Red Beds of the Canadian, with the excep-

---

[1] LEE, JOUR. GEOL, Vol. IX, No. 4, May–June, 1901, Sec. 1, p. 346.

tion of the upper 50 to 100 feet, seem to be identical with the lower series of the Rio Cimarron and the Purgatory. The Red Beds of the Canadian are referred to the Permian by Mr. R. T. Hill,[1] While the age of the Red Beds is not of first importance in my present purpose, it may be noted incidentally that no distinction was found between the Permian of Mr. Hill at the south, and the so-called Trias at the north and west.

The Exeter sandstone is separated from the Permian by a time break in the Rio Cimarron. Its character and general field relations are similar to the upper massive series of the Canadian Red Beds. While there was no evidence of unconformity noted in the Canadian, it is possible that the upper series is of the same age as the Exeter sandstone. Mr. Hill, in his description of the Texas Region, speaks of a thin formation overlying the Permian which is referred to the Trias with some doubt. He says: "The existence of the early Mesozoic (Triassic) is doubtful although possible. Rocks referred to this period overlie the Permian along the western part of the Central Province, and appear in small areas around the border of the plateau of the plains."[2] The latter region embraces the southern portion of the area under consideration in this paper. It is possible, then, that the upper part of the Red Beds of the Canadian and perhaps the Exeter sandstone of the Rio Cimarron may be of Triassic age. If this be true the shale formation rests upon both Permian and Triassic rocks.

On the other hand, the Exeter sandstone may belong to a later age than the Trias. If the upper series of the Canadian (the possible Trias) represent not the Exeter sandstone, but that portion of the Red Beds removed by erosion where the Exeter sandstone now occurs in the Rio Cimarron, then the Exeter may be a younger formation—possibly the Trinity sandstone. In Mr. Hill's folio of the Texas Region he gives a "section showing the geology of the Texas region." This region embraces

---

[1] "Physical Geography of Texas Region," *U. S. Geol. Surv. Topographic Atlas*, p. 2.

[2] R. T. Hill, *Physical Geography of the Texas Region*, p. 3.

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 Texas region.

Correlation.—The key to the correlation of the shale formation is found in the Walsenburg area, Colorado. Mr. Hills[1] describes the Morrison of that region as a series of variegated shales, sandstones, and limestones lying between the Red Beds and the Dakota sandstone. According to his map the Morrison is found along the mountains near the western border of the Walsenburg quadrangle and in the canyons at the eastern extremity. The Morrison, as described in his folio, is identical in lithologic character and stratigraphic position with the shale formation described in this paper. In the Spanish Peaks area, bordering the Walsenburg area on the south,[2] the Morrison is also thought to be represented in the uplift at the Spanish Peaks. From the exposures mapped by Mr. Hills along the mountains it is but a few miles to the outcrops of the shale formation along the foothills previously described in this paper. The sedimentary formations, including the shales, are upturned a few miles west of the western boundary of the Spanish Peaks area, hence do not appear in the map of that region. There is little doubt that the shales which I have described as occurring as far south as Gold Creek, N. M., is a part of the southward continuation of the Morrison formation.

Starting again from the Walsenburg area, the Morrison occurs

---

[1] R. C. Hills, *U. S. Geol. Surv.*, Walsenburg Folio, Colo.

[2] R. C. Hills, *U, S. Geol. Surv.*, Spanish Peaks Folio, Colo.

beneath the Dakota in the canyon of the Huerfano River. In the next canyon to the east, the Apishapa, similar shales, and similarly placed, occur beneath the Dakota. Still further to the east and south, in the Purgatory and its branch canyons the same shale series occurs, bearing numerous Dinosaur bones of undoubted Morrison type. From thence southward to the Rio Cimarron and the Canadian the shales are lithologically and stratigrapically the same. It seems evident, therefore, that the shale formation throughout the region under consideration should be referred to the Morrison. It seems evident, furthermore, that the Morrison originally extended uninterruptedly over the entire region examined. Since no evidence of diminution in thickness was found, it is safe to assume that the formation extends eastward and southward beyond this area. Whether they extend to the south and east and merge into the undoubted Lower Cretaceous, as previously suggested, remains as yet undetermined.

WILLIS T. LEE.

TRINIDAD, COLO.

THE PREPARATION OF A GEOLOGIC MAP.

THE following paper is a discussion of certain factors influencing the quality of a geologic map; and an attempt has been made to formulate the conditions which must be fulfilled before a map can be considered satisfactory. Two important branches of the subject, however, are not treated: the drafting and the process work. The quality of both is closely dependent on the amount of money available for the preparation of any particular map, and therefore neither can be discussed in a general way. Disregarding these more purely mechanical factors, the value of a geologic map depends upon the accuracy and the precision of the field work; on the completeness with which certain data, both geologic and geographic, are presented on the maps; and on the care with which scale, colors, conventions, etc., are chosen so as to give the best results.

A section might, perhaps, have been devoted to a consideration of the ethical questions involved in the preparation and publication of a geologic map. The writer has, indeed, discussed certain of these points, but from the point of view of expediency rather than of abstract justice. The ethical code for the cartographer is simple; he should give due credit for work done by others; and he should frankly acknowledge doubt or ignorance. The first canon requires that both the geologic and geographic data should be properly credited; the second, that geologically unknown areas should be left blank, that doubtful boundaries should be distinguished from those accurately traced; and that, if possible, the location of actual outcrops should be indicated.

I. ACCURACY AND PRECISION OF FIELD WORK.

The map should show geologic boundaries as precisely as the geographic and topographic accuracy of the base will permit.

When, as frequently occurs, a geologic map falls below this grade of accuracy, the fault is generally in the field work, and not in the map-drafting. Many geologists fail to realize in practice, though they may admit in theory, that geologic mapping on an atlas sheet is very different from mapping on a post-route map. It might seem hardly necessary to say that the geologic boundaries, when a contoured base is used, should be accurately fitted to the topography; but unfortunately evident violations of this rule are frequent. In one very recent instance a map, whose mechanical execution is admirable, is accompanied by structure sections which show that the geologic boundaries on the contoured map are in physically impossible positions.

Throughout much the greater part of the United States geologic mapping must be carried on in areas which have not as yet been mapped with any approach to accuracy. County, land-office, or post-route maps will be the only bases obtainable. In any inhabited area, roads are surveyed and mapped with tolerable accuracy long before any attempt is made to show drainage or relief. For this reason, in geologic mapping in a base known to be geographically inaccurate, boundaries and outcrops should be, when possible, referenced with respect to roads and road intersections, and not with regard to natural features. If thus referenced, these boundaries may be transferred to another base at any time, without necessitating the revision of the field work.

The accuracy of the field work is not a matter which interests the cartographer so much as its precision. If the field geologist has erred in determining the age or general relations of a certain formation, the cartographer cannot question the determination. He has, however, a right to ask that boundaries be traced and locations made with a certain degree of precision, a degree which will vary with the character of the base map used; and that the various elements of the manuscript map agree *inter se* (*e. g.*, that the areal mapping is not contradicted by the structure sections).

II. REQUISITE GEOLOGIC DATA.

Title.—The title of the map, omission of which is rarely permissible, should explain the character of the mapping (geologic, outcrop, reconnaissance, detailed, etc.), and should also describe the area covered by the geologic coloring. As to wording, the title should be as concise as possible, and grammatically correct. such expressions as "Geologic map of the —— river," or "Geologic map of the —— limestone," should be avoided. It is frequently necessary to publish maps of areas which for some reason cannot be readily located or described in words, so that the title (unless made unreasonably long) cannot be made entirely satisfactory in regard to its geographic precision. In such cases at least one meridian of longitude and one parallel of latitude should be introduced and properly numbered, to serve as an aid in locating the area mapped.

Author and date.—The name of the geologist or compiler should be given on the map, together with the date. So far as the latter is concerned, for most purposes the year will be sufficient; occasionally a more precise statement will be advantageous. This date should in every case be the date of completion of the manuscript map; its date of publication will be fixed by other evidence.

Acknowledgments.— In the case of a compilation, if space be available, credit should be given on the map to the various geologists whose partial maps were utilized. If space is not available on the map itself, reference should be made to the publication in which these acknowledgments are made. Remissness in this respect, whether intentional or not, is unpardonable. Plate I of Monograph V, United States Geological Survey, (*Copper Bearing Rocks of Lake Superior*), is particularly detailed in its acknowledgments, despite its comparatively small size.

Legend.—The amount of detailed information to be given in the legend is governed by two considerations. The first is, of course, the amount of space available on the map. The second, on which sufficient stress is rarely laid, is the liability of the map to be separated from the text. Every convention used on the map must be explained in the legend; but the extent to which this explanation should be carried depends largely on the form in which the map is published. A map issued in a roll or pocket will almost invariably become separated from the volume or paper which it is supposed to accompany; and the legend of a map published in that shape should accordingly be as detailed as possible. A map inserted as a plate is somewhat less likely to be used separately and the legend may be less detailed; while a map set in the text cannot well be separated from it and its legend may therefore be reduced to the briefest outline.

Boundary lines.—Every formation should be bordered by a definite boundary, unless transition or intergradation is meant to be shown. Except in this relatively infrequent case, it is not permissible to allow two colors or conventions to meet without an intervening boundary line. When possible, it is advisable to distinguish different grades of precision by the use of different conventional boundaries. For example, where the boundary has been traced in the field with a certain degree of precision, the separating line may be continuous; where the boundary is doubtful, or inferred, the line may be broken or dotted. Continuous lines indicating faults may be given double thickness, in order to distinguish them from continuous lines indicating precisely located boundaries,

Distinction of outcrops.—In detailed maps whose scale is sufficiently large to permit such treatment, precision is gained by distinguishing actual outcrops from areas whose geology is merely inferred. This distinction may be made by using for the outcrops either a pattern or a hachure or cross-lining under the color. The best examples of the latter method with which the writer is acquainted are to be found in Monograph XXXVI of the United States Geological Survey (*On the Crystal Falls Iron-Bearing District of Michigan*). In this volume, the practice is entirely consistent on the point in question, all its detailed geologic maps (Plates XVI, XVII, XVIII, XLIX, L, LI) distinguishing actual outcrops by means of cross-lining, disposed so as to show both location and size of these outcrops. Plate XXXI of Monograph XXXIII (*Geology of the Narragansett Basin*) distinguishes outcrops by means of cross-marks. Earlier publications on the Lake Superior region, both in monographs and in papers in the

Annual Report, have indicated actual outcrops, but the practice has not been general. It would seem that this distinction might profitably be made on maps included in the geologic folios, at least in those cases in which the geology of the area covered is complicated.

III. REQUISITE GEOGRAPHIC DATA.

Acknowledgments.—The geographic base should be credited and described, if possible, on the map itself; if the necessary description be too long for the space available, it should be contained in the textual discussion of the map. The value of a geologic map is greatly increased if the accuracy of its geography and topography can be estimated: and this is generally possible if the source whence they were derived be noted.

Scale.—Except in the case discussed in the next paragraph the scale should always be indicated diagrammatically on the map, by means of the familiar bar scale. The scale may, in addition, be indicated fractionally or verbally; allowance being made for reduction (if any) during reproduction. The shrinkage and expansion of paper due to changes in moisture are so great that these arithmetical or verbal statements of the scale are of little value; and they should never be used without a diagram.

In maps whose scale or area is so large that the effect of the earth's sphericity is appreciable, several meridians of longitude and parallels of latitude *must* be introduced and properly numbered, in order that the scale in different parts of the map be determined.

Contours.— If the base shows topography by means of contours, the datum plane and contour interval should be stated on the map.

Orientation.—When possible, the map should be so oriented with respect to the sheet on which it is printed that the north will be at the top. If this is not possible—and invariably if no parallels or meridians are introduced—the direction of a true north and south line should be indicated by the conventional arrow. In case the strike readings are quoted from the magnetic north, the declination of the needle should also be shown (the average for the district being taken) or stated verbally.

Projection.—In maps where scale or area is sufficiently large to render the information of value, the system of projection should be stated; or, better, it should be shown graphically by introducing a number of meridians of longitude and parallels of latitude. As noted under the discussion, in a previous paragraph, of the scale of the map, these meridians and parallels will serve a double purpose.

IV. CHOICE OF SCALE, CONVENTIONS, ETC.

Area of map and coloring.—The area covered by the map should not be larger than is necessary to illustrate the point under discussion. Whenever possible, the colors should be carried to the border of the map. Political divisions are rarely natural divisions; and it is therefore rarely advisable to stop the coloring abruptly at a political boundary, especially if the geologic value of the map can be increased by carrying the mapping into an adjoining political division.

Scale.—As the scale adopted directly affects the size of the map, the selection of the scale will frequently be affected by consideration of expense. Commonly, however, there will be room for choice, within certain limits; and in this case, or in rare instances where the question of expense may be disregarded, the selection of the scale will be subject to the following rules:

The scale should be sufficiently large to show all the geologic and geographic detail necessary. Curiously enough, this rule is rarely disregarded; the fault commonly committed being the adoption of too large a scale.

The scale should not be larger than is permitted by the degree of accuracy of the geologic field work, or by the geologic detail which must be shown. The degree of accuracy of the geologic field work will usually have been fixed by the scale of the field map on which the geologic observations were first plotted; and the published map, therefore, should not in general be on a larger scale than was this original field map.

Colors and conventions.—Whenever possible, the colors and patterns adopted by the United States Geological Survey should be adopted, for the sake of uniformity. Whether this be done or not, the maps issued by any one survey should be treated according to some one system. This is especially necessary when the maps so issued form a series, as in the publication of a number of county maps.

A formation should never be expressed by entire lack of color and pattern, as such a practice frequently leads to confusion. This, of course, refers particularly to black-and-white maps, as formations are rarely so treated on colored maps.

In small or local maps, particularly in such as are prepared for general use or to illustrate the distribution of economically important formations, the colors or conventions used for the different formations should be as distinct as possible. The smaller the areas to be distinguished, the greater will be the necessity for careful choice of colors or conventions, in order to obtain the greatest possible contrast.

In maps either of large scale, or covering large areas (in which case the geology will be of necessity much generalized), the general effect of the color scheme should be considered. In the allotment of colors and conventions to the different formations, it should be borne in mind that, the smaller the areas covered by any one formation, the brighter the color and heavier the pattern it will bear without seeming crude or obtrusive. As large maps are, in general, mounted and used as wall maps, a formation occurring mainly or entirely near the top of the map may be given a brighter color or more striking pattern than one in the middle or near the bottom of the map.

Patterns.—If patterns be used, with or without color, certain additional points must be considered. In the case of a formation occupying small areas, the pattern selected for that formation should bear some definite relation to the form and orientation of those areas. For example, a formation extended as a narrow belt should be given a pattern whose ruling is, as near as possible, at right angles to the general trend of the belt.

Experience has shown that, of the long list of patterns originally suggested for use, a certain few almost invariably fail to give good results in practice. Some of these are apparently poor, whatever paper is used; others fail only when the less highly surfaced papers are printed on. The last class are still serviceable for maps issued flat or in rolls; but can not be utilized with good results for folded maps, for which a highly surfaced paper is undesirable. Examination of a large series of maps on which patterns have been used will aid in determining which will be most effective in the special case under consideration.

In the preparation of this paper, the writer has made free use of the experience of this office, and has been greatly aided by the advice of Dr. F. J. H. Merrill. Maps issued by the United States Geological survey have been used as examples, in order to avoid the citation of maps published by the New York State Museum.

EDWIN C. ECKEL.

NEW YORK STATE MUSEUM,
Albany, N. Y.

THE NOMENCLATURE OF THE LAKE SUPERIOR FORMATIONS.

"The Iron Ore Deposits of the Lake Superior Region," by Professor C. R. Van Hise, recently published in the *Twenty-first Annual Report of the United States Geological Survey*, is a most noteworthy contribution to Lake Superior geology. While especially valuable to mining men, for whom it was prepared, its references to stratigraphy are most interesting to geologists. In a footnote (p. 317) it is stated that the evidence upon which the geological succession is based will be fully given in a monograph upon the Vermilion District to be published later. While for the most part in accord with the author's stratigraphy, I do not agree with his nomenclature, and this paper is written with the hope that by discussion unanimity may be reached in this matter also. Owing to its importance, I here quote almost in full the footnote referred to above:

> The foregoing papers render it unnecessary for me here to take up the general stratigraphy of the Lake Superior region. However, our work north of Lake Superior, in northeastern Minnesota and Canada, has upon two points modified our published conclusions as to succession and correlation. Those who compare this paper with earlier papers will note two important modifications. First, the Archean has heretofore been supposed to be composed wholly of igneous rocks; no sediments have been recognized in this division of the pre-Cambrian. The north-shore work, however makes it very probable that certain of the sedimentary iron-bearing formations must be included in the Archean. As examples of such are the productive iron formations of the Vermilion and Michipicoten districts. This modification is important from a theoretical point of view, since it will make changes necessary in my general definition of the Archean and of the Algonkian. The Algonkian has been defined to include all pre-Cambrian sedimentary rocks. The Archean has been defined to include all pre-Algonkian rocks, and has been supposed to contain igneous rocks only. These definitions must be modified so as to include in the Algonkian all pre-Cambrian series which are dominantly of sedimentary origin, or equivalent in age with those which are dominantly of sedimentary origin. The Archean must be defined

to comprise the rocks older than the Algonkian, which are dominantly of igneous origin, but which may include subordinate amounts of sediments. Recent work in northwestern Europe, and especially in Scotland, Scandidinavia, and Finland, where the ancient rocks are best exposed in Europe, shows that these modifications in the definitions of the Archean and Algonkian are also there applicable. The changes are quite in line with what might be expected; for in recent years no one feature in geological advance has been more significant than the sweeping away of sharp dividing lines between the various periods.

Second, the iron-bearing formations of the Vermilion and similar districts I have heretofore regarded as Lower Huronian. In placing these formations in the Archean I recognize three series in which productive ore formations are found, the Upper Huronian, the Lower Huronian, and the Archean.

The evidence upon which these modifications of my opinion concerning Lake Superior stratigraphy are based cannot be here presented in detail. It will be fully given in a monograph upon the Vermilion district, to be published later. In general it may, however, be stated that our work in the Vermilion district of Minnesota and on the Canadian side of the international boundary has convinced us that bands of sedimentary iron-bearing formations are interstratified with the upper part of the oldest series of the Lake Superior region, composed of greenstones, greenstone schist, and tuffs, although the thick productive belts of the Archean appear to rest upon the greenstones and greenstone schists.

Professor Van Hise here lends his weighty support to some views long held by others. It is admitted that true sediments occur in his old Basal Complex, though he does not carry this admission to its logical conclusion and attach the sediments to his Algonkian. Intrusive into these sediments are the granite gneisses of the Complex, a position held by Lawson,[1] Coleman[2] and others. Among these I now place Van Hise, for the Mona and Kitchi schists of Marquette containing banded jasper are pierced by the granites of the Basal Complex according to his description.[3]

The succession held by me is as follows:[4]

1. The Cambrian represented by the Lake Superior sandstone.

2. The Keweenawan.

---

[1] *Geol. Sur., Can.*, 1885 and 1887.

[2] *Reports Bur. of Mines, Ont.*

[3] *Mon. U. S. Geol. Sur.*, XXVIII, p. 186.

[4] *Cf. Am. Geol.*, XXVIII, 1901, p. 19.

3. The Animikie, mainly a sedimentary series, but locally containing great series of volcanic rocks.

4. The Upper Huronian, consisting mainly of sedimentary rocks.

5. The Lower Huronian, consisting of green schists and included sediments.

Besides these sedimentary series, the only proper factors in a time scale, there is an immense series of granites and gneisses largely of post-Upper Huronian age, which for convenience of reference have been given the old name Laurentian, a name applied to them when they were believed to represent the basement series.

This succession is almost identical with that given by Van Hise on page 316. The difference between us is largely one of nomenclature. Van Hise writes (p. 317):

> These series are called Huronian because they are believed to be equivalent to the Upper Huronian and Lower Huronian of the original Huronian district north of Lake Huron.

With this correlation I am not in accord. I believe the upper part of the original Huronian to be the equivalent of Van Hise's Lower Huronian, and the original Lower Huronian to be included in his Archean. If this can be substantiated, I have no doubt Professor Van Hise will view my nomenclature favorably, for no one is more anxious than he to recognize the work of Logan and Murray, the founders of the Huronian.

In 1858[1] Logan gave the name "Huronian" to the copper-bearing rocks north of Lake Huron, the distribution of which was being worked out by his assistant, Murray. In 1863[2] he gave a summary of the previous annual reports, and this may be fairly taken as representing his mature views. Detailed sections are given from the Sudbury, Michipicoten, and Mississaga districts. The rocks are mainly sediments, but interstratified with them are beds of amygdaloidal greenstone. Intrusive greenstones and granites are also recognized.

Two slate conglomerates were described separated by a

---

[1] *Rep. Geol. Sur., Can.*, 1857.

[2] *Geol. of Can.*, 1863, pp. 50–66.

narrow band of limestone. These were practically alike in every particular and Murray found himself unable to distinguish them where the limestone was lacking.[1] The Upper Conglomerate carries occasional pebbles of the limestone when near it, but usually none are to be found. The limestone band as shown in Murray's map is largely conjectural, the outcrops being very few. It seems probable that the break between the two conglomerates is not of great significance and that it would be well not to attempt a separation of them.

Many geologists have argued for a division of the Huronian, though they have not agreed on the horizon. Alexander Winchell[2] places the break at the top of the Lower Slate Conglomerate. Pumpelly and Van Hise[3] place it above the limestone band. The important break must, however, lie much lower. Pebbles of banded jasper and hematite occur in the Lower Slate Conglomerate, in great abundance in places, and must have been derived from some lower sediment. Logan's white quartzite often becomes a conglomerate and is evidently only a phase of the Lower Slate Conglomerate. Excepting the chloritic slates we have, accordingly, in all the lower part of the Mississaga Huronian area evidence of the existence of a lower sediment. The probable occurrence of this banded jasper was recognized by Logan himself, though outcrops were not discovered. This lower conglomerate with jasper and chert pebbles thus becomes of the greatest value in working out Lake Superior stratigraphy, a fact emphasized by Coleman in a paper on the subject.[4] Logan also recognized its value, and correlated slate conglomerates in the Temiscaming, Sudbury, Mississaga, Batchawana, and Michipicoten districts. In describing the Doré series in the last district he mentions[5] pebbles of a "chert-like stone," and near Batchawana Bay jasper conglomerate was found. In maps of both these regions there were included within the Huronian, rocks which are now recognized as the source of the jasper and

---

[1] *Rep. Geol. Sur.*, 1858, p. 94.

[2] *Bull. Geol. Soc. Am.*, II, 1891.

[3] *Am. Jour. Sci.*, III, 1892, p. 42.

[4] *Rep. Bur. of Mines, Ont.*, 1900, pp. 182–86.

[5] *Geol. Can.*, 1863, p. 54.

chert pebbles. In the Temiscaming region, also, banded jaspers, which are the source of the pebbles in the conglomerate, have been found within the area described by Logan as Huronian. Near Sault Ste. Marie banded quartz has been found within the Huronian area.[1]

There can be no doubt that Logan in 1863 included within his Huronian two series—the one typically represented by the banded jaspers, the other by the slate conglomerate and the jasper conglomerate. This has been uniformly followed from that time forward by all Canadian geologists and by many American, the vertical green schists and their interbedded banded jaspers being considered Lower Huronian. These schists have also been mapped as Huronian in nearly every case by the Canadian Survey. It is true that Lawson, in his reports on the Lake of the Woods[2] and of Rainy Lake, describes similar rocks as Keewatin, doubtfully correlating them with the Huronian north of the Georgian Bay. He recognizes, however, their resemblance to those of the Michipicoten area, a conclusion with which I agree.

The lowest rocks at Michipicoten are greenstones, often ellipsoidally parted, and volcanic tuffs. Interbedded with the latter are cherty iron carbonates, pyritic quartz rocks, ferruginous cherts, and ore bodies. Into these two are numerous intrusions of greenstone and granite. Above lies a slate conglomerate. The resemblance to the Ely greenstone, Soudan iron formation, and Ogishke conglomerate as described by Van Hise[3] is very close. The similarity of the two regions was pointed out by Coleman and Willmot in a paper published in 1899,[4] and it is recognized by Van Hise in the present paper (p. 411).

These schists and interbedded ferruginous sediments have, however, always been considered as Huronian or Keewatin. I see no reason for abandoning the term Lower Huronian for

---

[1] *Rep. Bur. of Mines*, 1901, p. 187.

[2] *Geol. Sur., Can.*, 1885, I, and 1887, III.

[3] *Iron Ore Deposits of Lake Superior*, p. 402.

[4] *Rep. Bur. of Mines, Ont.*

these earliest sediments. Because of the impossibility of separating the sediment from the inclosing greenstones and green schists except on very large scale maps, both will usually be mapped together. This must also be the case for many years over vast areas of Canada until the regions become more accessible. For this reason I doubt the advisability of attempting the separation of the volcanics and sediments except in limited areas of economic value. Here each would be given formational names, just as Van Hise has done with the Ely greenstone and the Soudan iron formation. In other places the volcanics and eruptives will take the name of the sediment with which they are associated. The lowest sedimentary series of the Lake Superior region is the Lower Huronian. These sediments were included in the areas mapped as Huronian by Logan in 1863, and, although not actually found in place by him, were recognized from their fragments, and to him should be given the credit. These rocks have always been mapped as Huronian by the Canadian Survey.

For these reasons, Lower Huronian is to be preferred to Archean in describing these rocks. Failing Lower Huronian, Keewatin should be adopted, for it too has priority over Archean as used in this connection.

If Lower Huronian is to be substituted for Archean it follows that Upper Huronian would properly replace Van Hise's Lower Huronian. Van Hise correlates (p. 411) the Ogishke conglomerate with the Doré conglomerate, and Logan considered this the equivalent of his Lower Slate Conglomerate. N. H. Winchell[1] and Alexander Winchell[2] both correlate the Ogishke conglomerate with Logan's slate conglomerate. With these correlations I agree on lithological grounds and because of the sequence all around the lake. This may possibly be proved, or at least supported in another way. Coleman has shown, in a paper already referred to,[3] the wide distribution of the slate conglomerates, and that all carry jasper or equivalent

---

[1] *Sixteenth Ann. Rep. Minn. Geol. Sur.*, 1887, pp. 12–40.

[2] *Ibid.*, pp. 145–71.

[3] *Rep. Bur. of Mines, Ont.*, 1900.

pebbles. Barlow has shown[1] that, in the Temiscaming region, the granite-gneisses are in eruptive contact with this conglomerate. I have shown[2] that Murray recognized the eruptive character of the gneiss in connection with his slate conglomerate, though he attempted to explain the facts by faults. I have also shown[3] that at Michipicoten the schist conglomerate is pierced by granite-gneiss. Lawson[4] shows in his Lake of the Woods and Rainy Lake reports that the granite-gneisses are in eruptive contact with the schist conglomerates of his Keewatin.

We have thus for eight hundred miles across Ontario: (1) a schist conglomerate carrying pebbles of jasper and chert; (2) large areas of granite-gneiss in eruptive contact with it.

It is, of course, possible that these eruptions did not all take place at the same period, but from their magnitude and close connection throughout the whole region it is probable that they did. Taken with the occurrence of a conglomerate carrying such peculiar pebbles as jasper, it may almost be considered proved that all are of the same age. For this reason, in addition to those given above, the original Upper Huronian is considered the equivalent of Van Hise's Lower Huronian,

It follows that the Animikie (and so the Mesabi and Penokee) is younger than the Huronian. This was Logan's position[5] who called the Animikie the lower group of his upper copper bearing rocks. McKellar[6] held on lithological and structural grounds that the Animikie was later than the Huronian. Lawson[7] points out that the conglomerates of his Upper Kaministiquia come out close to the shores of Thunder Bay and form the basement upon which the undisturbed Animikie rocks rest with strongly marked unconformity. Lawson's Upper Kaministiquia I consider Upper Huronian. They are included in the vertical schists which are cut by the eruptive granite-gneisses.

[1] *Geol. Sur., Can.*, X, p. 91, I.

[2] *Am. Geol.*, XXVIII, 1901, p. 18.

[3] *Ibid.*, p. 16.

[4] *Am. Geol.*, VII, 1891, pp. 320–27.

[5] *Geol. of Can.*, 1863, p. 67.

[6] *Trans. Roy. Soc., Can.*, V, 1887.

[7] *Am. Geol.*, VII, 1891.

In the vicinity of Port Arthur I have found greenish schist with included ferruginous sediments, and also conglomerates carrying pebbles of the first. Both of these have highly inclined dips and have granite-gneiss in eruptive contact with the first at least. The lower series has numerous beds of pyritic quartz rock exactly like the beds in the lowest sediments at Michipicoten. Clearly these two series correspond to the Lower and Upper Huronian, as above defined. Overlying both, and also the granite-gneiss with very gentle dip is the Animikie series.

That the Animikie is later than the Upper Huronian or "Original Huronian," as it is often called, may be shown in several ways:

1. Stratigraphically it is the third series of sediments upwards from the bottom of the geological column in the Lake Superior region—the Upper Huronian is the second.

2. Lithologically, the two series are quite different, and so presumably are of different age. There is very little conglomerate at the base of the Animikie—in the Huronian the quartzites, slate conglomerates, and jasper conglomerates are of great thickness. The oolitic jaspers found in the Animikie are quite absent from the Huronian. The shales, so important in the Animikie, are almost unknown in the Huronian. The laccolitic sills of the Animikie are lacking in the Original Huronian.

3. Structurally, the two series are usually said to be alike in that both lie flat and undisturbed. While this is quite true of the Animikie, it is only partially true of the Huronian north of the Georgian Bay, and is untrue of the Upper Huronian about Batchawana and Michipicoten. Coleman[1] and Murray[2] have described cases of vertical dip within the so-called Original Huronian, and others have been observed by myself. These seem to occur around the outer portion of the Huronian basin, and more gentle dips obtain in the central part. Evidently the Huronian has been subjected to forces which the later Animikie has escaped.

4. Assuming that the large areas of eruptive granite-gneisses

[1] *Bur. of Mines, Ont.*, 1901, p. 189.

[2] *Geol. Sur., Can.*, 1858, p. 95.

in the Lake Superior region are of the same age, we find that the Upper Huronian has in many cases been pierced by them, but that the Animikie always overlies them.

The conclusion seems inevitable that the Animikie is later than the Upper Huronian. If this is accepted, or if the Upper Huronian is accepted as the equivalent of Van Hise's Ogishke Conglomerate (his Lower Huronian), or if Lower Huronian is accepted as a preferable term for Archean Schist, if any one of these propositions is accepted as proved it seems to me the others should follow.

The succession in Lake Superior would thus be as follows:

Cambrian.
Keweenawan.
Animikie.
Upper Huronian.
Lower Huronian.

It may be urged that because of the enormous time break between the Lower and Upper Huronian, as here defined, the same name should not be applied to both systems. Providing that it is recognized that the terms are descriptive of systems, not of formations, it seems to me that they are quite as appropriate as Lower and Upper Marquette, Lower and Upper Cretaceous, etc. Moreover, in the reconnaissance work in the immense unsettled districts north of the great lakes, it is a distinct advantage to have a general word like "Huronian" to embrace the two systems which are easily separated from the remaining Archean, but are not easily separated from each other. Many areas have been mapped by the Canadian Survey as Huronian, which may or may not contain both systems. That will require more detailed work when the regions become more accessible.

There remains the question of a term of systematic value to designate the pre-Cambrian series. Should they be called Archean, Algonkian, or something else? The Lower and Upper Huronian, and those vast areas of eruptive granite-gneisses, which are mainly of post-Upper Huronian age, undoubtedly represent the old Laurentian and Huronian to which the term Archean was applied by Dana. The Basal Complex to which Van Hise restricted the name when he introduced the term Algonkian, no longer exists. The sedimentary part, with the accompanying volcanics, is in this paper called Lower Huronian. The eruptive granites and gneisses are at least post-Lower Huronian if not post-Upper Huronian in their final consolidation, and must be included with one or the other. There remains nothing below the Lower Huronian to which the term Archean is applicable except the theoretical original crust as yet undiscovered. On the other hand, the continued application of Archean to the rocks known as Huronian and Laurentian, as originally given and as subsequently continued by many, would seem most appropriate. A. B. WILLMOTT.

STUDIES FOR STUDENTS

BASELEVEL, GRADE AND PENEPLAIN.

CONTENTS.

Thesis of this essay.—The attention given during the last fifty years to the processes and results of land sculpture has naturally resulted in the introduction of various new terms, three of which stand at the head of this article. It is desired to point out that too many meanings have been attached to the first term, "baselevel," and that some of them should be transferred to the other two, "grade" and "peneplain."

The original meaning of "baselevel."—Although the control exerted by sea level on river action has long been recognized, the importance of the control was more generally perceived by American students of geology when it was explicitly formulated in the term "baselevel" by Powell in 1875. The term soon became so popular, especially with American writers, that a divergence of meaning has arisen with regard to it. It is therefore proposed to trace its history, with the hope of inducing geologists and geographers to use it in a somewhat restricted sense. It will be spelled here as a single word, disregarding the separation into two words by some authors and the hyphen of others, except in the first quotation.

Powell's original definition of "baselevel" is as follows, the parenthesis being in his text:

> We may consider the level of the sea to be a grand base level, below which the dry lands cannot be eroded; but we may also have, for local and temporary purposes, other base levels of erosion, which are the levels of the beds of the principal streams which carry away the products of erosion. (I take some liberty in using the term level in this connection, as the action of a running stream in wearing its channel ceases, for all practical purposes, before its bed has quite reached the level of the lower end of the stream. What I have called the base level would, in fact, be an imaginary surface, inclining slightly in all its parts toward the lower end of the principal stream draining the area through which the level is supposed to extend, or having the inclination of its parts varied in direction as determined by tributary streams.) Where such a stream crosses a series of rocks in its course, some of which are hard, and others soft, the harder beds form a series of temporary dams, above which the corrasion of the channel through the softer beds is checked, and thus we may have a series of base levels of erosion, below which the rocks on either side of the river, though exceedingly friable, cannot be degraded (1875, 203, 204).

"Baselevel" as thus defined seems to include three ideas. First, the grand or general baselevel for subaerial erosion is the level of the sea; second, a baselevel is an imaginary, sloping surface which generalizes the faint inclination of the trunk and branch rivers of a region when the erosion of their channels has practically ceased; third, local and temporary baselevels are those slow reaches in a river which are determined by ledges in its course further down stream.

There is some reason for thinking that Powell's intention may have been misunderstood with respect to the first and third of these ideas. The first, "the level of the sea," may have referred only to the actual area of the sea, and not to an imaginary extension of the sea level or geoid surface under the lands.

The third certainly referred to the faintly sloping reach of a river, and not to a level surface passing through the ledge of hard rock with respect to which the reach is worn down, although this latter meaning has become popular. The following citations will show that most writers seem to be agreed that baselevels may be local or temporary as well as general, but that there is no prevalent agreement as to the definition of either the general or the local baselevel.

Definitions of "baselevel" by various writers.—The following authors adopt the first of the above meanings. Gilbert writes:

> The land cannot be worn down below the level of the ocean. Geologists express this law by saying that the ocean is the "baselevel of erosion" (1896, 575).

Campbell says:

> If the streams are in their old age, the surface of the land will constitute a peneplain, and in their extreme old age, this peneplain will approach very closely to baselevel (665).

Tarr writes to the same effect:

> In no part of the valley can the stream cut below the sea level, or below *baselevel*, as it is called (265).

Russell quotes Powell, as if adopting his definition, but concludes that:

> The real baselevel toward which all streams are working is the surface level of the sea. . . . When a stream has lowered its channel nearly to baselevel, downward corrasion is retarded, but lateral corrasion continues. . . . The ultimate result of erosion is to reduce a land area to a plain at sea level (47–48).

Finally, Powell may be quoted again as follows:

> The baselevel of a plain is the level of the surface of the sea, lake or stream, into which the waters of the plain are discharged (1895, 34).

The second idea under the term "baselevel"—that of the imaginary undulating surface—does not appear to have been adopted by any of the many writers whose works I have looked over. It is perhaps on account of the elaborateness of this second meaning that it has not come more generally into use. Its partial adoption, however, is indicated by the following extracts. It should be noted that nearly all the writers here cited imply that, after baselevel is reached by a stream, downward corrasion ceases.

McGee describes the streams of the coastal plain at about the head of Chesapeake Bay as "at baselevel" (1888, 617).

Darton says, when describing the dissection of the Piedmont plateau of Virginia:

> As the cutting reached baselevel a series of wide terraces were cut (584).

Winslow writes:

> The streams of the prairie country [in Missouri] . . . . have, in large part, reached baselevel, and are developing meander plains (310).

Fairbanks states that in southeastern California:

> Erosion has reached an advanced stage with the production of excellent examples of baselevelling. . . . . One of the best examples . . . . is the western portion of a granite ridge lying south of the El Paso range. . . . . It is bordered by long gentle slopes of gravel and bowlders, which extending upward into the shallow cañons reach almost to the summit. Viewed from a distance of ten miles but little of the mountains appears to project above the plane of deposition (70).

Salisbury's statement is as follows:

> The time necessary for the development of such a surface is known as a *cycle of erosion*, and the resulting surface is a *baselevel plain*, that is, a plain as near sea level as river erosion can bring it. At a stage preceding the baselevel stage the surface would be a *peneplain*. . . . . It is also important to notice that when streams have cut a land surface down to the level at which they cease to erode, that surface will still possess some slight slope, and that to the seaward. Along the coast, a baselevel is at sea level. A little back from the coast it is slightly higher, and at a greater distance still higher. No definite degree of slope can be fixed upon as marking a baselevel. The angle of slope which would practically stop erosion in a region of slight rainfall might be great enough to allow of erosion if the precipitation were greater. . . . . The Mississippi has a fall of less than a foot per mile. . . . . A small stream in a similar situation would have ceased to lower its channel before so low a gradient had been reached (1898, 73, 79).

J. Geikie writes:

> Running waters will continue to deepen their channels until the gradient by the process is gradually reduced to a minimum and vertical erosion ceases. The main river will be the first to attain this baselevel — a level not much above that of the sea (47).

Marr does not use the term "baselevel," but says instead:

> A river which has established equilibrium . . . . is said to have reached its base-line of erosion, and no further work of erosion or deposit can occur until the conditions are changed (84).

Dryer states:

> The lower Mississippi has reached its baselevel, or the lowest level to which its current and load will permit it to reduce its bed. . . . . In the lower reaches of a river the valley is soon cut down to baselevel, where the slope is gentle and the current too slow to carry the full load of sediment it receives. Deposition occurs and downward corrasion ceases (79, 154).

Powell makes the following statement in a discussion of reaches and rapids:

> The slow reach is a baselevel, like that of a lake, below which the banks and hills on either side cannot be degraded (1894, 35).

Various other definitions, more or less aberrant from the original and discordant with each other, are found in the following citations:

Dutton took baselevel to be a condition:

> The condition of baselevel is one in which the rivers of a region cannot corrade. As a general rule it arises from the rivers having cut down so low that their transporting power is fully occupied, even to repletion. . . . . The recurrence of upheaval terminates the condition of baselevel (224, 225).

According to Willis baselevel is a slope:

> A baselevel is the lowest slope to which rivers can reduce a land area (1895, 189). The ideal lowest possible slope, which is called a baselevel, is perhaps rarely reached (1900, 27).

Hayes makes baselevel a mathematical plane:

> The term baselevel, synonymous with baselevel of erosion, is [here] restricted to Powell's original use . . . . the general baselevel being sea level. There may be an indefinite number of *local* baselevels in any region, each being determined by the outlet of the stream whose drainage basin is considered; but only one *general* baselevel. . . . . It should be clearly understood, then, that a baselevel is not a topographic form, but a mathematical *plane*, which may or may not, and generally does not, coincide with a land surface (21).

When describing erosion by rivers, Scott writes:

> A stage must sooner or later be reached when the vertical cutting of the stream must cease. This stage is called the baselevel of erosion or regimen

of the river, and it approximates a parabolic curve, rising toward the head of the stream (98).

Rice makes the following statement:

> The condition of balance between erosion and deposition [by rivers] has been called by Powell the condition of baselevel (140).

Brigham writes as follows:

> A baselevel is a plane to which denudation must reduce a stably poised land mass, and below which denudation cannot take place. The plane is that of the ocean surface . . . . The great river first cuts its bed close to the sea level, and we say that a portion of the valley is reduced to baselevel. It lacks a little of it, but the difference is so small that we neglect it. Gradually the valley widens, and the baseleveled strip extends up the stream toward the heart of the country (281).

Cowles gives a definition of "baselevel" which taken literally gives it the meaning of a process:

> Denudation of the uplands and deposition in the lowlands results in an ultimate planation known as the baselevel (178).

The derivative use of baselevel as the name of a worn-down land surface does not seem to be so common now as it was some ten years ago. A few examples will here suffice.

Keith made frequent use of "baselevel plain," or simply "baselevel," as the name for a surface that had been reduced to faint relief, even though now uplifted and more or less dissected. He discusses the "considerable variation in the altitude of different parts of the baselevel" or old Tertiary land surface in the Catoctin region district of Virginia (373). He mentions "hill tops marking the dissected baselevel" of the Shenandoah valley (374). The term seems to be applied in at least one instance to a peneplain in saying:

> It needs but little study of this baselevel to discover considerable inequalities in its surface (369).

Diller made equally free use of "baselevel plain" and of "baselevel" in his account of an ancient surface of erosion in northern California. He states that "the western edge of the baselevel, where it enters the mountains, has an altitude of 2,600 feet," and on a later page he suggests two ways in which the "deformation of the baselevel may be studied" (406, 430).

Kümmel writes of the "long erosion which resulted in the Cretaceous baselevel" of Connecticut (379).

Willis says:

> The tendency is in time to reduce the land to a gently sloping plain, which extends from the sea to the headwaters of the rivers. Such a plain is called a *baselevel*. . . . . A surface, which is almost, but not quite, a baselevel, is called a *peneplain* (1895, 188, 189).

Hill describes a persistent bench near Panama as:

> Representing an ancient baseleveled plain, which will be described as the Panama baselevel (197).

An essay by Van Hise describing a "baseleveled plain" is entitled "A Central Wisconsin Baselevel" (57).

I have had a small share in a similar use of "baselevel;" for example:

> The general upland surface of the Highlands [of New Jersey] is an old baselevel, in which valleys have been cut in consequence of a subsequent elevation (1889, 20: see also Davis and Wood, 384).

A review of the above citations, whose number might be greatly extended, shows that "baselevel" is given very different meanings by different writers. These meanings are: an imaginary level surface in extension of that of the ocean (the convex geoid surface); an imaginary mathematical plane; an imaginary surface sloping with the mature or old streams of its area; the lowest slope to which rivers can reduce a land surface; a level not much above that of the sea; a slow reach in a stream; a condition in which rivers cannot corrade or in which they are balanced between erosion and deposition; a certain stage in the history of rivers when vertical cutting ceases and their slope approximates a parabolic curve; an ultimate planation; and a plain of degradation.

Limitation of the meaning of "baselevel."—The diversity of the above definitions may be better perceived when it is noted that they are expressed in terms of very unlike quantities: imaginary surfaces, level, plane, or warped; a low slope; a part of a river; a condition of river development; a stage in river history; an ultimate planation; and an actual geographical form. It is evidently desirable to associate "baselevel" with at most only a few of these meanings, preferably with only one; and to leave the others unnamed or to associate them with other terms. It seems to me advisable to limit "baselevel" to the first meaning, an imaginary level surface, and to define it simply as the level base with respect to which normal subaerial erosion proceeds; to employ the term "grade" for the balanced condition of a mature or old river; and to name the geographical surface that is developed near or very near to the close of a cycle, a "peneplain," or "plain of gradation." The following paragraphs may make the need of this discrimination clearer.

A full understanding of the development of land forms can be gained only by tracing the progressive changes of a generalized example from the initial stage through the various sequential stages to the ultimate stage of an ideal geographical cycle. This problem is encountered in an elementary form at the beginning of the study of land sculpture in physiography or geology, and at the very outset it is necessary to make definite and simple statement regarding the limit with respect to which the processes of normal subaerial erosion (weather and streams, without significant aid from wind or ice) may act. If the limit is defined in terms of the slopes that the streams of the region will have gained when they have reached a maturely balanced condition, the definition will be of no service to beginners; indeed, a limit thus defined is elusive and difficult of conception even by experts. The limiting surface is certainly of so great importance to the beginner that it must be briefly defined for him in terms of known factors, and the definition thus framed should remain serviceable through all later study. These conditions are satisfied when the beginner is told that the limit of subaerial erosion is the "level base" or "baselevel," drawn through a land mass in prolongation of the normal sea level surface. The fact that rivers erode their channels near their mouths below sea level and that special processes of erosion (winds and glaciers) may work below sea level, does not invalidate the general statement at the opening of the whole discussion; but these special conditions must be explicitly considered later, especially those concerning glacial erosion. It suffices at first to recognize that in the ideal undisturbed cycle of normal erosion the baselevel must be more and more closely approached as time is extended.

This definition of "baselevel" as a level base certainly has the advantage of being easily conceived. Once conceived in the study of the ideal cycle, it needs no modification so long as the relative attitude of land and sea remains fixed. If the land rise or fall with respect to the sea, the baselevel takes a new position within the land mass, and further progress of erosion is then continued with respect to the new limit.

As the study of the cycle advances it becomes desirable to speak of various local or temporary controls of erosion: a rock ledge or a lake on a river course, the central basin of a dry interior basin either above or below sea level, the surface of a lake in such a basin. Nothing can be simpler than to imagine a level surface passing through any one of these controls, and rising or sinking as the control rises or sinks; and such a surface is naturally called a local or temporary baselevel. With the enlargement of conceptions that is required when the aggradation of depressions is considered at the same time with the degradation of elevations, Powell's more general term, "gradation," may replace "erosion;" the merit of this substitution will appear more fully in the following pages.

In view of the importance appropriately allowed to the idea of the level base with respect to which the erosion of valleys by rivers must proceed, it is curious that earlier writers did not give more explicit attention to it; but as far as I have read, they were so largely occupied with controverting the various older theories of the origin of valleys that it did not occur to them to give special name to limiting surface of erosion. Their understanding of the important principle here involved is to be read rather between the lines than in explicit statements. For example, Greenwood, in his curious book on *Rain and Rivers*, almost as remarkable for its admixture of jokes and polemics as for its many admirable expositions of rain and river work,[1] contains the following account of the problems here considered:

> Suppose a barrier of rock to run across any valley or river bed; when the bed of the valley or river on the upper side of the barrier has been worn down to a horizontal level with this barrier, it can *not* go lower. . . . . But as the barrier is cut through, the bed of the valley or river will be deepened *backward*, or from below upward, or towards the hills. . . . . The passage of the detritus and soil from the inclined upper parts of valleys is checked in the horizontal lower parts of valleys, and soil accumulates there. This is the origin of alluvial plains; and a river of any size, or any rapidity, may, at any distance from the sea, have *patches* of alluvial plain, where no lakes have ever been; that is, above every rapid or accidental barrier of hard ground. . . . . The only difference in the laws for the growth and gradient of these patches from those which regulate the growth and gradient of the plain at the level of the sea, is that they have no *increasing* cause for rising equivalent to the *forward* lengthening of the delta of the lower alluvial plain. These flat alluvial patches may be seen even in torrents, sometimes reaching from one cascade to the other. . . . . It is easy to perceive that these patches must be liable to constant change. They must be perpetually shortened by the recession of the lower barrier, and lengthened by the recession of the upper one. . . . . These principles are eternally at work on all valleys, from the smallest to the largest" (174–176).

The use of "horizontal" in describing the lower parts of valleys is curiously inexact in contrast to the keen recognition of the difference between what we should now call local and general baselevels, and of the aggradation of a flood-plain on account of the "forward lengthening of the delta."

The balanced condition of rivers.—Turning now more particularly to the problem of river action, we find that the balance between erosion and deposition, attained by mature rivers, introduces one of the most important problems that is encountered in the discussion of the geographical cycle. The development of this balanced condition is brought about by changes in the capacity of a river to do work, and in the quantity of work

---

[1] Here is a characteristic illustration of Greenwood's mixture of sense and nonsense: "The very soil on which we tread . . . . may be said to be on its road from the hill to the sea. . . . . No drop of rain *runs* an inch on the surface of the earth without, as far as it goes, setting some soil forward on its road to the sea, and it won't run back again. No return tickets are given. It will wait there, and go on by the nex-*t-rain*" (105).

that the river has to do. The changes continue until the two quantities, at first unequal, reach equality; and then the river may be said to be graded, or to have reached the condition of grade. This condition cannot be understood without rather careful thinking on the part of the expert as well as of the tyro. The idea of grade is not of almost axiomatic simplicity, like the idea of baselevel; its meaning must be gradually elaborated as it is approached. Moreover, a graded river does not maintain a constant slope; it changes its slope systematically with the progress of the cycle: but before taking up this element of the discussion a few paragraphs may be given to the consideration of "grade," as a common word used in a technical sense.

It should be noted in the first place that it is a condition of river development, not a surface, nor a stage, nor a form, for which the term "grade" is to serve as a name. The condition of grade must not be confused with the limiting under-surface of erosion, with respect to which the graded condition is developed; the name for this surface is "baselevel." Nor must it be confused with the stage in the history of river development in which the graded condition is reached; "maturity" is the name for that stage; but it may be noted in passing that the graded condition persists all through the old age as well as the maturity of an uninterrupted cycle. "Grade," meaning a condition or balance, must not be confused with the same word used in another meaning, namely, the slope or declivity of the river when the graded condition is reached; for "grade" meaning slope, varies in place and in time, while "grade," meaning balance, always implies an equality of two quantities. In fine, grade is a condition of essential balance between corrasion and deposition, usually reached by rivers in the mature stage of their development, when their slopes have been duly worn down or built up with respect to the baselevel of their basin.

There can be no question that the balanced condition of mature and old rivers deserves a name. It was to this condition that Powell called attention in his original discussion of land sculpture, and to which he devoted one of the meanings of his term "baselevel." A name had already been suggested for the balanced condition by various writers, who called it the "régime" or "regimen" of rivers, while the slope of a river under this regimen was called its "*penté d'équilibre*" by Dausse and the "*Erosions-Terminante*" by Philippson (1886, 71.) But (1857, 759) "regimen" may be better used as meaning the rule of river action under which the balanced condition is developed and maintained; while "slope of equilibrium" may be taken as a descriptive phrase, too cumbersome for ordinary or frequent use, but essentially synonymous with "graded slope." "Baselevel" seems at best a very inappropriate name for a condition in which the idea of slope is essential; and when another and equally important use is made of this excellent word, its employment as the name for the balanced condition of rivers is all the more unsatisfactory. "Grade" is the most satisfactory term for the balanced condition or state of equilibrium of rivers on several grounds, in spite of certain objections that may be urged against it. Let us consider the objections first.

Origin and use of the term "grade."—One of my correspondents has objected to "grade" because, in the sense here adopted, the word means, etomologically, a step and not a slope. This objection seems to me of small value on account of the freedom with which new meanings are given to old roots. Language does not grow by rule but by use; and use has decreed that one meaning of the English word "grade" shall depart somewhat from the meaning of its Latin ancestor. The chapter on "Transference of Meaning" 'in a work on *Words and Their Ways in English Speech*, by two of my colleagues, Professors Greenough and Kittredge, may be consulted to advantage in this connection.

Another correspondent objects because the word "grade" is already in common use, meaning among other things, a slope, and the ratio of the vertical to the horizontal in a slope; but as a matter of fact no practical inconvenience has arisen on this account. The context suffices to indicate which one of the several meanings of the word is intended. Moreover, if we should endeavor to escape the criticism of Scylla, by making up a new technical term in order to avoid the technical use of a common word in a new meaning, we should be met by the objections of Charybdis, who maintains that "every new technical term is a positive detriment to science." The objections to "grade" seems to me far outweighed by the many points in its favor, which may now be reviewed.

In favor of the term, it may be noted first that "grade," like "baselevel," is of a convenient form, ready for use as noun, adjective, and verb, after the handy fashion of the English language in many other cases. In the second place, the sense of the verb "grade," as employed by engineers (to prepare, by cutting and filling, a smooth bed of gentle slope for a railroad or other line of transportation), is closely analogous to the meaning here advocated for the verb "grade" as used by geologists and geographers: a river grades its course by a process of cutting and filling, until an equable slope is developed along which the transportation of its load is most effectively accomplished. In the third place, "grade" lends itself admirably to the formation of such terms as "degrade," "aggrade," and "gradation;" "degrade," in the sense of to wear down, has been in use for some time by geologists; "aggrade" is an excellent addition to our terminology, proposed by Salisbury (1893, 103) in the sense of building up; while "gradation" is Powell's term for the general process of wearing down elevations and filling up depressions, in the production of lowland plains (1895, 30). Finally, the word has already made a beginning towards acquiring a useful place in scientific writings.

The use of "grade," in the sense here advocated, was almost reached by Gilbert in his description of hills of planation, covered with stream gravels: "The slope of the hill depends on the grade of the ancient stream, and is independent of the hardness and dip of the strata" (1877, 130); and again in his account of how a river "tends to establish a single, uniform grade," and "an equilibrium of action" (1876, 100). It was in consequence of a suggestion from this philosophical writer that I introduced "grade" as a substitute for various paraphrases in my own work in 1893 (1894, 77).

McGee considers the control of the balanced condition of rivers under the "law of river gradation" (1891, 265).

Mill uses "grade" as a verb, essentially in the sense here advocated: "Ultimately the river grades its course and flows uniformly along a uniform slope" (56).

Gannett has adopted "grade" as a technical term in Folios 1 and 2 of the *Topographic Atlas of the United States.* In the first he writes:

> There finally comes a time when the river ceases to erode, or rather, it deposits as much as it erodes. . . . . A river is then said to be graded.

In the second, a special sheet with explanatory text is devoted to "A Graded River," the example chosen being the lower Missouri:

> At this stage the lower portion of its [a river's] course has been eroded to almost as low a stage as possible, and its slope has become very slight, so that its cutting power is trifling. This part of the stream is said to be "graded."

Johnson uses "gradation" as involving both degradation and aggradation, and as producing a "graded slope," a slope of "equilibrium easily disturbed, yet constantly maintained" (620).

"Grade" may therefore be regarded as having already gained recognition in the sense here advocated, as a replacement of one of the meanings of "baselevel."

There remain to be considered several reasons in favor of giving different names to the limiting base of sub-aerial erosion, and to the balanced condition in which rivers spend most of their lives while approaching the limit of their work. The first reason is based on the persistence of the base level surface all through the cycle, without change from its initially complete extension, in contrast to the gradual introduction and slow extension of the condition of grade during the mature and older stages of the cycle. The second is based on the fixity of the baselevel surface in contrast to the variation in the slope of graded rivers. The third springs from the essential simplicity in the meaning of "baselevel," in contrast to the complexity and variety of conditions ultimately gathered under the term "grade."

Baselevel is complete from the beginning, and permanent to the end; Grade is slowly introduced and gradually extended.—The conception of the general baselevel must be made at the outset as that of a completed surface extending beneath the land mass under consideration at the beginning of the cycle, and so remaining as long as the advance of the cycle continues undisturbed. In the ideal case, which provides the general scheme with respect to which all other cases are classified, the land mass once uplifted is supposed to stand still until it is worn down flat. This supposition is so artificial, and does so great violence to much that is known as to the behavior of the earth's crust, that some students are therefore disposed to discard the scheme of the cycle altogether in the study of the sculpture of land masses, overlooking the fact that however many movements of a land mass may be discovered, the many incomplete cycles that are separated by these movements must each be treated essentially according to the scheme of the ideal cycle. In every case, the processes of land sculpture, quickened or slackened in consequence of the new attitude given to the region, go on with respect to the new attitude of the baselevel within the land mass.

Even during the movement of the land mass, it must be conceived of as rising or sinking through a fixed and complete baselevel surface, with respect to which its carving is even then begun, and long afterwards continued, during the ensuing time of relative or absolute rest. Hence, for every cycle or partial cycle of erosion, the imaginary baselevel surface is immediately conceived as complete at the outset, and as thenceforwards remaining unchanged. Local baselevels are also complete, in extending at once as far as the imagination wishes to carry them; they rise or fall slowly with their control.

It is far otherwise with the development of the graded condition. The previous paragraphs have explained that the development of grade depends on the spontaneous adjustment of the capacity of a river to do work, and the quantity of work to be done by the river. It is well understood that this adjustment is realized by the larger streams relatively early in the cycle; by those of medium and smaller size at later and later stages; and hence that the condition of grade is deliberately introduced and systematically extended through all parts of a river system as the cycle advances. The condition of grade needs no mention when the scheme of the cycle is first presented. Truly, it might be considered as an accompaniment of the youth of a cycle in those special cases where a large river is running across a slowly rising region of weak rocks, for here the condition of grade may be continuously maintained during the period of uplift. But it is not in connection with special cases of this kind that a first acquaintance with the condition of grade is best made. Its fuller meaning is not likely to be well understood unless presented with something of the deliberation that characterizes the actual development of graded rivers. Indeed the conception of grade is likely to be an embarrassment if presented too early.

The extension of the graded condition over all parts of a river system introduces a thoroughness of organization in the processes of land sculpture that warrants the use of the term "maturity," as the name of the stage of the cycle in which the organization of river systems is chiefly accomplished. The growth of organization goes with the development of grade. In every reach of a river in which the graded condition has been attained, the lowest point on the reach is always coincident with and dependent on a controlling baselevel (as above defined) either general or local, and river action at any point in the graded reach is then delicately correlated with that at every other point. River action in such a reach may justly be said to be organized, inasmuch as a change in form or action at any one point involves a change at every other point. Adjacent reaches, separated by a fall on an ungraded ledge or by an unfilled lake, are independently organized; a change in one does not necessarily call for a change in the other. But when all falls and rapids are worn down, and all lakes are filled up, and the entire river system is graded, as is characteristically the case in the late-mature stage of a cycle, the organization of the system is so complete that all its parts are correlated. A change at any one point then involves a change, of infinitesimal amount perhaps, all through the system. It is this condition of organization that Gilbert alluded to in describing the "interdependence" that comes to be developed among the different lines of a river system, as a result of which "a disturbance upon any line is communicated through it to the main line and thence to every tributary"—(1877, 124).

The actual slopes of the different parts of a graded river system vary from a faintest declivity in the lower course of the trunk river to decidedly steeper declivities in the uppermost courses of the headwater streams. If any stream line is followed from head to mouth its profile will show a curve, approximating theoretically to the flatter part of one wing of a parabola;[1] but when studied in detail, the normally continuous decrease of slope down stream is found to be seldom realized. The entrance of a tributary is usually accompanied by a decrease of slope up-stream and an increase of slope down-stream from the tributary mouth; the spasmodic action of floods introduces some faint symptoms of disorder in otherwise simple slopes; and in this connection the inequalities due to what McGee has called "varigradation" are to be considered (1891, 269; see also Oldham, 1888). All these complications in the slopes of a graded river system make it extremely difficult to conceive of a surface which shall generalize the river slopes. Indeed, it is hardly worth while to attempt this conception, for the reason that all the value of the imaginary surface is to be found in the actual slope lines of the graded river systems by which the surface is guided. It is with respect to the sloping course of a graded stream that the valley

---

[1] It is evidently only under the assumption that the baselevel is not a convex level surface, but a plane that the profile of a river can be described as a parabola. The actual profile of a large river, such as the Mississippi, is convex to the sky.

sides are to be worn down; it is with respect to the graded lines of a river system that its whole basin is to be worn down. This conception, as announced by Powell, is of fundamental importance; but it does not seem to gain in clearness or strength by expressing the control of erosion in terms of a warped surface, guided by the branching lines of the graded river system, instead of expressing it distinctly in terms of the branching stream lines themselves. Reference will be made again to this aspect of the problem further on.

Not only do graded streams vary in slope in different parts of a river system; the slopes may vary greatly in two neighboring river systems at the time of the general establishment of their grade. This may be illustrated by considering the unlike conditions obtaining in two rivers, alike in volume, but one flowing through an upland of resistant rocks, the other through a similar upland of weak rocks. The first would have to cut down a deep valley to a gentle slope before grade was reached; because its load would be slowly delivered from the resistant rocks of its valley walls, and high walls would have to be produced by deep valley cutting before a balance could be struck between the increasing load from the walls and headwaters and the decreasing capacity of the river. The second river could not cut so deep a valley, however weak the rocks of its bed, because it would have an abundant load supplied by the rapid wasting of its valley sides, even when they were of moderate height, and a strong slope down the valley would be required in order to maintain a velocity with which the graded stream could bear the abundant load away. Only as the whole upland is worn down in the later stages of the cycle could the second stream wear down its valley to a gentle slope; and then the valley would be still shallower than when grade was first attained.

The principle here considered is clearly recognized by Gilbert, who instances the Platte as a river of the second kind, and states that Powell also had so described it (1876, 100). The difference between the two kinds of rivers is not satisfactorily indicated in terms of baselevel; but it is clearly presented by stating that one has developed its grade on a faint slope, the other on a stronger slope.

The incapacity of the Platte to deepen its valley leads Gannett to describe it as an "overloaded river(1900); but this phrase is not altogether satisfactory, because it overlooks the fact that rivers refuse to be overloaded. A river will most dutifully work up to its full capacity; it is ready to increase its capacity by increasing its slope through aggrading when necessary (as stated below), and thus it may become heavily loaded; but like the traditional llama it refuses to carry an overload. Like all streams with braided channels, the Platte is well graded, as well graded as the typical lower Missouri, although the quantity and texture of its load require it to maintain a relatively strong slope.

Baselevel remains fixed all through an uninterrupted cycle : the slope of graded streams must vary as the cycle advances.— After a river system has attained a maturely graded condition, it will maintain a graded condition through all the rest of the undisturbed cycle; but it is important to recognize that the maintenance of grade, during the very slow changes in volume and load that accompany the advance of the cycle, involves an appropriate change of slope as well. Instead, therefore, of having to do with a fixed control of erosion, such as is found in the general baselevel of a region, we have here to do with a slowly, delicately and elaborately changing equilibrium of river action, accompanied by a corresponding change in river slope. For example, a large river in a mountain valley may reach grade in the early maturity of its region. It will then flow with a rushing current on a rapidly sloping bed of cobblestones; and it may stand hundreds or even thousands of feet above baselevel. In the old age of the region, the same river will flow with a sluggish current on a nearly level bed of sand and silt through a peneplain, only a few tens or scores of feet above baselevel.

This is a point that is not generally enough recognized. It is too often implied — in the absence of explicit statement to the contrary — that when a river is once balanced between erosion and deposition its slope thenceforward remains constant. The beginner would gather this understanding of the question from several of the definitions of "baselevel" above quoted, but such is evidently not the case. When a stream is first graded, its channel is not level, and it has not reached the base of its erosive work. In virtue of the continual, though slow, variations of stream volume and load through the normal cycle, the balanced condition of any stream can be maintained only by an equally continuous, though small, change of river slope, whereby capacity to do work and work to be done shall always be kept equal. It might at first be thought that changes of this kind would be perceptible, and that there would be occasional departures of a river from the graded condition ; but such is not the case, because the change in the value of any variable in a unit of time is only by a quantity of the second order, by a differential of its total value. Once graded, a river will never depart perceptibly from the graded condition as long as the normal advance of the cycle is undisturbed. The slope of a river must necessarily be steeper on the first attainment of grade in early maturity, when an abundant load is received from the steep valley sides and the active headwater, than in late old age, when the valley sides have been worn down almost level, and when the even headwater streams are weak and sluggish. Hence, just as a graded river has slopes of varying declivities in its different parts at any one time, so the slope at any one part of the river must vary at different times in the successive stages of the cycle.

Not only so : it is eminently possible that the slope of a graded stream may have to be increased for a time after it has been first attained, for there is no necessity that the load should cease increasing just when its value has risen to equality with that which the stream can transport. There is much probability that, after grade is reached in a normal, undisturbed cycle, a river may have for a time to aggrade its valley floor until the time of maximum load is reached : and only after the maximum gives way to a decrease of load can there be a beginning of that very slow and long-continued decrease of river slope which continues through late maturity and old age. Furthermore, if at any time in the cycle a change of climate should occur, new slopes would have to be developed by the streams in order to bring about a new balance between erosion and transportation under the new relation of load and volume. If, for example, the changes were from humid to arid conditions, all the valley floors would have to be steepened by aggradation. If from arid to humid, the graded valley floors would be sharply trenched, and in time reduced to lower slopes. There can be little doubt that under an increased rainfall the "baselevel" described in southeastern California by Fairbanks would be sharply dissected, quite independent of any elevation of the region. I have already discussed certain aspects of this problem (1896, 377).

The clearest account that I have found of the normal variation of the graded slope is in the paper by Johnson already cited. He says that the graded slope "continually alters its inclination. There is a slow departure from equilibrium, and there is closely following readjustment toward recovery of it." The graded slope passes through its "transformations with a slowness comparable to that of mountain wear. . . . . It keeps pace with the slow growth of the débris mass following upon mountain lowering." But, if a stream be deprived of the greater part of its load by some abnormal changes, it "would at once attack its former slope of equilibrium, and rapidly, though at a progressively slowing rate, lower it. On the other hand, its load largely increased, the stream would rapidly build up the slope. In either case, however, it would come to a stand at a new grade of equilibrium" (1901, 621).

The same author attaches much importance to the effect of climatic changes on graded river slopes. When describing the dissection of the High plains, he says :

> It is not necessary, in order to account for change in behavior of the traversing streams, to appeal to deformation. A sufficient cause may be looked for in change of climate. There is record of erosion, with reversal to deposition and rebuilding, and reversal again finally to erosion, and there is reason

for believing that this series of interruptions of the gradation cycle was an effect of climatic oscillation rather than of earth movement (1901, 628).

This is by far the most striking actual example of varying graded slopes on record : an example that is easily defined in terms of changing grade, but not in terms of changing baselevel. It is much more satisfactory to describe the High plains in terms of stronger or fainter graded slopes than to consider them "near baselevel," as has been done in spite of their standing at altitudes of 4,000 feet and more.

The conception of grade must therefore include the conception of different and changing slopes in large and small streams, in mature and old streams, in streams dissecting weak and strong rocks, in streams of arid and humid regions. The conception is of the greatest value as a supplement to the simpler idea of baselevel ; but it is so intricate that it cannot be fully apprehended until the whole course of the cycle is patiently worked through. Yet a still further extension of the conception remains to be considered.

Baselevels are of only two kinds, general (permanent) and local (temporary) ; Grade includes not only the balanced condition of large and small, mature and old water-streams, but that of all kinds of waste streams as well.—A final reason for giving different names to the limiting base of subaerial erosion and to the balanced condition of the mature and old streams that are working with respect to the limiting base is found in the essential identity of conditions in graded water streams and in graded waste streams, and in the strong unlikeness between the attitude of a baselevel surface as defined in any of the above citations and the slopes often assumed by graded waste streams. These are points to which the geologists and geographers of the older schools gave little or no attention : indeed it is only about fifty years since some of the leaders of our science taught that rounded hills could not be formed by subaerial erosion and that they must be the work of the sea. It is now well understood, however, that slopes covered with soil of local or up-hill derivation are really "drained" by an association of many graded waste streams, whose behavior closely resembles that of graded water streams.

The first development of the balanced or graded condition in waste streams usually takes place on the outcrops of the weaker rocks that are exposed on freshly cut valley sides. Here graded waste slopes are locally developed; the adjoining waste streams form a sheet or cloak of waste which creeps slowly down the slope, while untamed ledges of harder rocks are still kept bare by the removal of waste from their surface as fast as it is formed. These represent the falls and rapids of water streams, because the waste from above the ledges passes over them quickly; while the graded waste-covered slopes represent the graded reaches of water streams, where the movement is more regular and leisurely. The less resistant of the bare ledges are the first to retreat under cover, permitting the grades below and above to unite in a single continuous slope; and so on, until all ledges are concealed under a graded sheet of waste, and the sharp, vigorous forms of youth and early maturity merge into the subdued and tamed forms of passing maturity and approaching old age.[1] During the progress of this change, there may be abundant examples of captures of one group of waste streams by the leading members of another group, especially in regions of tilted strata; thus increasing the resemblance of waste streams and water streams, until one is tempted to regard the difference between them as one of degree rather than of kind.

As maturity passes into old age all the elevations are worn lower and lower and the graded cloak of waste covers more and more of the surface. As the later stages of the cycle are approached, the whole region, monadnocks excepted, is reduced to moderate relief and bare ledges are rarely seen. On the faintly sloping forms of advanced old age the graded sheet of waste covers the entire surface between the water streams. Everywhere gently waste-covered slopes lead from the low

---

[1] I have pursued the comparison of water streams and waste streams somewhat further in my paper on "An Excursion to the Grand Canyon of the Colorado (1901, 176).

arched divides to the streams. The surface soil, greatly refined in texture by long exposure to the weather in its deliberate journey slowly creeps and washes to the streams, and the relief is reduced to smaller and smaller measures. The condition of grade, at first developed in the lower course of the larger rivers, next in their branches and headwaters, then on the valley sides and over the hills, has thus been extended all over the region. The organization that at maturity characterized the water streams has come in old age to characterize the streams and sheets of waste all over the land surface. From the beginning to the end of this process, there is steady progress without break or interruption through the normal cycle. There is an essential unity of development through the whole of it. It is very desirable that this unity should be expressed in the terms employed in the description of land sculpture and land form; and that the balanced condition of water streams and waste streams alike should be expressed by such a term as grade, rather than that an artificial distinction between them should be introduced by speaking of the balanced rivers as defining a "baselevel," while balanced waste streams are given some other name by which their close affinity to graded water stream is concealed.

An old land surface, sheeted over with a graded soil cover, is a peneplain of erosion or of gradation; it passes slowly into a plain of gradation. It is almost the realization of that imaginary baselevel surface described by Powell as "inclining slightly in all its parts toward the lower end of the principal streams draining the area through which the level is supposed to extend, or having the inclination of its parts varied in direction as determined by tributary streams;" but this imaginary surface is elusive and intangible, because of the impossibility of defining the stage of stream development when it should be introduced, and the length of graded stream course that it should follow; while on the other hand the graded land surface is a reality whose gradual development and slow change is one of its essential characteristics.

Until the imaginary surface is thus realized, it is hardly worth while to attempt to conceive it; for as far as the control of erosive processes is concerned, that is better exercised (as has been stated already) by the visible skeleton of the surface that is seen in graded streams than by the surface itself. It is always with reference to the graded course of the main river that the side streams are graded; it is with reference to all the graded streams that the slopes of the interfluves are graded. These relations of branch to trunk and of side slopes to streams are of the very greatest importance and must be considered with the utmost care; but the imaginary surface passing from river to river under the hills of the interfluves has relatively little importance as a control of the processes of erosion. With every extension headwards along the graded channels of branching streams, the surface becomes more warped and wrinkled, more difficult to conceive, more likely to differ as conceived by different minds. It must be not only irregularly warped when first defined, but it must vary slowly in form and slope. Just as no limit can be set to the headward part of the graded main stream or to the number of graded branch streams to be taken as guides for the imaginary warped "baselevel," so no limit can be set between the graded stream courses and the graded waste slopes of their head or along their sides. The imaginary surface should, if conceived at all, follow the lead of *all* the graded lines and surfaces as fast as they are developed; it should be extended as they are extended, modified as they are modified. But if this be agreed to, part of the imaginary surface becomes a real surface, and the rest may be neglected until it also is realized.

Just as every reach in a stream is graded with respect to the next down-stream barrier or local baselevel, so every waste slope is graded with respect to the ledge or cliff at its lower margin; the lowest reach, ending at the river mouth, is graded with reference to the general baselevel or the ocean; the lowest graded slope of a valley side is graded with reference to the stream (or flood plain) in the valley bottom. Again, every bare ledge on a mountain side will, in time, be graded (or consumed) by the headward growth of the graded slope next below it, just as every ledge of rocks that makes a fall or rapid at the head of a reach will, in time, be obliterated by the up-stream extension of the graded reach. (In both cases, when the time of extinction of the ledge is attained, the waste slope and the stream reach will probably have been worn somewhat farther into the land-mass, assuming a somewhat fainter declivity—that is, coming closer to baselevel—than was the case while the ledge still existed.)

The close similarity, the real homology between the two classes of streams, makes it all the clearer that "baselevel" is not a good term to apply to either. It is not desirable to say that a hillside ledge is "baseleveled" when it is worn back so far that it disappears under the slope of the growing sheet of waste; yet it is certainly desirable to indicate by the use of an appropriate terminology that the disappearance of the ledge has been accomplished by changes of the same kind as those which have caused the obliteration of falls and rapids in rivers. Hence it seems desirable to say that every ledge, in valley side or stream bed, will in time be graded—not baseleveled—with respect to the attitude assumed at that future time by the graded—not baseleveled—reach or slope next below it.

It is, perhaps, on account of the elusive character of the imaginary warped surface that its definition is sometimes couched in indefinite language. In the original definition, Powell said:

> I take some liberty in using the term level in this connection, as the action of a stream in wearing its channel ceases, for all practical purposes, before its bed has quite reached the level of the lower end of the stream. What I have called the baselevel would, in fact, be an imaginary surface, inclining slightly (1875, 204).

In a later paper he said again:

> It will be understood that the land plain which is brought down to the level of the sea has its margin on the seashore, and that it extends back from the shore a distance which may be miles or hundreds of miles. As it stretches back, its surface rises slightly. The whole plain is not

brought down absolutely to the level of the sea, but only nearly to that level (1895, 34, 35).

Salisbury states that "no definite degree of slope can be fixed upon as marking a baselevel." Geikie defines baselevel as "a level not much above that of the sea." Brigham writes:

> The great river first cuts its bed close to the sea level, and we say that a portion of the valley is reduced to baselevel. It lacks a little of it, but the difference is so small that we neglect it.

These qualified statements are apparently the result of attempting to define a surface in terms of its variable feature, slope, instead of in terms of its constant feature, balance of activities. Whatever slope is agreed upon must change to a fainter slope if more time is allowed; but the balance, once struck, is always maintained as long as the cycle endures. Another cause of difficulty in definition seems to have arisen from giving the same name to a variable and to its limit. Both the imaginary warped surface and the actual peneplain are essentially variables; their variations are similar and systematic; they both approach, but never reach the limiting base of subaerial erosion. The latter is essentially a constant, accurately definable from the beginning, and remaining unchanged while the variable surfaces approach it. It may be defined as the limit of either of these variables in a strictly mathematical fashion. The baselevel is the level base toward which the land surface constantly approaches in accordance with the laws of degradation, but which it can never reach.

Plains and peneplains.— The names for surfaces of ultimate and penultimate subaerial erosion deserve brief consideration. My own preference, prejudiced, perhaps, by a share that I have had in making up names, would be to avoid "baselevel" as a technical name for any geographical form, to use "plain" sparingly for surfaces of erosion, because of the rare occurrence of complete or ultimate planation; and usually to employ "peneplain" as the name for the penultimate form developed in a cycle of erosion. It was in order to avoid the implication of complete erosion, and the objections that such an implication aroused, that the term peneplain was suggested thirteen years ago. This word gradually came into use with quotation marks and an explanatory footnote. The footnote disappeared first, and now the quotation marks are frequently omitted as if the word had gained an established position, although among writers in Great Britain the need of the term is still so little felt that it is generally mentioned as an American invention when used at all, instead of being fully adopted, like delta and atoll, without explanation or acknowledgment.

There seems to be today less hesitation regarding the acceptance of the idea of far-advanced subaerial degradation than there was fifteen years ago—witness the use of "plain of erosion" by Hobbs (137) as a name for the worn-down surface, now uplifted and dissected in the uplands of Connecticut; nevertheless it still seems desirable to speak of such surfaces as peneplains in the absence of proof that they were actually reduced to plains. The alternatives for peneplain are as follows:

Powell contrasts "gradation or true plains" with "diastrophic plains" (plateaus), the former being produced by gradation, a "process accomplished through the agency of water," and the latter by the uplifting of the earth's crust. This use of "gradation" is a natural complement of the use of "grade" in the sense advocated in this essay. Gradation plains are then treated under four heads: sea plains, lake plains, stream plains, and flood plains. Of the first class it is said:

> Whenever in any region the process of slow upheaval comes to an end, and such district is still subject to degradation by rains and streams, the process of reduction goes on until the surface is brought down to the level of the sea . . . . The sea-level plain is permanent in the absence of diastrophism. . . . Low lands with surfaces more inclined, and with more swiftly running streams, are still called *plains* though they are not fully brought down to baselevel; sometimes they are, called *peneplains* (1895, 34, 35).

Sea plain has not come into general use, perhaps because of possible confusion with sea-cut plains, or plains of marine denudation. The following extract gives an example of the employment of the term with double meaning by Hughes, in describing the uplands of western Yorkshire :

> It is to both of the agencies above mentioned [marine and subaerial erosion], acting simultaneously throughout long ages, that we must refer the tremendous results that we have forced upon our attention . . . . We will refer to these great plateaux by the shorter term sea-plain ; to distinguish them from the river-plains or bed-plains (131).

Dryer uses the phrase, " graded plain," in a somewhat different sense. The reduction of the border of a land area to a submarine plain by sea action, while the rest of the land surface is reduced to "baselevel" by subaerial processes, would result in the production of a " graded plain, lying partly above and partly below sea level" (234). No example of this kind of plain is mentioned. Gradation plain is used by Adams for a locally developed peneplain between residual ridges (508).

The terminology employed by Hayes departs somewhat from that in use with other writers. He says :

> The processes which tend to produce a baselevel plain are embraced under the term *gradation*. This includes aggradation and degradation. . . . . A *baseleveled surface* is any land surface, however small, which has been brought approximately to a baselevel, either general or local, by the processes of gradation. When such a surface has considerable extent it becomes a *baselevel plain*. . . . . The term *baselevel peneplain* or simply *peneplain* is applied to a surface of which a greater or less proportion has been reduced to the condition of a baselevel plain, but which contains also some unreduced residual areas (21, 22).

It seems to me that it is going too far to say that " a baselevel surface is any land surface, however small, which has been brought approximately to a baselevel, either general or local." It would follow from this definition that, inasmuch as every point in a continuously graded river is a local baselevel for every other point further up-stream, the upper stretches of the flood plain or broad valley floor of a large river would be called a baselevel surface, in spite of their standing several hundreds or even thousands of feet above the general baselevel. The valley plain of the Platte, for example, attains altitudes of more than 3,000 feet, and cannot be fitly described as a baselevel plain, unless baselevel is taken to mean a sloping surface. It may be more appropriately called a graded valley plain, or a graded valley floor, for these terms do not contain any implication that the surface is either low or level.

Another objection to the above use of "baseleveled surface" is that it arbitrarily separates graded valley floors and graded hill sides, whose analogies with respect to the processes of gradation ought to be exhibited rather than concealed in a systematic terminology. It can hardly be supposed that anyone would today call a waste-covered hillside a "baseleveled surface," although it has every characteristic with respect to the processes of gradation that is possessed by a graded valley floor. A third objection to this use of "baseleveled surface" would be found when applying it to the High plains of eastern Colorado and western Kansas, which, according to the explanation offered by Johnson and cited above, were produced by aggradation during a time of less rainfall than at present. Here an extended surface was, as Hayes might phrase it, "brought approximately to a baselevel, either general or local, by the processes of gradation," and yet it was actually built up hundreds of feet above the pre-existent and the present valleys, and thousands of feet above the general baselevel, although there is no indication of any discontinuity in the graded surface between the High plains and the mouths of their aggrading rivers. The High plains are better called aggraded river-made plains, or *fluviatile plains;* and in this respect they resembled the great plains of northern India.

The geographical cycle.—The period of time during which an uplifted land mass undergoes its transformations by the processes of land sculpture, ending in a low featureless plain, has been called a geographical cycle, or, as Lawson phrases it, a "geomorphic cycle" (253). Hayes writes: "The term *gradation period* is employed for the entire time during which the baselevel remains in one position; that is, the interval between two elevations of the earth's surface of sufficient magnitude to produce a marked change in the position of sea level" (22), but on later pages he uses the phrase "cycles of gradation" or simply "cycles" instead of "gradation periods." It matters little which of these terms is used; but it would certainly be an advantage that only one should be retained to express the single idea here considered.

Denudation and degradation.— It seems worth while to call attention in this connection to the desirability of a more careful discrimination than is customary between the terms, denudation and degradation. Denudation might be advisedly used as the name of those active processes, chiefly operative in the youth and maturity of a cycle, by which rock structures are laid bare, literally denuded, because their waste is removed as fast as it is formed. Degradation on the other hand is more appropriately associated with those liesurely processes, characteristic of the later stages of the cycle, in which a graded slope is reduced to fainter and fainter declivity, although maintaining its graded condition all the while. Aggradation is naturally the opposite of degradation, and implies the deposition of rock waste by transporting agencies, the built-up surface being always kept essentially at grade. Thus defined, denudation would accompany the early work of downward corrasion by streams, and the longer-lasting work of valley widening by weathering and washing. It would be systematically transmuted into degradation as the processes that operate on the various lines of down-slope streaming attained the graded condition; the large rivers first, the smaller branch streams later; the headwater streamlets and the hillside waste streams later still. Retreating cliffs and summit ledges, the last strongholds of denudation, would pass into the phase of degradation when they are reduced under the graded waste cover in the stage of subdued relief, characteristic of late maturity and early old age; and thenceforward all further erosion would be by degradation alone.

Conclusion.—It may seem at first reading that this essay is concerned with words rather than with facts; but such is not my intention. My object has been primarily to secure a just and accurate recognition of facts, and only secondarily to attach words to the facts as convenient handles by which to bring the facts forward. It is a fact of large import that the wearing down of land masses proceeds in an orderly manner, involving the disclosure of bare rock ledges (denudation) in the earlier stages of the cycle of erosion, and the concealment of all ledges under a graded sheet of waste in the later stages of the cycle (degradation). It is a fact of much delicacy that streams tend to assume a balanced condition as to corrasion and transportation; that after once attaining this condition they preserve it as long as their work continues without disturbance; but that the slope of their graded courses must vary systematically through the stages of maturity and old age, as well as through changes of climate. It is a fact of great value in geographical description that the balanced condition of water streams is imitated so closely by that of waste streams that one set of terms applies to both kinds of streams.

There can be no question that the adoption of a suitable term as the name for a fact is a great aid to the general recognition of the fact itself. It is largely on this account, as well as in the interests of a precise terminology, that I have here written out a series of notes that have been gathered during the past two years, and of which some account was given at the meeting of the Geological Society of America in Washington, in December, 1899.

It is admittedly difficult always to use terms in a manner that is perfectly consistent with their definitions. It is rarely possible to limit terms to a single meaning. It is probable that in this attempt to reduce our terminology to greater simplicity and better order than now prevails I have laid myself open to criticism on the very grounds that are objected to in the course of this essay. Further discussion may therefore be advisedly directed to a settlement of open questions. It is certainly open to consideration whether "denudation" and "degradation" should be limited as above suggested; but the advisability of holding "baselevel" and "grade" to the meanings here indicated seems to me much less open to difference of opinion. The future meanings of these words will depend much less on the preference of the older geologists and geographers of today than on that of their younger successors. I therefore urge those who are now taking up the use of such terms as baselevel and grade, denudation and degradation, to consider carefully the meaning to be adopted for them.

W. M. DAVIS.

LIST OF AUTHORS CITED.

G. I. Adams, "Physiography of the Arkansas Valley Region" (abstract), *Science*, XI, 1990, 508.

A. P. Brigham, *A Text-Book of Geology*. New York: Appleton, 1901.

M. C. Campbell, "Drainage Modification and their Interpretation," JOUR. GEOL., IV, 1896, 567–587, 657–678.

H. C. Cowles, "Physiographic Ecology of Chicago and Vicinity," *Botan. Gazette*, XXXI, 1901, 73–108, 145–182.

N. H. Darton, "Outline of Cenozoic History of a Portion of the Middle Atlantic Slope," JOUR. GEOL., II, 1894, 568–587.

M. F. B. Dausse, "Note sur un Principe important et nouveau d'Hydraulique." *C. R. Acad. Sciences, Paris*, XLIV, 1857, 756–766.

W. M. Davis, "Geographic Methods in Geologic Investigation," *Nat. Geogr. Mag.*, I, 1889, 11–26.

—— "Physical Geography in the University," JOUR. GEOL., II, 1894, 66–100.

—— "A Speculation in Topographical Climatology," *Amer. Meteorol. Jour.*, XII, 1896, 372–381.

—— "An Excursion to the Grand Canyon of the Colorado," *Bull. Museum. Comp. Zoöl. Harvard College*, XXXIII, 1901, 107–201.

W. M. Davis and J. W. Wood, Jr., "The Geographic Development of Northern New Jersey," *Proc. Boston Soc. Nat. Hist.*, XXIV, 1889, 365–423.

J. S. Diller, "Tertiary Revolution in the Topography of the Pacific Coast," *Fourteenth Ann. Rep. U. S. Geol. Survey*, 1894, Pt. II, 397–434.

C. R. Dryer, *Lessons in Physical Geography*. New York: American Book Co., 1901.

C. E. Dutton, "Tertiary History of the Grand Canyon District," *Monogr. II, U. S. Geol. Survey*, 1882.

H. W. Fairbanks, "Notes on the Geology of Eastern California," *Amer. Geol.*, XVII, 1896, 63–74.

H. Gannett, "Physiographic Types," *U. S. Geol. Surv.*, *Topogr. Atlas U. S.*, Folio 1, 1896; Folio 2, 1900.

J. Geikie, *Earth Sculpture or the Origin of Land-Forms*. London: Murray, 1898.

G. K. Gilbert, "The Colorado Plateaux Province as a Field for Geological Study," *Amer. Jour. Sci.*, XII, 1876, 16–24, 85–103.

—— "Report on the Geology of the Henry Mountains," *Dept. of Interior, U. S. Geogr. and Geol. Survey, Rocky Mountain Region*, 1877.

—— "The Underground Water of the Arkansas Valley in Eastern Colorado," *Seventeenth Ann. Rep. U. S. Geol. Survey*, Pt. II, 1896, 551–601.

G. Greenwood, *Rain and Rivers.* London: Longmans, 1857.

C. W. Hayes, "Physiography of the Chattanooga District in Tennessee, Georgia, and Alabama," *Nineteenth Ann. Rep. U. S. Geol. Survey*, 1899, Pt. II, 1–58.

R. T. Hill, "The Geological History of the Isthmus of Panama and Portions of Costa Rica," *Bull. Museum Comp. Zoöl., Harvard College*, XXVIII, 1898, 151–285.

W. H. Hobbs, "The Newark System of Pomperaug Valley, Connecticut," *Twenty-first Ann. Rep. U. S. Geol. Survey*, Pt. III, 1901, 7–162.

T. McK. Hughes, "Ingleborough, Pt. I, Physical Geography," *Proc. Yorkshire Geol. and Polytech. Soc.*, XIV, 1901, 125–150.

W. D. Johnson, "The High Plains and their Utilization," *Twenty-first Ann. Rep. U. S. Geol. Survey*, 1901, Pt. IV, 601–741.

A. Keith, "Geology of the Catoctin Belt," *Fourteenth Ann. Rep. U. S. Geol. Survey*, Pt. II, 1894, 285–395.

H. B. Kümmel, "Some Rivers of Connecticut," JOUR. GEOL., I, 1893, 371–393.

A. C. Lawson, "The Geomorphogeny of the Coast of Northern California," *Bull. Dept. Geol. Univ. Cala.*, I, 1894, 241–271.

W J McGee, "The Geology of the Head of Chesapeake Bay," *Seventh Ann. Rep. U. S. Geol. Survey*, 1888, 537–646.

—— "The Pleistocene History of Northeastern Iowa," *Eleventh Ann. Rep. U. S. Geol. Survey*, 1891, 189–577.

J. E. Marr, *The Scientific Study of Scenery.* London: Methuen, 1900.

H. R. Mill, *The International Geography.* London: Newnes, 1899.

R. D. Oldham, "On the law that governs the action of flowing streams." *Quart. Jour. Geol. Soc.*, XLIV, 1888, 733–738.

A. Phillipson, "Ein Beitrag zur Erosionstheorie." *Petermann's Mitt.*, XXXII, 1866, 67–79.

J. W. Powell, *Exploration of the Colorado River of the West and Its Tributaries.* Washington, 1875.

—— "Physiographic Processes": "Physiographic Features," *Nat. Geogr. Monogr.*, 1895, 1–32, 33–64. New York: American Book Co.

W. N. Rice, editor of *Revised Text-Book of Geology*, by James D. Dana. New York: American Book Co., 1897.

I. C. Russell, *Rivers of North America.* New York: Putnam, 1898.

R. D. Salisbury, "Surface Geology," *Geol. Survey N. J., Ann. Rep. State Geol. for 1892–3*, 35–246.

—— "The Physical Geography of New Jersey," *Geol. Survey N. J. Final Report*, IV, 1898.

W. B. Scott, *An Introduction to Geology*. New York: Macmillan, 1897.

R. S. Tarr, *Elementary Physical Geography*. New York; Macmillan, 1895.

C. R. Van Hise, "A Central Wisconsin Baselevel," *Science*, IV, 1896, 57–59.

B. Willis, "The Northern Appalachians," *Nat. Geogr. Monogr.*, 1895, 169–202. New York: American Book Co.

—— "Paleozoic appalachia," *Maryland Geol. Survey*, IV, 1900, 23–93.

A. Winslow, "Lead and Zinc Deposits," *Missouri Geol. Survey*, VI, 1894.

EDITORIAL.

PROFESSOR A. B. WILLMOTT, in a paper upon "The Nomenclature of the Lake Superior Formations," found in the present number of this JOURNAL, proposes several radical changes from the succession as held by those who have for many years laboriously studied this region. At the present time I shall not discuss Professor Willmott's proposals. I merely wish to state that the evidence presented for them appears to me wholly inadequate, and I therefore record my dissent. At a later time I shall take up the modifications of the nomenclature of the Lake Superior Region which seem to me to follow from the recent work of the officers of the United States Geological Survey.

C. R. V.

A NEW edition of No. 1, Vol. I, of the JOURNAL OF GEOLOGY, has been published, and complete sets of the JOURNAL can now be furnished at the regular subscription price.

C.

REVIEWS.

Influence of Country Rock on Mineral Veins. By WALTER HARVEY WEED, United States Geological Survey, from the transactions of the American Institute of Mining Engineers, Mexican meeting, 1901.

ABUNDANT evidence is brought forth and satisfactorily stated in this paper to show three things: that the structural characters of vein fissures are affected by the country rock; that the mineral contents of ore deposits formed by metasomatic replacement vary with the nature of the enclosing rock; that no invariable relation can be established between rock types and ore deposits. Variation in structure of the fissure naturally, though not invariably, follows a change in texture, cleavage, and hardness of the rock through which it passes. In rocks which are fissile or easily fractured, fissures often lose their definite character and ramify the rock through which they pass, so that the ores which they carry lose their economic significance. In passing from soft to hard rock mineral veins are apt to grow narrow, and are often deflected. Regardless of the origin of the ore, there seems to be a connection between the nature of the mineral deposit and the country rock, where the mineral deposit is of the nature of a replacement. No such connection appears in the filling of open fissures. On account of differences in chemical constitution of the ore-forming solutions, the chemical reactions which took place in the process of vein forming in a rock of a given kind in different districts, were necessarily different, resulting in a variety of ore deposits. Within a limited district, however, the nature of the ore forming solutions was often very constant, and there is a uniform variation in vein content, with variations in the wall rock.

These generalizations are supported by an interesting body of evidence drawn from the literature on ore deposits, both American and German, and from the writer's personal observations. The principles deduced are moderate, and are for this reason all the more acceptable. They are an advance on anything that has been attempted along this line, and have both theoretical and practical value.

FRANK A. WILDER.

RECENT PUBLICATIONS.

—American Museum Natural History. Bulletins. Vol. XIV, 1901; Vol. XV, Part I, 1901; Vol. XI, Part IV (catalogue.)

—BROGGER, W. C. Om de Senglaciale og Postglaciale Nivaforandringer I Kristianiafeletet (Molluskfaunan). 1900–1901. Kristiania, Norway.

—CLAPP, F. G. Geological History of the Charles River. [Reprint from Technology Quarterly, Vol. XIV, Nos. 3 and 4, September and December, 1901.]

—ELLS, R. W. The Carboniferous Basin in New Brunswick. [From the Transactions of the Royal Society of Canada, second series, 1901–1902, Vol. VII, Sect. IV.] J. Hope & Sons, Ottawa.

—GORDON C. H. On the Origin and Classification of Gneisses. [Reprint from the Proceedings of the Nebraska Academy of Sciences, VII, November, 1901.]

—Gelogical Survey of Canada. General Index to the Reports of Progress, 1863 to 1884, compiled by D. B. Dowling. Part I, Districts Described in the Several Reports, Part, II, Special Examinations (Ores, Rocks, etc.). Part III, General Index to Reports.

—Geological Survey of Western Australia. Annual Progress Report for the year 1900, No. 29. Perth, Western Australia.

—MONROE, CHAS. E. Notes on a Collection of Fossils from the Town of Bethany, Genesee County, New York.

—SMITH, HARLAN I. The Saginaw Valley Collection in the Anthropological Department of the American Museum of Natural History. Supplement to the American Museum Journal, Vol. I, No. 12, November–December 1901.

—STANTON, TIMOTHY W. Chondrodonta, A New Genus of Ostreiform Mollusks from the Cretaceous, with Descriptions of the Genotype and a New Species. [From the Proceedings of the U. S. National Museum, Vol. XXIV, pp. 301–7 (with Plates XXV, XXVI).] Government Printing Office.

—U. S. Geological Survey. Bulletin No. 86, 1892; The Geology and Mineral Resources of a Portion of the Copper River District, Alaska, by Frank Chas. Schraeder and Arthur Coe Spencer.

—White, David. (1) Some Palæobotanical Aspects of the Upper Palæozoic in Nova Scotia. [Reprinted from the Canadian Record of Science, Vol. VIII, No. 5 for January, 1901.] (2) Two New Species of Algæ of the Genus Buthotrephis, from the Upper Silurian of Indiana. [From the Proceedings of the U. S. National Museum, Vol. XXIV, pp. 265–70.]

THE
JOURNAL OF GEOLOGY

FEBRUARY–MARCH, 1902

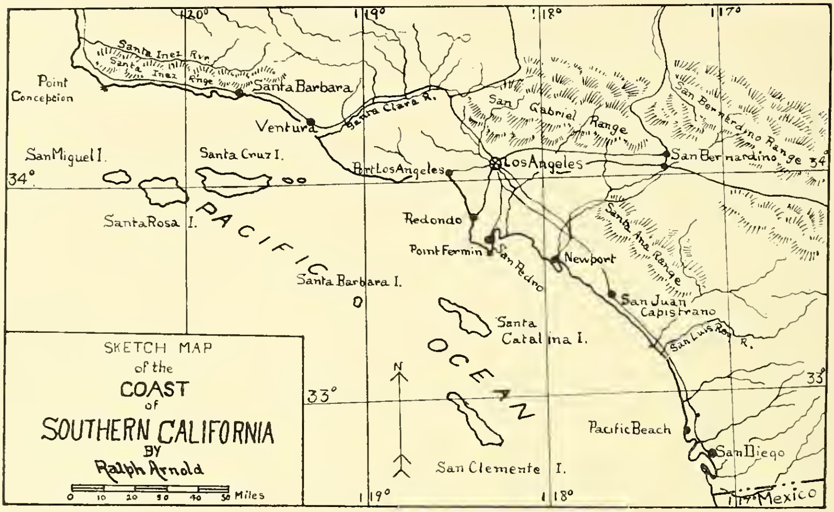
THE MARINE PLIOCENE AND PLEISTOCENE STRATIGRAPHY OF THE COAST OF SOUTHERN CALIFORNIA.

CONTENTS.

INTRODUCTION.

The best development of the marine Pleistocene of the Pacific coast of North America is found along the coast of southern

California, which extends from Point Concepcion on the north to San Diego on the south. A few references have been made by previous writers to the marine Pleistocene geology of western North America, but the inadequacy of their observations has failed to give a proper conception of the importance of the Pleistocene as developed along the southern California coast.



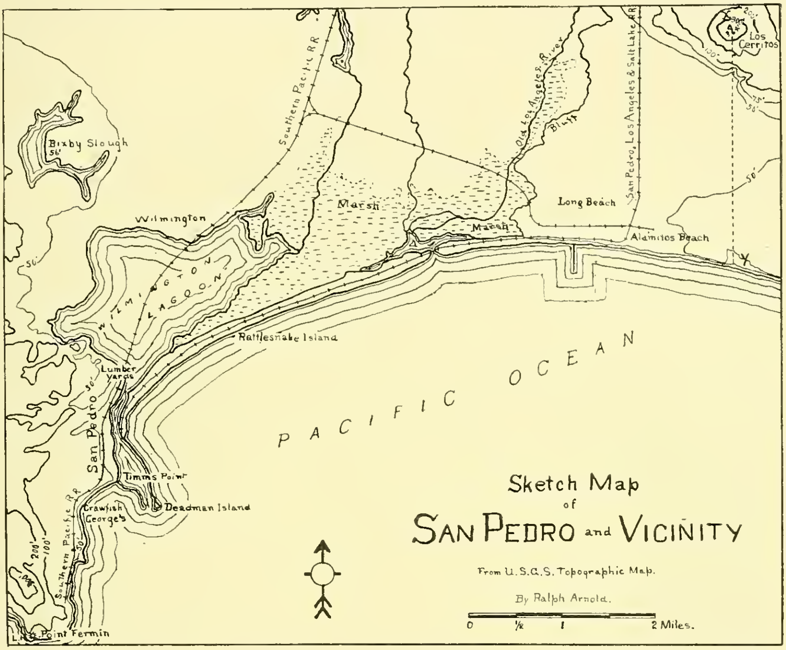
The field work upon which this paper is based has extended over a period of several years, during which time the writers have made a detailed study of the paleontology and stratigraphy of the Pleistocene and subjacent formations at San Pedro,[1] and have also visited and studied the formations at most of the localities from San Francisco to San Diego at which Pleistocene sediments are exposed. The deposits at San Pedro, being the best developed and most easily accessible, have been taken as the type series.

---

[1] The junior author has in press as a memoir of the California Academy of Sciences a paper entitled "The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, with Notes on Similar Formations of the Adjacent California Coast."

SAN PEDRO — THE TYPE LOCALITY.

Topography.—The Pliocene and Pleistocene formations studied by the writers are confined to the lowest terrace of San Pedro Hill (see map of San Pedro and vicinity). This terrace extends from a point one-half mile east of Point Fermin to a bluff one-half mile north of the business portion of San Pedro. A sea cliff averaging fifty feet in height bounds the terrace on the south, east, and north. Half a mile southeast of San Pedro is Deadman Island, a small fragment of the lowest terrace, fifty feet in height with an area on top of about eight hundred square yards. All of the formations exposed in the immediate vicinity of San Pedro are represented at Deadman Island, and it is this section which is taken as the type.



General geology.— The oldest formation in the lowest San Pedro terrace is the Monterey or Miocene shale series. These shales, much contorted, are exposed along the sea cliff from Point Fermin to Timm's Point, and at Deadman Island, where they form the basement series. After the desposition of the Miocene shales the beds were elevated, contorted, and subjected to erosion. Following this a submergence took place during the Pliocene epoch, and a deposit of fine yellowish-brown, clayey sand was laid down on the surface of the eroded Miocene shales. The maximum thickness of this Pliocene at San Pedro is fifty feet.

In post-Pliocene times this sandstone was elevated and subjected to erosion; the Deadman Island and Timm's Point brown sands being all that is left of the Pliocene near San Pedro.

A later submergence brought the surface of the Pliocene again below sea level and deposits of fine gray sand, fossiliferous in places, were laid down on it. The maximum thickness of the gray sand formation at San Pedro is fifty feet. This gray sand formation rests unconformably on the Pliocene at Deadman Island, but is probably conformable with the Pliocene at Timm's Point. On account of its fauna, lithologic characteristics, and unconformable position on beds of late Pliocene age the gray sand formation, called the lower San Pedro series, is thought to be of Pleistocene origin.

A period of uplift more or less pronounced followed the deposition of the lower San Pedro series. This uplift brought about conditions favorable to the formation of lagoonal, sand dune, and shore deposits. These deposits, which are called the upper San Pedro series, consist of coarse gravels and sands, which are characterized by the abundance of their fossil contents, by false bedding, and by indications of the changing conditions which prevailed during the period of their deposition. Evidence which indicates that the upper San Pedro series rests unconformably upon the subjacent formations is found at all the outcrops of this formation which have been examined by the writers. The upper San Pedro gravels and sands rest upon the Miocene shales at Crawfish George's, on the Pliocene at Timm's Point, and on the lower San Pedro series at Deadman Island and the

San Pedro bluff, reaching its maximum thickness of twenty feet at the last locality.

An elevation which raised the San Pedro deposits to near their present level occurred after the deposition of the upper San Pedro series; then after remaining at a constant level for some time another small uplift took place, which left the beds in their present position. This last period of rest and subsequent elevation is evidenced by a raised beach formation four feet thick and six feet above the sea level on the north end of Deadman Island (see Fig. 1).

Pliocene.—The Pliocene at Deadman Island (see Fig. 1 and Plate I) consists principally of a series of fine brown clayey sand layers having a dip toward the north of eight to ten degrees and a thickness of forty-five feet. The bottom layer of this series, which rests on the eroded surface of the jointed Miocene shale, is a fossiliferous stratum twelve inches thick of water-worn shale pebbles and sand. Many of the shale pebbles, and the surface of the eroded shale, show worm and pholas borings. About eight feet of fine yellowish-brown, rather incoherent, clayey sand rests on the gravel stratum. Well-preserved fossils are abundant in some parts of the clayey stratum. Four feet of hard, fine, porous, brown sandstone overlie the clayey stratum. Fossils are common in this hard bed, the most fossiliferous places being the harder, due to the cementing effect of the lime from the shells. On account of the great abundance of *Thyasira* (= *Cryptodon*) *bisecta* in this hard stratum it has received the local name of "Cryptodon bed." Twenty-five to thirty-five feet of faintly laminated brown sandstone overlie the Cryptodon bed. These uppermost brown sands are characterized by beautiful specimens of *Pecten caurinus*, *Lucina acutilineata*, and *Panomya ampla*.

The fauna of the Deadman Island Pliocene is somewhat similar to the fauna which is now living in twenty to fifty fathoms off shore from San Pedro. The Pliocene sediments are also analogous to the mud and fine sand now found on the bottom off the San Pedro shore. It is, therefore, safe to assume that

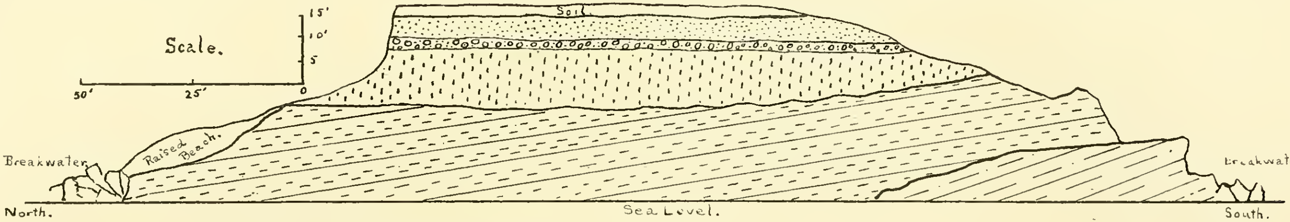


Fig. 1. Section through Deadman Island.

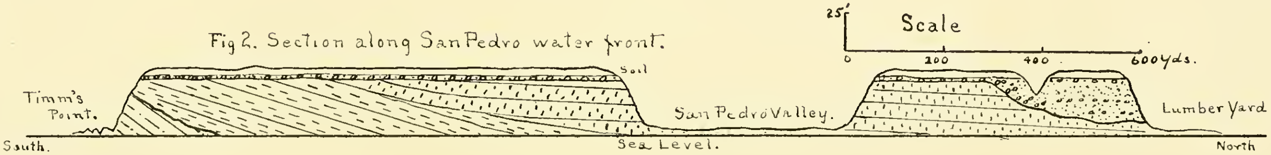


Fig 2. Section along San Pedro water front.

Fig. 3. Section Los Cerritos to Alamitos Beach.

PLATE I*a*.—West face of Deadman Island, looking east, showing Miocene, Pliocene, and Pleistocene formations (see Fig. 1 for explanation).

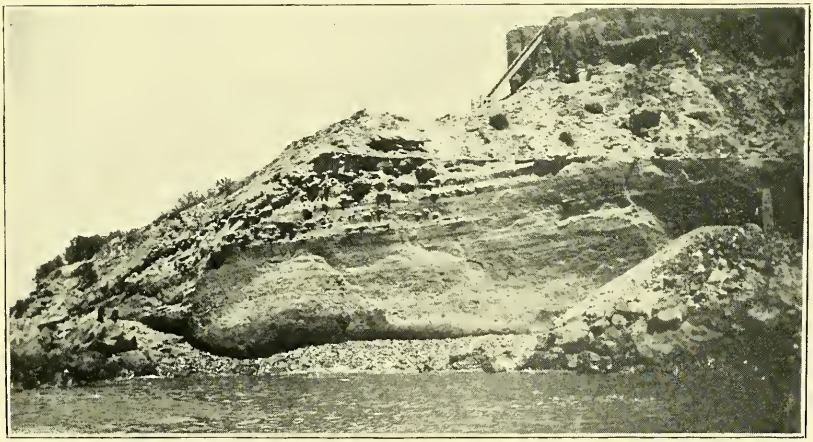


PLATE I*b*.—North end of Deadman Island, looking east, showing nonconformity between Pliocene and lower San Pedro (Pleistocene) gray sands (see fig. 1 for explanation).

the Deadman Island Pliocene was deposited under conditions somewhat analogous to those now prevailing in the ocean off San Pedro at depths of from twenty to fifty fathoms. There is a marked difference, however, between the Pliocene fauna and that now living off San Pedro, the former being characterized by the abundance of the individuals and species which are now found living only far north of San Pedro. To state it more precisely, out of the Pliocene fauna of eighty-seven species, 18.5 per cent. are found living now only north of San Pedro, and nearly all of the remaining species yet living show a decided predilection for boreal or subboreal conditions. The occurrence in large numbers in the Deadman Island Pliocene of *Pecten caurinus*, *Panomya ampla*, *Thyasira bisecta*, *Pecten hericeus*, *Lucina acutilineata*, *Natica clausa*, several species of *Trophon* and northern *Pleurotomidæ*, and other boreal and subboreal forms leads to the conclusion that these Pliocene strata were deposited in water much colder than that which is now found in the vicinity of San Pedro. Boreal or subboreal conditions so near the shore imply boreal or subboreal climatic conditions on the land, at least near the ocean. This being true, it is safe to assume that, during the latter part of the Pliocene epoch, the climate was much colder on the coast of southern California than it is at present.

The lowest, or brown sandstone, series of Deadman Island is called Pliocene for several reasons. First, it overlies unconformably the Miocene shales, from which it differs widely both lithologically and faunally. Second, it contains a fauna over 12 per cent. of which are extinct species, and many of the remaining species are those now found living only in places remote from San Pedro. This evidence precludes any possibility of its being Pleistocene. Third, the general aspect of the fauna is quite similar to that of the British Crag (Pliocene). That the Deadman Island Pliocene belongs to the latter part of that epoch is evidenced by its fauna, which gradually grades into that of the typical Pleistocene through that of the overlying lower San Pedro (Pleistocene). The gap between the Deadman Island Pliocene and Pleistocene is distinct, though not wide.

Dr. Dall[1] says of this Pliocene horizon: "It appears that on Deadman Island, near Point Fermin, at least three distinguishable strata appear, the uppermost of which is certainly Pleistocene, while the others are Neocene, and the middle layer probably Pliocene."

The brown Pliocene sandstone formation outcrops at Timm's Point (see Fig. 2), on the western side of San Pedro Bay. Here it lies unconformably on the Miocene shales as at Deadman Island; but its stratigraphic relation with the overlying lower San Pedro (Pleistocene) beds is not so easily determinable, although the faunal break between the two formations is as pronounced as at Deadman Island.

Pleistocene: the San Pedro series.—The evidence brought forward in this paper demonstrates that most of the marine Pleistocene as developed on the Pacific coast is represented by the strata of Deadman Island and San Pedro. The writers, therefore, propose the name San Pedro series for all of the strata of Deadman Island and San Pedro lying stratigraphically above the brown Pliocene sandstone formation and below the raised beach formation of Deadman Island. The San Pedro series may be divided into two distinct horizons, a lower and an upper, separated at all points in the vicinity of San Pedro by an unconformity.

Lower San Pedro series.—A stratum of gray sandstone averaging about twelve feet in thickness rests unconformably upon the brown Pliocene sandstone at Deadman Island (see Fig. 1). This gray sandstone is incoherent in some places but very firmly cemented in others, the harder portions usually being the more fossiliferous. No bedding is visible in the gray sand, but the formation lies nearly horizontal. This lower San Pedro stratum at Deadman Island, and also the contemporaneous strata in the San Pedro bluffs (see Fig. 2), as indicated by their lithologic characters and fauna, were deposited in water shallower than that in which most of the underlying brown Pliocene

---

[1] W. H. Dall and G. D. Harris, *Correlation Papers: Neocene. U. S. Geol. Surv., Bull. No. 84*, p. 216, 1892.

strata were laid down. The sediments consist for the most part of medium grained gray sands, such as are being deposited at the present time quite near shore off San Pedro. The abundance in the lower San Pedro deposits of certain species which live only between tides also offers evidence of deposition of the strata near the shore.

The fauna of the lower San Pedro series is one of transition from the boreal or subboreal fauna of the late Pliocene to the semi-tropical fauna of the upper San Pedro series. Two causes account for this change: (1) The deposits being laid down in shallower water than that in which the Pliocene sediments were deposited would necessarily contain fewer of the colder, deeper water forms of the Pliocene; and (2) the lower temperature prevailing during the latter part of the Pliocene epoch was giving place to warmer conditions, which caused the boreal species to migrate and brought in more of the species which commonly inhabit warm waters. Of the fauna of nearly 250 species found in the lower San Pedro series, over 17 per cent. are now found living only north of San Pedro. This percentage is only a little lower than that of the northern species found in the Pliocene, (the latter being 18.5 per cent.), and indicates, considering the fact that the lower San Pedro beds are shallower water deposits than those of the Pliocene, that the climatic conditions had changed but little during the period, intervening between the deposition of the Pliocene and the overlying lower San Pedro series.

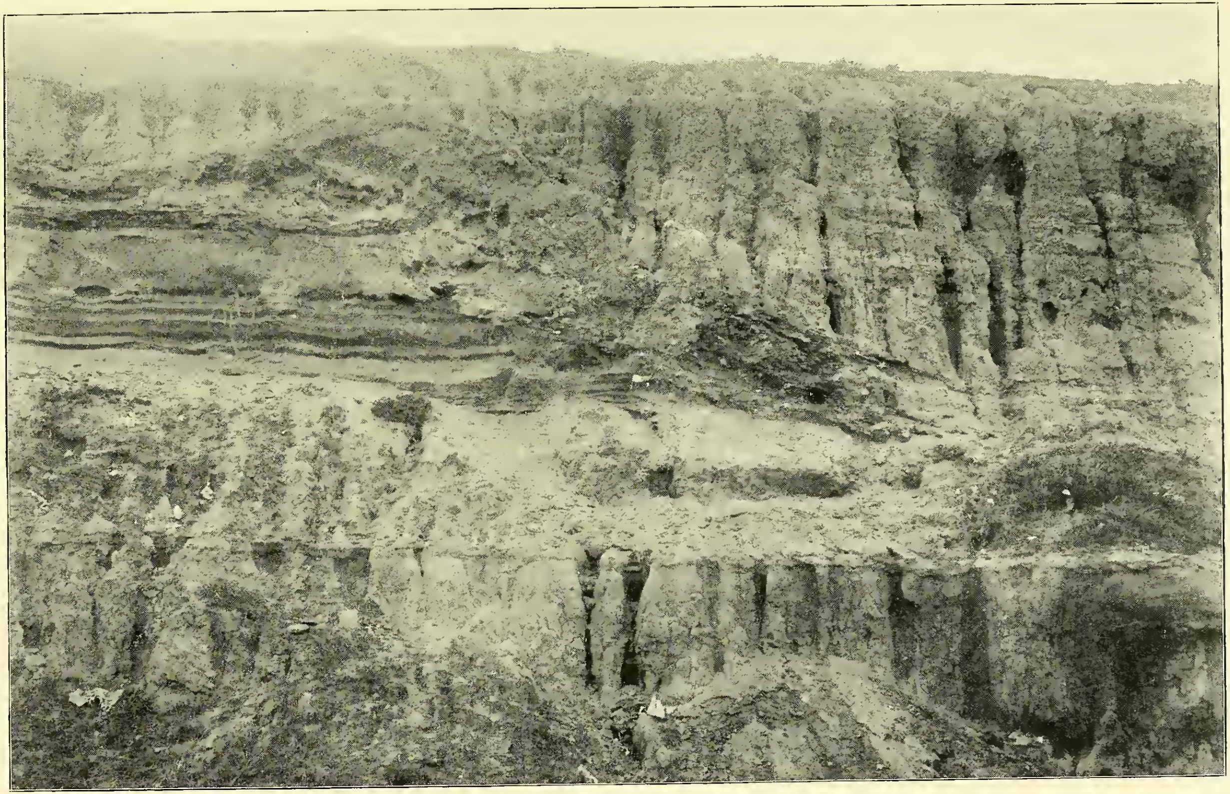
The evidence afforded by several species in the lower San Pedro series (about 4 per cent. of the fauna of that series), which are now found living only south of San Pedro, shows that the conditions were changing from cold to warm. Besides the distinctly northern forms which either disappear or become scarce in the period between the Pliocene and lower San Pedro, there are many species now more commonly found in northern waters, which, though common in the Pliocene, become rarer in the Pleistocene; while species showing a predilection for southern conditions become common in the fauna of the latter period.

All of the evidence shows that the conditions were changing from boreal toward subtropical during the time just preceding and during the deposition of the lower San Pedro series; but boreal conditions still predominated.

This series is placed in the Pleistocene primarily upon paleontologic evidence. The low percentage of extinct species and the occurrence of the three living echinoderms *Strongylocentrotus purpuratus*, *S. franciscanus*, and *Echinarachnius excentricus* offers strong evidence of the Pleistocene age of this series, the three species of echinoderms having never been found in any of the beds on this coast commonly accepted as Pliocene. The general aspect of the deposits, the state of preservation of the fossils, and the unconformable position of the lower San Pedro series on upper Pliocene beds strengthen the faunal evidence.

These beds are exposed in the bluffs north of Timm's Point (see Fig. 2), where they rest on the brown Pliocene sandstone and are overlain unconformably by the upper San Pedro gravels. There is some doubt as to the relation between the Pleistocene and the underlying Pliocence in these bluffs, although most of the available evidence is in favor of the conformability of the two formations.

Upper San Pedro series.—The gray sandstone of the lower San Pedro series at Deadman Island (see Fig. 1) is overlain unconformably by a three-foot stratum of fossiliferous gravel hardened by lime, above which are about seven feet of fine sand. This gravel stratum and the overlying sand makes the upper San Pedro series at Deadman Island. The gravel stratum is continuous over nearly the whole of the lower, or fifty-foot, San Pedro terrace, and at nearly every exposure it is seen to lie unconformably upon the subjacent beds. This evidence shows that the deposition of the upper San Pedro beds followed a period of erosion. The best development of the upper San Pedro series is found in the bluff at the lumber yard north of San Pedro (see map of San Pedro, and also Fig. 2), where the alternating fossiliferous beds of gravel and sand attain a thickness of twenty feet.



San Pedro. Peculiar nonconformity between lower and upper San Pedro series (Pleistocene) beds, in water front bluff south of lumber yard (photographs by Dr. H. W. Fairbanks).

The deposits of the upper beds in the vicinity of San Pedro consist for the most part of coarse gravels and sands which show alternating dune and water bedding, and have the appearance of having been laid down during a period of rapidly changing conditions.

The fauna of the upper beds is southern in character, and, as would be expected, approaches more nearly the present living fauna of the San Pedro region. Since the fauna of the upper beds inhabited shallower water than that in which either the Pliocene or lower San Pedro faunas lived, one would expect to find in it fewer of the cold water forms and more of the species found between tides and in the warm shallow waters of lagoons. Such is the case, but further, it is a noticeable fact that in the upper beds over 14 per cent. of the fauna are species which are now found living only south of San Pedro. This is not only true, but of those species found in the upper beds which are still living at San Pedro, a great majority are forms which are commoner in the waters south of that place.

Although over 6 per cent. of the upper San Pedro fauna are found now living only north of San Pedro, these northern species are only very rarely found in this formation. On the other hand most of the distinctly southern forms and those which, though now living at San Pedro are commoner further south, are commoner in the upper beds, thus giving it a semitropical aspect. Such species as *Cardium elatum*, *Arca labiata*, *Pecten dentatus*, *Mactra exoleta*, *Venus gnidia*, *Murex leeanus*, *Eupleura muriciformis*, *Cancellaria tritonidea*, and *Bulla punctulata* give this fauna its southern character. The evidence afforded by the southern forms outweighs the evidence of the northern species in another respect, for it would require a great change in conditions from those prevalent during later Pliocene times to cause these southern species to migrate northward to the San Pedro region; while this same change in condition would not so materially affect the northern species, for they could simply migrate into deep water where the conditions would more nearly approximate the boreal. This latter has been the case with such species as *Lucina acuti-*

lineata, *Chrysodomus tabulatus*, *Solariella cidaris*, and *Solariella peramabilis*, which now inhabit northern waters near shore, but which have been dredged in the deep water between Catalina Island and the mainland.

The upper San Pedro series is separated from the lower for three reasons: (1) on account of the unconformity existing between the two; (2) on account of the difference in their lithologic characters, the former consisting of gravels or coarse sands, while the latter is made up wholly of rather fine gray sands; and (3) because of the great difference in the faunas of the two; that of the former being one indigenous to warm water, that of the latter, one which is now found living where sub-boreal conditions prevail.

The occurrence of Pleistocene deposits younger than the upper San Pedro beds at several points along the coast, and the crustal movements and elevation of the coast that have taken place at several places since the deposition of the upper San Pedro beds indicate that quite a long period of time has elapsed since the latter were laid down.

A raised beach on the north end of Deadman Island (see Fig. 1), six feet above sea level and four feet thick affords evidence of another period in the Pleistocence. The shells in this deposit are the same as those found in the beach at Deadman Island at the present time, and the most of them retain their original coloration. This raised beach represents a very late Pleistocene horizon.

Post-Pleistocene Deposits.—The marine deposits of Deadman Island and the San Pedro terrace are overlain by alluvial deposits which contain large quantities of shells in certain places. These shell heaps are ancient Indian kitchen middens. Shells of a kind that would be used for food, such as *Haliotis cracherodii*, *Pecten æquisulcatus*, *Chione succincta*, *Tivela crassatelloides*, *Tapes staminea*, *Saxidomus aratus*, and others are found mixed with pieces of charcoal, flint chips and animal remains in these ancient accumulations. These Indian kitchen middens are often mistaken for fossil deposits, especially the one at Port

Harford, San Luis Obispo county, where the deposits of shells in the adobe soil attain a thickness of over six feet.

SAN DIEGO.

General geology.— Next to San Pedro, the best development of the marine Pleistocene of Southern California is found in the vicinity of San Diego. The geologic history of San Diego has been somewhat similar to that of the San Pedro region. During late Pliocene times the territory now occupied by San Diego Bay and the region to the northwest was occupied by an arm of the sea in which were deposited several hundred feet of coarse gravels, and these in turn were overlaid by fine grained sandstones. An uplift took place at the close of the Pliocene or in early Pleistocene times, followed by a period of erosion during which the terrace or mesa which extends from San Diego to Pacific Beach was planed off. Following the period of uplift a slight depression took place, and the gravels and sands of the upper San Pedro series (Pleistocene) were laid down on top of the eroded Pliocene sandstone. Since the deposition of the latest beds an uplift of at least fifty feet has taken place.

Pliocene.— The writers have examined the Pliocene strata at Pacific Beach, and near the Russ School (San Diego well). The Pliocene at Pacific Beach makes the lower part of the sea cliff which begins at Ocean Front and extends northward for at least a mile and a half (see Fig. 4). Two hundred feet of yellowish-brown sandstone, dipping south at an angle of about 10 degrees and overlain unconformably by Pleistocene gravel, are exposed in this section. The upper layers of the sandstone are fossiliferous, while the lower portion, which rests on an unknown thickness of coarse gravels, is without fossils.

There are two horizons in the fossiliferous section of the sandstone which may be separated upon paleontologic evidence. The lower horizon comprises all of the exposed fossiliferous beds with the exception of the uppermost three or four. It is characterized by a unique fauna among which are found the following species which are not known outside of the San Diego province: *Pecten expansus*, *Pecten subventricosus*, *Opalia varicostata* and *Opalia anomala*. This lower horizon is correlated with the Deadman Island Pliocene. The upper horizon is characterized by *Pecten hemphilli*, *Crepidula grandis*, *Macoma secta*, *Echinarachnius excentricus* and *Strongylocentrotus purpuratus*, and is correlated with the lower San Pedro series (Pleistocene).

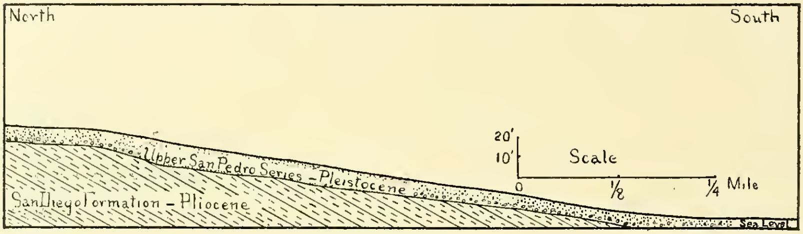


FIG. 4.— Section along Pacific Beach, near San Diego, showing the relation between the San Diego formation (Pliocene) and the upper San Pedro series (Pleistocene).

A formation similar to that of the Pacific Beach Pliocene outcrops near the Russ School, in the northern part of San Diego. The San Diego well, which is located just south of this outcrop, gives an instructive section of this Pliocene series. The well is at the bottom of a ravine (see Fig. 5), the sides of which are of strata containing a fauna similar to that of the upper Pliocene horizon at Pacific Beach. The strata above the well dip gently south toward San Diego Bay. The well is 149 feet deep,[1] and

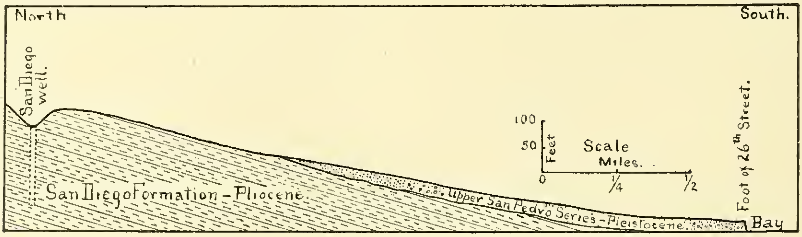


FIG. 5.— San Diego. Section from San Diego well to bay at foot of Twenty-sixth street, showing relation of San Diego formation (Pliocene) to upper San Pedro series (Pleistocene).

---

[1] The writers are indebted to Mr. Henry Hemphill, who collected fossils from the San Diego well during the course of its excavation, for the data concerning it.

Plate III.

Pacific Beach. San Diego formation (Pliocene) overlain unconformably by upper San Pedro (Pleistocene) gravels (see fig. 4 for explanation).

penetrates fossiliferous strata for its entire depth. The lowest beds are below the lower fossiliferous horizon of Pacific Beach, and are characterized by the large *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

Pleistocene.—The tilted brown sandstone of Pacific Beach is overlain unconformably by a layer of fossiliferous gravel and sand from two to fifteen feet thick (see Fig. 4), which probably covers much of the terrace of which the Pacific Beach sea cliff is the bounding escarpment. In this respect the gravel layer is similar to the gravel stratum which covers the San Pedro terrace. The gravel and sand series is characterized by a fauna which is entirely different from that of the underlying sandstones, but which is almost identical to the fauna of the upper beds of San Pedro. Upon this evidence the gravel and sand layers are placed in the upper San Pedro series.

At the foot of Twenty-sixth street (see Fig. 5), and at Spanish Bight, beds of rather incoherent sands and fine gravels are exposed in the bluffs which form the shore line of the bay at these localities. These beds are richly fossiliferous, the fauna being similar to that of the upper San Pedro series at San Pedro, with which the Twenty-sixth street and Spanish Bight beds are correlated.

REGION BETWEEN SAN DIEGO AND SAN PEDRO.

The sea cliffs from a few miles north of Pacific Beach to near Newport are composed for the most part of soft dark colored shales and incoherent sandstones and gravels of late Pliocene and Pleistocene age. These deposits are mostly horizontal, but have been elevated in places to several hundred feet above sea level.

W. L. Watts[1] reports a formation, probably contemporaneous with the San Diego formation, at San Juan Capistrano in which the remains of a mastodon were found. Mr. Watts[2] has also reported

---

[1] W. L. WATTS, "Oil-and Gas-Yielding Formations of California," *Bull. No. 19, Cal. State Mining Bureau*, pp. 59, 222, 1900.

[2] *Op. cit.*, pp. 61, 223.

deposits in the vicinity of Newport, which, from their fossil contents, have been correlated with the upper San Pedro series (Pleistocene) by the writers.

At Bell Station,[1] near Los Angeles, a typical lower San Pedro (Pleistocene) fauna was obtained from a well between the depths of 920 and 1,320 feet. This shows the amount of sedimentation that has taken place in the Los Angeles basin during part of the Pleistocene epoch.

Gravels containing a typical upper San Pedro fauna are found at an elevation of about 350 feet on Los Cerritos Hill, near Long Beach (see map of San Pedro). The gravel stratum dips away from the top of the hill towards the ocean, and is part of the same series of sediments which is exposed in the sea cliff in front of Long Beach and Alamitos Beach (see Fig. 3).

REGION BETWEEN SAN PEDRO AND VENTURA.

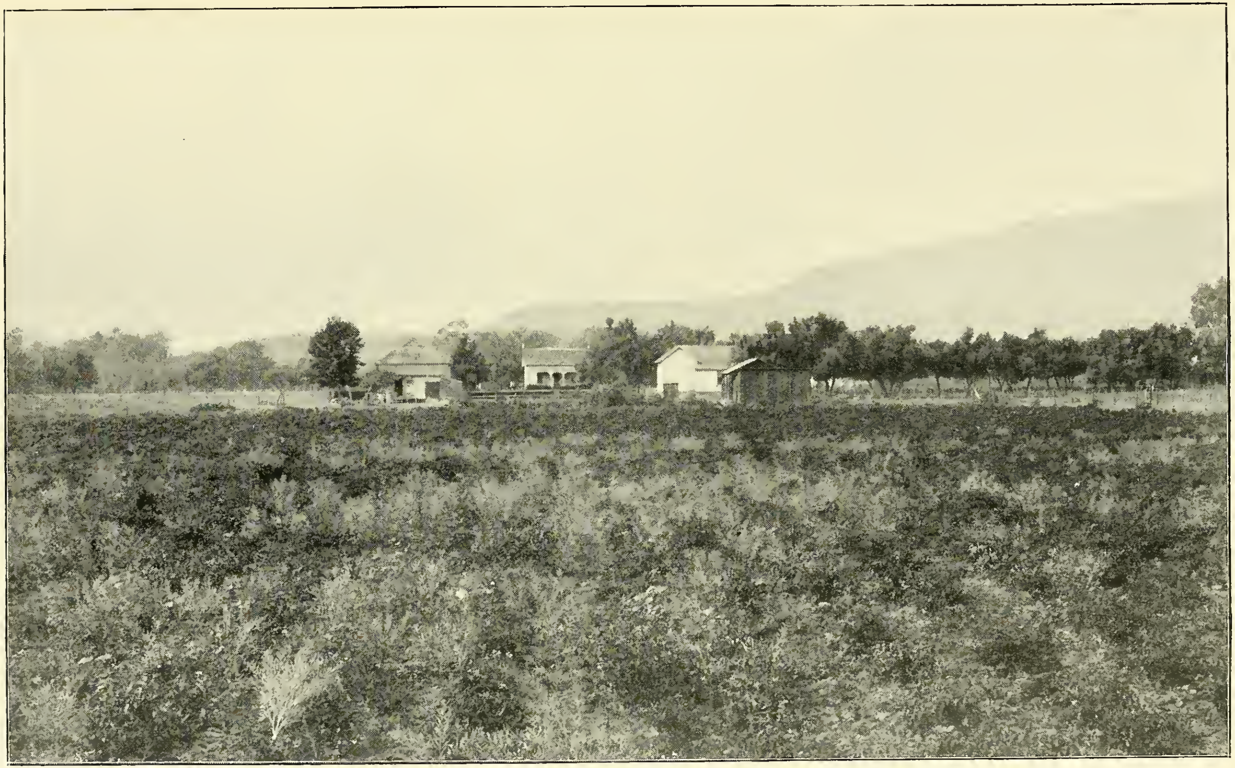
The only locality between San Pedro and Ventura which has been examined by the writers is near Port Los Angeles. At this locality the sea cliff is nearly two hundred feet in height, the upper portion being composed of rather incoherent unfossiliferous sands and gravels probably of upper San Pedro (Pleistocene) age. These upper beds overlie, probably unconformably, hard strata of sandstone which contain a fauna similar to that found in the lower San Pedro series at Deadman Island.

VENTURA.

The most important fact about the geology in the vicinity of Ventura is the great thickness, steep inclination, and great elevation above the sea of the upper San Pedro (Pleistocene) sediments. The range of hills north of Ventura, which have an elevation of from five hundred to one thousand feet above sea level and which extend for several miles east and west of that city, are composed for the most part of soft, thickly laminated, yellowish-brown sandstones dipping away from the axis of the range. Along the old irrigating ditch which skirts the hills east of Matilleja Valley, west of Ventura (see Fig. 6), there is an

---

[1] W. L. Watts, *op. cit.*, p. 233.



Ventura. Wave-cut terraces in Pleistocene sediments one mile west of Ventura.

exposure of over one thousand feet of these soft sandstones, tilted at an angle of from 40 to 50 degrees toward the ocean. The fauna of these beds indicates their contemporanity with the upper San Pedro series, although the fauna near the bottom resembles more that of the lower San Pedro. A fauna of over sixty recognizable species was obtained from soft beds in the hills north of Barlow's ranch, three miles east of Ventura, at an elevation of between seven and eight hundred feet. The strata from which these fossils came are inclined at an angle of over 40°, but are not contorted. The fauna is typically upper San Pedro, all of the sixty species (with the possible exception of one which is a variety of a living species) being living forms.

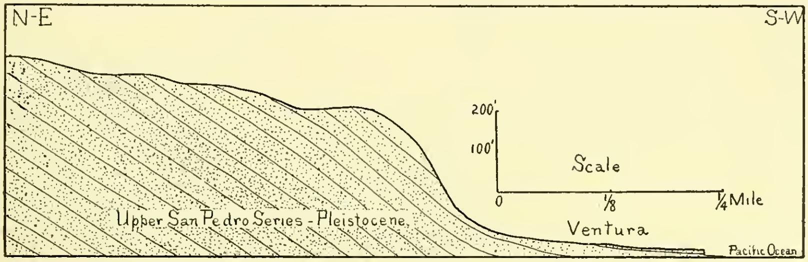


FIG. 6.— Section through Ventura, showing thickness of upper San Pedro series (Pleistocene) sediments, and a wave-cut terrace in the sediments.

Wave-formed terraces plane off the Pleistocene beds in the hills about a mile west of Ventura (see Plate 5). These terraces represent a period of time later than the upper San Pedro, and are probably of late Pleistocene age. The accumulation of comparatively great thicknesses of sediments, their elevation to at least one thousand feet, and their configuration by wave-cut terraces shows how active the geologic agencies have been in the vicinity of Ventura during comparatively recent times.

The region along the coast from Ventura to Santa Barbara is characterized by unfossiliferous, incoherent sands and gravels probably of Pleistocene age. Some of these sands and gravels are impregnated with asphaltum from the underlying Miocene shales.

SANTA BARBARA.

The later deposits in the vicinity of Santa Barbara resemble quite closely those of San Diego. At Packard's Hill, west of Santa Barbara, a thickness of over two hundred feet of alternating hard and soft beds of brown sandstone is exposed. These beds have a dip of S. 30° W. 50° toward the ocean. They are correlated by the writers with the Deadman Island Pliocene. Their fauna, however, shows a greater resemblance in some respects to the fauna of the San Diego formation (Pliocene).

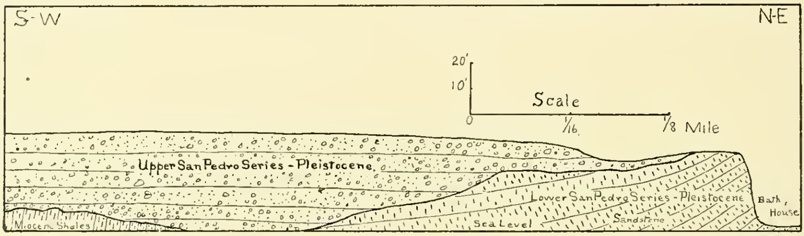


FIG. 7.—Santa Barbara. Section along coast southwest of bath house, showing relation between the Miocene and lower and upper San Pedro series (Pleistocene).

A thickness of thirty feet of alternating hard and soft beds of sandstone and sandy marl are exposed in the bluff west of the bath house on the Santa Barbara ocean front (see Plate V and Fig. 7). These strata are quite similar lithologically to the Packard's Hill Pliocene and probably lie conformably above it. The fauna of the bath house beach beds is more recent than that of the Packard's Hill deposits, and contain *Strongylocentrotus purpuratus*, *Echinarachnius excentricus*, and several other Pleistocene species not found in the Pliocene. Upon paleontological evidence the bath house beach deposits are correlated with the lower San Pedro series.

Beds of unfossilferous gravel and sand are exposed in the bluff west of the bath house beach fossiliferous strata. In some places these beds overlie the fossiliferous strata, while in others they overlie the basement series of Monterey shale. These sands and gravels, which are correlated with the upper San

Santa Barbara. Lower San Pedro (Pleistocene) strata west of bath house (see Fig. 7 for explanation).

Pedro series, are probably unconformable with the lower fossiliferous strata (a fossiliferous fragment of the latter being found in the former) although the exact relation between the two horizons was not definitely determinable stratigraphically, owing to the prevalence of false bedding in the upper beds. Asphaltum impregnates the gravels and sands in several places where they rest upon the Miocene shales. An Indian kitchen midden overlies the Pleistocene deposits one-eighth of a mile west of the bath house.

RELATION BETWEEN THE SOUTHERN CALIFORNIA PLIOCENE AND PLEISTOCENE AND THE MERCED SERIES.

A series of sandstones and shales over five thousand feet in thickness is exposed in the sea cliff which extends for a few miles south of Lake Merced on the San Francisco peninsula. This series of beds has been described by Dr. A. C. Lawson,[1] who named it the Merced series. Dr. Lawson places the whole series, with the exception of about one hundred feet of strata at the top, in the Pliocene. Dr. G. H. Ashley[2] draws the Pliocene-Pleistocene line further down in the series, or at the base of a fossiliferous stratum which has received the local name "upper gastropod bed." A study of the faunas of the different layers of the merced series has led the writers to draw the line in the same place that Dr. Ashley has drawn it. Although there is a distinct faunal break between the "upper gastropod bed" and the subjacent layers, there seems to be no indication of any decided interruption in the sedimentation in this part of the series.

Dr. Dall[3] places the San Diego formation, with which he correlates the Deadman Island Pliocene, below the Merced series. This does not agree with the conclusions arrived at by

---

[1] A. C. LAWSON, "The Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept. Geol.*, *Univ. of Cal.*, Vol. I, pp. 142–50, 1892.

[2] GEORGE H. ASHLEY, "The Neocene of the Santa Cruz Mountains, *Proc. Cal. Acad. Sci.*, 2d Series, Vol. V, pp. 312–37, 1895.

[3] W. H. DALL, "Correlation Table of North American Tertiary Horizons," *Eighteenth Ann. Rep. U. S. Geol. Surv.*, Pt. II, p. 335, 1898.

the writers after a study of the stratigraphy and faunas of the formations under discussion. The San Diego formation, with which are correlated the Deadman Island Pliocene and the Santa Barbara (Packard's Hill and bath house beach) formations are placed in the upper part of the Merced for the following reasons: (1) the strata of the Merced series wherever examined by the writers show much more contortion than the strata of the San Diego formation or its equivalents; (2) the fauna of Deadman Island Pliocene grades over by easy stages into the fauna of the Pleistocene with only a slight break between the two, thus precluding the possibility of the intercalation of such a distinctive fauna as that of the Merced series between the Deadman Island Pliocene (equivalent of the lower San Diego formation) and the San Pedro series (Pleistocene); (3) the occurence in only the very uppermost layers of the Merced series of *Echinarachnius excentricus*, which is found in the upper horizon of the San Diego formation; and the total absence of the common Merced echinoderm, *Scutella interlineata*, from the San Diego formation and all of its equivalents and overlying beds; (4) the abundance at the very bottom of the San Diego formation (in the lowest part of the San Diego well section only) of the typically characteristic middle Merced pelecypod *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

The probability of an overlap of the time periods represented by different formations, Merced, San Diego, and San Pedro, is considerable; in fact the term Merced series, as used by Lawson, probably includes nearly, if not all, of the San Diego formation, and probably part of the San Pedro series.

The following correlation table gives the relation between the different formations of the Pliocene and Pleistocene of the coast of California as understood by the writers.

CONDITIONS PREVALENT DURING THE PLIOCENE AND PLEISTOCENE.

Basing the conclusions upon the evidence offered by the faunas of the Pliocene and Pleistocene formations it is seen that there has been a fluctuation of conditions along the California

CORRELATION TABLE

OF THE UPPER PLIOCENE AND PLEISTOCENE FORMATIONS OF SOUTHERN CALIFORNIA.

[NOTE. — Wave lines show conformability; straight lines, unconformability.]

TOTAL THICKNESS.	PLIOCENE.		PLEISTOCENE.			EPOCH.
		SAN DIEGO FORMATION.				FORMATION.
		Lower.	Upper.			
			SAN PEDRO SERIES.		RECENTLY RAISED BEACH'S.	
			Lower.	Upper.		
	MERCED SERIES.					
PLEISTOCENE. 70′ PLIOCENE. 180′		San Diego well. 150′	Russ School. 50′	Foot of 26th street. 20′		SAN DIEGO SECTION.
				Spanish Bight. 20′		
		Pacific Beach (lower horizon). 180′	Pac. B. (up. hor.) 20′	Pacific Beach. 15′		
PLEISTOCENE. 100′ PLIOCENE. 50′		Deadman I. 45′	Deadman Island. 12′	Deadman Island. 10′	D'man I. 4′	SAN PEDRO SECTION.
		Timm's Point. 50′	San Pedro Bluffs. 50′	Lumber yard. 20′		
				Crawfish George's. 3′		
			Los Cerritos Hill. 50′	Los Cerritos Hill. 20′		
				Long Beach. 50′		
PLEISTOCENE. 1000′+			Old irrigating ditch (?)	Old irrigating ditch. 1000′+		VENTURA SECTION.
				Barlow's ranch. 100′+		
PLEISTOCENE. 60′ PLIOCENE. 200′+		Packard's Hill. 200′+	Bluff at bath house. 30′	Bluff ¼ mile west of bath house. 25′		SANTA BARBARA SECTION.
				Bluff 2 miles east of wharf. 30′		
PLEISTOCENE. 350′± PLIOCENE. 5000′+	Section from Lake Merced to Mussel Rock below the "upper gastropod bed." 5000′+		"Upper gastropod bed" to nonconformity. 150′±	Strata above nonconformity ("terrace formation"). 200′±		LAKE MERCED SECTION.
MAXIMUM PLEISTOCENE. 1320′ (BELL'S STATION). MAXIMUM PLIOCENE. 5000′ (LAKE MERCED).		San Juan Capistrano.		Newport, Orange county.		OTHER LOCALITIES.
				Bell's Station, Los Angeles county. 1320′		
			Port Los Angeles, fossiliferous horizon. 50′±	Port Los Angeles, upper unfossiliferous beds. 150′		
				San Pablo Bay, Contra Costo county. "Oyster beds."		
				Fort Ross, Humboldt county.		

coast since the beginning of Pliocene times. The San Pablo (middle Neocene) and Merced faunas contain an abundance of such genera as *Arca*, *Dosinia*, *Pinna* and other southern forms which indicate that southern or warm conditions prevailed during the period of deposition of those two formations. Following the Merced (or, more strictly speaking, the middle of the Merced) comes the San Diego formation with its fauna of such northern species as *Pecten caurinus*, *Panomya ampla*, *Purpura crispata*, several species of *Trophon* and many other species indigenous to northern waters, which shows that northern or boreal conditions prevailed during the later Pliocene and early Pleistocene times. The transition from the boreal conditions of the late Pliocene to the semitropical conditions of the upper San Pedro series (typical Pleistocene) is indicated by the transition fauna of the lower San Pedro series. The upper San Pedro fauna contains so many southern species that it is safe to assume that conditions more nearly approximating those of the coast of Mexico at the present time, prevailed along the coast of southern California during that part of the Pleistocene in which the upper San Pedro beds were deposited. Since these latter strata were deposited a slight change has taken place, and the conditions now prevailing were inaugurated.

DELOS ARNOLD,
RALPH ARNOLD.

STANFORD UNIVERSITY,
California.

INDIVIDUALS OF STRATIGRAPHIC CLASSIFICATION: DISCUSSION.

THE exceedingly suggestive paper appearing in a recent number of the JOURNAL,[1] under the above title, brings up for discussion some of the very practical problems which confront the geologist in his daily work. Their importance will perhaps warrant a supplementary discussion of the subject from the point of view of the mining geologist; not that this is necessarily the most important point of view, but rather that geologists in their devotion to the interests of pure science are apt to overlook the needs of fellow workers in applied science. The debt of science, as expressed in the generous appropriations of the various states and the general government for geological surveys and similar institutions, is too great to warrant us in failing at any time to give the highest possible return in practical results. While the great purpose of geologic science, to reconstruct the past history of the earth, must be kept steadily in view, it is well, if we would have the means to carry on that work, that we should keep no less steadily in view the wants of the plain citizens who are developing our country's resources.

The paper in question is particularly welcome to the mining geologist because it emphasizes the importance of mapping many of those features which will help him most in directing the development of mines and mineral deposits. One engaged in such work needs somewhat more complete data in regard to the lithology of the rocks and the geographical distribution of the more minute rock units than are necessary for ordinary geological research. He needs also a very minute knowledge of local structure and as perfect a knowledge as may be of the processes of change through which the rocks have passed.

In studying the genesis of any ore deposit it is needful, first,

---

[1] BAILEY WILLIS, *Individuals of Stratigraphic Classification*, JOUR. GEOL., Vol. IX, No. 7, October-November, 1901, pp. 557–69.

to determine, if possible, the exact conditions under which the country rock was laid down, so as to know what the original content of the rock in mineral is likely to have been. Since the conditions under which deposits accumulate are reflected in the character of the material accumulated, lithology is of primary importance at this stage of the investigation. In the second place it is important to determine the changes which the rock has undergone since its original formation. This at once leads into the general study of metamorphism, and again the expression of the results is best accomplished by lithologic mapping. Since, however, different materials under the same or different processes of metamorphism may produce rocks which in their final stages are lithologically identical, a map to express the full facts must be constructed so that by means of various colors, patterns, symbols, or prefixes in the legend, the lithologically similar but historically different rocks may be readily distinguished. The structure of the region must be thoroughly understood before any general plan of development can be formulated. All these facts can and should be represented upon any geological map intended for the use of a mining population.

In general the mining geologist is called upon to do two things: (1) to report upon some mine or tract of presumably mineralized land in order to determine whether the showing warrants the undertaking of development work; (2) to direct the further development of mines already partially opened up. In reporting upon properties he is oftenest sent to regions which are very little developed and which generally are not geologically mapped. In such a region he must rely in the first instance upon such reconnoissance maps as may be available, but in the main upon his own efforts. In the nature of the case the first detailed mapping in mineral districts must in a majority of instances be the result of individual initiative. The maps made in this way are more detailed than official maps can be expected to be, but they are also entirely unrelated, and each covers a very limited territory. So far, then, as the primary development of mineral districts is concerned, reconnoissance maps are the best that can be rightly expected by the mining geologist. For his purpose it is more important that he should have such maps of the whole country, and that such facts as are represented on them shall be accurate, than that they should show great detail. For example, if such a map shows the presence of limestone and porphyry, together with a structure generally similar to that of the Leadville district, he will feel warranted in having prospecting undertaken within the area. The exact distribution of the limestone and porphyry areas is a very minor consideration, and errors in this particular will not greatly injure the usefulness of the map. A mining company must always make independent and careful surveys in any event in locating and patenting the property.

Since it is generally true that rocks of the same age are apt to bear the same or related minerals, any suggestion as to the age of the rocks becomes immensely helpful. If the age is in doubt the fact can be indicated by a question mark in the legend, but even a guess is helpful in suggesting the thought of one who has studied the territory more widely than is possible to one working against time to select the best locations in a given district.

There is apparently a growing sentiment against reconnoissance and general maps. This is unfortunate if the interests of the miner are to be taken into account. It is true that such maps must in the nature of things be not only incomplete but inaccurate. Yet they are the maps which in nearly every case are used in the development period of a mining camp, and in making them the geologist does the greatest service, quantitatively at least, to the mining industry that he is capable of. It is impossible to make an accurate and serviceable geologic map of a mining district, such as the maps of the Telluride and Butte folios of the United States Geological Survey, in advance of a certain amount of mining development. Such general maps, however, as are found in the Hayden *Atlas of Colorado* can be made readily and at comparatively low cost. They are at once available and serviceable. In the present oil development at Boulder, Colo., the Hayden map has been of the highest service. No doubt a more detailed map would be much better, but upon the Hayden base each oil expert can make a map of his own. If the investor were to wait until a proper map could be made by government or state officials, he would find the best territory all pre-empted and drilled.

So far, then, as helping in the development of new mining districts is concerned, it should be the first duty of the geologist to furnish good reconnoissance maps giving general data regarding (1) lithology, (2) structure, and (3) age. In spite of the limitations and inaccuracies of such maps their tremendous usefulness is sufficient warrant for their production.

I would not be understood as decrying the making of detailed maps. By no means. Let us have as many of such maps and as much detail as possible; but let us have first the reconnoissance maps and later, after the prospector and miner have developed a few good properties and opened up the ground enough to enable the geologist to get a right understanding of the structure and the ore bodies, let as detailed a map as possible be made. Such a map will be of the highest service in the development of a general plan of operation; the laying out of long cross-cut tunnels or the locating of deep shafts. Studies of the genesis of the ores made at the same time will indicate the probability as to the permanence of the ore bodies and give a reliable answer to the question of the erection of large permanent works, the building of railways, smelters. etc. In the beginning of mining operations these questions do not need to be answered. It is fortunately true that the initial operations are nearly always small and individual. It takes time to interest capital, to reconcile conflicting interests, and to bring about the economic conditions necessary to operations on a large scale. During the interval the general map is sufficient. There are no large works to be planned and it would be impossible to carry them out if there were. When, however, the development of a camp has reached a stage where these questions arise, no map can be too detailed to be serviceable. In making such a map all available facts bearing on the original condition of the rocks and the subsequent changes they have undergone should be shown as far as possible.

H. FOSTER BAIN.

IDAHO SPRINGS, COL.,
February 17, 1902.

THE PHYSIOGRAPHIC FEATURES OF THE KLAMATH MOUNTAINS.

CONTENTS.

INTRODUCTION.

THE Klamath Mountains were first recognized as a group deserving to be distinguished from other Coast Ranges and the Sierra Nevada when C. E. Dutton and J. S. Diller began their reconnaissance work in northern California and southern Oregon. It was first outlined in 1886 by Captain Dutton[1] as including all the mountains lying to the west of the upper Sacramento and Rogue River valleys, and probably other mountains of a similar age joining them on the north and south. The group was more definitely defined and characterized by Mr. Diller in 1892–93,[2] and their limits were extended southward beyond the fortieth parallel and northward to include the Rogue River Mountains, and some of the mountains of the upper Umpqua basin. According to Mr. Diller the name was first proposed by Major Powell many years earlier.

Geologically, the group of ranges now known as the Klamath Mountains resembles the Sierra Nevada in age and in the character of their formations, both igneous and sedimentary, though but little has yet been done to show their geological features,

---

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, pp. 97–103.

[2] *Fourteenth Ann. Rept. U. S. Geol. Surv.*, Pt. II, pp. 403–34.

except in their broader outlines. They embrace both sedimentary and igneous rocks, ranging in age from the Paleozoic to the Tertiary, though the later rocks form only a small portion of their mass and occur only in the larger valleys of the region. This group of mountains, which is clearly separated from the Sierra Nevada by the broad structural valley of the Sacramento, has been distinguished from the Coast Ranges to the north and south mainly upon geological hypotheses, it having been supposed that the ranges on either hand were of more recent origin, involving essentially younger strata. It yet remains to be shown, however, whether a satisfactory boundary can be so established, particularly upon the south. The metamorphic rocks of the Klamath system, including its schists and limestones, appear to be represented along the coast at intervals even as far south as San Francisco or even farther. The slates, cherts, and limestones of the Franciscan series, moreover, have their representatives among the Klamath Mountains and throughout the Coast Ranges.

GENERAL FEATURES.

The chief ranges.—The mountains included in the Klamath group have generally been regarded and described as a physiographic *complex*—a group of mountains without any definite order or relation, occupying a position at the junction of all the other systems in this portion of the coast. It is the purpose of this paper to call attention to a few of the more prominent facts pertaining to this question and to point out if possible some general system in their arrangement that has heretofore escaped notice. While it cannot be denied that the group holds in the main the position above described, it is believed that their disorder has been largely imagined. On the whole the group embraces a number of more or less independent ranges, some of which are much more prominent than others, some of them not having yet been distinguished by recognized names. They may be readily classed into two main systems which are believed to have a definite relation to the dynamical history of the region, probably representing two or more periods of revolution.

The two systems of ranges cross each other nearly at right angles. The most conspicuous ranges, among which are the Rogue River, Siskiyou, Scott, and Trinity mountains, have a westerly, or south of westerly trend, while the Yallo Bally, Bally Choop, South Fork, and Salmon River Mountains, and many of the less important spurs and ridges approximate a more northerly or northwesterly course. The fold represented in the Salmon River range particularly can be followed from the Trinity basin nearly continuously northward to the Rogue River Mountains, crossing perhaps all of the ranges running toward the coast. Of the east and west ranges it should be noticed that while all of them apparently terminate in the vicinity of the Cascades, this termination, for two of them at least, is more apparent than real. The east and west axis, for example, that is represented by the Rogue River Mountains crosses the Cascade range near Mount Thielsen and continues in a north of easterly direction through eastern Oregon toward the equally old cluster of the Blue Mountains, and forms a broad though high divide between the drainage of the Klamath Lakes and the Deschutes and Crooked rivers, flowing toward the Columbia.

In a similar manner the high range traversing northern California in almost a parallel direction, along the southern border of Siskiyou county, has an eastern projection which crosses the Cascades in the vicinity of Mt. Shasta and forms a high divide which separates the drainage of the Klamath Lakes and river from that of Pitt River and the Sacramento. Midway between these two folds is the Siskiyou range, almost parallel to the others, but not traceable beyond the Cascades. On either side of the Siskiyou range are the valleys of Rogue River and the Klamath. Each of the three ranges contains old crystalline rocks, including granites, gabbros, and peridotites, whose age undoubtedly antedates the later Cretaceous rocks to be described presently. While it is not clear that these crystalline elements have any direct bearing upon the question, it cannot be denied that these ranges represent axes of structural development that are very old compared to others that may be described.

Notwithstanding the fact that they have an east and west course, that has had a controlling influence upon the greater drainage, still it is not difficult to also recognize the north and south lines of folding traversing the country. South and west of the Trinity River the northwesterly direction of folding is shown by the course of all the larger streams. But even in the more central and most confused section of the Klamath group, that lying between the drainage basins of Rogue River and the Trinity, the north and south trend of the ranges impresses itself upon an observer, and the crossing of the ranges forms a magnificent spectacle for one who appreciates the larger features of mountain topography—and the influence of the factors controlling them is carried even into the smaller structural details of the country, regulating even the course of many smaller streams as well as that of dikes and auriferous veins.

Evidences of a peneplain.— Possibly to these facts is due in a measure the appearance in many portions of the group of a great uplift and dissected plain. Standing on any of the higher elevations of the country, say at an altitude of about five thousand feet, and looking over the surrounding mountains, one is often struck by the comparative uniformity of their outlines against the sky. From four to five thousand feet is for the most part their greatest altitude, and there are long ranges and ridges that stretch for miles at nearly a uniform level within these limits. One of the best examples of this fact is the South Fork range on the western boundary of Trinity county, which makes an even sky line for forty miles or more at an altitude above five thousand feet. The Siskiyous, the Yallo Bally, and Bally Choop ranges all furnish good examples of the same character. The general effect of this uniformity of level is that already suggested as a great uplifted and dissected peneplain that has been warped and diversified by differential movements subsequent to its development. South of the latitude of Cape Mendicino, Dr. Lawson has stated,[1] there is a broad peneplain that rises from a

---

[1] *Bull. Geol. Depart. Univ. Cal.*, Vol. I, pp. 242–44.

general elevation of 1,600 feet along the coast gradually toward the interior. Its eastern margin may be seen from the Sacramento valley, and, as viewed from the railroad, it has somewhat the effect of an escarpment that gradually rises toward the north. If the level effects of the mountains north of the Trinity basin are properly regarded as a peneplain, it is in a sense the northward continuation of the one described by Professor Lawson, and which rises gradually toward the north as well as toward the east. This approach to a peneplaination has been recognized by Mr. Diller,[1] and correlated with that represented in the broad western slope of the Sierra Nevada, which has been described as an inclined baselevel, the deformation of which took place at a comparatively late epoch. The great north and south fold already referred to rises above this level to an altitude generally of seven or eight thousand feet, as in like manner do also the Siskiyou, the Scott, and the New River ranges. The peneplain is distinctly noticeable along the coast in northern Humboldt and Del Norte counties, passing into Oregon, where it generally has an altitude between two thousand five hundred and four thousand feet.

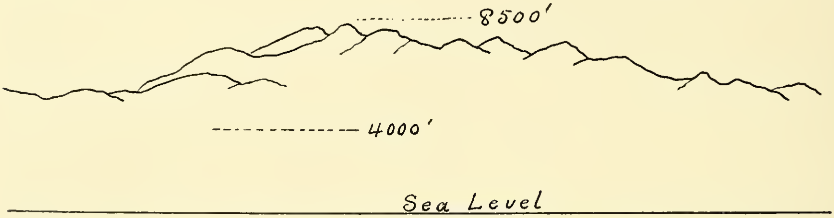


FIG. 1.—Profile view of the great Salmon mountain fold, south of the Klamath River.

The valley depressions.—All the larger valleys of the Klamath Mountain region are structural valleys. For the most part they may be included in two or three systems or basins, the significance of which has not yet been sufficiently recognized. One of these systems describes a broad curve across the northern portion of the Klamath Mountains, the other crosses them at the south.

---

[1] *Eighth Ann. Rept. U. S. Geol. Surv.*

As will be shown later, Shasta and Rogue River valleys are easily united, while the latter may be followed westward, toward and into a somewhat close connection with the valley of the Illinois River. On the other hand, the valleys of the Trinity basin may be linked together, connecting on the east with the valley of the Sacramento through a low divide between important ranges. Looking westward from the Sacramento valley in the neighborhood of Red Bluff one sees a low depression, separating what otherwise appears to be a continuous range of mountains bordering the Great Valley along the west. This depression is a low divide leading into the Trinity basin between the Yallo Bally and Bally Choop ranges. Beginning at this point a broadly curved line may be drawn in a northwesterly direction down the valley of a southern tributary of the Trinity, including the Hay Fork, Hyampom, South Fork, and Hoopa valleys, and extending to the mouth of the Klamath River. A little farther to the north a similar line may be drawn along the course of the main Trinity River, which merges into the former at the junction of the South Fork and the main branch of the Trinity. The two are included in what is here called the Trinity basin, which probably should be regarded as the southern limit of the Klamath Mountains, unless a purely geological or lithological basis of definition is to be employed, in which case they should be extended southward nearly, if not quite, to the Bay of San Francisco.

Type of valleys.—A peculiarity of all the intermontane valleys of the Klamath system is the manner of their drainage. Almost without exception their outlets cross one or more ranges through a narrow gorge or canyon. Shasta valley, for example, lying on the eastern flank of the older mountains, is drained, in common with the valley of the Klamath Lakes, by the Klamath River, which traverses a broad stretch of mountainous country to the westward for nearly one hundred miles before it emerges into the broader valley near its mouth. In its course it crosses the axis of the Salmon River range and other smaller ranges, through which its valley is reduced to the character of a gorge. And these valley-basins sometimes contrast rather strongly with their drainage canyons. Scott valley, for example, lying entirely within the limits of the Klamath Mountains, has a nearly level bottom with general dimensions of eight by twenty-five miles, into which converges the drainage of more than twenty miles radius, yet the outflow from this valley goes through a canyon more than twenty miles in length, which is almost impracticable for a wagon road to follow. Indeed, in some places the walls of the canyon rise precipitously for more than a thousand feet. Most of the interior valleys are of this type, including the valley of the Hay Fork, Hyampom, Trinity, and Hoopa valleys, the Salmon River, the Illinois, and others.

Deductions.—The explanation of this interesting fact is that already suggested in a former paragraph. It is evidently a result of the cross-folding of the country—that is, to the development of folds transverse to the course of a drainage that had already been established. It is not maintained that this north and south system is entirely younger than the drainage, for this is not true, but it appears to be evident that there has been an uplifting of these transverse ranges after the drainage of the region had become established. The progress of this movement was not more rapid than the erosion of the streams in a downward and opposite direction. The transverse barriers are mainly north and south, or, to be more exact, a few degrees to the west of north.

These observations apply equally to the Trinity River, the Salmon River, the Klamath, and Rogue River, and, as has been said, to Scott River, the Illinois, and to some of their smaller tributaries.

THE LARGER BASINS.

The larger basins already outlined probably had their origin in the midst of, or prior to, the Cretaceous period. The Rogue River basin, while it does not topographically include the valley of Shasta River, yet in a geological sense it includes not only this, but also the valley of the Klamath Lakes as well. The Trinity basin has been already shown to extend from the upper Sacramento and to include the larger valleys tributary to the

Trinity River. Between these basins lies that of the Klamath and Salmon River drainage, the history of which has been only in part parallel to the others. The history of these basins can be best known from a study of their later sedimentary deposits.

THE LATER SEDIMENTARY DEPOSITS.

The later sedimentary deposits of these basins include only those of later Cretaceous and of Neocene ages.

The Chico deposits.—The Cretaceous deposits are largely those of the Chico, and consist of shales, sandstones and conglomerates, the lighter materials generally forming the lower portions of the series. As a rule they are fairly fossiliferous, and often extremely so. In their distribution the Cretaceous deposits occupy both of the basins above described, which appear to have been distinct and separate inlets from the sea. Although it has been the opinion of Mr. Diller[1] and others, including the writer, that the Cretaceous deposits of southern Oregon and the upper Sacramento valley have had a connection through what has been called "the Lassen Peak straits," the proof of such a connection has not yet been satisfactorily shown, and there is evidence in favor of a different conclusion. Mr. Diller himself has expressed a conviction[2] that many of the topographic features of the Klamath mountains have remained only partially modified since Cretaceous time. In this connection it is worth while remembering that the granitic and basic crystalline rocks of the Klamath Mountains are the counterparts of those in the Sierra Nevadas, but in the latter range they are generally conceded to have antedated the later Cretaceous. An axis of such rocks certainly extends eastward beyond Mount Shasta, and the probability is that the high divide between the drainage basins of the Pitt and Klamath rivers is of pre-Chico age, even including some of the older lava flows of Mount Shasta and the range to the eastward. This is rendered especially probable by the fact that the Chico beds almost on the western slope of Mount Shasta contain bowlders and pebbles

---

[1] *Eighth Ann. Rept. U. S. Geol. Surv.*, pp. 411–13.

[2] *Bull. Geol. Soc. Am.*, Vol. V.

of andesitic lava that could hardly have come from any other source. But one of the strongest evidences of disconnected basins during the later Cretaceous is found in a comparative study of the Chico faunas of southern Oregon and the Sacramento valley. The dissimilarity of these basins has been partially brought out by the writer in a former paper on the "Cretaceous Deposits of the Pacific Coast."[1]

The Cretaceous basin of southern Oregon represented in the deposits of Rogue River valley extended therefore southward to the foot of Mount Shasta and eastward, as shown by fossiliferous deposits, into the basin of the Klamath Lakes, and was perhaps bounded along the north, at least in part, by the older mountains of the Rogue River range. This basin connected with the ocean along the present course of Rogue River valley. In the basin of the Trinity River the later Cretaceous deposits occur, but whether the outlet of the basin was toward the Sacramento, or westward toward the ocean, has not yet been determined. But the Cretaceous deposits (probably the Chico) have a considerable distribution along the different tributaries of the Trinity, and the outlet may have been in both directions. Chico deposits have been found as far west as the Hay Fork valley, or even on some of the tributaries of the South Fork at an altitude that might easily connect them with the Pacific. Eighteen miles southwest of Hay Fork these deposits occur at an elevation of three thousand feet above sea level.

The Eocene period left no deposits in the Klamath Mountains, as restricted, that have yet been recognized, nor have they been discovered anywhere in the region between the Marysville Buttes and the valley of the Umpqua River. Throughout these basins, wherever the Neocene deposits occur, they rest nearly conformably on the Chico, or on the older basement rocks. The conformity of these beds upon the Chico is so marked that it is often difficult to distinguish them.

The Neocene deposits.— The Neocene deposits of these basins consist very largely of non-marine sediments, often plant bear-

---

[1] *Proc. Cal. Acad. Sci.*, 3d ser., Vol. II.

ing, and containing evidence of volcanic activity. Two members have been generally recognized, the Ione formation, and the Tuscan tuff. Mr. Diller states that the Ione formation on Little Cow Creek, Shasta county, has a thickness of five hundred feet and that to the east of this there is a great thickness of clays, sands and gravel which are sufficiently indurated to be called shales, sandstones, and conglomerates, and which he calls Ione. The lower half of the Ione formation on Little Cow Creek is composed chiefly of sandstones and shales, with a bed of coal and carbonaceous material twelve feet thick, with an abundance of fossil leaves.

In the basin of Shasta valley similar beds occur with plants and carbonaceous layers, and entirely similar deposits occur along the western slope of the Cascades in the Rogue River valley. These beds are best exposed a few miles to the east and to the north of Ashland, Ore. Four miles north of Ashland, where the series has been well exposed by faulting. they have a thickness of about three hundred feet. Similar deposits occur also throughout the Trinity basin, as at Weaverville, Big Bar, Hay Fork, and Hyampom. In the Hyampom valley, in western Trinity county, these beds are well exposed, and contain layers of coal and carbonaceous matter, and the leaves of many Neocene plants, including the Sequoia.

Lake systems of the Neocene.—As in the Cretaceous, so also during the Neocene period, the basin to the north of Mount Shasta appears to have been separated from the Sacramento and Trinity valleys. In the northern basin the Ione deposits form almost a continuous line from Shasta valley northward to Rogue River, or even farther. Regarding their extent eastward, there has been considerable conjecture. They have not yet been definitely traced beyond the summit of the Cascades; but this may be due to their being buried beneath volcanic eruptions. The Ione deposits are evidently those of fresh water, the period being one of extensive lakes lying to the south and east of the Klamath Mountains. In the Rogue River basin, which, as here used, includes the basin of the Klamath Lakes, it has yet to be proved whether the beds occurring along the western slope of the Cascades should be regarded as the western margin of deposits underlying the Klamath Lakes, or belong to an independent body. It seems almost certain, however, that the basin of the Klamath Lakes must contain similar deposits, and that the Neocene drainage of the same basin was westward, and therefore that there was at least a connection with the deposits of Rogue River valley. Probably the connection was closer than one of mere drainage. But in any case it yet remains to be seen by which channel these waters reached the sea. If the outlet was by the present course of the Klamath, it must have traversed a mountainous country for at least one hundred miles, crossing masses of eruptive rocks like so many barricades, and the present dimensions of the canyon seem hardly proportional to the time and the volume of water that should have been discharged.

On the other hand, an alternative but little less difficult remains in supposing the outlet was through the Rogue River valley. Still, as we have said, the Rogue River valley is a structural depression dating at least from late Cretaceous time; and this fact lends a strong degree of probability for an outlet through this channel. Furthermore, the Cretaceous deposits of the Rogue River valley, as well as the older formations upon which they rest, show a broad line of terracing similar to that described by Mr. Diller in the upper Sacramento valley. This could only have been done in the presence of a body of water in post-Chico times, or by the reducing action of a large stream. It seems most probable, therefore, that the Neocene drainage of the upper Klamath basin was through the Rogue River valley, and that more recently it has been diverted to the present channel of the Klamath.

Overlying the Ione deposits, if there are such in the valley of the Klamath Lakes, are lake deposits apparently of a younger age. Possibly they may represent those of the Lahontan epoch described by Russell.[1] They consist for the most part of white diatomaceous and clayey beds extending far to the south, east,

---

[1] *Monograph XI, U. S. Geol. Surv.*, p. 143 *et. seq.*

and north of the present limits of the lakes, and aggregating a thickness of two to three hundred feet. They are occasionally, if not generally, interstratified with beds of volcanic sand and ash, and sometimes coarser material, and are often overlain by heavy beds of tuff, and in many cases by lava flows of quite local origin. These diatomaceous beds are accompanied by marginal terraces that plainly mark the former level of the water, probably at its maximum height. These terraces are especially observable in the vicinity of Klamath Falls and along Lost River and elsewhere, though they have been considerably disturbed by faulting and volcanic eruptions.

In the basin of the Trinity River, upon the southern border of the Klamath Mountains, Neocene deposits occur that Mr. Diller no doubt correctly correlates with the Ione of the Sacramento.[1] Here, as in the Rogue River basin, they have nearly a conformable relation to the Cretaceous deposits wherever they are found in contact, and they have not yet been satisfactorily distinguished from each other.

VOLCANIC ACTIVITY.

The Cascade range.—There has been more or less discussion at different times regarding the character and age of the Cascade range. It is now generally conceded to be pre-eminently volcanic in character, but as to its age there is less agreement. There can hardly be any doubt, however, that the Cascade range as a mass of volcanic rocks, is the northward continuation of the volcanic elements of the Sierra Nevada, and that it contains representatives of the lava flows that have covered so much of the Great Basin.

Lavas of the region.—J. E. Spurr has recently summarized some of the facts already known[2] relating to the age and succession of lavas in the Sierra Nevada and the Great Basin. It is apparent that the volcanic activity of this region has extended over long periods of time, beginning at least with the early Tertiary (Eocene) and continuing to the present. It is therefore

[1] *Fourteenth Ann. Rept. U. S. Geol. Surv.*, Pt. II, p. 419.

[2] JOUR. GEOL., Vol. VIII, No. 7, 1900, pp. 621—.

probable that the Cascade range is an accumulation of volcanic materials of as many different epochs. In many places, as near the Klamath River, this succession of periods, as well as the succession of minor flows, is well illustrated. At the head of the Little Shasta River, no less than four epochs are represented by as many different effusions. Dutton recognized the same long duration of volcanic activity in the Cascades of southern Oregon stating that it probably prevailed throughout nearly the whole of the Tertiary.[1]

The Tuscan tuff.—One of the later periods of volcanic activity is represented by what has been called the *Tuscan tuff*. This consists of a series of volcanic fragmental material, sometimes stratified and sometimes without stratification. It has a wide distribution in the upper Sacramento valley, where it has been described and mapped by Mr. Diller.[2] The volcanic tuffs of the Cascades north of Mt. Shasta, as well as the Ione and the Chico, demonstrate the secular accumulation of the lavas forming the range. As a rule the tuffs are interstratified with lava flows of somewhat different characters, some of which are older and some younger than the tuffs. Rhyolitic and andesitic tuffs have a wide distribution to the east of the Cascade Mountains, occurring abundantly in the basin of the Klamath Lakes, where they overlie, for the most part, the diatomaceous deposits as already stated. They also form thick deposits in the region of Silver and Summer lakes.

Faulting of the region.—A large amount of faulting has taken place subsequent to the distribution of these tuffs, often leaving them exposed in conspicuous cliffs. These fault lines, in so far as they occur in the region of the Klamath Mountains, are only outlying members of the great system of faulting traversing northern Nevada and southeastern Oregon, and which have been described by King,[3] Russell,[4] and others.[5]

---

[1] *Seventh Ann. Rept. Geol. Surv.*, pp. 100–1.

[2] *Eighth Ann. Rept. U. S. Geol. Surv.*, Pt. I, pp. 422–24.

[3] *Fortieth Parallel Repts.*, Vol. I, 1878, p. 735 *et seq.*

[4] *Monograph XI, U. S. Geol. Surv.*, 1885, p. 26 *et seq.*

[5] *Proc. Cal. Acad. Sci.*, 3d ser., Vol. I, p. 262 *et seq.*

Contemporaneous Neocene deposits are now found at all elevations in the Klamath Mountains, up to four thousand feet, and in such relations that it is clear that differential elevation of the region has occurred since their deposition. Probably some of these disturbances were coincident in time with the faulting that has been described as occurring in the Great Basin. In the interior of the Klamath group, faulting on a scale comparable to that of the Great Basin has not yet been clearly recognized, though many minor faults occur that perhaps coincide in time. Sharp flexures, as that along the western border of Scott valley, occur, some of which may be traced for many miles, but there are no well established extensive fault lines.

DEVELOPMENT OF THE PRESENT DRAINAGE.

During middle or late Neocene times there existed among the Klamath Mountains and along their southern and eastern borders extensive series or systems of lakes that have left their deposits in unmistakable evidence. These deposits rest conformably upon those of later Cretaceous, in such a manner that they have not always been distinguished.

During the period which intervened between the deposition of these two series of strata—the Eocene—we are left to infer that there was unrestrained erosion and aereal reduction throughout the region, covering indeed the long interval between the close of the Chico and the opening of the Ione, to the effects of which those of the Ione itself were added. Whatever traces there may be, therefore, of an ancient peneplain in the Klamath Mountains, it must doubtless be in part referred to this time. The fact should be emphasized that the drainage of the Klamath Mountains is westward, and it has probably remained so since Cretaceous time. There is no drainage that can properly be called eastward from these mountains, while the streams leading to the west derive their waters even from the eastern limits of the group, and probably during the Neocene period it was much the same. The canyons, or river channels of the period had been developed approximately to their present length and are fairly represented in those of the present, except as to depth. The canyon of the Klamath had retreated nearly to the drainage of the Klamath Lakes, and was possibly separated from it by only a low divide. As to the causes which led the drainage of the Klamath Lakes from Rogue River to the present outlet, it is not quite clear whether it was by the choking of the Rogue River outlet by later lavas, or by faulting, or by both combined. To the north of the Klamath River there is evidence of considerable faulting along the western slope of the Cascades, the upthrow of which could have cut off the outlet from the lakes in the direction of Rogue River, while in the vicinity of the Klamath no great amount of faulting has been observed, but on the contrary there is a depression of the Ione and Tuscan deposits. Furthermore, the Klamath River cuts these deposits in such a manner as to harmonize with this view.

SUMMARY AND CONCLUSIONS.

The physiographic features of the Klamath Mountains are in general those of crossing ranges and intervening structural valleys, modified to a considerable extent by the effects of ordinary river erosion. Evidences of an elevated peneplain are unmistakable at an altitude of four or five thousand feet above sea level. This peneplain is to be referred in part to degradation during the Cretaceous period, and in part to such action during the Tertiary. This peneplain has been subjected to disturbances ranging in time from inter-Cretaceous to the present. The earlier differential movements were those which originated the structural features that are conspicuous at present. The later movements have developed folds with north and south axes, the evidences of which are many. The principal north and south fold coincides with the Salmon River range, seen to the west of Scott valley, and its continuation on the north and south toward the Rogue River Mountains and the Trinity basin. It crosses all of the principal rivers of the region in a manner that demonstrates its secondary age, which was probably in part comparatively recent. The streams have maintained their westward course across this fold developing in nearly every case deep and narrow canyons, and proving its gradual elevation. The result of this action is a type of valley peculiar to this region, namely, that of valleys entirely inclosed by mountains and drained through deep narrow canyons. The larger basins of the Klamath Mountains include the Rogue River basin and that of the Trinity River. Both contain upper Cretaceous and Neocene deposits, almost or quite conformable, overlain by beds of volcanic tuff or lavas. During both of these periods the valley of the Klamath Lakes was connected with the Rogue River drainage, which condition extended into the latest Tertiary times.

The lake systems of the Neocene were two, that of the upper Rogue River (Klamath) basin, and that of the Trinity basin. Throughout the Tertiary, volcanic eruptions were in progress, and following this period occurred some of the later flows of lava and the formation of beds of volcanic tuff throughout the Cascade range and eastward. The latest flows accompanied by more or less faulting diverted the drainage of the Klamath Lakes from the Rogue River to the Klamath, and accompanying movements in a similar manner disturbed the drainage in other portions of the Klamath Mountains.

F. M. ANDERSON.

BERKELEY, CAL.,
1901.

BOSTON MOUNTAIN PHYSIOGRAPHY.

Upon a careful perusal of Professor A. H. Purdue's recent article on the "Physiography of the Boston Mountains, Arkansas,"[1] it will appear that he dissents from the opinion that there is represented in the summit of that range a plain of denudation older than that which is usually supposed to be widely developed over the Ozark plateau north from the Boston Mountain; and this interpretation he bases upon comparison of the erosion forms characterizing the two areas, finding that the lower and heretofore supposedly "newer" region (considered from the standpoint of the physiographer), in reality has by far the older type of topography. It seems to the present writer that Professor Purdue has overvalued some of the evidence and minimized or totally ignored other factors which may have an important bearing on the question at issue.

Ever since my paper on the "Peneplains of the Ozark Highland"[2] left my hands I have been conscious of a slight discrepancy in my interpretation of the topographic development of west-central Arkansas, and I wish to take advantage of this opportunity to set it aright.

In identifying the truncated summit of the Boston Mountain as a remnant of the same supposed dissected "Cretaceous" peneplain, as is indicated in the summits of the Ouachita ranges south of the Arkansas river, I dwelt too strongly on the general correspondence in height of the two systems of ridges, and later vitiated the conclusion based thereon by developing the probability that the present elevated condition of the Boston Mountain region is largely due to differential uplift in the early part of the Quaternary era.

Dr. C. R. Keyes, in his article on the "Composite Genesis of the Arkansas Valley Through the Ozark Highlands,"[3] seems to

---

[1] Jour. Geol., Vol. IX, No. 8, p. 694.

[2] *American Geologist*, January, 1901, p. 21. [3] Jour. Geol., Vol. IX, No. 6, p. 486.

appreciate the true significance of the evidence, and the figure which he gives on p. 487 is virtually in accord with my present conception of the subject. It is believed (for the same reason that a dissected peneplain is recognized in the summits of the Appalachian ridges) that the summits of the Ouachita mountains are remnants of an old plain of denudation (whether in age Cretaceous or early Tertiary matters not), and that this plain would descend rapidly to the axis of the Arkansas valley had it not been totally destroyed over that broad structural and topographic depression; and that then it would rise northward because of a monoclinal folding inaugurated in early Quaternary time, and perhaps continuing today. The question is, Would this projected plane coincide with the summit of the Boston Mountain?

Let us eliminate later deformation and straighten out the supposed lower or "main Tertiary" plane of erosion baselevel. Our theory supposes that the earlier or "Cretaceous" baselevel plane would first become distinctly differentiated from the later in southern Missouri, and the difference between them would have increased to about five hundred feet on the northern edge of Boston Mountain. Continued to the first ridge of the Ouachita system, the difference between the two planes might be expected to be one thousand feet, but through the concavity common to the border of all symmetrical dome-like uplifts it would be natural to expect an increase to at least the present difference in level of the planes at the summit and base of Sugar Loaf Mountain, about 1200 feet, I believe.

But Professor Purdue has raised a question of the validity of this interpretation by his erosion studies, the pertinence of which cannot be ignored. He says, in reference to the Boston Mountain region:

> The drainage of the region is that intermediate between youth and maturity. The streams are vigorous and have completely dissected the plateau by the formation of gorges from 500 to 1000 feet deep, thus producing a very rugged topography over the whole region. Between these gorges the slopes often meet, forming more or less rounded hills; but more frequently

> the intervening area is occupied by flat-topped, sandstone-capped hills of limited extent.

Of the lower plain to the north, he says:

> This is a region of great denudation. . . . . Its streams are mature, the valleys comparatively wide, and the topography in general presents the aspect of much greater age than that of the Boston Mountains.

"Youth" and "maturity" as applied to streams and valleys are terms relating to types and not to age as measured in years. The topography and drainage of a land never greatly elevated, and possessed of a humid climate and soft formations may be ever so senile in type and yet no older in years occupied in its development than another region characterized by immaturity of its physiographic features. This is an axiom of the science of physiography. The less mature character of the drainage and erosion forms of the Boston Mountain region than of that on the north does not necessarily militate against a reference of the development of its summit plain to an earlier cycle of erosion.

Some of the causes which have tended to bring about this result are as follows:

Boston Mountain owes its prominence and preservation as a residual on the "main Tertiary" peneplain largely to the resistant properties of the Upper Carboniferous sandstone which enters so largely into its composition. On the south, the Arkansas valley was developed on a belt of soft shales and all traces of residuals were swept away. On the north, the elevation of the land was less, the streams soon cut down to baselevel and could devote a large part of the cycle of erosion to widening their valleys. The Boston Mountain was on the main divide between the White and Arkansas river systems, and only very small streams operated on it while the country on either hand was being ground away by powerful trunk streams. The latter developed meandering courses indicating maturity, but we could hardly expect to find similar winding courses in the small headwater streams of the main divide.

The evidence of youth in the Boston Mountain valleys is somewhat deceptive, especially on the southern slope. Here I recognize valleys of several cycles trenched beneath each other and coalescing so as to be apparently the product of a single cycle of erosion. (I am using the term "cycle" as referring to the time between uplifts with rejuvenations of the drainage.) Eliminate all those portions of the valleys which are below the supposed "main Tertiary" baselevel plane, say five hundred feet below the general summit level of the mountain, and much of the youthfulness will disappear; the valleys remaining will be comparatively broad and flat-bottomed.

Another indication of immaturity recognized is the flat summits. This feature is maintained by the rather resistant sandstone strata capping the hills and its importance is exaggerated by its abnormal character.

If the summit plain of the Boston Mountain was not developed anterior to that of the lower county on the north, it must have been elevated by faulting. The northern face of the Boston Mountain is "an irregular, but bold escarpment from five hundred to one thousand feet high." This is entirely too sinuous to be a degraded fault scarp. Great promontories project out into the plain country on the north. The phenomena are characteristically those of differential erosion. If a fault with a throw of five hundred or one thousand feet existed, it must have dislocated the Upper Carboniferous sandstone in such a conspicuous manner as would long since have attracted attention. In short, I cannot see any escape from the conclusion that the Boston Mountain was a residual on the baselevel represented by the plain to the north—the Ozark plateau.

The criteria on which I would base the recognition of a dissected peneplain on the nearly horizontal rocks of the central Mississippi region are: (1) many of the summits must be truncated; (2) these flat summits must fall into a single plane, only very slightly tilted; (3) the plane must pass across diverse formations without deformation; (4) the plane must to some extent bevel the edges of the slightly inclined strata; and (5) the dissected plain must be extensive enough to make it improbable that it was developed by marine erosion. Such other phenomena as meandering stream courses and monadnocks are valuable adjuncts, but not essentials. How do these principles apply to the Boston Mountain region?

In arriving at the most natural explanation of the uniformity in height of the Boston ridges, six hypotheses may be briefly examined: (1) That it is a plain of aggradation of Upper Carboniferous age which remained intact until very late geologic time because of having stood virtually at sea level. This is calling into play a possibility which is not a probability. From what is known of the history of the continent in post-Carboniferous time, it may be considered unnatural. However, even allowing that such a strange coincidence may have occurred, I should still claim the summit plane of Boston Mountain as representing a baselevel of subaerial erosion, an appendage to a true peneplain. (2) That it was planed off by marine erosion and a thin sheet of Cretaceous or Tertiary sediments deposited on it. A submarine shelf, twenty miles in width, would have a considerable thickness of sediment resting on its seaward portion, and some remnants should remain on the flat-topped hills. If the submergence was very short, I should claim the reduction of the area to a plain condition to have been virtually the work of subaerial denudation, very slightly aided by marine action. As a matter of fact, there is no collateral evidence of such submergence in post-Carboniferous time and the drainage system is against it. (3) That the uniformity in height of the separate ridges which together constitute the Boston Mountain can be attributed to the intersection of the slopes of valleys having a common baselevel is an untenable position because most of the ridges have truncated summits. (4) The conditions of the soil, climate and amplitude of elevations are not such as to give value to any argument based on differential protection by vegetation. (5) That it is a structural plain resulting from the unequal resistant properties of the Carboniferous strata eroded. This implies that there be strict parallelism between the plain and the bedding of the rocks, for studies in the western states where this agency has had full play in the production of topographic forms, make it certain that there must be no general beveling of hard and soft layers. Professor Purdue says:

> Structurally, in the western part of Arkansas, these mountains are a broad flat anticline, the strike of which is east and west. According to the geologists of the Arkansas Geological Survey, it appears that the extreme eastern part of the region is monoclinal in structure with the dip to the south.

The dissected plain is also slightly tilted and slightly bowed, but I invite someone to show that it is strictly parallel to the structure. Specific data on this point are wanting. I believe that the plain actually bevels the slightly inclined strata, and if the summit-plane of the outliers on the north be admitted into the argument, I know that it does. (6) By elimination, the peneplain hypothesis comes to the front as that which furnishes the most natural explanation of the phenomena observed and violates no established principles of physiography. I believe the peneplain character of Boston Mountain is as firmly established as that of any other recognized dissected peneplain in eastern America. It is not proved and perhaps never will be as proof is made in other departments of science. A strong suspicion now existing that an ancient peneplain is represented may be strengthened as more precise data are recorded and in time the critics may cease opposition. At present their activity is desirable as stimulating the collection of evidence.

As precedents for disregarding, in the conclusion that the dissected plain at the summit of Boston Mountain has an age greater than that of the "main Tertiary" peneplain, the argument drawn by Professor Purdue from the contrast in stage of maturity of drainage and topography on the two areas, I will mention the plateau of West Virginia with its narrow valleys, standing as a residual on a Tertiary baselevel which in other portions of the Appalachian region has broad basins and mature topography; and the Niagara plateau of northeastern Iowa, rising prominently above a lower dissected plain whose valleys are equally as large.

OSCAR H. HERSHEY.

BERKELEY, CAL.,
Jan. 21, 1902.

DRAINAGE OF SOUTHERN INDIANA.

INTRODUCTION.

Area to be discussed.—Only those features of the drainage of southern Indiana which are dependent upon geological structure and are not controlled primarily by glacial drift will be discussed. This limits the discussion to that portion of the state that lies south of a line running from Indianapolis east to the Ohio state line, and from Indianapolis southwestward along the course of West White River to the mouth of that stream.

While the eastern tributaries of the West White River from Indianapolis to the mouth of Bean Blossom Creek, and the tributaries of East White River in northern Shelby and Johnson counties, owe their positions largely or entirely to the drift,[1] the main streams of the area referred to are controlled by the underlying strata.

The driftless and drift-covered regions.—The driftless region of southern Indiana is an irregularly triangular area, with the base of the triangle along the Ohio river, reaching from Mount Vernon to a point a few miles above Jeffersonville, a direct distance of 135 miles, and the apex of the triangle near the northeast corner of Monroe county, 135 miles northeast of Mount Vernon and 85 miles slightly west of north from Jeffersonville. All other portions of the area under discussion are, or have been, more or less covered by the drift.

Over most of the region both directly east and directly west from the unglaciated area the covering of drift is comparatively thin. In the region to the east especially, the drift covering is rarely as much as 100 feet thick, and many of the streams have cut down through it and into the underlying rocks. In some cases these streams occupy preglacial channels; in others the

---

[1] These small streams are not included in the following remarks regarding the drainage. Neither are the streams between West White and Wabash rivers discussed, although those streams are shown on the map, Plate VI.

valleys have been cut out entirely since glacial times, leaving the drift in remnants only upon the hilltops and uplands.

Effect of the structure in the region thinly covered by the drift.—The thin mantle of drift that covers that portion of the state east of the driftless area lies on strata that dip gently to the southwest, and on an old surface whose general contour prior to the deposition of the drift was similar to that of the present time. Therefore, while the minor lines of drainage have been modified by the drift, the general south and southwest drainage of the country is such as would be logically developed in a country of such combinations of hard and soft southwestward dipping strata as southern Indiana possesses, and it is practically the same now as it was in preglacial times.

The series of strata that control the topography and drainage.—There are in southern Indiana three thick series of shale beds, between which are groups of harder and more resisting limestones and sandstones. In going from east to west across the state these groups are as follows: (See the numbers on the cross sections shown on the accompanying drainage map, Plate I.) (1) the Hudson River shales, along the east side of the state; (2) the resisting Niagara limestone, and limestones at the base of the Devonian; (3) the New Albany and Knobstone shales, all soft and easily eroded beds; (4) the Knobstone sandstones and overlying Carboniferous limestones, which are in turn overlain by the sandstones at the base of the Coal-measures;[1] (5) the soft Coal-measures, shales, and sandstones of the west side of the state.

Postglacial and preglacial topography.—The softer groups of strata, viz., 1, 3, and 5, form drainage areas (discussed below as the eastern, central, and western drainage areas respectively) that are more or less separate from each other in each case, while the harder groups, 2 and 4, form the highlands or watersheds between those areas.

---

[1] The Lower Carboniferous limestones are eroded more easily than the beds lying both east and west of them, but their denudation has not been so great as to form a separate drainage basin in the area underlain by them.

The strata that form the different drainage areas and the watersheds between them in the southern part of the state extend northward under the glacial mantle for some distance beyond the boundary of the accompanying map (Plate I). Therefore it might be expected that the preglacial relief of the country underlaid by those strata was similar to the present relief in the unglaciated area to the south, and this is found to be the case.

The effect of the highlands (formed by groups 2 and 4) where they plow northward under the glacial mantle and lift it up, is noticeable for many miles north of the southern limit of the drift. These buried highlands show that the preglacial topography of the region thus affected was similar in general lines with the present topography which is almost, or entirely, unaffected by the drift at the southern part of the state. Well records show that the central drainage area, or trough, and its eastern rim extended as far north in preglacial time as the north side of Clinton county at least, while the highlands west of it certainly extended as far north as northern Montgomery county.

The preglacial topography makes it seem quite probable that the preglacial drainage of this trough was from the eastern rim down the dip of the underlying limestones to the southwest, along lines generally parallel with those of the present streams further south, which are in accordance with, and are controlled by, the geologic structure.

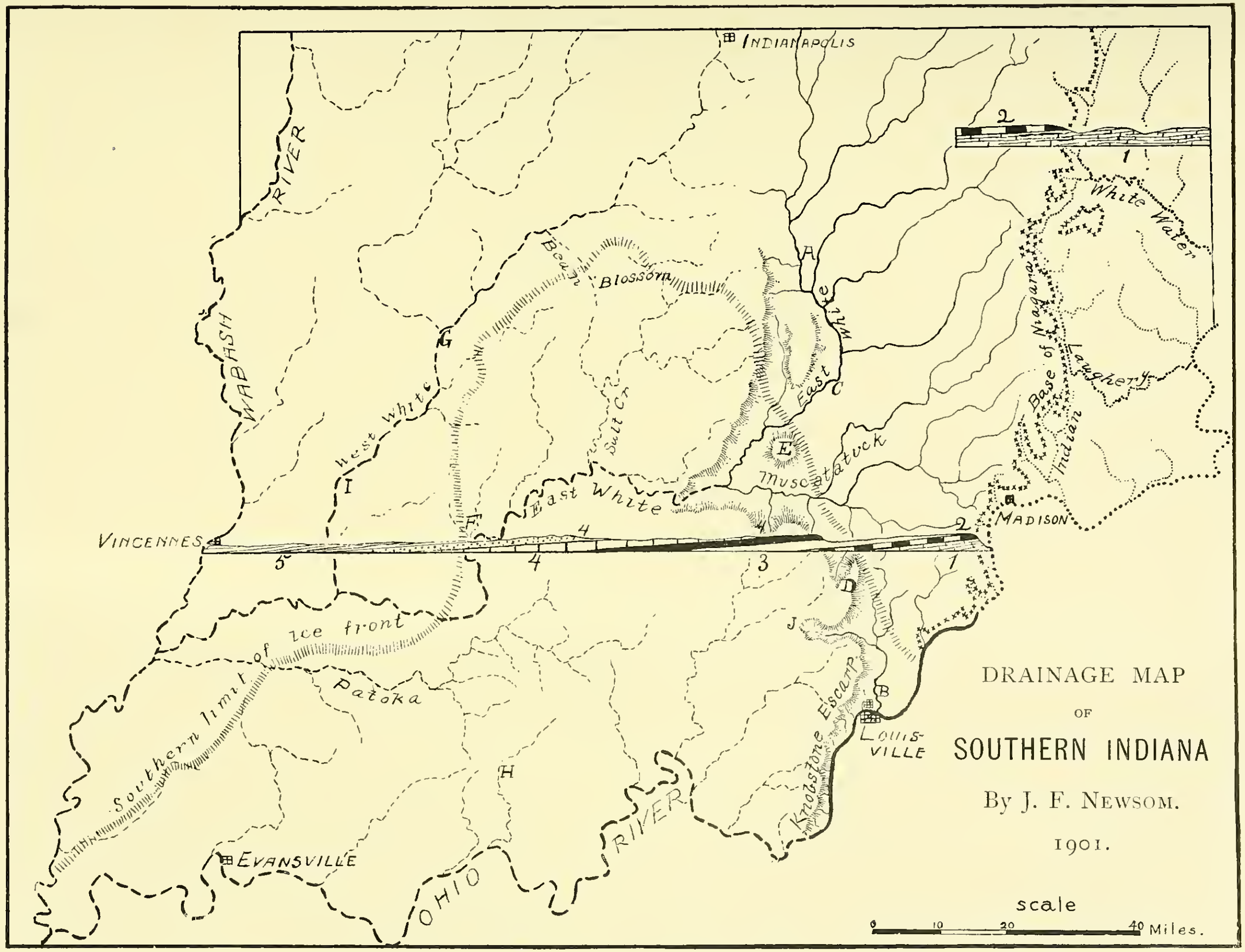
The relations of the different drainage areas and the structure controlling them is shown by the cross sections on the drainage map, Plate VI.

It will be seen, therefore, that the drainage of southern Indiana may be treated in accordance with the groups of strata that control the topography of the region.

Relations of the structure to the drainage.—An examination of the geology in its relation to the drainage shows that there are the three following general drainage areas:[1] (1) the eastern area, covered by rocks of the Hudson River group, and including

---

[1] These areas cannot be regarded as basins in the proper sense of the term, for each area is drained by many different streams.



Drainage Map of Southern Indiana. The streams of the eastern drainage area are shown by dotted lines, those of the central drainage area are shown by solid lines, and those of the western drainage area are shown by broken lines. (Glacial boundary after Leverett.)

ON CROSS SECTIONS:

5 = Coal-Meas. shales.
4 = Mansfield s's't., Low. Carb. l's't., Knobstone s's't.
3 = Knobstone shale., Devonian shale.
2 = Devonian l's't., Niagara l's't.
1 = Hndson River shales.

some short streams that rise on the Niagara strata and flow eastward into the Hudson River area; streams of this area are shown by dotted lines on the accompanying map, Plate VI; (2) the central area, covered by the strata between the base of the Niagara and the Knobstone sandstone; streams of this area are shown by solid lines on the accompanying map, Plate VI; (3) the western area, covered by the rocks from the Knobstone sandstone to the top of the Coal-measures; streams of this area are shown by broken lines on the accompanying map, Plate VI. This last area includes the entire southwestern part of the state, and in the eastern part of it the streams have in many places cut down through the limestones and Knobstone sandstones, and into the Knobstone shales. These shales, however, have had no part in the formation of the western drainage area, which, while largely underlain by sandstones and limestones, has its eastern watershed along the Knobstone escarpment within a few miles of the lowest part of the central area.

From each of the watersheds, viz., between the eastern and central, and the central and western areas, the streams that flow east across the dip of the strata are short and have steep gradients, while those that flow west with the dip of the strata, are long and have low gradients.

The larger streams of southern Indiana flow through filled valleys. The depth to which the valleys have been filled varies from a few feet to over one hundred feet.

The different drainage areas will be taken up in their order, and the features of their drainage so far as these depend upon the structure of the underlying rocks will be pointed out. The boundaries between these areas do not follow exactly the outcrops of the strata which form the divides between them, for short streams which belong to the area underlain by Hudson River beds, for example, may rise in the Niagara beds and flow eastward across the dip of those beds for a short distance before entering the area of the Hudson River strata. The same is true of streams belonging to the central basin, which rise at the top of the Knobstone escarpment. On the other hand, the streams flowing westward sometimes cut down through the hard strata that form the watershed, exposing the underlying softer strata. These facts must be kept in mind in treating the general drainage areas in accordance with the underlying strata.

THE EASTERN DRAINAGE AREA.

While the highest points in the eastern area are almost as high as the watershed at its western side, the streams of this area have cut out valleys from one hundred to four hundred feet deep in the soft Hudson River strata, and the average level of the country is therefore considerably lower than that of the country immediately west. The Hudson River strata are almost horizontal, and with few exceptions the streams flow more or less directly to the Ohio River.

Attention should be called, however, to the upper courses of the Whitewater River,[1] Laughery Creek, and Indian Creek.

The upper courses of these streams are almost in line, they flow nearly due south, parallel with the watershed formed by the Niagara strata, and only a few miles east of that watershed.[2] Excepting those of Indian Creek, the tributaries of these streams that enter from the east and north are comparatively long, while those from the west which rise in the Niagara strata and flow eastward across the dip are short. The main drainage lines and their relations to the controlling beds to the west are shown on Plate VI.

Indian Creek, which drains portions of Ripley and Jefferson counties, flows southward parallel with the watershed at the west, but owing to its shortness and its proximity to the Ohio, this is the course that would be expected of it regardless of the dips of the rocks of the area. It should be noted also that when the Ohio strikes the region of outcropping Niagara limestone at Madison it makes an abrupt turn to the south, and flows south

---

[1] Whitewater River flows through a preglacial valley below Connersville (Leverett).

[2] It seems probable that these streams have been shifted to these positions by the westward inclination of the beds, although this inclination is very slight.

for about eighteen miles before turning to the southwest and cutting through the Niagara strata.

It is seen, from what has been said above, that the area covered by the Hudson River strata has its main drainage lines parallel with its western rim; that for the most part there are southward flowing streams in the area immediately east of and practically all along this rim, that the tributaries from the west are short, while those from the east are long, and that these features of the erosion may be due to the gentle westward inclination of the strata at the west edge of the area. As the streams approach the Ohio their relations to the watershed at the west are lost, as is seen by the abrupt eastward turn of the Whitewater in northeast Franklin county, and of Laughery Creek in southeast Ripley county.

THE CENTRAL DRAINAGE AREA.

The central drainage area has its eastern watershed formed by the Niagara and Devonian limestones, while its western watershed is formed by the Knobstone sandstones and overlying limestones that form the crests of the hills known as the Knobs.

The east-west profile of this area and its geological relations are shown on that portion of the cross section (Plate I) extending from the Niagara strata to the Knobstone sandstones. The east side of the basin has a gentle slope to the west, while the west side has a steep slope to the east.

The shape of the central drainage area is shown on Plate I, where its streams are shown by solid lines. This area is about fifty-five miles across in its widest part at the north and narrows down until it is less than a mile wide along the Ohio river at the south.

On Plate VI this trough, the axis of which extends from near Edinburg (*A*, Plate VI) slightly east of south to the Ohio River near New Albany (*B*), is shown. From Edinburg to the Ohio the axis is followed approximately by the line of the Jeffersonville, Madison & Indianapolis railroad. The central area, in which the control of the structure upon the drainage is more clearly marked than in either the eastern or western areas, is made up of two districts: a southern district from which the streams flow directly into the Ohio River, and a northern district, drained by East White River and its tributaries into the Wabash.

The southern district.—After cutting through the Niagara and Devonian limestones the Ohio River flows west and southwest across the southern district until it reaches the strata of the Knobstone group west of New Albany. Here it is deflected to the south and runs close under the bluffs formed by the Knobstone standstone and overlying limestones for about eighteen miles to Taylor township, Harrison county, where it turns to the west and cuts through the Knobstone sandstones and overlying limestones. The southern deflection of the Ohio west of New Albany is very similar to its southern deflection by the Niagara and Devonian limestones just west of Madison. The valley of the Ohio is wider where it crosses the central area, in the neighborhood of New Albany and Louisville, than it is either immediately above or below that locality. This widening of the valley is due to the character and relations of the strata crossed, and in no way indicates that the former size or course of the stream differed greatly from its present size and course. Neither does it indicate that the present river valley at this locality crosses the wide north-south valley of a former large stream.

The streams that enter the Ohio from the west below New Albany are short and have steep gradients. Most of these streams have noticeable down-stream deflections where they enter the Ohio bottom lands, their mouths having been shifted down stream by the deposition of sediments on their up-stream sides.

Above New Albany, Silver, and Fourteen Mile creeks are the principal streams. Silver Creek rises in the Knobstone hills at the south side of Scott county and flows almost due south until it reaches the Ohio above New Albany (*B*). Muddy Fork, one of the tributaries of Silver Creek, rises well over in the Knobstone area near the west edge of Clark county and flows eastward for fifteen miles, across the dip of the strata, before entering the main stream and turning south to the Ohio.

Fourteen Mile Creek rises in the southwestern part of Jefferson county, flows slightly west of south with the dip of the strata and enters the Ohio three miles southeast of Charleston. In its lower portion Fourteen Mile Creek cuts down into the Hudson river strata. Other shorter streams have their sources in the area covered by the Niagara limestones, or the Devonian strata, and flow more or less directly into the Ohio across Hudson river strata. While the general courses of these streams are such as might be expected from the structure of the underlying strata (with the exception perhaps of Muddy Fork of Silver Creek, which rises at *P*, Plate VI, and flows eastward across the dip of the Knobstone strata), the influence of that structure on them is by no means so clearly marked as it is on the streams in the district next to be considered.

The northern district.—It is in the northern district (that portion of the central area lying north of the southernmost cross section, Plate VI), drained by the East White and Muscatatuck rivers, that the effect of the structure upon the drainage is most clearly seen.

The streams that drain the northern district rise for the most part near the watershed which separates this from the eastern drainage area, within a few miles of the main drainage lines of the eastern area, and flow westward down the gentle slope that owes its inclination to the dip of the underlying beds. In their upper portions most of the streams have gradients greater than the dip of the underlying beds and have consequently cut down from newer into older strata. In their lower courses the gradients are less than the inclination of the strata, and the streams pass across successively newer beds.[1] The streams that rise on the western rim of the northern district and flow eastward are short and have steep gradients.

Except for the course of East White River below Seymour

[1] This feature is well shown by the tributaries of Stucker's Fork, in townships 3 north, 8 and 9 east. These streams rise in the Devonian shale area, flow westward with the dip, but cut down through the shale, exposing the underlying limestones for a distance of about six miles, and then, the fall becoming less than the dip of the underlying beds, again pass out into the shale area.

(with which is included the lower course of the Muscatatuck), the drainage lines of the central area are evidently controlled by the geological structure of the country. The effect of the structure upon these streams is well shown in the case of Ramsey Creek — a tributary of the Muscatatuck — which rises just west of Madison near the northeast corner of township 3 north, 9 east, within one and one-half miles of the Ohio River, and 360 feet above that stream. The waters of Ramsey Creek flow into the Muscatatuck, then through East and West White rivers, and the lower Wabash, and finally empty into the Ohio at the extreme southwestern corner of the state, a direct distance of 170 miles from the source which was within one and one-half miles of the Ohio.

From Edinburg to Rockford, a distance of twenty-seven miles, East White River flows southward, parallel to the Knobstone hills and but a few miles east of them. Its tributaries from the west are short and have steep gradients. Those from the east and northeast are long. They rise at the watershed formed by the Niagara strata and flow with the dip down the southwestward slope of the country. The sources of some of the eastern tributaries of East White River are but a few miles west of the Whitewater River — the main drainage stream of the eastern area. The asymmetry of the area drained by East White River is shown by the accompanying drainage map (Plate VI).

One of the most interesting features of the drainage of the central area is the course of East White River below Rockford (*C*, Plate VI). From Edinburg to Rockford this stream flows south along the bottom of the trough east of the Knobstone hills. But while this trough extends on southward to the Ohio River and is apparently the line along which White River could have most easily developed its course, that stream, instead of following the valley (*A*, *C*, *B*, Plate VI) to the Ohio, turns to the west at Rockford and flows through broad bottom lands until it is joined by the Muscatatuck, at the south side of Jackson county. Just below the mouth of the Muscatatuck it enters a comparatively narrow valley, which has been cut down through the Knobstone strata, the overlying Lower Carboniferous limestones and the Mansfield sandstone. This valley varies in depth from less than fifty to over two hundred and fifty feet ; its length is about seventy-five miles. In width the bottom of the valley (which is filled with alluvium from fifty to seventy-five feet or more), varies from one-half mile to over one mile.

Thus it is seen that instead of carving out a valley along the strike of easily eroded strata, southward from Rockford directly to the Ohio, a distance of fifty miles, East White River turns to the west, flows through a valley cut across hard strata, and finally reaches the Ohio through the Wabash at a point over 150 miles from Rockford.

Two hypotheses may be advanced in explanation of the course of East White River below Rockford.

The first is that the present is approximately the original course of the river; that as this region was first elevated the drainage from the land at the east was deflected to the south parallel with the Knobstone sandstones and behind (*i. e.*, east of them), or else that it shifted itself to this position during its early history; that in the vicinity of the present village of Rockford the drainage turned to the west, cutting across the edges of the strata, and that it deepened its valley in this position as the strata were elevated—gradually establishing itself in approximately the position now occupied across the Knobstone, the Lower Carboniferous limestone, and the Mansfield sandstone. Even though this entire region may have been approximately baseleveled since the orginal drainage was established, elevation subsequent to the baseleveling would have re-established the main drainage along its original lines.

The width of the valley throughout its length from the Muscatatuck to the Coal-measures suggests an age greater than has elapsed since the ice invasion, and makes the above explanation seem probable. The present course of the stream through its gorge below the mouth of the Muscatatuck cannot be explained by stream capture, if it be supposed that East White River originally entered the Ohio in the neighborhood of New Albany. If it originally entered the Ohio near New Albany, its course below Rockford (*C*, Plate VI) would have been along the strike of easily eroded shales, and directly to the Ohio, a distance of fifty miles from Rockford. It is 150 miles southwest from Rockford to the mouth of the Wabash, through which East White River at present reaches the Ohio, and one-third of this distance is across the strike of resisting limestones and sandstones. It is obvious, therefore, that East White River could not have been captured at or below Rockford by a stream which flowed to the southwest across those hard strata. Moreover, there is no evidence to show that the former course of the stream was directly into the Ohio at New Albany.

Reversion, owing to elevation of the strata to the east and northeast is not regarded as a probable explanation of the lower course of White River, even if it be supposed that the original course of that stream was toward the east or northeast.[1]

The second hypothesis is as follows: It presupposes that prior to the ice invasion, the upper portion of East White River, (viz., east of the present mouth of the Muscatatuck) flowed either north or northeastward, or possibly emptied directly into the Ohio at New Albany—in any event that it flowed generally parallel with the Knobstone hills, east of those hills, and did not cut through them; that short tributaries of this main stream entered from the west, occupying about the courses of the East White and Muscatatuck rivers for fifteen miles above the present junction of those streams, but flowing in the opposite direction; that these short eastward flowing streams formed the triangular *cul de sac* in the Knobstone hills, in the center of which stand the Brownstown Knobs (*E*, Plate VI) with the Silver hills of Scott county (*D*, Plate VI) projecting east of the main line of hills; that west of the Knobstone escarpment the general drainage to the southwest was the same as at the present time[2] and that a

---

[1] The details of the preglacial drainage north and east from Rockford are obscured by the drift. The general preglacial contour of this part of the country, however, must have been about the same as that of the present time.

[2] In *Monograph XXXVIII, U. S. Geol. Surv.*, Pl. IX, MR. FRANK LEVERETT shows the supposed preglacial westward drainage of this region.

low pass was formed between the westward flowing streams and those flowing eastward which formed the corner of the *cul de sac* above referred to.[1]

During the glacial period the ice passed immediately east of the Knobstone hills in western Bartholomew county, through Jackson, and crowded up against the projecting knobs known as the Silver hills in Scott county (*D*, Plate VI). If the suggested conditions existed at that time, the triangular *cul de sac* in the Knobstone hills would have had its eastern outlet completely shut off by the ice, and the basin thus formed would have filled with water from the melting ice until it poured over the pass into the westward flowing streams; the pass would have been cut down, and finally the stream would have become firmly established in its new course, and into this it would have led the waters of its entire drainage basin as the ice retreated.

The shape of the *cul de sac*, in which the Brownstown hills stand with the eastward projecting Silver hills (*D*, Plate VI), against which the ice was pushed to the south, makes this second hypothesis seem probable. The principal objection to it is found in the general width of the valley of East White River below the mouth of the Muscatatuck. There are no *narrows* in the canyon to correspond with the position of the supposed original divide between the east and west flowing streams. The bottom, or present flood plain, of the valley varies in width from one-half mile to over one mile, and would certainly seem to antedate the ice invasion.

THE WESTERN DRAINAGE AREA.[2]

The main drainage lines of the western area are such as would be developed by the structure of the country, and they

---

[1] A condition of affairs quite similar to that hypothecated here exists at the present time in townships 1 south and 1 north, 5 and 6 east, where Muddy Fork of Silver Creek forms a triangular valley opening out to the east, while the divide between this stream and Blue River, which flows southwest is quite low. (*J*, Plate I.)

[2] The drainage of southern Indiana, in its relations to the glacial period, is discussed and mapped by LEVERETT in *Monograph XXXVIII, U. S. Geol. Surv.*, p. 97 *et seq.* See also Mr. LEVERETT'S discussion, Pt. IV, Eighteenth Ann. Rept. U. S. Geol. Surv., pp. 446–58.

are practically the same at the present as they were in preglacial times. The Knobstone sandstones, with their capping of limestones, rise in an eastward-facing escarpment unbroken, except where cut through by East White River, from the Ohio River at the south side of Harrison county to the northeast corner of Brown county. This escarpment rises from 200 to 400 feet above the lowlands of the central drainage basin immediately east of it, while to the west the country is rolling and descends gradually. The streams rising near the escarpment at the east flow down the gentle slope to the west and finally enter the Ohio, White, or Wabash rivers.

The control of the structure upon the drainage lines of this area is best seen immediately west of the Knobstone escarpment between the East White and the Ohio rivers (Plate VI). North of East White River apparently only the general course of the drainage is controlled by the structure; while in a general way the longest tributaries of the streams are those coming in from the east and northeast, this feature is by no means clearly marked, even in the area underlain by the comparatively hard Lower Carboniferous limestones and Mansfield sandstone.

It is noticeable that the streams of the western area which flow across both the area underlain by the Lower Carboniferous limestones and that underlain by the sandstones at the base of the Coal-measure (Mansfield sandstone) are not deflected as they pass from the limestone into the sandstone area.

The Mansfield sandstone is often massive and forms a rugged topography in the region in which it outcrops, and it might be expected that the streams would be deflected to the north or south by it. However, no such change in the stream courses is to be seen; instead of being deflected they pass directly from the limestone area across the sandstones, through which they have cut deep valleys, until they reach the comparatively flat region underlain by the soft Coal-measures shales at the west side of the Mansfield sandstone.

These conditions lead to the conclusion that the streams from the land at the east cut directly across the Mansfield sandstone as it was first raised above the water and thus early established themselves in approximately their present courses.

In the region underlain by the soft sandstones and shales of the productive Coal-measures the only systematic arrangement noticeable in the streams is that of their general southwest directions.

Attention should be called in this connection to the sudden southward deflection of the east and west forks of White River, where these streams, after passing through the Mansfield sandstone areas, strike the area of the productive Coal-measures in Martin (*F*, Plate VI) and Greene (*G*, Plate VI) counties. The deflected portions of these streams are in a line with the south course of Anderson River between Spencer and Perry counties (*H*, Plate VI), in the extreme southern part of the state.

The coinciding deflections of these streams are suggestive, as they occur in a line approximately parallel with the position that must have been occupied by the shore line during a portion, at least, of productive Coal Measures times, and the suggestion is made that these streams had their courses turned parallel with the old shore line at that time, and that the streams have occupied approximately that position ever since. In this connection the south deflection of the Wabash near Covington and its due south course from Covington to Terre Haute, parallel to the above-mentioned portions of the two forks of White River and in a line with the southward deflection of West White River northeast of Vincennes (*I*, Plate VI), is of interest and suggests the same causes.

The region underlain by the Lower Carboniferous limestones is pitted with sinkholes and is often almost devoid of surface drainage systems, owing to the cavernous nature of those limestones and the well developed underground drainage in them.

East White River flows from the central across the western area and forms one of the principal streams of the western area.

North of the north line of Monroe and Brown counties the tributaries of West White River flow through glacial débris and are left out of the discussion, as are also those streams that flow across the productive Coal Measures west of West White River.

SUMMARY.

In summing up the discussion of the drainage systems of southern Indiana attention is called to the following points :

1. The drainage in the region but thinly covered with drift, as well as in the driftless region, is controlled by the geologic structure.

The drainage (except in the eastern area) is toward the southwest, with the dip of the strata, and is such as would logically develop from a gradual elevation of a land surface, beginning at the east part of the state, and a corresponding recession of the water toward the southwest. The evidence points to the conclusion that the present drainage has developed from such an ancient initial drainage, and the writer believes this to have been the case.

2. The writer is unacquainted with any evidence in southern Indiana that the drainage has ever been toward the north and east.[1]

From above Madison to the southwestern corner of the state the Ohio River cuts more or less directly across successive groups of hard and soft strata. This is the position that would have been occupied by the stream had its course been developed across the groups of strata in question as those strata were gradually raised above the water at the west side of the land mass formed by the Cincinnati Arch, and a corresponding retreat of the water to the west. It is believed that the present course of the Ohio from and below the neighborhood of Madison has been developed from such ancient initial drainage — with many periods of comparative rest, and of activity, of course, corresponding with depressions and elevations of the land surface of the region traversed.

---

[1] See GERARD FOWKE, "Preglacial Drainage Conditions in the Vicinity of Cincinnati," *The Ohio State Academy of Sciences Special Papers*, No. 3, p. 68 *et seq.* Evidence is produced to show that the Ohio flowed northeastward in preglacial time, from near Madison.

If the preglacial drainage of southern Ohio and southeastern Indiana (the eastern area, of the present discussion) was toward the north and east, as some writers believe, then the watershed between such northeastward drainage and the southwestward drainage of Indiana was the highland formed by the Niagara and Devonian limestones, *i. e.*, the present watershed between the eastern and central drainage areas of southern Indiana.

How far north this watershed may have extended cannot be conjectured, but it probably extended as far north as Clinton county, and east of that county.

3. It is believed that that portion of the state in which the preglacial topography and structure were similar to the present topography and structure of the driftless area had also preglacial drainage systems parallel in a general way with the present drainage systems of the driftless region. This includes most of that portion of the state which lies west of the southwestward dipping Niagara and Devonian limestones.[1]

(By "driftless region" is here meant that region in which it is obvious that the present drainage systems are not controlled primarily by the drift.)

J. F. NEWSOM.

STANFORD UNIVERSITY,
California.

---

[1] The drainage through the north end of the central area , or trough — *i. e.*, in the region of Clinton county and northward from there — may have been toward the northwest, so far as the structure is concerned.

GLACIATION IN THE ATLIN DISTRICT, BRITISH COLUMBIA.

In the Atlin district of Northern British Columbia the topography east of the coast range is characterized by wide main valleys having a general elevation of a little over 2,000 feet above sea level ; between these main valleys are groups of mountains separated by other wide but more elevated and sloping valleys.

Both of these valley systems show evidence of glacial action but both also appear to have been deep drainage channels before the advent of this glacial action, and, to have received since that period no great modification in their form.

The upper system of valleys, broad, flat and inclined at a moderate grade, look too big for the comparatively small and rapid streams which drain them. These streams moreover have only cut narrow gutters to no great depth below the general floor of these valleys.

In this district there is evidence of two glacial periods, a regional glaciation, and a local glaciation, in part, over the same ground, at a later time. There is also a present active and extensive local glaciation now going on in the coast ranges to the westward. The latter may be a survivor or remnant under more favorable conditions of the two former periods.

The earliest regional or Cordilleran glacier left its evidence upon the main valley floors, and upon the upper slopes of the highest mountain groups in the district, a difference of about 5,000 feet in altitude. The movement was in a northerly direction.

The later local glaciation may have been due to the action of a remnant of the regional glacier, but appears more likely to have been the result of a later dispersion from a local névé. This glaciation followed these upper valleys and slopes, leaving the upper mountain groups above their action.

Regional glaciation.— As evidence of the regional or Cordilleran glaciation may be taken the occurrence of foreign rounded bowlders or erratics upon the upper slopes of the more or less isolated mountains of this district.

A light colored feldspathic granite and jasper are occasionally found at heights of over 4,000 feet above sea level, and 2,000 feet above the lower main valleys.

Mount Minto rises steeply from Atlin lake to a height of 4,700 feet above it, and 4,000 feet above the surrounding flats. The base of this mountain is hornblende-biotite granite, the upper portion of it is hornblende porphyrite ; resting upon this porphyrite, near the peak, are rounded bowlders of a light colored granite and jasper pebbles.

East of Teslin Lake, on the mountains above Ptarmigan Flats, there is a glaciated rock surface at a height of 5,490 feet above sea level, and about 3,000 feet above the floor of Teslin Valley, which is also glaciated.

Near this place there are bowlders of a peculiar granite, having large crystals of hornblende. Such granite was only seen in place in the high, massive range six miles to the south and westward, across the deep intervening valley of Hurricane River, over 2,000 feet below these opposite ranges. If this valley existed at the time of bowlder transportation, it appears to have had little directive power.

Local glaciation.— The local glaciation appears to have originated from the water shed between Atlin and Teslin lakes. This is a district of wide, upland valleys and arctic moors, for the most part above timber line.

Such local glaciers did not cap the mountain groups apparently, but filled in the depressions between them, acting as carriers and pulverizers of the local rocks only.

This glacial occupation seems to have been confined to these elevated flats and slopes, and the valleys leading down from them, in much the same way as with the present coast glaciers. At the present time these elevated valleys, which are sometimes over a mile wide, are largely covered with more or less assorted gravels, bowlder clay and morainic material, all of which is quite local in origin, the country rock being itself local and characteristic.

Elevated valleys.— The lower portions of Pine and Spruce creeks are terraced, the middle portions have false bedded material and bowlder clay. The upper valley of Spruce Creek is covered with little hills of morainic material. Occasional bowlders of rock, foreign to the present drainage basin, are attributed to the erratics of the regional glaciation. (See accompanying photograph.)

The streams now flowing through these valleys appear small in comparison with the wide troughs through which they run. Although rapid, and at times torrential, these streams have only cut narrow gutters into the drift and the rock floor beneath it. In doing this they have cut down to an older pre-glacial drainage and stream bed. The direction, grade and level of these pre-glacial stream gravels is very much the same as that of the present creeks, Pine and Spruce. These earlier gravels were traced, and apparently undisturbed, for two miles along Spruce Creek, lying directly beneath the mantle of gray blue glacial drift. They contain coarse gold. If it is assumed that coarse gold is concentrated by mechanical action in fairly rapid streams these gold bearing gravels should have been on the stream bed of a pre-glacial V-shaped valley, otherwise they would not have represented concentrations from the adjacent mountains, unless, like the present streams, they derived their gold and gravels from earlier stream or glacial deposits.

It appears probable that these pre-glacial gravels existed in the ordinary V-shaped troughs of mountain drainage originally, and that, local ice action, cleared out and widened the existing valleys without doing much towards deepening them. Such action appears to be borne out by a consideration of the existing glacier immediately to the south of Atlin Lake.

Llewellyn Glacier.—From the southern shores of Atlin Lake, flat-bottomed, fjord-like valleys lead up to tongues or lobes of the Llewellyn Glacier. These ice fronts are, in some cases, only a few feet higher than the level of the lake, and a mile or so back from it. The intervening valley is flatly floored with quicksand or gravel, and is at times a mile wide at the ice front.

A rather small collection of morainic dumps lies in front of the ice. Swift glacial streams issue from beneath the ice front over beds of quicksand or gravel. These are heavily charged with sand and silt, but do not appear to bring out coarser material. These streams remove much of the coarse medial morainic material as it is gradually dumped over the ice front, and this may account for the small terminal moraines.

These medial moraines form wide low ridges of unassorted rock matter, stretching far back into the ice field, until they are lost to sight on the skyline or beneath fresh fallen snow.

The ice front rises very gradually backwards into the nearly level field of ice and snow, which continue south and westwards to Taku Inlet and the Pacific coast, a distance of 60 miles.

The upper surface of this ice field is about 5,000 feet above sea level, or 3,000 feet above Atlin Lake. Out of the general level of this inclined plain, mountain groups and peaks project, leaving wide, level gaps between them. Near the ice fronts the glacial surface is traversed by many small streams, which soon fall into crevasses. These probably supply most of the water which issues from the glacier front. Water action must be very slight within the interior region of the main glacier.

It appears that any loose material formed on the projecting mountain sides above the glacier will be removed. Frost and snow slides are very active agents in breaking up rock masses. The broken material finds no angle of rest. It falls between the ice and the shore and becomes a grinding agent, or else is borne out to feed the great medial moraines, hence it seems that this glacial action is very largely a widening one, continually trimming the sides of its directing walls, and acting as a carrier.

In such a way it may have widened out the water-worn troughs of the preglacial drainage, leaving at times portions of the deep stream bed unremoved.

J. C. Gwillim.

Nelson, British Columbia.

ON THE OCCURRENCE OF APLITE, PEGMATITE, AND TOURMALINE BUNCHES IN THE STONE MOUNTAIN GRANITE OF GEORGIA.

Aplite and pegmatite.—Careful field study of the larger and principal granite areas in Georgia, by the writer, indicates the general absence of true aplites therefrom. They have been observed in association with the granite masses only at one locality in the state. Since the border portions of the granite masses are usually covered with a considerable depth of residual decay and are seldom exposed, it is not possible to say whether aplites as border phenomena exist, as described by Kemp,[1] in some of the southern Rhode Island and Connecticut granites.

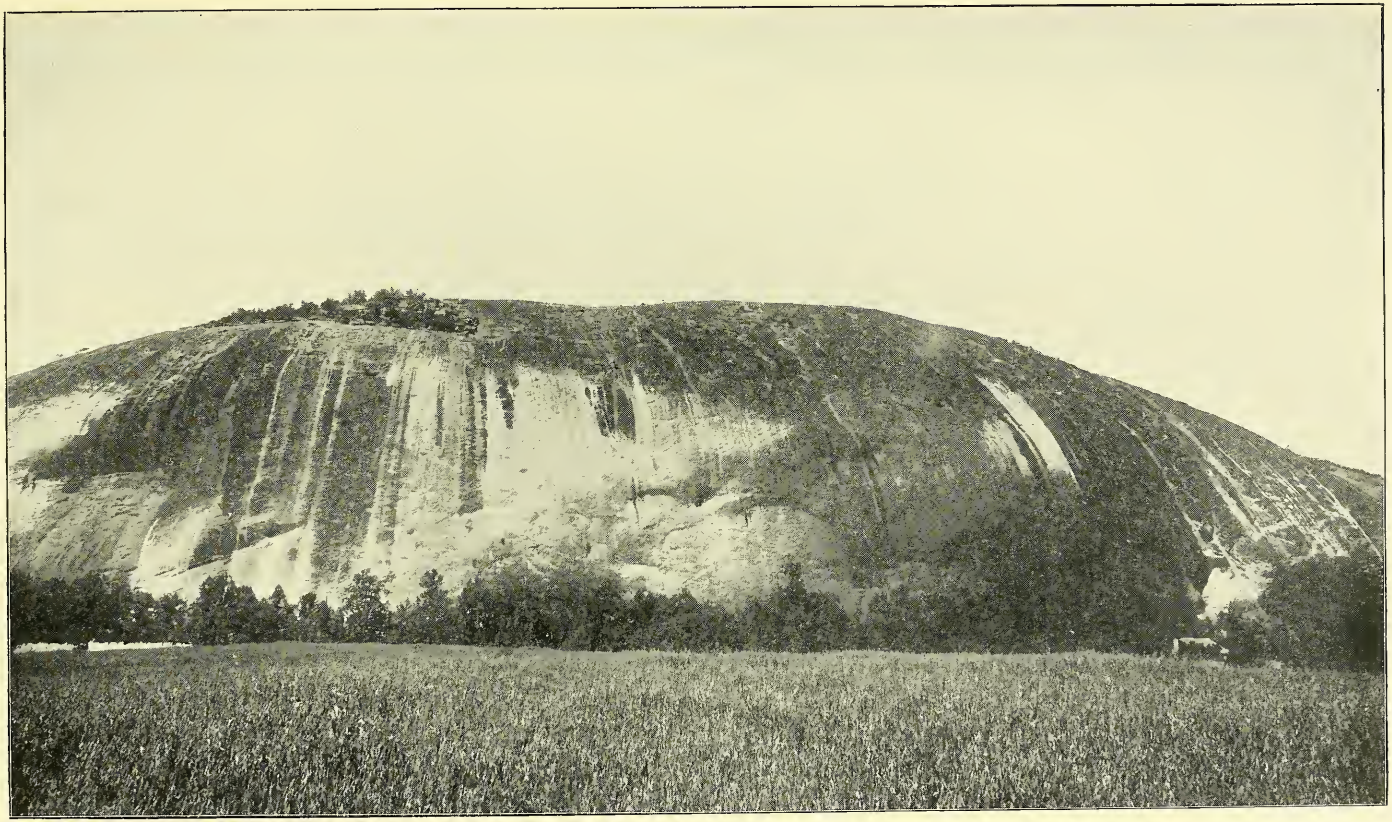
Several aplite dikes less than six inches in width are exposed in the quarries opened on the northwest side of the huge doming ridge known as Stone Mountain, sixteen miles east of Atlanta (Plate VII). Pegmatites are common associates in the Stone Mountain granite and also in the other larger granite masses examined in the state. They consist chiefly of coarse intercrystallizations of potash (orthoclase and microcline) and soda (albite) feldspars with quartz, subordinate amounts of both biotite and muscovite, and occasionally red garnet and tourmaline. So far as my observation goes, the feldspars in the pegmatite greatly exceed in amount the quartz. The granitic pegmatites are sometimes replaced, however, by those of practically pure quartz. In the Stone Mountain pegmatites the dark minerals, mica, tourmaline, and garnet, are frequently concentrated along the central axis of the dike or vein, rather than distributed through the light-colored quartz-feldspar portions. Where observed the granitic pegmatites are monotonously alike, and present no unusual features.

The principal aplite in the Stone Mountain granite is banded with pegmatite, the aplite forming the border next the granite

---

[1] *Bulletin Geol. Soc. Amer.*, 1899, Vol. X, p. 372.

Plate VII.



Stone Mountain, Georgia. An unreduced residual of granite, rising 686 feet in elevation above the surrounding Tertiary Piedmont plain. Seven miles in circumference at its base. (Photograph by W. S. Y.)

and the pegmatite the middle layer of the dike. The junctions between the granite, aplite and pegmatite are regular, entirely sharp and well defined. Apart from its being more compact and of much finer-grained texture, the aplite is easily distinguished in the hand specimen from that of the inclosing granite by its lighter color — marble white — and by its containing but little mica. Biotite is entirely absent and muscovite is only sparingly distributed through the rock as minute foils. Occasional very small crystals of red garnet are sometimes present.

In thin section the aplite shows no essential difference in mineral composition from the granite, except in the entire absence of biotite and decreased muscovite. The rock is a holocrystalline mass composed chiefly of the potash (microcline and orthoclase) and soda feldspars, and quartz. Microperthitic structure consisting of interlaminated orthoclase and microcline with a second feldspar, albite, is common. Somewhat irregular, stout laths of a well striated acid oligoclase are numerous. The small percentage of CaO, less than 1 per cent., and the increased Na_2O shown in the analysis, column I, indicates the preponderance of the soda molecule (albite), which is corroborated by the microscope. Sporadic inclusions of apatite occur.

Megascopically, the inclosing rock is a compact, medium-grained biotite-bearing muscovite-granite of light gray, nearly white, color. Biotite is only sparingly distributed through the rock, displaying considerable tendency to segregate in places. Thin sections of the granite show quartz, orthoclase, and microcline frequently intergrown with albite as microperthite, considerable oliogclase, muscovite, occasional biotite, and some prismatic inclusions of apatite.

The striking similarity between the inclosing granite and aplite is sufficiently shown in the chemical analyses of the rocks given below.

The analyses show more SiO_2 and less K_2O in the aplite than in the granite, with close agreement indicated in the other constituents. A striking feature of the analyses is the low

	I.[1]	II.	Ia.	IIa.
SiO_2	74.30	72.56	1.2383	1.2093
TiO_2	none	.....	......	......
Al_2O_3	14.73	14.81	.1444	.1452
Fe_2O_3[2]	0.78	.....	......	......
FeO	.....	0.85	......	......
MnO	trace	.....	......	......
CaO	0.90	1.19	.0161	.0212
BaO	none	.....	......	......
SrO	none	.....	......	......
MgO	strong trace	0.20	......	......
Na_2O	4.61	4.94	.0743	.0796
K_2O	4.52	5.30	.0481	.0563
H_2O (Ignition)	0.21	0.70	......	......
P_2O_5	trace	.....	......	......
Total	100.05	100.55		

I. Aplite, Stone Mountain, Georgia. Watson, analyst.
II. Stone Mountain granite inclosing aplite. Packard, analyst.
Ia. Molecular ratios of I.
IIa. Molecular ratios of II.

percentage of lime with practically no magnesia, and increased soda, which equals in amount the potash, indicating the predominance of the albite molecule over that of the anorthite, and in case of the aplite the nearly entire absence of magnesia harmonizes with the absence of a ferro-magnesian accessory. Calculating all the lime as anorthite, all the soda as albite, and all the potash as orthoclase or microcline, the mineral composition of the aplite and granite becomes:

	Aplite.	Granite.
Potash-feldspar	26.69	31.14
Soda-feldspar	38.77	41.95
Lime-feldspar	4.45	2.50
Quartz	28.30	21.09
Excess of Al_2O_3	.61	.....
Excess of Fe_2O_3	.78	.....
Excess of FeO	.....	.85
Excess of MgO	.....	.20
Excess of CaO	.....	.67
Excess of H_2O	.21	.70
	99.81	99.10

---

[1] Analysis *made* in the chemical laboratory of Denison University.

[2] All iron determined as ferric oxide.

In the aplite there is an access of Al_2O_3 after deducting the amount required of the feldspathic contituent of .0059 molecules corresponding by weight to 0.6 per cent., which is probably combined as mica. From the above calculations the ratio of soda feldspar to lime feldspar is 9 : 1 in the case of aplite and 17 : 1 in the case of the granite, corresponding to lime-bearing albite of Ab_9An_1 and $Ab_{17}An_1$ respectively, when the albite and anorthite molecules are combined to form soda-lime plagioclase. The potash feldspar in both the aplite and granite is part orthoclase and part microcline. According to the calculations the relative abundance of the constituents in the aplite may be expressed as follows: Oligoclase > quartz > orthoclase and microcline > muscovite. In the case of the granite the potash feldspars are slightly in excess of the quartz, otherwise the order of relative abundance of the constituents is the same as for the aplite.

	I.	II.	III.	IV.	V.	VI.
SiO_2	75. 7	76.03	76.00	74.21	77.14	74.30
TiO_2	0.09	0.07	0.04	0.30	0.29	none
Al_2O_3	13.07	13.39	14.88	14.47	12.24	14.73
Fe_2O_3	0.61	0.48	0.65	0.35	0.29	0.78
FeO	0.39	0.31	0.10	0.50	1.04	....
MnO	trace	trace	trace	none	trace	none
CaO	1.49	1.28	0.19	1.71	0.35	0.90
SrO	0.03	trace	none	trace	....	none
BaO	0.14	0.04	trace	none	....	none
MgO	0.14	0.05	0.06	0.28	0.06	strong trace
K_2O	5.62	5.18	2.77	0.10	4.47	4.52
Na_2O	2.51	2.98	3.52	7.62	4.64	4.61
Li_2O	trace	none	0.20	trace	....	....
H_2O at 100°	0.14	0.15	1.42	0.15	0.14	0.21
H_2O above 100°	0.24	0.34		0.23		
P_2O_5	trace	0.03	0.11	0.07	....	trace
	100.44	100.33	99.94	99.99	100.66	100.05

I and II. Potash aplites. Described by H. W. Turner, JOUR. GEOL., 1899, Vol. VII, p. 160; also *Seventeenth Ann. Rept. U. S. Geol. Surv*, p. 521. W. F. Hillebrand analyst.

III and IV. Soda aplites. Described by H. W. Turner, JOUR. GEOL., 1899, Vol. VII, p. 152. III, W. F. Hillebrand, analyst. IV, H. N. Stokes, analyst.

V. Aplite. Described by H. S. Washington, JOUR. GEOL., 1899, Vol, VII, p 107. H. S. Washington, analyst.

VI. Aplite. Stone Mountain, Georgia. Thomas L. Watson, analyst.

The percentage ratio of the alkalies in aplites, potash and soda, forms a ready basis for grouping them into potash-aplites, soda-aplites, and aplites of equal potash and soda percentages. The Stone Mountain aplite, as shown in the analysis, forms a striking illustration of the third or last type in which the percentage ratio of the potash to soda is equal. To make more emphatic this grouping, and for convenience of comparison, I have tabulated above analyses of some of the recently described well-known aplites from the eastern and western United States:

Tourmaline areas.—A noteworthy feature of the Stone Mountain granite is the somewhat abundant occurrence of small areas of aggregated black tourmaline crystals throughout the entire mass of granite, so far as revealed by quarry operations. Hardly a block of the stone is quarried that does not show a few of these areas. The occurrence of the mineral is not that of a characterizing accessory, as has been noted in some granites, as at Predazzo in the Tyrol, in which the tourmaline takes the place of mica or amphibole, but is more after the order of segregations in the biotite-bearing muscovite granite. Neither are the tourmaline aggregates sufficiently numerous and crowded together in the granite, nor of large enough size, to add to the color of the rock. While clearly visible in every case they do not in any measure detract from the good qualities of the stone for building purposes, for the reasons already stated, and also because of the practical unalterable nature of tourmaline under normal atmospheric conditions.

The tourmaline rarely occurs as isolated or single crystals in the granite proper, but nearly always as radiating and roughly parallel groups, which occupy the centers of perfectly white areas of quartz and feldspar, from which the two micas, muscovite and biotite, have been excluded. The quartz-feldspar areas vary in size from a fraction to several inches in diameter, according to the number of grouped single tourmaline individuals occupying it; and in shape they vary from oblong, irregularly rectangular to complete spherical or circular outlines, with all gradations between. The tourmaline individuals consist of slender pris-

A view of one of the quarries opened on the northwest side of Stone Mountain, Georgia. Aplite-pegmatites exposed in places over the floor of quarry, now clear of the quarry waste shown in the foreground of the photograph. (Photograph by W. S. Y.)

matic forms, varying from a fraction to several millimeters in cross-section without terminal faces; jet-black in color; and in every case examined they are considerably fractured. The number of individuals in a group varies greatly, usually from a half dozen or thereabouts to several times that number. The width of the border zone of the feldspar-quartz areas, or that portion of the white mass extending from the outer part of the tourmaline aggregate to the junction formed with the gray granite, is also variable, but is wider in proportion to the size of aggregate occupying the center, and is apparently proportional therefore to the intensity of the action controlling the tourmaline formation.

The quartz-feldspar areas are as strongly contrasted in color with the light gray granite as are the black tourmalines. The junction between the areas and the granite are entirely sharp and distinct, and in no case observed is there any tendency shown toward a gradation or merging of color of the white mass into the granite.

A number of thin sections of the feldspar-quartz areas and their included tourmaline aggregates were examined microscopically. The sections indicated a mosaic of interlocking quartz and feldspar, similar in all respects to, and consisting of the same feldspar species as the granite. No difference in texture and size of the component grains from that of the granite is observed. With few exceptions the feldspars were perfectly fresh. Cataclastic structure is quite strongly accentuated in the feldspar and quartz grains, the cracks are rather wide, and are now filled with a colorless, high double refracting mineral. Primary muscovite is not present in those slides examined, but plentiful small foils of the mineral distributed over the feldspar surfaces are seen in places, and from its association must be regarded as distinctly secondary. In transmitted light the tourmaline is deep brown in color and strongly dichroic. It is closely associated with both the quartz and feldspar, filling at times the interspaces. It is more intimately associated with the feldspar, however, and its distribution through some of the large microcline and oligoclase individuals as partially connecting irregular and ragged granules closely resembles the poikilitic structure. In some cases the tourmaline is entirely confined to the feldspar individual, while in others it cuts well into the quartz and feldspar grains in such way as to clearly indicate its subsequent formation. In cross-section the mineral appears in some cases to be irregularly rounded and granular rather than bounded by sharp crystalline boundaries, but most of it is so very irregular that it is best described as having an exceedingly ragged outline. In a few instances the prism faces are indicated under the microscope. The mode of occurrence of the tourmaline and its association with the feldspar suggests beyond reasonable doubt its derivation in part from the feldspar, by fumarolic action.

The tourmaline cannot be regarded as a product of contact phenomena, since it is generally distributed throughout the entire mass of granite, so far as quarrying operations extend—not more abundant at one point than at another. I have elsewhere shown[1] that the present granite ridge, Stone Mountain, is the unreduced remnant or "core" of a once more extensive mass. The evidence favoring this is that, on the north, west, and south sides of the ridge, a belt of the same granite, reduced to the same general level of the surrounding Tertiary Piedmont plain, skirts the ridge for a distance varying from a quarter to more than a mile in width. In this reduced granite zone numerous quarries have been worked yielding the same beautiful light gray nearly white Stone Mountain granite. The rock quarried in this zone is strikingly free from the tourmaline aggregates, less than a half dozen in all having been observed. The areas, then, are confined to the ridge portion of the granite mass, and do not characterize the border portions of the granite nor of the adjoining schist and gneiss where exposed.

Black tourmaline as isolated single crystals and aggregates is rather a common associate in the Stone Mountain pegmatites,

---

[1] *A Report on the Granites and Gneisses of Georgia, Geological Survey of Georgia.* In press.

and in several instances veinlets of twelve and more inches long of tourmaline-felt (fine acicular tourmaline), as much as an eighth of an inch in width, have been noted in the granite in the northwest quarries of the ridge. While no distinct evidence bearing on the contemporaneous origin of the tourmaline aggregates in the granite with those of the pegmatite and the tourmaline veinlets, it seems reasonable to assume such contemporaneity.

The very nature of the areas oppose the hypothesis of direct secretion out of the eruptive granite magma. On the other hand, the characteristic mode of occurrence and intimate relationship to certain other mineral species present, as shown both macroscopically and microscopically, make it reasonably certain that the tourmaline areas have resulted from fumaroles highly charged with boric acid acting on the feldspars and mica.

THOMAS L. WATSON.

GEOLOGICAL LABORATORY, DENISON UNIVERSITY,
Granville, Ohio.

ICE WORK IN SOUTHEASTERN MICHIGAN.

OUTLINE.

- Introduction.
- General topography.
    - Surface topography.
    - Rock topography.
- Drift of the region.
    - Till.
    - Moraines.
- Ice action in Wayne county.
    - Late Wisconsin.
    - Early Wisconsin.
    - Iowan
    - Illinoian.
    - Rock shattering.
- Scorings in Monroe county.
    - Eastern portion.
    - Central portion.
    - Western portion.
- General considerations.

INTRODUCTION.

Owing to its geographic position, lying directly athwart the southwestward movement of the great Laurentide ice-sheet, with the maximum extent of international boundary, far enough distant from the great center of ice accumulation as well as from the southern limit of its movement, the state of Michigan must theoretically have borne the brunt of the Canadian ice invasion. Surrounded as is no other state by rock-basins, only partially occupied by our present Great Lakes, the evidence is not wanting that the Laurentide ice operated with exceptional vigor over the two peninsulas and the adjoining regions. So far as at present known, the most extensive and interesting exposures of ice activity within the state are to be found in the southeastern counties of Wayne and Monroe, bordering Lake Erie and the Detroit River. The following report upon this region is based mainly upon work carried on for the Michigan Geological Survey and is here published with the consent of State Geologist Dr. Alfred C. Lane. The series of Huron-Erie moraines, which lie to the west of the Upper Maumee beach in Washtenaw and Lenawee counties, as well as the beach itself, were traced upon the accompanying map from field maps of Mr. Frank Leverett, to whom the writer is indebted for many suggestions concerning the interpretation of the glacial features of this region.

GENERAL TOPOGRAPHY.

Surface topography.—With the exception of the extreme northwestern corner of Wayne, the two counties especially considered here were under the waters of the series of glacial lakes Maumee, Whittlesey, and Warren, which were ponded back by the late Wisconsin ice as it slowly retreated to the north and east. The result of this was that the surface elevations left by the ice-sheet were, in the main, leveled by the waves and currents while the depressions were silted up and there was produced a remarkably flat topography, the slope of which is discoverable only by the surveyor's level or the small streams which meander over this plain. The general surface rises very gently, six to seven

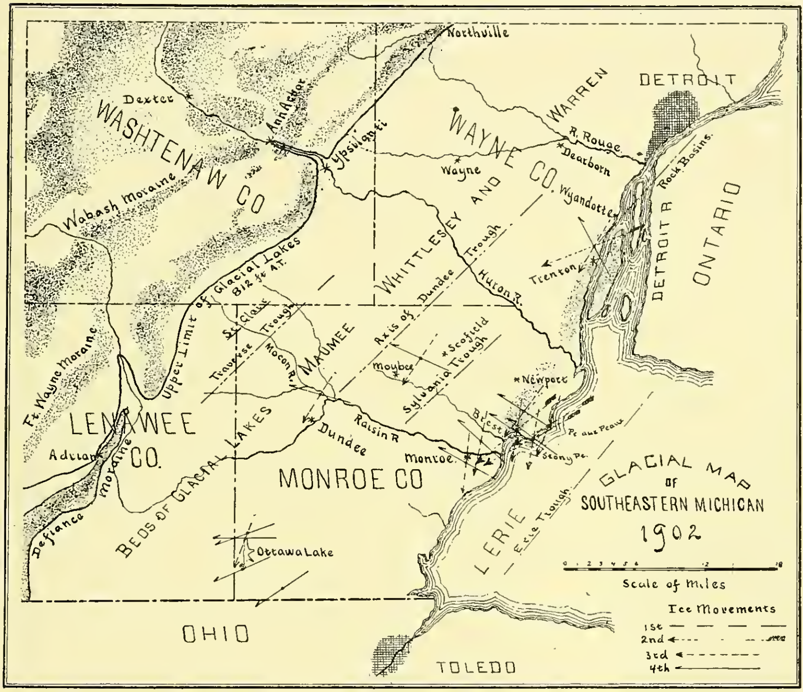


FIG. 1.—Glacial map of southeastern Michigan, showing the general directions of the four movements of the Laurentide ice. The upper limit of the glacial lake waters and the moraines to the west were located from the field maps of Mr. Frank Leverett.

feet to the mile, from the level of Lake Erie (573 feet A. T.) outwards towards the Belmore beach. The evenness of this slope is shown in the left half of Fig. 2, although the slope itself is much exaggerated by the vertical scale adopted. This Belmore beach, which was made by the waves of glacial Lake Whittlesey, has a northeast and southwest course in this region, parallel with the Detroit River and present beach of Lake Erie and some eighteen to twenty-five miles inland. For over three-quarters of a century this "ridge" has been recognized as marking a higher stage in the lake waters, but it seems to have been the only one which was so recognized. The position of the Upper Maumee beach, recently traced by Leverett, is shown in Fig. 1, marking the highest limit of glacial waters. The elevation of this beach, just west of Ypsilanti, was determined during the past summer by the United States Topographical Survey as 812 feet, A. T. Between these two beaches there is a strip varying in breadth from two to six miles, having an average slope upward and outward of twelve to thirty feet to the mile. Throughout this narrow strip the topography is more uneven, the morainic hills not having been completely obliterated by the waters of glacial Lake Maumee, thus testifying to its limited breadth in this region, or to its short duration. To the west of the Upper Maumee the land becomes markedly morainic, due to the crowding together of the various members of the Huron-Erie series, which are entirely separate in Ohio and Indiana. Some of the knobs in the northwestern part of Washtenaw county attain a height of 1,000 to 1,100 feet, A. T.

Between the Belmore beach (739 feet, A. T.) and the present Erie beach there are found three approximately parallel belts of sand which mark different stages in the history of glacial Lake Warren. In certain sections this sand has been scattered by the winds and tossed into dunes, which give some relief to this otherwise flat topography. Three small river systems, the Rouge, Huron, and Raisin, have been developed since the retreat of the ice, and drain this region to the southeast. A few small creeks reach the lake and the Detroit River independently.

Rock topography.— Throughout the main region under discussion the bed rock consists, in descending order, of Genesee shale (St. Clair), Hamilton shale and limestone (Traverse), Corniferous limestone (Dundee), and Waterlime dolomite with an intercalated bed of very friable sandstone (Sylvania). The strata have a general northeast and southwest strike and dip to the northwest at an angle of two to five degrees. An embossment of rock, ten to twenty miles broad, underlies the greater part of Monroe county, and extends northeastward into Wayne, gradually dropping toward Detroit. The highest elevation attained by this bed rock is about 680 feet, at the head of Ottawa Lake, southwestern Monroe county. Upon the broad crest of this embossment are carried three minor ridges, one in the eastern part, another in the central, and the third toward the western part of the two counties. These ridges seem to correspond with the strike of the layers, and presumably consist of somewhat harder rock. They furnish the various natural and artificial exposures now available for study, the most northern of which is at Trenton (see Fig. 2).

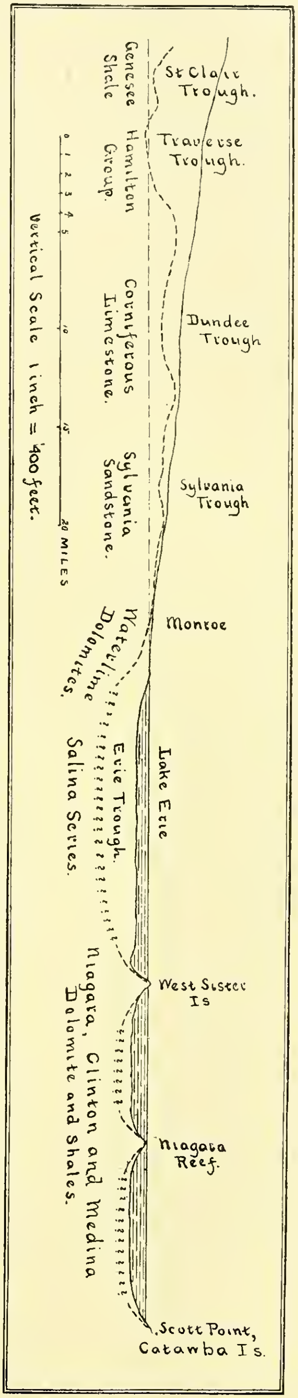


FIG. 2.—Vertical section from the northwestern corner of Monroe county, through Monroe to Scott Point, Catawba Island. The full line represents the surface of the land and the lake bottom; the broken line represents the rock surface, so far as it is known. Based upon the Lake Survey charts, railroad elevations, and individual well records.

Between these ridges lie two broad, shallow troughs, which have been named from the geological beds out of which they have been carved, the Dundee and the Sylvania.[1] The trend of these trough-like valleys is indicated upon the map, and also their extent, so far as recognized. The Dundee is the more pronounced of the two, having a breadth of two to four miles, and sloping downward towards Detroit at the average rate of four to five feet to the mile. Towards Dundee it is broader, and less well defined, as shown in Fig. 2. It seems to have been carved from the richer and softer strata of the Corniferous limestone, but in Wayne county it continues its direct course, while these strata are deflected eastward. Were it not for the deposit of drift, this trough would be filled with an arm of the lakes as far south as the southern boundary of Wayne county, standing one hundred feet deep at Detroit. The Sylvania trough begins in the west-central part of Monroe county, cutting eastward across the Waterlime dolomite until it strikes the outcrop of Sylvania sandstone, when it turns northeastward and becomes more accentuated in that portion which lies parallel with the Dundee The valley then follows the strike of the Sylvania sandstone eastward and flattens out. In the northwestern part of Monroe county there occurs a double trough cut from the Genesee shale and the Hamilton shales and limestones, the latter being the best defined and having the same general direction and slope as the Dundee trough. The slope northeastward averages some nine feet to the mile so far as it has been followed in the well records. Were the drift removed, this trough would also be filled with water to a distance of three to four miles into Monroe county.

In the southern half of the eastern part of this county the rock surface drops rather rapidly towards Lake Erie, although the rock strata dip in the opposite direction, thus showing that much material has been removed by some agencies. The drop averages twenty-five to thirty feet to the mile, bringing the rock surface about one hundred feet below the Erie level by

---

[1] *Geol. Surv., Mich.*, Vol. VII, Pt. I, 1900, p. 122.

the time the lake is reached, forming the western slope of a very much larger trough underlying the western end of Lake Erie. An inspection of the Lake Survey chart shows that the eastern slope of this broad trough is terminated by a rock-ridge upon which are located West Sister Islands and Middle Sister Islands, running S. 35° W. Northeastward, towards the Ontario shore, occur Colchester reef and other rock. Toward the southwest this broad trough is continued beneath Toledo for a long distance as the Maumee trough, which would be filled with water were the drift removed, standing one hundred feet deep at Toledo, and extending seven miles further west than at present along the Ohio-Michigan line. Eight miles east of the ridge above-mentioned there occurs a second one running across the lake S. 32° W., and indicated by Niagara reef, East Sister Islands, and several other shoals and reefs. Between these ridges a second trough reaches across the lake, having its axis parallel to all the others. Beyond the second ridge, and between it and the string of islands which stretches continuously from Catawba Island northeasterly to Pointe Pelée, there is a narrower and less well-defined trough, but parallel to the two other Erie troughs. The position of this series of troughs, their direction and approximate parallellism, their shape, and, so far as known, their direction of slope toward the northeast, all suggest that the primary agency was ice, acting with exceptional vigor straight out from the center of Laurentide accumulation. It so happened that the strike of the rock-strata in this region coincided with the main axis of ice movement, and the troughs in all cases were formed in the softer beds. It is not improbable that preglacial streams occupied some of these valleys, as in the case of the Sylvania, and that where the valley had the same trend as that of the ice movement it received the maximum ice erosion. The ice mass appears to have been too great at this stage to permit of its following the valleys when they turned aside from its general course. We seem to have here, but on a much larger scale, a similar phenomenon to that observed by Gilbert in western New York.[1]

---

[1] *Bull. Geol. Soc. Am.*, Vol. X, p. 121, 1899.

DRIFT OF THE REGION.

Till.— A mantle of typical Wisconsin till covers the rock, except over the limited areas where the rocks are naturally exposed, or where it has been artificially removed about the quarries. This would average from forty to fifty feet in thickness in Monroe county, and perhaps seventy-five to eighty feet in Wayne. In the Traverse trough the drift is 140 to 150 feet thick, somewhat less beneath Detroit and Windsor. Westward toward the Defiance moraine the till thickens in Washtenaw county to two hundred feet west of Ypsilanti. We have no evidence of more than one sheet of this till. Occasional well records in southern Wayne and northern Monroe counties speak of seams of a black, combustible substance, generally referred to as "coal," but no continuous layer of black soil or peat exists. "Hard-pan" is not infrequently mentioned, and it is not improbable that isolated patches of early Wisconsin or pre-Wisconsin till may have escaped the late Wisconsin ice. At present writing, the twelve-foot shaft of the Michigan Rock Salt Co. has just penetrated seventy-one feet of till at Ecorse, just south of Detroit. This section gives four feet of muck; two feet of mucky clay; four feet of a mottled lake clay, yellow, brown, and blue in color, with shells, but no pebbles; and some seventy feet of soft, bluish-drab till, carrying pebbles and bowlders. The only break in this sheet of till was found at a depth of thirty feet, where a six to eight-inch layer of gravel was encountered. In certain regions the till may be discolored to a depth of several feet, the maximum being fourteen, as reported at Dundee. Generally, blue clay can be found quite near the surface. Bowlders are distributed sparingly over the two counties, lying upon the surface or embedded in the deposits from the glacial lakes. Huge masses of limestone, of the nature of "transported ledges," have been found in the till and mistaken for outcrops of bed rock.[1]

---

[1] WINCHELL, "Some Indications of a Northward Transportation of Drift Materials in the Lower Peninsula of Michigan," *Am. Jour. Sci.*, 2d ser., Vol. XL, pp. 331–38. Also *Geol. Surv. Mich.*, Vol. VII, Pt. I, p. 22.

Moraines.—The moraines of the region mapped belong to the Huron-Erie series, and have a northeast and southwest direction. The most easterly and youngest is a water-laid moraine consisting of continuous and very symmetrical till ridges from five to twenty feet in height. They make their appearance between Wyandotte and Trenton, swinging in from the islands of the river, and they may be followed southward to within a mile of the Huron River. South of the river the moraine is indicated only by an unusual bunching of cobblestones to the east and southeast of Newport. In the vicinity of Brest there is a suggestion of morainic topography, the ridges running eastward into the lake and apparently marking the southern limit of this moraine. This is probably Taylor's Detroit moraine,[1] although it has not yet been followed into Ontario. The Defiance moraine lies just west of the Upper Maumee beach, the position of which it determined in this region. It is a relatively narrow moraine of comparatively weak expression, containing low knobs of sand and gravel, some of which were submerged by glacial Lake Maumee. Westward, the members of the Huron-Erie series become more and more massive, and so crowded that they cannot with certainty be distinguished from one another. Between them lie outwash gravel plains and ancient drainage channels, through which the water from the ice escaped to the west.

ICE ACTION IN WAYNE COUNTY.

Late Wisconsin.—Although there are rock exposures upon the islands of the Detroit River and near Gibraltar, still the surface of the waterlime dolomite is so much weathered that the striæ are entirely obliterated. Undoubtedly they are preserved under the heavier covering of till, but these portions of the rock-surface have not yet been exposed. The most favorable locality in the county for the study of glaciated rock is at the extensive Sibley quarry, operated by Church & Co., one mile north of Trenton, and about fourteen miles south of Detroit.[2]

---

[1] JOUR. GEOL., Vol. V, No. 5, 1897, p. 423.

[2] The station "Sibley's" may be reached from either Detroit or Toledo very conveniently by either steam or electric cars.

The rock here consists of heavily bedded and remarkably pure Corniferous limestone which is being quarried for building purposes, road metal, and the manufacture of beet sugar and soda ash. Some thirty-five acres have been opened about which there is always to be seen a variable margin of glaciated surface from which the till has been stripped. A huge embossment of rock here represents the northern terminus of one of the rock ridges described previously. The rock surface dips in all directions from the crest, but less rapidly towards the southwest, so that conditions were most favorable here for receiving and recording the effects of any ice-sheet moving across this region from the west, north, or east.

The marginal strip of rock surface, nearly a mile in length, shows pronounced glaciation by the late Wisconsin ice-sheet. The limestone has been planed down, striated, and gouged, and to a slight extent polished, but there are no furrows. The striæ and gouges have a rather unique northwestward direction, forty-eight observations about the quarry giving an average of N. 28.8° W. (true reading), with a range of 43° (N. 43.5° W. to N. 0.5° W.). The general appearance of the rock surface, with its intersecting gouges, is shown in Fig. 3.

The direction of ice movement is fully attested by a variety of phenomena, which were all clearly described by Chamberlin in 1888.[1] Striæ are frequently found of the nature of the one shown in Fig. 3, beginning as a fine scratch, passing gradually into a gouge and ending abruptly toward the northwest, as the stone was suddenly crushed. Projecting masses of the bed rock were bruised and scratched upon the southeast side, while the northwest side is rough and unglaciated. "Chatter-marks" are numerous with their convexities invariably turned toward the southeast and "plucking" is frequently to be seen upon the northwestern side of the elevated ledges. Previously formed furrows which have a northeast-southwest direction have their northwestern sides bruised and rounded, while the southeastern sides of these furrows meet the general rock surface with a well

---

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, p. 244.

defined angle and generally retain the earlier set of striæ. The most interesting and conclusive of all these evidences of the direction of ice movement is that of the so-called "knobs and trails."[1] These are now to be seen on the northern and northeastern sides of the quarry, and five years ago also upon the southern side. Certain layers of the limestone contain silicified fossils and irregular nodules of chert. On account of their superior hardness these were worn away less rapidly by the ice than the limestone in which they are embedded and consequently they project above the surface. On the northwest side of many of these knobs there are found "trails" of limestone which diminish in height gradually to the general surface of the lime-

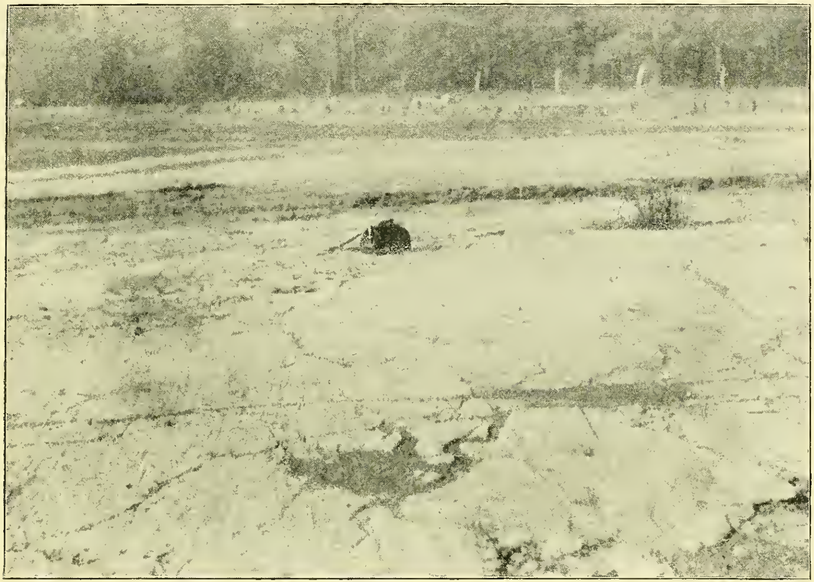


FIG. 3.—View of the late Wisconsin glaciation, Corniferous limestone, Sibley quarry, showing parallel and intersecting striæ and gouges. Looking northwest in the direction of ice movement. At the right of the small satchel is a gouge fourteen feet long, N. 20° W., which begins as a pin-scratch but gradually broadens northwestward, expanding distally to four inches and terminating abruptly.

---

[1] GILBERT, *Geol. Surv. of Ohio*, 1873, Vol. I, p. 539.

stone but maintain the breadth of the protective knob. This phenomenon is shown quite clearly in Fig. 4. As a rule narrow and relatively deep furrows were plowed out in front of and at the sides of the knobs, the lateral furrows being prolonged a considerable distance backward before they disappear. Of the various properties imputed to ice for the purpose of explaining the movement of glaciers, *plasticity under pressure* can alone satisfactorily explain this phenomenon of "knobs and trails," with their frontal and lateral grooves.

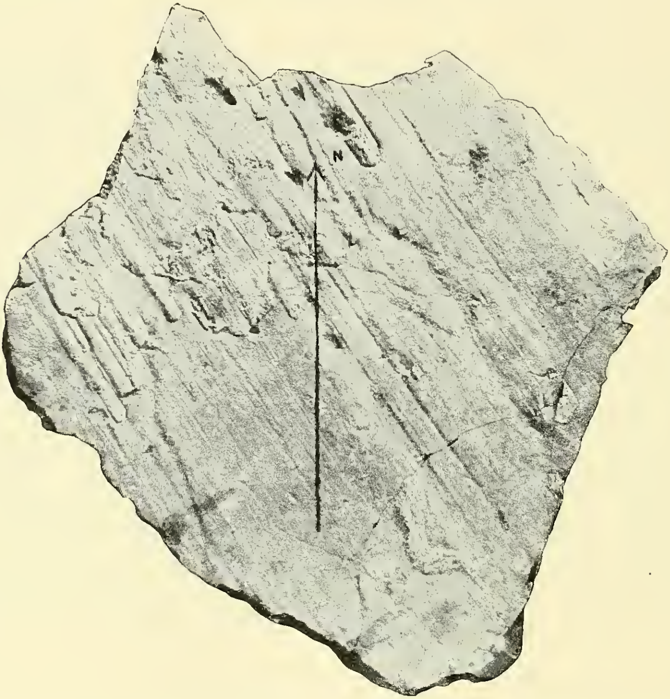


Fig. 4.—"Knob and trail" phenomena produced by the late Wisconsin ice-sheet, testifying positively to the direction of northwest movement. Northern part of Sibley quarry. The main central gouge shows "chatter-marks" indistinctly in its lower half, while in the upper part of the view there are evidences of "plucking." A shallow, tortuous groove crosses the left hand portion of the slab, cut subsequently to the glaciation by a small stream of water flowing between the rock and the till covering.

Associated with this late Wisconsin glaciation, but slightly later and cutting across it some 18° further to the west, as though made by a slight advance of the ice, is an erosion feature not known to have been previously noted. This is to be seen at the southwestern corner of the quarry, where it will be destroyed in a few more months, as the quarry is being extended in that direction. This consists of patches of miniature rock basins and narrow grooves, crowded together, in approximately parallel positions and covering some three to four square yards, so far as at present exposed. The limestone here is shattered, but essentially homogeneous, and has the appearance of a pavement formed of irregular blocks with edges rounded. The patches of basins are more conspicuous upon those blocks which are slightly higher than their neighbors and are better defined toward the stoss side of the blocks. It was found impracticable to get the basins to show satisfactorily in a field photograph, in which the lighting could not be controlled, so plaster casts were made of a number of patches for detailed study. Fig. 5 gives a reduced view of a cast, with the mold from which it was made at the left.

The basins are typically of a more or less elongated elliptical shape, sharply outlined, rather shallow and have the steepest slope toward the iceward side. The distal sides of the basins show a more gradual slope up to the general rock surface. The deepest part of the basin is either at the center, or placed nearer the iceward end, as is the case with the larger rock-basins of heavily glaciated regions. Some of the basins can be observed only with the help of a magnifier, while the largest noted has a length of 35^{mm}, a breadth of 15^{mm} and depth of 2^{mm}. Considering those of all sizes they are very numerous and closely placed, occasionally overlapping and superposed. The interiors of these basins are very generally perfectly smoothed and slightly polished, although with a magnifier delicate scratches may be detected. Occasionally some are seen which appear rough and have a bruised appearance. Some of the basins become elongated into U-shaped troughs, which may be either straight or curved. In the case of the curved ones the slope is much steeper on the concave side, with a well defined crest, while that upon the convex side of the curve is less steep and flatter. This is the reverse of what we find in the case of stream erosion. In places these troughs have the appearance of branching and anastomosing, but this is probably due to the overlapping of those which have the curved form. Indeed, we have here in miniature glacial canyons, fjords, and a great variety of rock-basins, showing all their essential characteristics. If these have been difficult to account for satisfactorily how much more

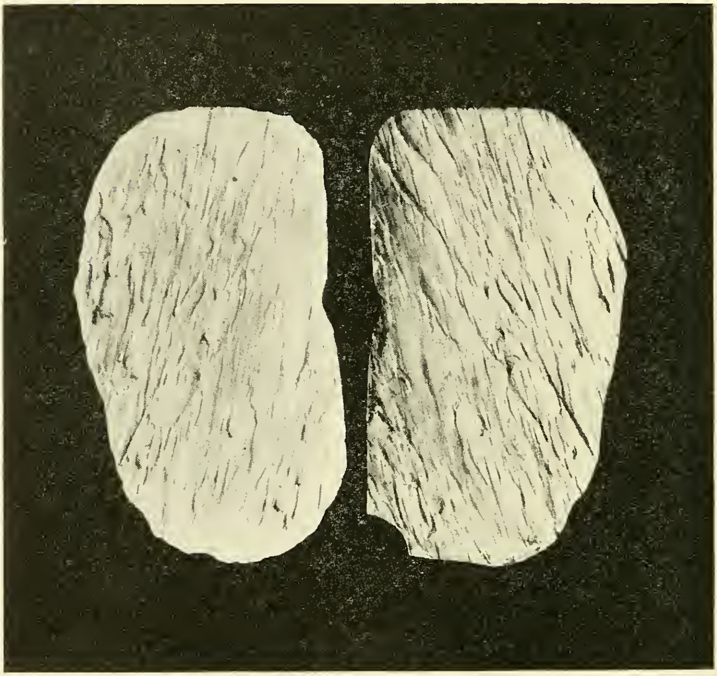


FIG. 5.—Mold and cast of a patch of miniature rock-basins, Sibley quarry. The ice movement was from above, downward. The continuous parallel grooves which pass diagonally across the cast were made by the preceding (late Wisconsin) ice movement, but were slightly emphasized by the movement which produced the basins. Careful examination of both the cast and mold will show that the miniature ice currents were deflected by these grooves for a short distance, but that the general direction was then resumed.

so will be these toy affairs, for which differential ice action can scarcely be invoked! Pebbles embedded in the ice do not come into action suddenly and do not thus gouge the rock. Hard pebbles from about which the clay may have been washed and upon which the ice during its slight readvance may have settled could hardly have been thus forced into the limestone by the plastic ice. If the ice was not plastic then what became of these pebbles, there being no evidence of their having been crushed in the basins or troughs? These are some of the difficulties the writer has encountered in trying to arrive at an explanation of the phenomena.

Early Wisconsin.— Previous to the glaciation just described there was a general and more vigorous movement south-southwest across this region, which must be referred to the early Wisconsin stage. On the north side of the quarry there are to be found "lee and stoss" phenomena, "knobs and trails" and the above described effect upon the distal side of previously formed furrows. The general effect upon the rock surface was very largely obliterated by the late Wisconsin ice and the striæ and gouges are preserved mainly in furrows made by this earlier sheet itself or in those already in existence when it invaded this region. The mean of twenty-one observations taken on all sides of the quarry gives for the general direction of movement S. 30.8° W., with a rage of 19.5° (S. 20.5° W. to S. 40° W.). This direction makes an angle of 120° with that of the late Wisconsin in this vicinity, it is manifestly older and there is evidence that it acted more vigorously, was presumably more massive and capable of reaching further south.

Iowan?— A still earlier set of striæ than that above described is to be seen in certain rock-basins and troughs partially exposed at the northeastern part of the quarry, and in some of less size at the southeastern part. At the time of a visit to the quarry five years ago a few readings were made in a trough which has been since partially removed, these readings averaging S. 64° W. During the past fall fifteen additional readings gave a mean of S. 68.6° W., with a range of 12.5° (S. 65.5° W. to S. 78° W.).

Most of these were made at the southwestern end of a partially uncovered rock-basin, or trough, across which they cut in such a way as to show that the basin was already in existence when they were formed upon its distal side. The striæ are shown in Fig. 6, emerging from the basin toward the right and diagrammatically in Fig. 7, upon the upper side, marked second movement. An inspection of this diagram shows why they were not obliterated by the third, or early Wisconsin ice, being slightly in the lee of the western side of the basin. They are here intersected sufficiently, however, in order to settle the question of their relative age. Their position is such as to have rendered their removal probable by the late Wisconsin ice, but either its

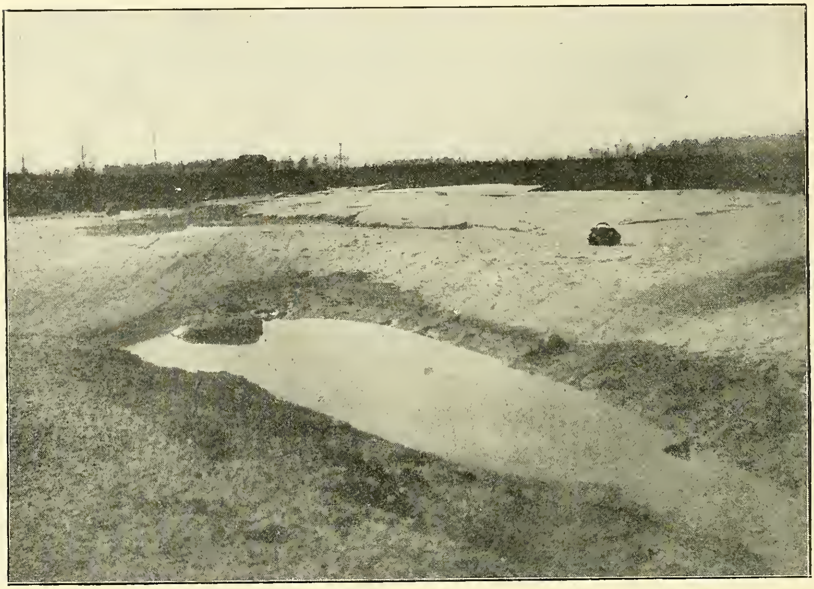


FIG. 6.—Southwestern end of a rock-basin, Sibley quarry; partly filled with till and water. Two sets of striæ are seen emerging from the basin; the set at the left being early Wisconsin, that toward the right pre-Wisconsin, probably Iowan. The basin itself is believed to have been formed by the Illinoian ice. In the background is seen the effect of the late Wisconsin upon the projecting ledge, with stoss phenomena toward the southeast.

weight was not great enough to force it into the basin sufficiently, or else the basin was filled with till. So far as observed the evidence is that the ice producing these striæ acted less vigorously than did the early Wisconsin sheet. It does not seem to have produced any furrows or troughs of sufficient size to escape obliteration at the hands of the two later sheets. There may be a question as to whether this set of striæ should not be connected with the early Wisconsin described. Its general direction of movement differs, however, by some 38° and the two sets lack 25° of coinciding at their limits. Undoubtedly a larger number of readings would tend to connect the two series in this region, but further south they diverge still more widely. In the rock-basin figured this set lacks that freshness of appearance which characterizes the Wisconsin scorings and it is believed to be pre-Wisconsin, probably Iowan. The general direction of movement harmonizes with what is known concerning the distribution of the Iowan drift, its relative age and the intensity of ice action are also consistent with this view. Further, the Iowan ice is known to have crossed this region, and such an independent sheet would have been much more liable to have left its record than would simply a minor advance of either the early Wisconsin or the Illinoian.

Illinoisan.—At the northeastern corner of the Sibley quarry there is at present a series of partly uncovered rock-basins, one of which is shown in Fig. 6. This has an apparent breadth of twenty-five to thirty feet, is eight to ten feet deep and some eighty-five to ninety feet of its length are in sight. There are four other basins, or troughs, in this same vicinity having with this one the approximate directions S. 37° W., S. 54° W., S. 39° W., S. 36° W., and S. 43° W. A small one running S. 17° W., belongs more probably with the preceding stage of glaciation. At the southeastern corner of the quarry a heavy double furrow running S. 45° W., contains pre-Wisconsin striæ and is to be included in the series. The average trend of these basins is found to be S 42° W. These basins lie upon the stoss side of the Sibley embossment, where they were plowed out by the ice as it was forced up and over the slope. The rock here is of uniform hardness over the area affected so that the basins were the result of differential ice action. A glance at Fig. 1 shows that the general direction of these basins corresponds perfectly with that of the troughs previously described, and the conclusion is irresistible that they were all made by the same ice-sheet, which moved very steadily straight out from the center of Laurentide accumulation to the southernmost limit of glaciation in southern Illinois. It is apparent that this sheet acted with a vigor far in excess of that of any previous sheet, that it showed an utter disregard of topography; indeed, it seems probable that it had more to do with the *making* of our present rock topography, than the other three sheets combined. These facts suggest that it was the most massive of the Laurentide sheets and presumably able to reach a more southern latitude than any of the other three, that it was in reality the Illinoian. The following diagram will serve to make clear the relation of the striæ to the principal basin.

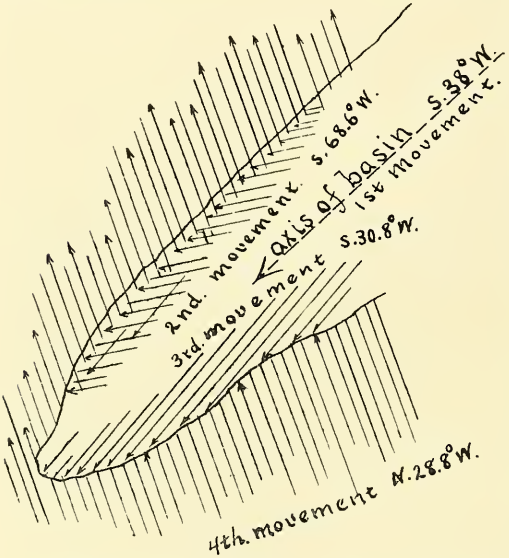


FIG. 7.—Diagram of the principal rock-basin at present exposed at the Sibley quarry. The arrows indicate the direction of each general movement, numbered in order from the first, or Illinoian. The central part of this basin is still covered with till.

Rock-shattering.—It has been observed in all the quarries and natural exposures in southeastern Michigan that the upper three to five feet of limestone strata are much shattered and apparently thin bedded. The strata become more solid and have the appearance of being more heavily bedded as they occupy a deeper position in the series. The same stratum dipping from the surface may have the disrupted condition just beneath the till which is shown in Fig. 8 and still be as solid and compact at a depth as the lower strata shown in this figure. This condition of the rock is believed to have been caused by a tremendous weight of ice slowly and spasmodically creeping over the rock surface, the effect of which was to open up the inconspicuous sedimentation seams to a considerable depth. This permitted the entrance of water, the freezing of which would tend to completely disrupt the strata and give them the thin-bedded, shattered appearance.

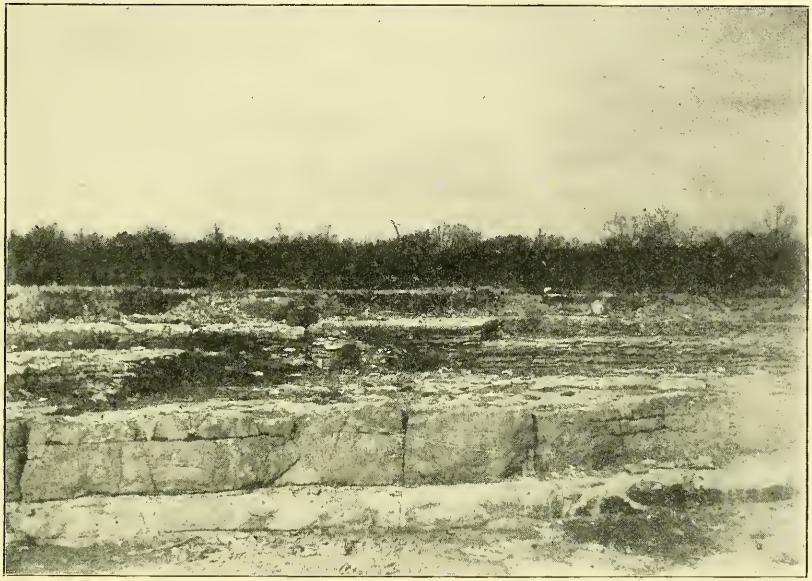


FIG. 8.— View showing shattered condition of the upper strata at the Sibley quarry, west wall. This is believed to be due to the slow creeping movement of a vast ice-sheet, combined with the subsequent action of frost.

SCORINGS IN MONROE COUNTY.

Eastern portion.— This county furnishes more numerous exposures of the rock surface than does Wayne, but none are so extensive as that at the Sibley quarry. At many of the localities where rock comes to the surface it is in such weathered condition that all scoring is obliterated. In the eastern part of the county, in the vicinity of Monroe, there are six accessible localities where well preserved striæ may be studied. The most northern of these is the Sissung quarry, one and one-half miles southeast of Newport. Here the two sets of Wisconsin striæ are seen, the late Wisconsin being the more abundant and averaging N. 57° W., having swung 28° further west from their direction at Sibleys. The early Wisconsin striæ maintain nearly their same direction, averaging S. 37° W. As early as 1839 the striæ at Brest and Point aux Peaux were observed and reported upon by Bela Hubbard, an assistant upon the first geological survey of the state.[1] At the former place he found two sets N. 50° E. (S. 50° W.) and N. 65° W. At Point aux Peaux he reported but one set N. 60° E. (S. 60° W.), which is to be correlated with those of the second movement at Sibley's (Iowan ?). At the present time the only striæ seen here have a general direction of S. 21° W., representing the early Wisconsin, the late Wisconsin not being exposed. Some twenty years after Hubbard's observations were made Winchell took the bearings of striæ which had been exposed by the waves at Stony Point. These he found to extend N. 60° W. and S. 60° W.[2] The writer now finds at this locality the two Wisconsin sets, averaging N. 54° W. and S. 10° W. At Brest the same two appear N. 57° W. and S. 9° W. At the quarry of the Monroe Stone Co., three miles southwest of Brest, the striæ average N. 48° W. and S. 12° W. Just south of the city of Monroe, at the Plum Creek quarries, we find them running N. 61° W. and S. 6° W. A comparison of the above data with those at Sibley's shows that the late Wisconsin striæ have shifted toward the west, the early Wisconsin toward the south, and that the supposed Iowan appears only at the three localities nearest the Erie shore, this representing the stoss side of the Monroe embossment for this movement. The general direction of this series is more south-

---

[1] *Second Ann. Rept. State Geologist*, p. 113. [2] *Report for 1860*, p. 127.

westerly. At most of these localities the late Wisconsin are the most abundant, although the early Wisconsin are well represented, testifying to the more energetic nature of the latter sheet. The amount of range in the direction of the striæ of the two Wisconsin series is very notably less in this region than to the west and north. This is to be explained by the fact that we are here nearer the axis of the Huron-Erie lobe, along which the movement was theoretically only slightly divergent.

Central portion.—The only satisfactory exposure of striæ upon the central ridge of the county is found at the Woolmith quarries, in the north central part of the county, between Maybee and Scofield, upon the Detroit & Lima Northern Railroad. The striæ of the two Wisconsin glaciations are well preserved about the main quarry, but those of the earlier series are more conspicuous. Thirteen readings give an average of S. 34.1° W., with a range of 27° (S. 22.5° W. to S. 49.5° W.). The late Wisconsin series is alone found in the small Hoffman quarry to the south. From both quarries twenty-two readings were taken and found to average N. 65.7° W., with a range of 40° (N. 91.5° W. to N. 51.5° W.). It is of interest to note that here, upon the Macon and at the Sibley quarry, some distance out from the main axis of movement, when a considerable number of observations were made, the range is from 40 to 50°, or about 25° on either side of the mean. It is not probable that doubling or trebling the number of readings would much alter the amount of this range. This amount of divergence is due to the fact that the ice moves out continually at right angles to the margin of the lobe, as pointed out some years ago by Chamberlin.[1] In the case of such a lobe as the Huron-Erie of the late Wisconsin ice, with its main line of movement toward the southwest, at any point some distance to the north of this central axis the striæ would have a more northerly course when the lobe was small and be deflected more and more to the west as the lobe increased in size. Theoretically the striæ on the northward side of the mean direction of movement should indi-

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, 1888, p. 201.

cate less vigorous ice action than the striæ upon the opposite, or westward side of this mean.

Western portion.—Upon the western rock ridge the finest exposures of striæ are to be found north of Dundee about the mouth of the Macon River. As these are in the bed of the Macon and Raisin, the best time for a visit is in the late summer or early fall when the water is low. The past season proved favorable and a satisfactory set of readings was obtained. The most conspicuous scorings to be found were made by the early Wisconsin, thirty-six observations giving a mean of S. 32.2° W., with a range of 46.5° (S. 3.5° W. to S. 50° W.). The rock ledges in the bed of the Raisin, just below the entrance of the Macon are heavily gouged by this series. The late Wisconsin sheet seems to have had but little effect upon the rock surface as the series of moraines was approached. At but one locality in the bed of the Macon are any striæ of this series to be found, giving a mean of N. 74.3° W. The movement becomes more westerly as we pass southward and south of west as the Ohio boundary is reached. At the head of Ottawa Lake a limited exposure shows the two sets S. 89° W. and S. 21° W. Just north at the quarries the few readings averaged S. 70° W. and S. 25° W. At the "Inlet" a single gouge runs S. 65° W. and three miles to the southeast in the bed of Halfway Creek four readings were obtained giving a mean of S. 56° W. In thus passing southward we approach the main axis of the late Wisconsin lobe and its striæ again predominate over those of the early Wisconsin.

GENERAL CONSIDERATIONS.

1. There is no evidence in this section of Michigan of any general southeasterly ice movement.

2. All the scoring action observed may be referred to four stages in the history of the Laurentide ice-sheet.

3. The first and oldest ice movement was to the southwest, being the most vigorous of all, quite independent of topography and presumably the most massive. Parallel with the main axis of the Illinoian glaciation its reference to this stage of the

Laurentide ice seems justified. About the western end of Lake Erie where the strike of the softer beds coincided with the direction of ice movement, broad, shallow troughs were excavated.

4. A second general movement followed west-southwesterly, intermediate in point of time between the Illinoian and early Wisconsin and less vigorous than either. This glaciation probably represents the Iowan.

5. The third ice movement was south-southwestward, second in vigor and massiveness only to the Illinoian and presumably capable of attaining also a low latitude. This is quite certainly the early Wisconsin. This ice is believed to have produced the series of outer discordant moraines in southern Ohio and Indiana. With this evidence, so far back from the southern limit of the Wisconsin ice, of distinct difference in direction of movement, in steadiness, vigor, and massiveness, more of a break between the early Wisconsin and late Wisconsin probably existed than has been yet recognized.

6. The fourth and final movement was the late Wisconsin, which resulted in the formation of the concentric morainic loops of northern Indiana, northwestern Ohio, and eastern Michigan. The ice was more influenced at this stage by the topography than at any previous time, was less vigorous and presumably less massive. The movement was in the main southwestward, but upon the upper side of the Huron-Erie lobe was outward toward the moraines, having less and less effect upon the rock surface. As the ice front retreated northeastward water was ponded back in the low country of the Maumee valley, Lake Erie region and southern Lake Huron and the series of glacial lakes was formed.

7. In the region under report the rock surface was lowered but slightly by the three later ice-sheets, the amount to be expressed most probably in inches. Knobs and trails produced by the early Wisconsin in exposed position are but slightly affected by the late Wisconsin. Moderately heavy gouges and striæ of the early Wisconsin escaped obliteration in many

localities. The relation of the striæ to the rock-basin seen in Figs. 6 and 7 shows that the adjoining rock surface was but little lowered by the early Wisconsin. In the Lake Erie region the pre-Wisconsin gouges on flat surfaces were not obliterated by both Wisconsin sheets. So far as our rock topography in this region is due to ice action this was accomplished by the first movement, that of the Illinoian. Judging from what is known concerning the rock topography of the Great Lakes region, the writer ventures to suggest as a "working hypothesis" that the real axes of all the major troughs and rock basins throughout this wide area point approximately to the Laurentide center of ice accumulation and that they were produced by the earliest of the four general movements.

W. H. SHERZER.

MICHIGAN STATE NORMAL COLLEGE,
Ypsilanti, January 30, 1902.

EDITORIAL.

In the United States Geological Survey the geologic branch is reorganized by the appoinment of Mr. C. Willard Hayes to the position of geologist in charge of geology, to take effect March 1, 1902. Mr. Hayes has been connected with the Survey since 1887, and has served with ability in various relations as assistant geologist, geologist, and since 1900 as geologist in charge of investigations of non-metalliferous economic deposits. He is now placed in administrative control of the geologic branch in order that the director may be relieved of executive details and the organization may be strengthened by the undivided attention of its head to carrying out the director's general policy. By this appointment Mr. Willis, who since 1897, as assistant in geology to the director, has performed the administrative work of geology, is freed from that duty and will be at liberty to give more attention to the division of areal and stratigraphic geology, of which he has charge.

In announcing these changes at a meeting of geologists in the office of the survey on February 20, the director called attention to the plan of organization of the geologic branch set forth in the *Twenty-first Annual Report*, pp. 20 and 21, and more fully elaborated in the forthcoming *Twenty-second Annual Report*. The fundamental idea of the organization is that scientific direction and supervision may be and in most cases should be separated from administrative control. Specialists are placed in charge, each one of investigations in a particular subject, Becker, Chamberlin, Day, Emmons, Hayes, Stanton, Van Hise, and Willis having been thus appointed, but their authority is in general limited to consideration and approval of the scientific aspects of the work. Administrative authority remained immediately with the director, and is now in a degree transferred to the geologist in charge of geology, Mr. Hayes.

B. W.

REVIEWS

Moræner i den Islandska Palagonitformation [Moraines in the Palagonite Formation in Iceland]. By HELGI PJETTURSSON. From Oversigt over det Konglige danske videnskabernes sellskabs forhandlinger, 1901, No. 5.

THE author has before this[1] described the occurrence of ground moraines in the palagonite of Iceland. The present paper is a brief summary of this earlier account and a report on some later observations, with a statement of conclusions drawn from the same.

All former writers on the geology of Iceland have recognized as glacial deposits only such morainic accumulations as overlie the palagonite, and the latter has been regarded as a Tertiary eruptive containing local aqueous sediments. The present author finds ground moraines in palagonites and breccias lying under doleritic lavas that have heretofore been regarded as preglacial. The material is indurated and stony, cut by joints and dikes, but has the characteristic texture of ground moraines. He thinks that there can be no reasonable doubt that this material is of glacial origin, and he presents four good reasons for his view, viz.:

1. The structure of the beds.

2. The nature of the included blocks. These are usually somewhat rounded. Quite often they exhibit beautiful scorings. One of the most perfectly scored bowlders the author had ever seen, he found in a "breccia" 100 feet thick, which appears as a gray belt on the bare rocky wall of Búrfells.

3. The "breccias" in some cases may be seen to rest on typically striated bed rock.

4. In some places where "breccias" resembling moraines rest on basalt, the upper surface of the latter is broken into fragments, which are worked into the base of the "breccia." One can see that some blocks of the basalt lie near where they were broken off, while other blocks have been carried farther away and are mingled with somewhat rounded bowlders.

---

[1] See *Scottish Geographical Magazine*, May, 1900.

These old glacial deposits occur on the north as well as on the south side of the island and frequently have a considerable thickness. At times lavas are interbedded in a way which suggests close proximity in time of the volcanic and the glacial forces. At other places there appear to be indubitable proofs of a general absence of glacial conditions at times of great volcanic activity. Doleritic lavas with their upper surface scored by the latest moraines, rise several hundred feet above old eroded surfaces of earlier glacial drifts. How many there are of the latter one cannot yet definitely say. Apparently there are more than one. It is noted that all these older moraines are associated with the palagonite tuffs, and there is some reason to think that they were made at some period during Miocene-Pliocene time. This, the author remarks, is a strange indication, in view of the what is known concerning the glacial age on the continent. But further investigations are needed to determine the age. The relation of the moraines to some fossil-bearing crags on the north coast promises more light on this question.

In the south half of the island the breccia plateau was for the greater part built after the moraines were made. The principal relief features of the land, as for instance the south lowland, are younger than even the uppermost of the palagonite moraine.

The heavy and extensively distributed ice-scored doleritic lava flows, show that there was a long interglacial period, for they overlie unconformably older moraines. The fossil-bearing crag at Tjörnes, already referred to, may prove to belong to this stage. Heretofore this deposit has been regarded as belonging to the Pliocene.

J. A. Udden.

The Cement Industry. Descriptions of Portland and Natural Cement Plants in the United States and Europe, with Notes on Materials and Processes in Portland Cement Manufacture. Reprinted from the *Engineering Record*, New York.

This interesting series of papers gives a very fair idea of the development of the cement industry at the time of their first publication a few years ago. Originally written for the *Engineering Record* by S. B. Newberry, Frederick H. Lewis, and others especially interested in cement, as independent articles describing typical cement plants of Europe and America, they are now published, together with an appropriate introductory chapter on the nature of material suitable for Portland and natural cement. Considerable space is devoted to a description of kilns, intermittent, continuous, ring, and rotary, and their relative merits are fully discussed. In the thirty or more plants which are described in detail, the wet, the half-wet, and the dry processes are represented, and the criticisms of the authors in regard to the fitness of each process for the material used is, on the whole, judicious. If the writers were preparing a series of articles today, however, they would probably include in their descriptions a larger percentage of mills using hard material, and have occasion to lay more stress on the ball mill as a suitable device for grinding. The matter is presented in a practical way, with numerous diagrams and illustrations. The impression is given that the American cement industry compares favorably with that of Germany, and that both of these countries now outrank England, the first producer of Portland cement. The trade in general is beginning to realize this fact, and today American cement is not discounted by the foreign product.

The volume is a useful one both for students of economic geology and technology, and for those otherwise interested in the manufacture and use of cements.

F. A. W.

Adephagous and Clavicorn Coleoptera from the Tertiary Deposits of Florissant, Colo., etc., etc. By S. H. Scudder, Monograph XL, U. S. Geological Survey.

Professor Scudder's investigations upon the fossil insects of the Florissant basin are well known. In Monograph XXI of the United States Geological Survey the rhynchophorous Coleoptera of North America were fully treated, and the present monograph is a temporary completion of the descriptions of North American Tertiary beetles. The new material described is nearly all from the Florissant basin, and is confined almost exclusively to the Adephagous and Clavicorn families. In addition to the new material described, however, a complete systematic list of the known non-rynchophorous Tertiary Coleoptera of North America is given, with bibliographic references and notes on geographic and geologic distribution. A large amount of new material from various western localities still remains to be studied, which will doubtless add much to our knowledge of these Tertiary insects.

S. W.

RECENT PUBLICATIONS

—American Museum Natural History, Bulletin of the. Vol. XII, Part I, pp. 1–32. The Huntington California Expedition. Basketry Designs of the Indians of Northern California, by Roland B. Dixon. New York, February 12, 1902.

—ANDREWS, E. C. Report on the Yalwal Gold-Field, New South Wales. Department of Mines and Agriculture, Mineral Resources No. 9, Sidney, 1901.

—BRANNER, JOHN C. Geology of the Northeastern Coast of Brazil. [Bulletin Geological Society of America] Rochester, N. Y., February, 1902.

—DUBOIS, PROF. EUGENE. On the Supply of Sodium and Chlorine by the Rivers to the Sea. [Reprinted from the Proceedings of the Meeting of Saturday, January 25, 1902. Koninklijke Academie Van Wettenschappen te Amsterdam, February 19, 1902.]

Les Causes probables du Phénomène Paleoglaciaire Permo-Carboniferien dans les Basses Latitudes (deuxieme étude.)

[Extrait des archives Teyler Serie II, T. VIII, Premiere Partie] Haarlem, 1902.

—FOERSTE, AUGUST F. Silurian and Devonian Limestones of Tennessee and Kentucky. [Bull. Geol. Soc. America, Vol. XII], Rochester, N. Y., October, 1901.

—Geological Survey Western Australia. Annual Progress Report No. 29, for year 1900. Perth, 1901.

—HARRIS, W. T. The Place of Geography in the Elementary Schools. [Reprinted from the "Forum" for January, 1902.]

—LAWSON, ANDREW C. and PALACHE, CHARLES. The Berkely Hills. A detail of Coast Range Geology. [Bulletin of the Department of Geology, University of California. Berkeley, January, 1902.]

—MOBERG, JOH. CHR. Om Kalkfyndigheten vid Klagstorp. [Aftryck ur Geol. Fören I, Stockolm, Förhandl. Bd. 23, H. 7, 1901. P. A. Norstedt & Sons, Stockholm, 1902.]

Didmograptusskiffer. Bd. 24, H. 1, 1902.

Pterograptus Scanicus N. Sp. Bd. 3, H. 5, 1901.

—Matthew, W. D. Fossil Mammals of the Tertiary of Northeastern Colorado. [Memoirs of the American Mus. Nat. Hist., Vol. 1, Part VII.] November, 1901

—Museum of Comparative Zoölogy, Bulletin of Harvard College. Vol. XXXVIII. Leuctite-Tinguaite from Beemerville, New Jersey, by John E. Wolfe.

The Geology of the Northeast Coast of Labrador, by Reginald A. Daly. Cambridge, Mass., February, 1902.

—Rosenbusch, H. Studien im Gneissgebirge des Schwarzwaldes. II, Die Kalksilikatfelse im Rench-und-Kinzigritgneiss. [Sonderabdruck aus den Mitteilungen der Grossh. Badischen Geologischen Landesanstalt IV Bd., 3. Heft; 1901. Verlag von Carl Winter's Universitäts-buchhandlung in Heidelberg.]

—Smyth, Jr., C. H. Geology of the Crystalline Rocks in the Vicinity of the St. Lawrence River. [Reprinted from the Nineteenth Annual Report of the State Geologist. Albany, N. Y., 1901.]

—Schrader, Frank Charles, and Spencer, Arthur Coe. The Geological and Mineral Resources of a Portion of the Copper River District, Alaska. [Department of the Interior, U. S. Geol. Surv., 1901.]

—Todd, J. E. Hydrographic History of South Dakota. [Bulletin Geological Society of America, Rochester, January, 1902.]

University of Texas Mineral Survey, Bulletin No. 2. Sulphur, Oil and Quicksilver in Trans-Pecos, Texas. VonBoeckmann, Schutze & Co., Austin, Texas.

—Van den Broeck, Ernest. Le Dossier Hydrologique de Régime Aquifère en Terrains Calcaires et le Rôle de le Géologie dans les Recherches et Études des Travaux d'eaux Alimentaires. [Extrait du tome XI (de 1897) fascicule V (publie en 1901) du bulletin de la Société belge de géologie, de paléontologie et d'hydrologie.] Bruxelles, April, 1901.

—White, I. C. Geological Horizon of the Kanawha Black Flint. [Bulletin of the Geological Society of America, Vol. XIII, pp. 119–126.] Rochester, N. Y., March, 1902.

THE

JOURNAL OF GEOLOGY

APRIL–MAY, 1902

GEOLOGIC FORMATIONS *VERSUS* LITHOLOGIC INDIVIDUALS.

A RECENT article in this JOURNAL by Bailey Willis, entitled "Individuals of Stratigraphic Classification,"[1] renews a discussion of both fundamental and practical questions coming before the geologist engaged in areal mapping, which has gone on since the earliest days of geology and seems destined to go on indefinitely. The writer recognizes that Mr. Willis voices the beliefs of many geologists, among them being Edwin C. Eckel, whose still more recent contribution to the discussion[2] indorses the statements by Mr. Willis. But there is another and fundamentally different view of the matter, also held by many working geologists, and the writer wishes to present a few remarks from that standpoint. It is desired particularly to discuss the proposition maintained by Mr. Willis that the proper cartographic units, representing "Individuals of stratigraphic classification," are "lithologic individuals," discriminated by the geologist solely on lithologic characters. Mr. Willis cites the rules of the United States Geological Survey, established some twelve years ago, concerning cartographic units, upholding them in their most literal interpretation. But the writer does not

---

[1] JOUR. GEOL., Vol. IX, p. 557.

[2] "The Formation as the Basis for Geologic Mapping," JOUR. GEOL., Vol. IX, p. 708.

now wish to touch upon the cited rules or actual practice of the government Survey, since the question of revising those rules is, at the time of writing, under consideration by a committee appointed by the Director. There is ample room, however, for a discussion of the natural objects of a geological map and an analysis of the actual conditions facing the geologist endeavoring to express geologic facts upon a map. The writer aims to do this in no controversial spirit, making frequent reference to the articles cited simply because they are the latest expressions of a view held by many geologists.

Before entering into the discussion of the geological problem, the writer wishes to express a protest against a tendency of the time to impoverish the language of ordinary speech by the appropriation of many of its commonest terms, having universally adopted and understood meanings, to technical and specific purposes. This is found in other languages than our own, and in the literature of other sciences than geology, but for both general and specific reasons some of the terms necessarily employed in this discussion may be mentioned as cases in point. When such terms as "group," "division," "series," "period," and "formation" are appropriated for special and limited uses the geologist is decidedly hampered in his general discussions and obliged either to employ unusual terms for common concepts, or to carefully and repeatedly explain his use of terms as he goes along. That restricted definitions of some of the terms mentioned have the sanction of the International Congress of Geologists merely makes the situation worse. The importance of this matter appears not to be limited to the indirectness of statement forced upon a writer in discussing the commonest points of geology and to the inconvenience of so doing, for unless a writer does explain his use of terms there is often uncertainty as to his meaning, and the unnatural limitation imposed may well act at times as an obstacle to clear thinking.

It seems desirable to refer to this matter because the uses of the word "formation" and of the expression "lithologic individual" or "unit" by Messrs. Willis and Eckel, in their cited articles, undoubtedly obscure the meaning of their discussions. It is true that their usages are in accordance with the cited definitions of the United States Geological Survey regarding cartographic units, and that the usage is now becoming common, so that no special criticism of their course can be intended in this reference. But as will appear, the writer's conception of the geologic formation is of something which does not receive recognition in the articles by Messrs. Willis and Eckel, while we are all nominally discussing the same thing, namely: the desirable and practicable scope of the geological map and the nature of the problem presented to the geologist in making such a map. In all frankness the writer is unable to decide to what extent the conception of the geologic formation entertained by him is actually coincident with that of the nominally restricted "formation" or "lithologic individual" in the minds of Messrs. Willis and Eckel, although it is clear that, in spite of the definitions they profess to follow, some other factors than those of the definitions are really there.

Mr. Eckel entitles his article, "The Formation as the Basis for Geologic Mapping." Under the restricted technical use of the word he soon states that he means "lithologic unit," something discriminated and defined solely on lithologic characters. But in the discussions of Mr. Eckel and Mr. Willis, and of other writers professedly dealing with a formation thus defined, there is continual evidence that to some extent other factors enter into their idea of what they designate a "lithologic unit," such as stratigraphic continuity, even if accompanied by change of lithologic character. The terms "lithologic individual" or "unit" used in defining *formation*, or given as practically synonymous with it, refer in their common or apparent meaning to a *rock*, one of the units treated by the systematic science of petrography. Mr. Willis constantly refers to the mapping of rocks. The definition of the "formation" as a "lithologic individual" lays stress on the idea that it is a result of continuity of physical conditions, securing to the sandstone or limestone mass its unity of lithologic character. But in the acknowledgment of the fact that fossils may be necessary to "identify" this *lithologic unit* is evidence of the entrance of other ideas than those of lithologic characters into the underlying conception of the *formation*. Stratigraphic position, continuity—giving it structural importance—and something of age, relatively or absolute, are clearly there but unexpressed.

The writer's conception of the geologic formation is the broad and general one, commonly entertained before the restricted use of the word "formation" was advocated—and still held, he is happy to believe, by many geologists; it is of something entirely unsystematic. The known portion of the earth consists of rock masses of various modes of origin, in which the record of earth history lies. In considering the geology of any portion of the earth, one naturally separates these rock masses into individuals or groups, large or small, for the purpose of deciphering or expressing geology. Each division possesses a certain unity varying in degree or kind according to the point of view. All but the broadest divisions may be properly called geological formations.

Each rock mass assuming importance from the geologist's standpoint stands for many things. It may be viewed from a narrow standpoint and considered to have individuality from the factors of that standpoint only. The lithologic characters may be taken into account and then it is "a lithologic individual;" its faunal contents considered, it may possibly be correct to speak of it as "a faunal unit;" but when it is spoken of as a geologic formation, there should be involved the entire geologic record it contains. Only when the student considers it in its entirety is he entitled to call himself a geologist; otherwise he is but a specialist—a paleontologist, a lithologist, a stratigrapher, or a physiographer. The writer understands the geological map to be a representation of certain geologic formations, selected to express, so far as cartographic limitations permit, the geology of the area covered.

The writer will use the term "geologic formation" in its broad sense and, in courtesy to his colleagues, consider that they must also conceive of the geological map as more than a map of lithologic individuals could be. Mr. Willis states, with justice, that we are often perplexed to know what the divisions or cartographic units of a map are intended to represent.[1] That is particularly true of formations purporting to be "lithologic individuals," which are actually heterogeneous in lithologic character and do not represent continuity in conditions of deposition. The writer believes that every definition of a geologic formation chosen as a cartographic unit should contain a statement of all the factors determining and justifying its discrimination, with due emphasis on the most important features of each case.

Mr. Willis addressed himself in the cited article to the question "Should geologists map the record of physical conditions or the record of biological conditions—rocks or fossils?" and his answer was: "Both, but with distinctions." The question might be assumed to be broad enough to cover the problem of the geological map if the term "physical conditions" could be interpreted as referring to the general physical development of the earth as recorded in rock masses. But Mr. Willis's whole discussion is directed to maintaining the idea that geology is in such an elementary state of development that our present object must be restricted to mapping "lithologic individuals, while our associates, the paleontologists, distinguish the faunal units of stratigraphy."[2] "The record of physical conditions" must then be regarded as referring only to the conditions causing the lithologic characters, by which the so-called "lithologic individuals" are to be discriminated. As already stated, the writer believes that geologists should map *geologic formations*, not rocks or fossils. A map of lithologic individuals, discriminated on the restricted grounds advocated by Mr. Willis, is not entitled to be called a geological map; it is a *lithological map*, pure and simple.

The question under discussion is really, "What should a geological map represent?" The writer's answer is that it should represent as much of the geologic development of the earth

---

[1] *Loc. cit.*, p. 557. [2] *Loc. cit.*, p. 569.

recorded in the area covered as is practicable. To that end its cartographic units must be established with regard to *all* the facts and conditions of the case, and not upon the restricted basis of any part of those facts. Of course this discussion does not refer to the mechanical limitations of map-making, nor to local maps of large scale designed for some special purpose, but to the problem involved in the mapping of a geologic province on a scale similar to that of the *Atlas of the United States Geological Survey.*

This idea of the geological map is based upon the consideration that geology is the broad science of the earth, viewing it as originating in a manner still a matter of hypothesis, as developing through a long succession of changes, from that uncertain state to the present conditions. Geology deals with all the processes involved, their modes of operation, and the results. Development implies a succession of events, a series of changes, a history, and so some conception of geological chronology is inseparable from the discussion of rock masses as *geologic formations.* The available record of earth history prior to the present time is in the rock masses and their relations to each other. Geological mapping, therefore necessarily consists chiefly in representing the distribution of rock masses. The map will fulfill the purpose of expressing geologic development in proportion as the units of representation are discriminated with reference to *all the record* contained in them. If the cartographic units are determined by consideration of only a part of the information which may be used, the map will be restricted, and unnecessarily so.

It seems to the writer that the proposition to map "lithologic individuals," and to call the result even by courtesy a geological map, ignores very largely the fundamental distinction between the *rock*, as an object of certain petrographic character, and the *geologic formation*, a mass of importance in the crust of the earth, and containing far more than the record of physical conditions controlling its formation. The separation of petrography from structural geology was made nearly one hundred years ago, and to that step as much as to the recognition of paleontology is due the present science of structural and historical geology. Perhaps Mr. Willis did not intend to use the term "rock" in its natural and limited sense, yet the proposition to make a geologic map a representation of "lithologic individuals" discriminated solely on "lithologic character" affords no basis for the supposition that he had in mind the idea of the geologic formation, properly speaking. To advocate such a map is practically no advance upon the time of John Macculloch, who in 1821 published his celebrated *Geological Classification of Rocks*, etc., having stratigraphy in mind, and with no idea of the necessity for a science of rocks. There is in the idea, however, a curious combination of this old-time misconception with an element of the so-called "new geology," which is chiefly occupied with physical conditions under which the earth is sculptured and detrital rocks are formed, although this branch of geology is no more *new* than any other.

From the statements by Mr. Willis that he "by no means advocates disregard of fossils in the *identification of formations;*" that "there is a difference between using fossils as one of several means of *identification* and employing them as *essential* characters;" and that "they should not set limits in the discrimination of formations" (*italics* the present writer's), it appears that there is an unrecognized or imperfectly expressed acknowledgment that the Jenkinsville sandstone, for example, is more than a sandstone exposed in a ledge at Jenkinsville—that it is, in fact, a geologic formation. But the writer confesses that he does not fully understand the use of the terms "identify" and "essential" in these quotations. Apparently Mr. Willis would *discriminate* and *define* "formations" by their lithologic characters as the only "essential" factors, but still realizes that such formations may not be *recognizable* by their "essential" characters and that the accidental or unessential factors, fossils, may then be useful or necessary. How and where would Mr. Willis express the facts concerning certain fossils in relation to the Jenkinsville sandstone which warranted or made possible their use in *identifying* that "lithologic individual"? If any object be defined as having certain essential characters and it develops from experience that the object cannot always be identified by those characters, or, conversely, if it be found necessary to use supposedly unessential factors in its identification, there is something logically wrong in the conception of the object.

Viewing sedimentary formations as documents of geological history, the deciphering of their complete record of events requires consideration of many things. The most striking fact in many cases is the lithologic character of the formation. From this character the mass receives its petrographic designation, and from it some of the conditions of sedimentation and of local physiography at the time of deposition may be inferred. Often these factors permit further inferences as to the events preceding or following the deposition of a given stratum. But all the strictly lithologic characters have no chronologic significance. A sandstone, shale, conglomerate, or limestone may have been deposited at any time from the Algonkian to the Tertiary. As Mr. Willis clearly expresses it, "we now know that the physical characteristics of rocks are repeated from time to time, and are diverse in different provinces at the same time, and that therefore they do not afford criteria of contemporaneous deposition.[1] Much more of the record of earth development may be found in the sedimentary deposit, however, if other data are considered. Such deposits consist usually of chemical precipitates, fragments of older rocks, or of organic remains.

Lithologically the source of materials for a clastic rock may be of no consequence. A conglomerate is a conglomerate, whatever the age may have been of the rocks which were destroyed to furnish sand or pebbles. But viewing the conglomerate as a geologic formation, it is of great importance to note what earlier rock formations are represented in any given case. Even a single pebble or bowlder may throw more light upon the chronologic position of the conglomerate, and the

---

[1] *Loc. cit.*, p. 557.

extent and importance of the erosion which exposed the rock of that pebble, than is afforded by all other data combined. Two conglomerates in close proximity, and so situated at the locality where they are exposed that they seem to belong to the same general period of sedimentation, may possess in their pebbles evidence of events of great importance in the interval imperfectly represented by the stratigraphic line between them.

Lithologically a shell limestone is one largely composed of shells, and a coal of certain properties is bituminous coal, whatever shells or plants, respectively, may have produced the rocks in question. But viewing the coal beds and limestones, or other fossiliferous strata, as geologic formations, not "lithologic units," the significance which paleontology shows may be attached to the particular fossils found in a given case is of great importance. The record here referred to is not that of life history, but of earth history. The fossils of a "lithologic individual" may be the most significant characters it contains bearing upon its age, the extent and importance of earth development in the epoch preceding its deposition, the characters of the waters in which it was formed, and the climatic conditions of the time. From the standpoint of the investigator striving to make out the full significance of a sedimentary deposit, a constituent pebble of a recognizable older rock of known structural position is a feature possibly equal in importance to a shell, a bone, or a plant, of certain paleontologic character. Both are fossils, in a sense.

The mode of origin and the characteristic features of igneous rocks render the evidence of geologic history to be obtained from them limited as compared with that which may be derived from sedimentary formations. But it appears to the writer that much more effort should be made to read these records and to represent the information obtainable on geological maps than is commonly attempted.

The petrographic, or lithologic, character of an igneous rock serves to show its proper systematic position and leads to its designation. Such characters testify that a magma of certain chemical composition consolidated at the place where a given rock is seen, under conditions producing the mineralogical and textural result observed. What some of these conditions were can be inferred, and something of the eruptive history may be read in the petrographic characters. But these features give but little more data bearing upon geological chronology than do those of a sandstone or conglomerate. To be sure, one may be more warranted in assuming that an observed granite is of ancient formation, or that a leucite-bearing lava is of Tertiary age, than one would be in concluding that a sediment of almost any common lithologic character belonged in any particular part of the stratigraphic column. This is, however, due more to the circumstances of the exposure of an igneous mass than to any known connection between age and petrographic character.

Geologically it is of interest to know whether igneous masses are extrusive or intrusive. Although an indefinite relative age is all that is commonly determinable, there are many instances where the chronologic relation between the eruption of certain magmas and the deposition of certain sediments can be established. In a given province a certain series of eruptions may be visibly connected with a known volcanic center, while other igneous rocks of the same region are clearly independent of that center, and may be demonstrably very different from its products in age.

When any of these, or of other, geologically significant relations of igneous rock masses may be determined, and it is practicable to express them on a geological map, such representation should certainly be attempted. If such relations are ignored the map fails to satisfy the legitimate demands of the geologist for the same reason that a map of sedimentary "lithologic individuals," fails of its full usefulness.

Metamorphic rocks have been derived from all kinds of igneous and sedimentary rocks by a great variety of processes. In numerous cases the derivation of the metamorphic product is clear and it may be found in association with comparatively unaltered portions of the original mass and exhibiting transition stages. But the great majority of these interesting records of earth history belong to the oldest periods of geologic time of which we have evidence in the rocks, and the nature of the primary mass can never be established. The discrimination and representation of metamorphic rock formations should, however, be intended to express as much as practicable of this phase of earth development.

The belief that a geological map of today must be limited to the exhibition of the distribution of local "lithologic individuals or units," seems to the writer not only inconsistent with the true conception of the object of the geological map but to ignore the known facts of the stratigraphic column. It is now desired to consider a few of the practical problems presented to the areal geologist in the preparation of a geological map.

In the first place, it will be assumed that the terms "lithologic unit" or "individual" and the proviso that "they shall contain between their upper and lower limits either rock of uniform character or rock uniformly varied in character," imply that this unity in character has been derived from actual continuity or regular oscillation of conditions of sedimentation during the epoch in which the formation was deposited. If such implication is not intended, it may be remarked that a map of such units would so effectually obscure geological conditions that it could not be included within the scope of the present discussion. But the writer wishes to assert his belief, on the one hand, that many extensive sections of the stratigraphic column cannot be completely divided into mapable units of the significance above implied, and on the other hand, that the inference of continuity of conditions, suggested by lithologic character alone, must be tested by all available facts of the case to avoid falling into serious error. This belief is based upon the writer's personal experience in the stratigraphic section of the Rocky Mountain province, ranging from the Algonkian to the Tertiary, and upon his knowledge of some of the experiences of his colleagues in the United States Geological Survey work.

Where lithologic uniformity or regularity in variation of character actually stands for continuity of conditions, as far as existing facts indicate, the writer is as ready as any one to acknowledge that that fact should be recognized on the map, because it represents a fact both of geological history and of local conditions. The local importance of such a formation is surely to be recognized where it does not obscure facts of more fundamental significance. In this belief he has, for example, discriminated and mapped the *Mancos shale* of the Telluride and La Plata quadrangles in Colorado. This Upper Cretaceous formation is nearly two thousand feet in thickness, rests on the Dakota sandstone and embraces strata deposited during the Benton, Niobrara and Pierre epochs, as indicated by fossils occurring near the base and near the top of the shale complex. It is at present a matter of inference that some of the shales of this complex correspond in time of deposition to the strata assigned to the Niobrara formation, as it has been generally discriminated elsewhere in Colorado.

The Ouray limestone of Colorado, first described and named in 1900 by A. C. Spencer,[1] then the writer's assistant, was at first supposed to be wholly of Devonian age. It is nearly three hundred feet in thickness, and while not actually homogeneous is in very large part a limestone formation. Near the center a marked Devonian invertebrate fauna has been found, and above that horizon no persistent line can be drawn on lithologic character. It has been recently ascertained, however, that Lower Carboniferous fossils occur in certain places in the very uppermost layers of this local limestone unit. As study of this formation progresses it is plain that some, and possibly a considerable, thickness of Lower Carboniferous limestone was eroded from its upper portion in the time interval preceding the Upper Carboniferous. In its present partially metamorphosed condition the Ouray limestone seems in large degree a unit of continu-

---

[1] "Devonian strata in Colorado," *Amer. Jour. Sci.* (4), Vol. IX, p. 125.

ous deposition, from the period represented by the Devonian fauna to that of the Lower Carboniferous. The writer then, for the present, accepts the local lithologic fact, and the absence of an observed explanation for the faunal change, as determining the treatment of the formation as a unit. If in the tracing out of the Ouray limestone it should be found that the inference of continuous sedimentation is incorrect and that a traceable and really sharp line, indicating a stratigraphic break, exists near the center of the apparent unit, the writer would favor an expression of that fact upon the map, if feasible. How that should be done is a matter of detail, from his standpoint. If the break in question should be found to represent a period of orogenic disturbance, with overlap of the Lower Carboniferous member, the desirability of expressing that fact wherever the limestone complex is found would be great. But for the region in which the apparent lithologic unit is now known it may be best that it should receive a single name, even if its lower and upper members be designated, respectively, as Devonian and Carboniferous.

Another phase of the problem of establishing cartographic units may be illustrated by the stratigraphic section of the Rico Mountains, in southwestern Colorado, studied by a party in charge of the writer, which was cited by Mr. Willis[1] as an example of unwarranted departure from the rule requiring that lithologic character alone should be used in discriminating "formations." The section in question has a total thickness of about 4,500 feet, and lithologically presents a series of irregularly alternating conglomerates, sandstones, shales, limestones, marls, and all manner of transition beds, few of which exceed one hundred feet in thickness. There are probably fifty or sixty lithologic divisions which might be established and traced for some distance, most of which would have a fair degree of lithologic uniformity. Only by such detailed mapping can the conditions of deposition be graphically expressed. Any grouping of unlike units obscures that expression. There is no "lithologic individ-

---

[1] *Loc. cit.*, p. 561.

ual" except the comparatively thin bed. The mapping of these lithologic units, however, would involve topographic maps of large scale and great accuracy, and an expenditure of time which, in view of the present condition of the survey of Colorado, renders such detailed work inadvisable. But assuming that the mapping of each "lithologic unit" were feasible and that it had been carried out, without some grouping of these units the map would be merely a lithological map. It seems improbable that even Mr. Willis would be content with such a map, in view of the range of this section. The problem of grouping the units is, however, the same as that of dividing the entire section for the purpose of representing the main ascertainable facts of geologic development.

It is known by fossil and structural evidence that the section in question embraces practically all that is present in the region of the Carboniferous (including Permian) and Triassic systems. In earlier reconnoissance surveys and reports touching the province, this general distinction has been drawn. The upper half, which has a reddish color, has been distinguished as the "Red Beds" of assumed Triassic age; the lower half, which has no prevalent reddish color, has been referred to the Carboniferous from scanty fossil evidence. In the recent areal work of the geological survey in charge of the writer, it has been found that the reddish color line is both indefinite, through gradations, and variable as to horizon. For any but crude reconnoissance work the red color line is not a practical guide. Through careful study of the section in several quadrangles, it has been found that the lower two thousand feet of the complex contains in its limestones and shales a persistent Lower Carboniferous invertebrate fauna. While extensive collections have been made from various horizons, the paleontological opinion rendered by Mr. G. H. Girty is to the effect that no faunal groups are indicated warranting a suggestion that any particular one of the many planes of lithologic change represents an interval of unrecorded events, or gives grounds for a division, for the expression of correlation with structural members of the Upper Carboniferous elsewhere known. The actual Triassic age of the upper portion of the "Red Beds" has been established by scanty but significant vertebrate, invertebrate, and plant remains, occurring within a limited vertical range. The problem, alike for the geologist, endeavoring to make an adequate geological map, and for the lithologist, required to express the grouping of the many small lithologic individuals in the structural divisions of the Carboniferous and Triassic systems, is here to find the correct line between them.

In the Rico Mountains it was found that above the complex of two thousand feet of beds characterized by the Lower Carboniferous fauna there was a series of strata about three hundred feet in thickness, generally somewhat reddish in color, sometimes markedly so, containing a fauna described by the paleontologist as distinctly different from that known in the two thousand feet of strata below and as intermediate in character between the Carboniferous and Permian faunas thus far known. The change takes place abruptly, *i. e.*, within fifteen feet. The Permo-Carboniferous fauna occurs in thin limestones through a section containing lithologic members much like strata above or below. Above this series comes an apparently unfossiliferous section of frequent and irregular changes in lithologic character. Many of the strata here are extremely like beds of the complex containing the Permo-Carboniferous fossils.

In the *Report on the Geology of the Rico Mountains* by the writer and A. C. Spencer the heterogeneous group of strata containing the Lower Carboniferous fauna was designated as the "Hermosa Formation;" that containing the Permo-Carboniferous fauna as the "Rico Formation;" and the remainder of the section was provisionally assigned to the "Dolores Formation."[1] The latter formation had already been defined as intended to include the Triassic portion of the heterogeneous "Red Beds" section of the region and apparently including the whole. The object in making the three divisions was to express

---

[1] WHITMAN CROSS and ARTHUR COE SPENCER, "Geology of the Rico Mountains, Colorado," *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1900.

geologic history, though imperfectly. The divisions were not intended to be "faunal divisions" as Mr. Willis states, but *geological divisions.* They were founded primarily on the evidence of fossils, because lithologic character utterly failed to indicate the importance of the events which must have occurred before and after the Rico epoch. The lower line of the Rico formation is accurately determinable in the field so far examined by the relations of a thin black limestone, a thin-bedded series of sandstones, fifteen feet in thickness, above it, and a reddish sandy-looking limestone. The thin black limestone is a guide because it is full of a foraminifer, *Fusulina cylindrica*, common in the Hermosa limestones and absent from the Rico beds; the other limestone because it is crowded with the Permo-Carboniferous fauna. The upper line of the Rico formation, as at present mapped, expresses the fact of the apparent limitation of the Rico fossils. The succeeding strata have been referred provisionally to the Triassic system because no known evidence gives a basis for recognizing the Permian or any other geologic unit expressive of the important events which clearly must have occurred between the Rico epoch and the deposition of the fossiliferous Triassic strata. The fact that a lithologically heterogeneous section must be scrutinized most carefully to detect planes of relative geological importance is well illustrated in this series of "Red Beds" above the Rico formation. The Rico fauna is a marine fauna; the vertebrates and invertebrates of the Triassic beds, one thousand feet above, are fresh water or land forms. No more marine sediments occur in the section of this region until the Upper Cretaceous rocks are reached. It is not now known whether strata of Permian age are present in this section or not. If that question is ever settled it will be on fossil evidence. Ultimately, the knowledge will be acquired indicating further subdivision of this section in order to express the sequence of events so imperfectly recorded in the rapidly and irregularly changing lithologic character of the strata.

The absolute necessity of using fossils in discriminating geologic formations is frequently illustrated in the areal mapping of Tertiary deposits in the Coastal Plain region, and even in establishing the boundary between Cretaceous and Eocene systems, although that line may represent a stratigraphic break. Thus in the Uvalde quadrangle of Texas Mr. T. Wayland Vaughan describes the uppermost Cretaceous and the adjacent Eocene formations as presenting such complex and rapidly changing lithologic characters, and as so similar in these variations that the stratigraphic line of much significance between them is not determinable except on fossil evidence. From lithologic character one would necessarily conclude that conditions of sedimentation alternated irregularly through the period represented by the section in question and no one line of change would be suggested as of special importance, or at least the one which is of greatest significance would not be indicated. There is, however, a sharp line present, indicated by the fossils of two beds in close proximity, one carrying a Cretaceous fauna, the other Eocene forms, and no single species of either the extensive Cretaceous fauna below, or of the Eocene above, has been found to cross this line. The use of this information in discriminating cartographic units is thus essential to a representation, which is entirely practicable, of important geological facts concerning this quadrangle and the Gulf province to which it belongs.[1]

Another example of the insufficiency of lithologic characters alone as means of discriminating the desirable cartographic units of a province is afforded by the southern Appalachian region. At the time when the areal work of the United States Geological Survey there was in charge of Mr. Willis, he described the conditions as regards the Paleozoic section as follows:

> Thus the Paleozoic sediments are a great complex of lenses of every grade of lithologic character, from pure limestone to conglomerate, and lithologic distinctions cease to be of value except when used as guides in small districts or when variations are traced out by continuous detailed study.[2]

Mr. Willis further explains (in the same place) that as a

---

[1] "Uvalde folio," *Geologic Atlas of U. S.*, No. 64.

[2] *Tenth Ann. Rept. U. S. Geol. Surv.*, p. 121.

result of this condition it had been decided by Mr. G. K. Gilbert, his predecessor in charge of the work, to establish the cartographic units of each area mapped upon the lithologic characters there displayed. But, as a matter of fact, the section in question contained fossils, and the present excellent representation of the geologic development of the southern Appalachians, afforded by the combined atlas sheets already published, is due in large degree to the use by Mr. Willis's successors of fossils as guides in discriminating proper geologic formations where lithologic characters failed. By the use of fossils important stratigraphic horizons were recognized which had been entirely overlooked so long as local lithologic features were regarded as the only practical means of establishing cartographic units.

The general chronologic scheme of geology has been established to express the evolution of the known portion of the globe. Its foundation lies in the fossils of the rocks, their demonstrated distribution and the evolution they show. At times the paleontologist, engaged in the biological side of the study of fossils, has seemed to believe that the chronologic scheme of geology was established to express the evolution of life upon the earth rather than the evolution of the earth itself. Sometimes the geologist, engrossed in the problems of the "new geology," appears to forget his own rights and to concede to the paleontologist of the narrow view mentioned the correctness of his claim. But in these later days, as the geologist and paleontologist work more and more in harmony, such limitations of view are certainly becoming rarer, and it is more generally recognized that where a common scheme of time divisions fails to adequately express the known facts of earth development and life evolution some new provision is necessary. The ideas upon this subject recently advanced by H. S. Williams[1] seem to the writer to contribute much toward the adjustment of these difficulties. But it is not desired at this time to discuss the

[1] "The Discrimination of Time-values in Geology," Jour. Geol., Vol. IX, p. 570.

basis of *time scales*, meaning graduated measures of time involved in either earth or life history. With Mr. Willis, the writer believes that much further investigation is necessary before complete adjustment of the time scales of geology and of paleontology can be made. In that condition lies no ground for the assumption that the geologist may not use paleontologic evidence at any time in accordance with the best knowledge of that time in deciphering the geologic record and in choosing formation units for its cartographic representation. Doctrines of catastrophism and special creation have yielded to the theory of evolution. A precise diagnostic value for a fossil in taxonomy is no longer claimed. But we still have a chronology of geology. We are now better informed than ever before as to the sequence of geologic events and as to the actual value of fossils to the geologist in all his researches.

The knowledge that life has been continuous, that faunas and floras migrate, that shore lines migrate, shows that time divisions of exact synchronous value can never be established upon either faunal changes or lithologic character of sediments alone. What the basis of the future time scale of geology will be cannot now be safely predicted. That is a matter which does not materially affect the problem under discussion.

The task of the geologist mapping a given province is to express the facts of geologic development there. He may know that his stratigraphic divisions are not to be accurately correlated with those of distant provinces. His province has its own history and his units of mapping, call them as you will, are to be discriminated primarily for the practical expression of that history. He knows that in the main the broader correlations with the history of other provinces will hold good, and he should express correlations indicated by all the evidence known.

The fact, now commonly recognized, that some faunas or floras cannot be used to establish the exact time equivalence of the beds containing them, in widely separated areas, does not seem to the writer to in the least warrant the conclusion that all correlation on fossil evidence is at present undesirable or unjustifiable.

Mr. Willis speaks of a faunal map as something desirable:

> When the map of formations [lithologic individuals discriminated without regard to fossils] is made, the way is prepared for the paleontologist to ascertain the number and bounds of the faunal units and to draw the faunal map.[1]

While the writer desires to see a discussion of the object and practicability of such a map from the paleontological standpoint, he desires, with all due diffidence, to make a few comments upon this idea.

A fauna regarded as the aggregate of associated forms living at a certain time or during a certain period of the past, embraces forms which have run their race and are disappearing, a larger number of those which may be said to be enduring, and still others appearing for the first time. Any fauna is, then, an aggregate of forms whose periods of endurance overlap in most complicated manner, not only because they appeared at different times, but because some are persistent and others comparatively ephemeral. Why should the biologist wish to map the distribution of one fauna rather than that of the many others which overlap it? If he desires to express conditions of life during various epochs, the imperfections of the fossil record, the sequence of periods or stages of development, his purpose is adequately met by a geological map.

From another standpoint, there are various contemporaneous faunas, and also a flora, the existence of the last being sometimes overlooked. There are marine, fresh water, and land faunas, vertebrate and invertebrate, living at the same time but only in part represented in any one formation. It would appear that the biological needs for maps of distribution could scarcely be represented on any one "faunal map."

It is an old simile to speak of "the book of nature." Perhaps in no line of scientific investigation is the aptness of this simile more striking than in the field of geology. The rock formations are so many historical documents of varied scope

---

[1] *Loc. cit.*, p. 560.

and magnitude. Some are like pamphlets, mainly devoted to a single subject; others are monographic in character, either condensed or expanded. A uniform sandstone bed, free from fossils, is a comparatively simple record; a section like the Norwegian "Silurischen Etagen 2 and 3," described by Brögger, is a monograph of many parts and chapters. The thickness of the book is no indication of its scope.

The investigation of the geology of any given area may be described, continuing this similitude, somewhat as follows: The various rock formations spread out over the area must be viewed as historical documents. Each one contains a record of its time, local or provincial, limited or comprehensive in scope and has, also, chapters relating to earlier epochs. Each has usually various parts, and it may be expressive to say that they are written in different languages. The longest chapters may not contain the most important parts of the record. Indeed, if the observer's eyes are not properly trained, he may not realize the presence of the most valuable chapters. Clearly the geologist cannot recognize the essential characters of these documents if he fails either to note the important chapters, or, noting them, is unable to decipher their meaning. For the latter case, however, he may rely on the interpretation of others, provided he gives them opportunity.

The difficulties of these historical studies are greatly increased by the imperfections, or the gaps, in the record. Some records are not in the rocks themselves, but in their relations, as seen. Some volumes are now dismembered, and parts may have been lost. Juxtaposition of leaves in the present relations does not necessarily imply that they belong to a single volume. Chapters on the same phase of history, belonging to various volumes, may be indistinguishable and lie so related that the student who is a specialist in this phase will quite surely group them incorrectly in a single volume if he ignores, or is unable to see, the other chapters, by which their proper relations are indicated. It is the geologist's duty to group the various chapters correctly in parts and volumes, with an appreciation of their broad significance.

The geological map is comparable to a locality index to this mass of records. It shows where the records may be found, and in a measure the proper chronologic arrangement, the character, and the grouping of the works. It is the whole history which the compiler of this index must have in mind. If he presents merely an index to the lithology of the region, he is doing the work of the specialist. Of one thing he may rest assured, namely, that his arrangement and his characterization of the records will be scrutinized by other students, and if his estimate of a given volume is based upon half knowledge, the other chapters will be read by more thorough investigators and the superficial or limited character of his own work pointed out

WHITMAN CROSS.

LOESS WITH HORIZONTAL SHEARING PLANES.

WHILE engaged in field work on Pottawattamie county for the Iowa Geological Survey in the summer of 1900, a peculiar structure in the loess came under my observation. This appeared to me so unique as to merit special notice.

The loess in Pottawattamie county is of the usual western type. It is lighter in color, slightly coarser, and of a more open texture than the loess in the eastern part of Iowa and in Illinois. It is also heavier, and contains a greater number of fossils than the latter. In the east bluffs of the Missouri river it averages not far from a hundred feet in thickness in this county, and occasionally this measure is exceeded. It frequently contains fossils. In the north part of the county, and sometimes also in the south, it rests on a somewhat darker and more ferruginous deposit. This is similar to loess in appearance, but is less calcareous, in places sparsely pebbly, and much less pervious to water, owing to the presence among its particles of an exceedingly fine and silty ochreous ingredient. It resembles in general the "gumbo" which has been described by Leverett[1] as occurring under the loess in some parts of Iowa, Missouri, and Illinois. This gumbo changes downward into the old leached and weathered upper part of the underlying till. Its upper surface is sometimes marked by an old soil horizon.

The peculiar structure noted in the loess involves the horizon where the two formations just described come into contact; the level where the gumbo changes, gradually or abruptly, upward into loess. Perhaps it would be more accurate to say that it affects the top of the gumbo as well as the base of the loess.

Examining closely one day the lower part of the loess in an excavation southeast from the Pierce Street School in Council Bluffs (near the corner of Voorhees street and Franklin avenue), the lower part of the embankment was seen to be laminated, and

---

[1] *U. S. Geol. Surv., Mon. XXXVIII,* p. 28.

the lamination was apparently quite unlike that which results from sedimentation. To better ascertain the nature of this lamination a block of considerable size was detached and gently split by fracture along the planes of the laminæ. To my astonishment it revealed a surface strongly reminding of some gently fluted ice-scorings (see Fig. 1). I replaced the lower half of the block and took the bearings, south 60° west and north 60° east. Repeating the observation at several points along the embankment, I found the fluted ridges to pursue strictly the same trend at all places. I also noticed that this trend lay neither in the direction of a tangent nor of a radius to the periphery of the hill in which the excavation was made.

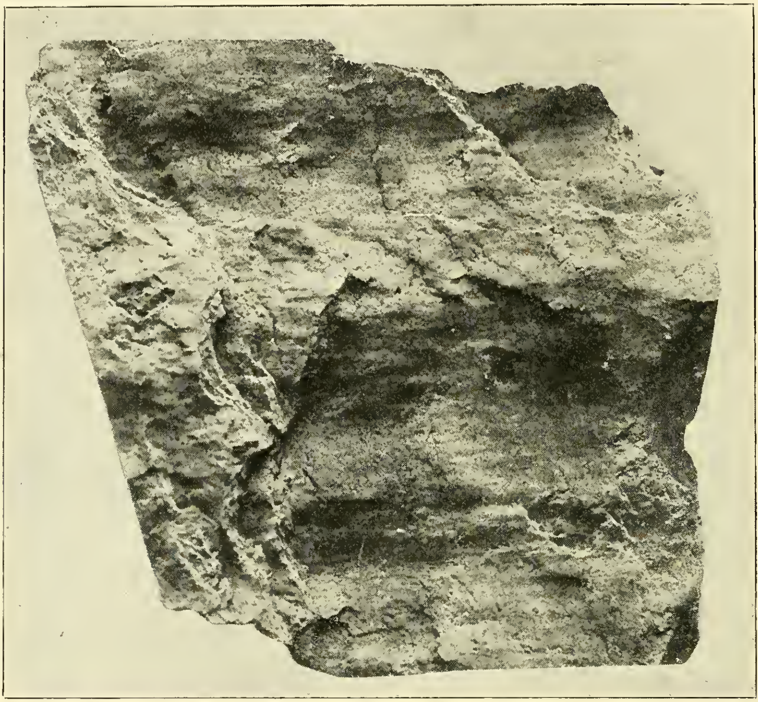


FIG. 1.—Fluted shearing-planes in the loess in Pottawattamie county, Iowa (slightly reduced).

In the continuation of my work in the north half of the county this lamination was observed at a number of other places as follows :

1. *Norwalk township*, in the west bank of the wagon road one-fourth of a mile south of the northwest corner of Section 9. Direction of flutings, S. 65° W.–N. 65° E.

2. *James township*, near the wagon road one-fourth of a mile south of the northwest corner of Section 12. Direction of flutings, S. 20° W.–N. 20°E.

3. *Boomer township*, in the left bank of the wagon road in the north bluff of Pigeon Creek, near the center of the northwest quarter of Section 33. Direction of flutings, S. 70° W.–N. 70° E.

4. *Neola township*, in the bank of the wagon road leading up the hill near the center of Section 24 (on the west border of the town of Neola). Direction of flutings varying from S. 70° W.–N. 70° E. to S. 78° W.–N. 78° E.

5. *Minden township*, in the wagon road near the center of Section 10. Direction of flutings, W. 15° N.–E. 15° S. Also in the north bank of the deep cut of the Chicago, Rock Island & Pacific Railroad about one-fourth of a mile north of the center of Section 21. Direction of flutings, W. 5° N.–E. 5° S. Also in the ditch on the north side of the embankment of the Chicago, Rock Island & Pacific Railroad about one-fourth of a mile east of the northwest corner of Section 19. Direction of flutings, W. 8° N.–E. 8° S. Also in both banks of the railroad cut just south of the bridge across Mosquito Creek in Section 19, east of the town of Neola. Direction of flutings, W. 10° N.–E. 10° S.

6. *Pleasant township*, in the west bank of the Chicago, Rock Island & Pacific Railroad, in the southeast quarter of Section 5. Direction of the flutings, S. 58° W.–N. 58°E. Also in the north bank of the wagon road near the southeast corner of Section 12, and again nearly one mile farther west along the same road. Direction of flutings in both places, S. 78° W.–N. 78° E.

7. *Knox township*, in the west bank of the wagon road just east of the bridge across Biddle Creek, north of the southeast corner of Section 2. Direction of flutings, N. 45° W.–S. 45° E.

8. *Layton township*, in the deep cut of the Chicago, Rock Island & Pacific Railroad, near the west line of Section 13. Direction of flutings, S. 14° W.–N. 14° E.

As seen at these points the laminæ vary from one-eleventh to one-thirtieth inch in thickness, one-sixteenth inch being the most common. There was nowhere any difference in the texture of the material of which they were composed. They are marked off from each other by sharply defined planes, along which the mass may be caused to split more or less readily. Occasionally layer after layer may be peeled off by the insertion of the blade of a knife in the seams which separate them. In one instance the surfaces exposed in this way were smoothened, as it were, by a thin film of dark ferruginous material which evidently had been deposited by infiltration along the seams separating the layers. The flutings are straight, compound folds in the layers. When the latter are viewed in a section vertical to the trend of the flutings, they appear as parallel, very shallow waves an inch or two in width. On these there is a second parallel system of small folds only about an eighth of an inch wide. These also have a very shallow depth, which barely renders them perceptible. Occasionally the layers wedge out, the seams separating them running together. To one familiar with the appearance of ripples and ripple marks, a glance at the surface of these layers in the loess suffices to show that they have nothing in common with the former. The ridges of ripple marks are never straight. Their opposite slopes are regularly unsymmetrical, always steeper in one and the same direction for successive waves. There is no second series of smaller waves parallel with the larger ones. Ripples are also somewhat uniform in size. They are invariably associated with sorting of coarse and fine materials. In vertical section the flowing curves of ripples constantly intersect. None of these characteristics appear here. The folds and flutings in the loess are straight, it might be said rigidly straight. The slopes of the folds are symmetrical, or irregularly unsymmetrical. There is also a considerable variation in size of the folds. As stated before, there is no sorting by which coarse materials have been separated from the fine. The partings between the layers tend to run parallel. When they do run together it is not with the flowing curves seen in the ripple marks. But an analysis of the difference between the two phenomena really blurs the vividness of the intuitive distinction perceived by direct inspection. The character of the surface exposed when the laminæ are laid bare along their partings is much more like that of slickensides or of stylolitic joints or of glacial fluting. There is no doubt whatever in my mind that *these partings represent shearing planes and that they have been produced by differential motion of the layers which they separate*.

What may have caused such shearing is a question difficult to answer. Local creeping appears to be the least far-fetched explanation. On steep and high slopes the ground sometimes slowly yields to gravity and moves forward and downward on an inclined plane. The horizontal ingredient in such motion is more or less vertical to the "strike" of the slope. Observations on the trend of these flutings soon brought out the fact that this bore no relation whatever to local or minor topographic features. Their direction maintains itself with only small variations for short distances, and at some places, apparently for miles, irrespective of local topography. Thus at Council Bluffs, in Kane township, in Norwalk, Booner, and Neola townships, the bearings of the flutings are respectively 60°, 65°, 70°, and 75° west of south and east of north. At the latter place, near Neola, it is variable, 70°, 75°, 78° west of south and east of north having been noted within a distance of twenty rods in the west part of the village. East of the town it is 10° north of west. For the next five miles east this direction prevails, three points showing a trend of 8°, 5°, and 20° north of west, all in Minden township. East of this the trend is again to the southwest, except at a point three miles northeast of Avoca, where it is west 45° north and east 45° south. On opposite sides of a hill or of a valley, it seems from some observations that the direction is the same, whether it be parallel, vertical, or at any other angle with the local relief contours.

The general trend of the flutings may be said to be from the northeast to southwest. This generalization is based on observations made at only fifteen localities, which are scattered over a territory thirty-six miles from west to east and fifteen miles from north to south. This seems an insecure and insufficient basis from which to draw the conclusion that the flutings have been produced by general movements of the loess in the direction indicated. Still this suggests itself as an alternative hypothesis, and it should be kept in mind, pending further investigation. The trends of the flutings are by no means more variable than the trends of ice scorings produced by glacial movements (see Fig. 2).

To account for such a general motion, which conceivably may have been very small, two different hypotheses suggest themselves: (1) Tundra conditions may have prevailed. On a sloping plain the annual temperature changes in a frozen tundra land would be apt to produce extensive creeping in the direction of least resistance, as toward a river. This would, no doubt, result in differential motion near the base of the frozen ground. (2) There may have been glacial conditions. With a sudden onset of arctic climate the area of accumulation of snow might extend far out beyond the margin of the ice pushing out from the region of greatest accumulation, and were the most severe climate not of too long duration, the main continental glacier might come short of extending over all of such extra-marginal and perennial fields of snow. There might then be an extra-morainic névé. Perhaps a certain distribution of precipitation might favor such

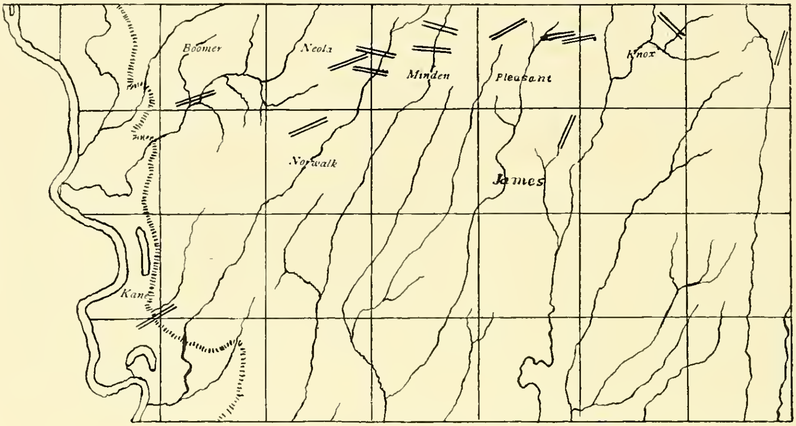


FIG. 2.— Map of Pottawattamie county, Iowa, showing the locations and the directions of flutings observed in the loess.

results. Over a snow-covered region of this kind there would be ideal conditions for loess-making. A slow creeping of the entire field might very well be supposed to take place in the direction of the general slope of the land.

It is not my desire to discuss these possibilities here. The object of this communication is merely to call attention to this new feature of the loess, and, if possible, thereby to secure more observations on its occurrence.

J. A. Udden.

Augustana College,
Rock Island, Ill.

THE PALÆONTOLOGICAL COLLECTIONS OF THE GEOLOGICAL DEPARTMENT OF THE AMERICAN MUSEUM OF NATURAL HISTORY.[1]

THE geological department of the American Museum of Natural History completed in December, 1901, the publication of a catalogue of the types and figured specimens in its possession, by R. P. Whitfield, assisted by the author of the present note. This work has been under way for several years, and in its published form makes up a book of more than five hundred pages, forming Volume XI of the *Bulletin* of the Museum. This is one of the oldest departments of the museum, and its chief possession is the great James Hall collection, which was acquired in 1875, and which placed it at once in the front rank of American museums containing similar material. This collection will always be the standard reference series for all workers in North American Palæozoic palæontology, since it contains a very large proportion of the specimens described and figured by Professor Hall in the course of his work on the *Palæontology of New York* up to the time of the purchase of the collection by the American Museum. From time to time the department has received other collections, through exchange and other means, but, with the exception of the Holmes collection, they contained few types at the time of their acquisition. Most of the "figured specimens" in the collections of the department are those which were identified, re-described, illustrated, and published by Professor Hall in the *Palæontology of New York*, and therefore they have almost the dignity and value of types.

Of the specimens described and illustrated in the quarto volumes of the *Palæontology of New York*, the Museum possesses two-thirds of those in Volume I, covering the Cambrian and Lower Silurian systems; nearly eight-tenths of those in Volume

---

[1] Read before the Geological Society of America at Rochester, N. Y., January 2, 1902.

II, extending from the Medina to the Onondaga stages, inclusive; three-fourths of those in Volume III, which treats of the Lower Helderberg and Oriskany groups; more than one-third of those in Volume IV, which describes the Brachiopoda of the Devonian system from the Upper Helderberg to the Chemung; about 30 per cent. of the specimens illustrated in Volume V, Part I, which is devoted to the Lamellibranchiata of the Upper Helderberg (or Corniferous), Hamilton, and Chemung groups; and a nearly equal proportion of the Cephalopoda and Gastropoda illustrated in Volume V, Part II. The collection, however, contains only about seventy-four of the specimens of Bryozoa given in Volume VI, and about seventy of the Crustacea illustrated in Volume VII of the *Palæontology of New York*. Much of the material for Volume VIII, on the Brachiopoda, was prepared for publication prior to 1876, hence a large proportion of the specimens used for illustrations are to be found in the American Museum, especially of those used for the plates bearing the name of R. P. Whitfield.

Most of the species in the volumes above mentioned were first published in the *Regents' Reports on the Condition of the State Cabinet* (or State Museum, as it is now called), but material from other states than New York was also used in these reports, and the American Museum has the fossils from the Wisconsin-Minnesota Cambrian beds described and figured in the *Sixteenth Report;* the Niagara material from Waldron, Ind., published in the *Twenty-eighth Report;* and the graptolites and the Wisconsin Niagara species given in the *Twentieth Report*. The Trenton fossils from Wisconsin described in the *Report of Progress of the Geological Survey of Wisconsin for 1861* are here, and the original descriptions have been republished with illustrations and notes by R. P. Whitfield in the *Memoirs of the American Museum of Natural History*, Volume I, Part II. The Museum has all the Warsaw fossils from Spergen Hill, Ind., originally published without figures by Hall in the *Transactions of the Albany Institute*, Volume IV, and republished by Whitfield with figures in *Bulletin Am. Mus. Nat. Hist.*, Vol. I. The collection also includes the type fossils from the Clinton beds at Arisaig, Nova Scotia, described by Hall in Volume V of the *Canadian Naturalist and Geologist;* many of the Devonian and higher forms described by the same author in the *Geology of Iowa* and the *Supplement to the Iowa Report*, the latter being republished with figures by Whitfield in *Mem. Am. Mus. Nat. Hist.*, Volume I, Part I; several type specimens of the Dictyospongidæ, some of which have been described by Whitfield in the *Bulletin of the Am. Mus. Nat. Hist.*, Volume I, and others by Hall and Clarke in a *Memoir on the Palæozoic Reticulate Sponges;* Hall and Meek's types from the Cretaceous of the Bad Lands of Dakota, Nebraska, and Wyoming, described in the *Memoirs of the American Academy of Science and Arts*, Volume V; the fruits and seeds from the Eocene beds at Brandon, Vt., described by Lesquereux and published in Hitchcock's *Geology of Vermont;* and some of the Cephalopoda, Gastropoda, and Lamellibranchiata described by Whitfield in his U. S. Geological Survey monographs on the *Cretaceous and Tertiary Fossils of New Jersey*. The museum also has the Holmes collection, which includes more than two hundred of the specimens described and figured by Tuomey and Holmes's *Pleiocene Fossils of South Carolina* and in Francis S. Holmes's work on the *Post-Pleiocene Fossils of South Carolina*. The fossils described in the various bulletins and memoirs of the American Museum of Natural History are here as a matter of course. In addition to the republication of certain of Hall's types already mentioned, there have been described and illustrated in the *Bulletin* a large series of fossils of Chazy and Birdseye age from Fort Cassin, Vt.; Beekmantown, N. Y., and other localities on Lake Champlain, and many Cretaceous forms from Beirût, Syria, and from Jamaica, W. I.

The catalogue has been issued in four parts. Part I, including the Cambrian and Lower Silurian forms, was issued in July, 1898; Part II, containing the Upper Silurian specimens, was issued in October, 1899; Part III, comprising the Devonian forms, came out in October, 1900; Part IV, containing the specimens from the Lower Carboniferous to the Quaternary inclusive.

and the index, preface, and table of contents of the whole volume, bears date of December 27, 1901.

This work has determined that there are in this department of the museum at least 6,166 type specimens, representing 2,222 species and 71 varieties; and 2,179 figured specimens, not types, representing 499 species and 119 varieties. Three-fourths of this material has come from the Palæozoic systems above the Cambrian.

EDMUND O. HOVEY.

PALÆONTOLOGICAL NOTES.

Lysorophus tricarinatus.—In 1877 Cope described from the Permian bone bed of eastern Illinois, three small vertebræ which he referred to a new genus and species, *Lysorophus tricarinatus*. The specimens were later redescribed and figured by the author in the Journal of Geology, Vol. VIII, p. 714, Plate II, Figs. 12*a*, 12*b*, 12*c*. This genus has not previously been recognized from any other locality, but in looking over a portion of the University of Chicago collection of Permian vertebrates from the Texas region I find the genus represented by some very interesting specimens. In a very restricted locality I found (the author collected the specimens here described) several series of vertebræ with attached ribs, which were peculiar in that the animal was evidently closely coiled when fossilization took place. This is such a persistent feature that some trace of it is noticeable in even the shortest series of vertebræ. It is difficult to explain this feature; the late Dr. Baur, before the specimens were identified, suggested that they might be embryos, but this seems rather improbable from the persistence with which the vertebræ cling together, and the very perfect degree of ossification. Another peculiarity is that the ribs are almost always attached but are crushed down and to the rear and are closely folded upon the vertebræ. In Fig. 1, Plate I, is shown one of the series of vertebræ with attached ribs, the curvature is not shown as it lies in the plane, perpendicular to the paper, but it is very noticeable in the specimen.

In the type specimens only the centra were known, and the deep pits on the sides, with the sharp intervening keels were made the determining characters of the genus. In the specimens from Texas, the neural arches are still in position, but the line of suture is very distinct; in the few vertebræ which have lost the neural arch, the characteristic angulation of the articular face of the centrum for the base of the neural arch, and the deep pit in the floor of the neural canal between the arches are very distinct. A further point of interest lies in the fact that the two sides of the neural arch are united at the top by suture only, this remains distinct through life, as it is clearly seen in the largest and best ossified specimens. The ribs have but one head, and there seems to be no articular face preserved, indeed, in many of the specimens it looks as if the rib had been anchylosed to the end of the transverse process and broken off when the ribs were bent down to their present position. In some of the vertebræ the end of the transverse process shows the articular face for the rib. The top of the neural arches was expanded so that it forms a broad, low arch which is longer than the centrum and overlies rather widely the anterior zygapophyses of the succeeding vertebræ, Fig. 2, Plate I, shows one of the larger vertebræ twice natural size.

MEASUREMENTS.

Height from bottom of centrum to top of neural arch, - -	7^{mm}
Greatest length of centrum, - - - - - - -	5
Greatest length of the upper portion of the neural arch, - -	7

With the specimens of the vertebral column of *Lysorophus* was found a fragment of a small skull consisting of the anterior portion of the snout as far back as the middle of the orbit, and the anterior portion of the attached lower jaw. There is no reason to connect this specimen with the others, except that it occurs in the same restricted locality, a few square yards, and that no other bones were found, even after a careful search. So far as the specimen goes, it corresponds almost exactly with the description and measurements of *Isodectes* (*Pariotichus*) *megalops* Cope. From the character of the deposits it seems very probable that the skull belongs with the other specimens, and that we may have the skull of *Lysorophns*, if so, however, the genus *Isodectes* must be removed from the *Pariotichidae* as the vertebral column of that family has nothing in common with that of *Lysorophus*. No trace of the limb bones were found, and this with the coiled and firmly articulated vertebral column with its strong ribs has a very snake-like character, and it seems probable that the animal was very long-bodied and slender.

Pelycosauria.—Among the specimens in the Chicago collection is a single sacral vertebra which presents some very interesting points. It is the anterior one of the sacral series, and to one side is attached the sacral ribs in the natural position. The rib is united by a close articulation to the centrum, and the distal face is much expanded and turned somewhat to the rear. The lower edge of the centrum is preserved, and shows that it had the same peculiar oblique form characteristic of the cervical and sacral series of the Texas *Pelycosauria.* But the main interest centers in the neural arch as shown in Figs. 3 and 4, Plate I.

The base of the neural arch is perorated on each side by a large foramen. Between the posterior zygapophyses a stout ridge extends up the middle of the spine, and there is a rudimentary articular process at the base of the ridge. The upper half of the posterior face of the centrum is broad and flattened, and evidently served to form a very strong articulation with the second sacral. This seems to indicate the beginning of a sacrum, or it may be pathological. Unfortunately the specimen was isolated when found, so that the relation to the succeeding vertebræ cannot be exactly determined.

The pelvic and thoracic girdles of the American *Pelycosauria* have as yet been almost unknown. Cope published a figure of the scapula and coracoid of *Dimetrodon* and the author published with Dr. Baur a figure of a second specimen of the same; both of these specimens were somewhat incomplete. In 1886 Cope published a figure of the interclavicle of a *Pelycosaurian.* A peculiarly perfect specimen in the Chicago collection makes it possible to restore the thoracic girdle with much certainty. There are preserved the clavicles of both sides, the interclavicle, the scapula with attached coracoid and epicoracoid bones of one side and less perfectly the same bones of the other side. One of the clavicles lies upon the outer, under, side of the anterior expanded end of the interclavicle and the other lies upon the scapula.

The interclavicle is somewhat broken and the outer edges of the expanded portion are broken away in places, but the main

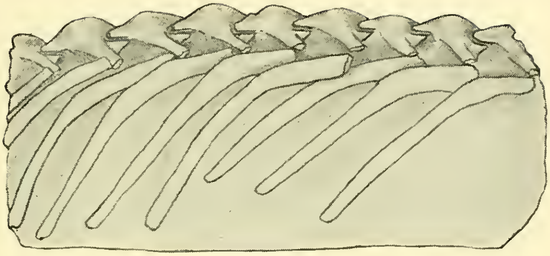


Fig. 1.

Fig. 2.

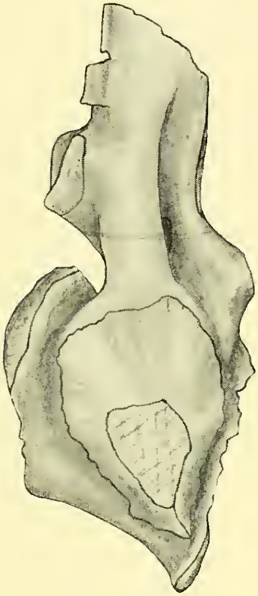


Fig. 3.

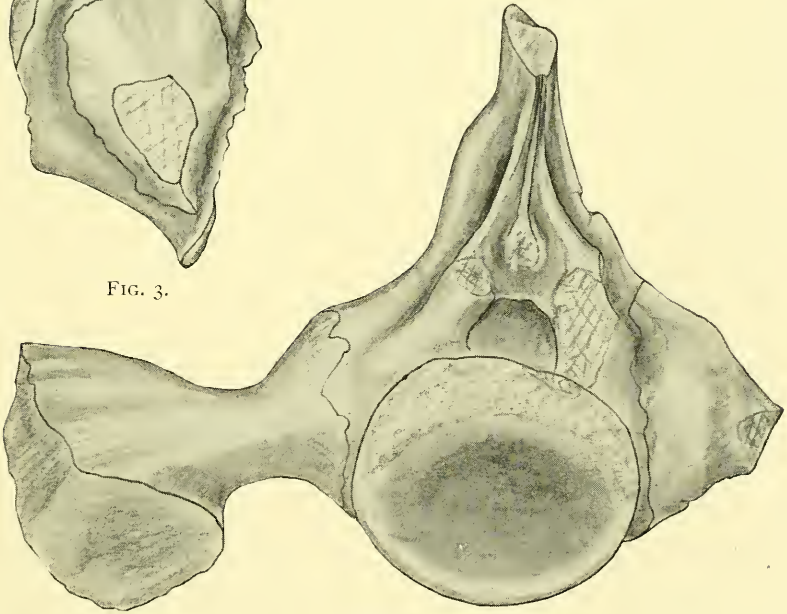


Fig. 4.

portion is preserved and it is evident that it does not differ materially from the form figured by Cope in 1886. The expanded end is very thin and the edges ended in digitate expansions. The posterior elongation is thicker in the middle, but thins out at the edges.

The clavicles are peculiar bones, widely expanded at the inner extremity where they overlap the interclavicle and with almost rectangular anterior inner corners. Toward the outer extremities they come almost to a point and in life overlay the middle portion of the scapula. The whole bone is slightly curved to conform to the girdle and is thin and plate-like at the inner portion and stouter and more rod-like distally. The prominence near the middle of the distal side is rugose and evidently served for ligamentous attachment.

The scapula and epicoracoid of one side are preserved almost complete and in the natural curvature; the coracoid is equally well preserved, but, as is common, separated from the others. (In the figure of the thoracic girdle the scapulæ appear slightly too long as in the representation on the flat the curvature does not appear.) The bones are quite similar to those figured in the papers cited, but the epicoracoidal edge is more rounded; the whole epicoracoid is very thin. The suture between the epicoracoid and scapula runs through the middle of the articular face for the humerus and then fades out into an almost complete anchylosis of the bones near the anterior edge. Fig. 6, Plate II, shows the scapula and epicoracoid without the coracoid in profile, giving a good idea of the curvature of the shoulder girdle.

The pelvis of the *Pelycosauria* has not previously been made out. Cope described what he considered to be the pelvis of *Dimetrodon*, but later discoveries showed it to be the pelvis of the amphibian *Eryops*. The same specimen which furnished the thoracic girdle described above affords an almost perfect pelvis. The bones are preserved in the same refractory iron-sand cement as the rest of the specimen and the slender edges of the bones have suffered accordingly, but the main portion of the bones remain and enough of the edges to make the restoration here given fairly accurate. The three bones meet in the center of a wide and rather shallow cotyloid cavity with a very prominent inferior-posterior lip projecting from the ischial portion. The ilium is rather blunt anteriorly and tapers posteriorly, the inferior edge is thicker and rather rod-like and the upper portion is thinner and more plate-like. Attached by the iron cement to the inner side of the ilium are the distal ends of three sacral ribs, the anterior shows the same characters as figured in the solitary sacral vertebra described above. The anterior upper edge of the pelvis, formed by the adjacent portions of the ilium and pubis is rather rugose. The pubis is rather elongate, the upper edge is thicker and the lower thinner and plate-like. The ischium has a very thick acetabular portion which forms a prominent lip as described ; the rest of the bone is very thin and is rather rounded in outline. Closely cemented to the inner face of the ischium figured is the lower portion of the same bone of the opposite side. This ischium differs quite markedly from another in the same collection which is much more elongate and slender.

It is peculiarly unfortunate that a specimen which is so completely preserved should be preserved in a cement so hard that it is only by the sacrifice of the superficial layer of the bone that it can be removed. Any attempt to remove the cement is an almost hopeless task as it strikes sparks from the chisel; however, enough has been made out to show that it contains a nearly perfect half of the skull, the majority of the vertebral column, most of the limb bones, and a nearly perfect anterior foot, all of which the author hopes to describe and figure at an early date.

E. C. Case.

State Normal School,
Milwaukee.

EXPLANATION OF PLATES I AND II.

Fig. 1.—Series of vertebræ from the middle portion of the column of *Lysorophus tricarinatus*. One-half natural size.

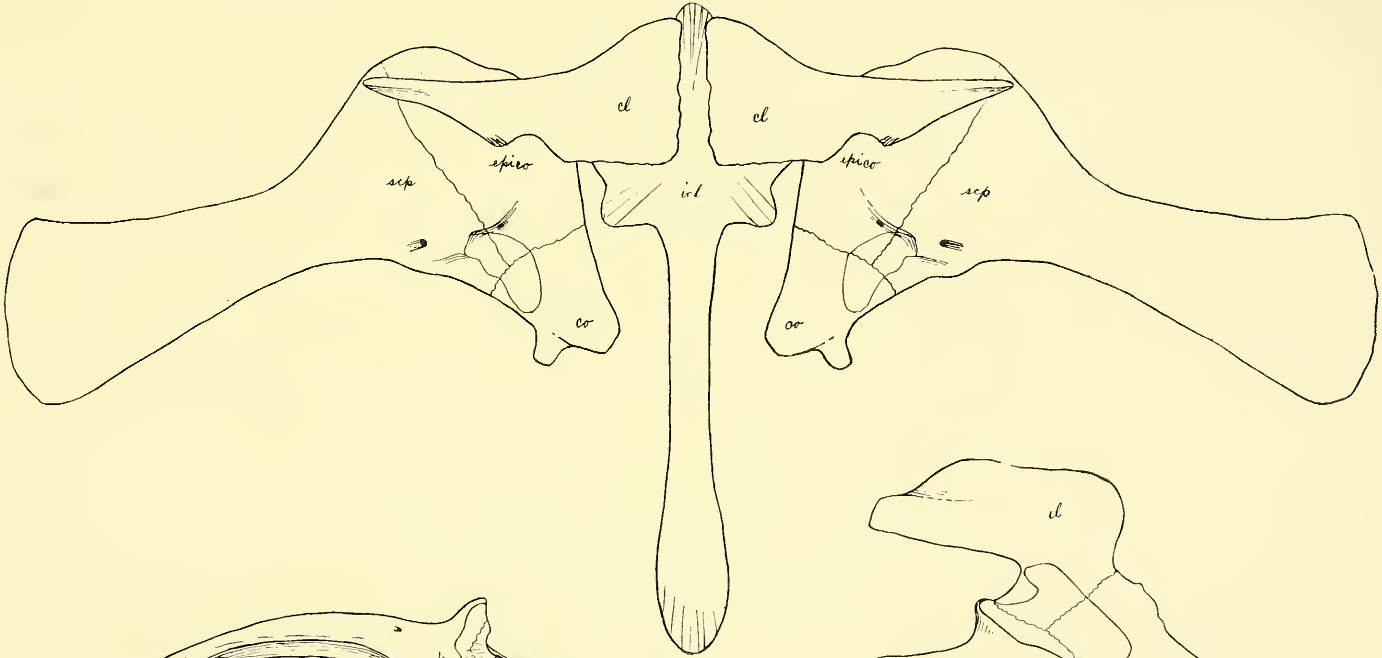


Fig. 5.

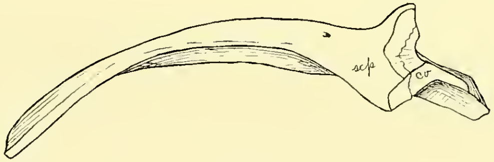


Fig. 6.

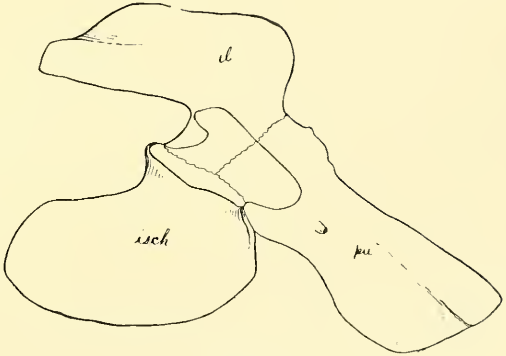


Fig. 7.

FIG. 2.—Vertebra from the middle portion of the column of *Lysorophus.* Twice natural size.

FIG. 3.—Lateral view of the first sacral vertebra of an undetermined Pelycosaurian. Natural size. The distal end of the sacral rib is detached.

FIG. 4.—Posterior view of the same vertebra with the distal end of the rib attached. Natural size.

FIG. 5.—Restoration of the shoulder girdle of a *Pelycosaurian*, *Embolophorous* (?). One-fourth natural size.

FIG. 6.—Profile view of the scapula and epicorcoid shown in Fig. 5. The coracoid is not shown. One-fourth natural size.

FIG. 7.—Restoration of the pelvis of the same animal as shown in Fig. 5. One-fourth natural size.

THE SUNBURY SHALE OF OHIO.[1]

CONTENTS.

INTRODUCTION.

Overlying the well-known Berea grit of Ohio is a black shale of somewhat variable though never very great thickness. It forms, however, a marked horizon in the Waverly series, and is very presistent in outcrop, extending from the Ohio river to northern Ohio, thence east nearly to the Pennsylvania line, and perhaps enters the state. On the south it crosses into Kentucky; but its extent in that state is not known. The older names, the Waverly black slate of Andrews and the Berea shale of Meek, when first applied to this shale were preoccupied, being in use for other geological divisions.

Professor Hicks at a later date gave the name "Sunbury shale" to a rather meager exposure on the bank of Rattlesnake Creek, about two miles east of the village of Sunbury, in the eastern part of Delaware county, Ohio, which is the first distinctive geographic name applied to this shale and therefore the one which, it appears to the writer, ought to be accepted for this formation. Recent examination of outcrops of this shale at different localities across the state has acquainted the writer with its characteristics, and furnished him with some facts which are perhaps worthy of record.

---

[1] Published by permission of Professor Edward Orton, Jr., state geologist of Ohio.

HISTORICAL REVIEW.

There have been different opinions regarding the age of the Sunbury shale, and mistakes in regard to its correlation between the northern and southern parts of the state, so that it is thought advisable to give a brief review of its literature.

The shale was first recognized and named by Professor E. B. Andrews, in 1870, from outcrops in the Ohio valley in Adams and Scioto counties. He stated:

> There is a remarkable exception to the general character of the Waverly group, in a stratum of highly bituminous black slate, which is found about 137 feet above the base. It is sixteen feet thick, and remarkably persistent in the Waverly, and is said by my associates to be found in the northern part of the state. . . . . It contains the same mollusca, genera and species, as the black slate [Huron shale] viz., Lingula sub-spatulata M. & W., and Discina capax? White. It also contains similar scales of small ganoid fishes. Besides these fishes there are remains of larger fishes.[1]

To this shale Professor Andrews gave the name of Waverly black slate, and reported that it "is evidently a very widespread stratum. It is not only found extending through the Waverly formation to the north, but it evidently accompanies the Waverly rocks in their dip under the Coal-measures."[2]

In 1873, in describing the geology of Cuyahoga county, Dr. Newberry mentioned that the lower part of the Cuyahoga shale immediately overlying the Berea grit at Berea and Chagrin Falls contained "myriads of *Lingula melie* and *Discina Newberryi.* With these are a few scales of *Palæoniscus*, a Carboniferous ganoid and teeth of *Cladodus*, a Carboniferous shark."[3]

Under the description of Summit county occurs a similar statement, where it is reported that "at the base of the formation [Cuyahoga shale], however, immediately over the Berea grit, the Cuyahoga shale is sometimes crowded with millions of *Lingula melie* and *Discina Newberryi.*"[4]

In 1874, Dr. Newberry apparently correlated the Waverly

---

[1] *Geol. Surv. Ohio,* "Rept. of Progress in the Second District" [in 1869], 1870, p. 65.

[2] *Ibid.*, p. 66.

[3] *Rept. Geol. Surv. Ohio,* Vol. I, Pt. I, pp. 185, 186.

[4] *Ibid.*, p. 212.

black shale of southern Ohio with the Cleveland shale of northern Ohio. It will be remembered that the Bedford shale underlies the Berea grit in northern Ohio, and next lower is the Cleveland shale, which Dr. Newberry considered as the lowest division of the Waverly group. Dr. Newberry wrote that from northern Ohio "south to the Ohio river, the Cleveland shale is met with in various sections of the Waverly, but diminishing in thickness in this direction."[1]

And in reference to Professor Andrews' report of 1870 is the statement that he "mentions in his report that two fossils, *Lingula subspatulata* and *Discina capax*, are common to the Huron shale and the 'Waverly black slate' (Cleveland shale). This is probably an error of identification as, so far as yet known, the fossils of the two formations are quite distinct."[2]

The above interpretation of Dr. Newberry's correlation is supported by Dr. Orton's account of the Waverly group of Pike county, in which he states that:

> Immediately above the Waverly quarries comes in a very interesting formation, to which attention has been repeatedly called in the previous reports of the survey. The formation in question has been designated by the chief geologist the "*Cleveland shale*," and by Professor Andrews the "*Waverly black slate*." It consists of a black shale more highly charged with bituminous matter than the great black slate below it, the proportion sometimes rising as high as 24 per cent. Unlike the slate below it, viz., the Huron, it is often highly fossiliferous. Two species of brachiopods are especially abundant in it, viz., *Discina capax* and *Lingula sub-spatulata*. The remains of fishes are also of frequent occurrence. Its thickness, as measured in the Scioto valley, varies from seventeen and a half feet to twenty-seven feet.[3]

Dr. Orton also describes this black shale in his account of the geology of Ross county, and correctly reported the names of the two fossils which are abundant in the shale. His account is as follows:

> The greatest thickness yet observed in this formation is found in Franklin township, near the mouth of Stony Creek, where it measures not less than twenty-seven feet. It is charged at this point with its characteristic

---

[1] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. I, "Geology," 1874, p. 93.

[2] *Ibid.*, p. 96.

[3] *Ibid.*, p. 624.

fossils, *Lingula melie* and *Discina Newberryi*, and the remains of fishes, often in an excellent state of preservation, can hardly be called rare. The teeth and the plates are the parts generally shown.[1]

Professor N. H. Winchell, who wrote the geological description for several counties in northern Ohio, identified numerous outcrops of the Berea grit in northern central Ohio in Crawford, Morrow, and Delaware counties,[2] but probably did not find outcrops of the superjacent black shale, as it is not mentioned. There was no doubt in his mind regarding the identification of the Berea grit, as may be seen by the statement at the close of his account of the sections and the distribution of the formation in Delaware county, where he says:

> In general, the Berea grit in Delaware county is a very excellent stone for all purposes of building, and is very extensively quarried at Sunbury. It appears however, to be of a finer grain than in the northern part of the state, and the massive beds that characterize it in Lorain county are entirely wanting.[3]

Professor Winchell had studied the Berea grit at typical localities in the northern part of the state, and he correctly identified it as far south as near the southern line of Delaware county, in Harlem township. Had his correlation been accepted by later observers, the confusion which existed for several years regarding the correlation of the Waverly formations of northern and southern Ohio would have been obviated.

In 1875 Meek, in giving the horizon of *Discina* (*Orbiculoidea*) *Newberryi* Hall, stated that certain specimens came "from the Berea shale, a member of the Waverly group of the Lower Carboniferous,"[4] which is apparently the first usage of this name in a stratigraphical sense, although it does not clearly appear that Meek intended to recognize the shale as a stratigraphic unit.

In 1878, Dr. Orton published his *Report on the Geology of Franklin County*, in which it was stated that in the county the following divisions of the Waverly series arranged in ascending order are shown, viz., Waverly shales, ten to twenty feet; Wav-

---

[1] *Ibid.*, pp. 648, 649. [2] *Ibid.*, pp. 240, 259, 280. [3] *Ibid.*, p. 282.

[4] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. II, "Palæontology," 1875, p. 278; also see statements in explanation of Plate XIV.

erly quarry system, sixty feet; and Cleveland shales fifteen feet.[1]

There was also reported a band of red or chocolate colored shale from fifteen to twenty feet in thickness at Taylor's Station, Jefferson township, and at several points in the eastern bank of Big Walnut Creek in Mifflin and Blendon townships,[2] which Dr. Orton considered the uppermost part of the Huron shale. This red shale, however, and the overlying Waverly shales represent the Bedford shale of Dr. Newberry's classification in northern Ohio. The Waverly quarry system is the Berea grit, although Dr. Orton in referring to Professor N. H. Winchell's report on Delaware county, in which outcrops at Sunbury and other localities in that county are correlated with the Berea grit, stated that "The Sunbury stone is erroneously referred in Vol. I [Vol. II], p. 282, to a higher division of the Waverly, viz., the Berea grit."[3] Finally, Dr. Orton stated, concerning the upper division of the Waverly as reported for Franklin county, that:

> The Cleveland shale of Dr. Newberry, the Waverly black shale of Professor Andrews, ... is known at but a single locality in the county, viz., at Ealy's Mills, in Jefferson township, on the banks of Rocky Fork. From ten to fifteen feet of this formation are here shown within the compass of an acre. The stone immediately underlying the black shale is quarried for local use, so that the line of junction is very distinctly seen at several points. The black shale lies upon the flat surface of the sandstone without the interposition of any other material whatever. A geological boundary cannot be more distinct than this. . . . . The surfaces of many slabs are thickly covered with the teeth and plates, and bones of the sharks and ganoids of this early day. Two brachiopods also, *Lingula melie* Hall, and *Discina Newberryi* Hall, are abundant here, sometimes wholly covering the surface of the beds. The anomalous but very interesting fossils termed *conodonts* are found in great numbers and in exquisite preservation in the shales of this locality.[4]

It is now known that the Cleveland shale is older than the Waverly black shale of Professor Andrews, and that the black shale on Rocky Fork is the continuation of the Berea shale of

---

[1] *Rept. Geol. Surv. Ohio*, Vol. III, Pt. I, "Geology," p. 639.

[2] *Ibid.*, p. 638. [3] *Ibid.*, p. 642. [4] *Ibid.*, p. 642.

Meek, which is represented in the Ohio valley by the Waverly black shale of Andrews.

In July, 1878, Professor L. E. Hicks, of Denison University, published "the discovery that an unmistakable outcrop of Cleveland shale exists two miles east of Sunbury in Delaware county, southern [central] Ohio, on the land of Horace Whitney. It lies *above* the calcareous sandrock of the Sunbury quarries, which Professor N. H. Winchell, a special assistant on the Ohio Geological Survey, identified as *Berea grit.* My discovery *demonstrates* the incorrectness of that identification, and raises strong presumption, amounting almost to a certainty, that he was equally wrong in respect to his Berea grit in Morrow and Crawford counties." [1]

Professor Hicks was mistaken in this identification, and his conclusion regarding Professor Winchell's work was likewise erroneous ; for the black shale which Hicks called the Cleveland is the Berea shale of Meek resting on top of the Berea sandstone, and therefore Professor Winchell's identification was correct.

In the September number of the same periodical, Professor Hicks named and described the divisions of "the Waverly group in central Ohio," or, "the strata lying between the Huron shales (Devonian) and the base of the Coal-measures," selecting "names derived from localities in Licking and Delaware counties." [2] In ascending order these names are (1) "Sunbury calciferous sandrock," 90 to 100 feet thick, which is the Berea grit; (2) "Sunbury black slate," from 10 to 15 feet in thickness, which is the Berea shale; (3) "Raccoon shales," 300 feet thick, a good exposure of which occurs on Moot's Run, a tributary of Raccoon Creek, four and one-half miles west of Granville, which are the equivalent of at least the lower and middle portions of the Cuyahoga shales of northern Ohio; (4) "Black Hand conglomerate and Granville beds," 85 to 90 feet thick; and (5) "Licking shales," from 100 to 150 feet thick.[3] In addition to

---

[1] *Am. Jour. Sci. and Arts*, 3d ser., Vol. XVI, p. 71.

[2] *Ibid.*, p. 216.

[3] *Ibid.*, p. 216.

the localities suggested by the names of these last two divisions the quarry beds of No. 4 are excellently shown in the Vogelmeier and Haven's quarries south of Newark and the Licking shales in "the gorge" to the southeast of Haven's quarry and Newark. These last two divisions of southern central Ohio were termed by Dr. Orton the Logan group.

In this paper Professor Hicks states:

> The Cleveland shale has been assumed by the Ohio geologists to be equivalent to the Waverly black slate, which is undoubtedly the same as that at Sunbury. At the time I discovered the outcrop at Sunbury I supposed there was no doubt of the correctness of this assumption. Now, however, Dr. Newberry asserts positively that there is *no evidence*, that they are identical.[1]

This is the first published statement, as far as the writer is informed, calling in question the correlation of the Waverly black slate of southern Ohio with the Cleveland shale of the northern part of the state; so it would appear that, as early as the summer of 1878, Dr. Newberry was aware of the mistake in his earlier correlation of these shales. Furthermore, Professor Hicks states that if Professor Winchell was correct in calling the Sunbury quarry stone the Berea grit, then "the chocolate shale described by President Orton as constituting the upper part of the Huron may be of the same age as the Bedford shales, as they were supposed to be by Dr. Newberry.[2] This appears to be the first published tentative identification of the Bedford shale in central Ohio, for in Dr. Newberry's account of the Carboniferous system, published in 1874, he stated:

> South of the Western Reserve the Bedford shales are scarcely distinguishable as in the central and southern portions of the state they assume the prevailing character of the Waverly group, and blend with the other portions of the series.[3]

The writer is not aware of any published opinion of Dr. Newberry's regarding the correlation of these red shales of Franklin county with the Bedford shale of northern Ohio.

In August of the following year, Dr. Orton published a

---

[1] *Ibid.*, p. 221. [2] *Ibid.*, p. 221.

[3] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. I, p. 92.

"Note on the Lower Waverly Strata of Ohio," in which the black shale of southern Ohio is for the first time correctly correlated with the black shale overlying the Berea grit in northern Ohio. Dr. Orton said:

> The identify of the Waverly black shale of southern Ohio and the Cleveland shale of northern Ohio, which was suggested as probable ten years since by Dr. Newberry, and which has since been adopted by most of those who have written on the geology of the Waverly group in Ohio, proves to be an error. . . . . The Waverly black shale finds its place directly above the Berea grit to the northward. The stratum has been distinctly described in the reports on the northern counties, but it has not been distinctly named. It has been treated of as the dark, fossiliferous shale at the base of the Cuyahoga shale. No better name could be found for it than Berea shale — for it makes the roof of the Berea quarries, just as it does of the lower Waverly quarries of Pike county.[1]

Dr. Orton made no reference to the paper of Professor Hicks of the preceding year in which he gave the name of Sunbury black slate to this formation in central Ohio; nor to Winchell's earlier correct identification of the Berea grit in central Ohio.

Dr. Orton gave a table correlating the Waverly formations of northern with those of southern Ohio. In this table the 75 feet of Bedford shale in the north is given as synchronous with the 90 feet of Waverly shale in the south; the 60 feet of Berea grit is equivalent to the 60 feet of the Waverly quarries and overlying blue shale; and the 10 feet of Berea shale is correlated with the 15 feet of Waverly black shale; while the 150 to 250 feet of Cuyahoga shale is represented by 300 to 400 feet of shale and sandstone in southern Ohio.[2]

In 1881, Dr. Orton read a paper before the American Association for the Advancement of Science, at Cincinnati, on "The Berea Grit of Ohio," in which he emphasized the fact that there is no serious difficulty in tracing the formation across the state, and again reviewed the correlation of the Waverly formations between northern and southern Ohio. In reviewing the earlier correlation he said:

> It will be observed that a comparatively thin bed of black shale occurs

---

[1] *Am. Jour. Sci.*, 3d ser., 1879, Vol. XVIII, p. 138.

[2] *Ibid.*, p. 139.

in northern Ohio, overlain and underlain by blue shales, viz., the Cleveland shale, overlain by the Bedford and underlain by the Erie shale. A bed of black shale with similar boundaries has been noted in southern Ohio, viz., the Waverly black shale of Andrews. This latter stratum was assumed to be the true equivalent and extension of the Cleveland shale, and its fossils soon came to be credited to the latter. This identification placed the Berea grit of the north and the Buena Vista quarries of the Ohio valley on the same horizon.[1]

Dr. Orton stated that Professor N. H. Winchell first traced the Berea grit to central Ohio, as has already been shown in this paper; but he further said that "the Waverly quarry stone had been followed from the southward" to this part of the state, and "to abandon the preconceived error . . . . cost time and trouble." This, as far as the writer is aware, is the nearest published reference made by Dr. Orton to his classification of the Waverly rocks in the Franklin county report which has already been reviewed. Dr. Orton also reported that:

> The Waverly black shale of southern Ohio proves to be the black base of the Cuyahoga shale of northern Ohio, instead of the Cleveland shale, to which it was at first referred. The Waverly blue shale of southern Ohio is the Bedford shale of the north, like it also carrying enough peroxide of iron to redden it in many instances.[2]

In 1882, in discussing the source of the bituminous matter in the Devonian and Subcarboniferous black shales of Ohio, Dr. Orton wrote as follows:

> There are three strata of black shale in the Devonian and Subcarboniferous series of Ohio, viz., the Huron and the Cleveland shales of Newberry and the Waverly black shale of Andrews. The latter name I have followed Meek in replacing by the designation "Berea shale." It constitutes the base of the Cuyahoga shale of Newberry. . . . . The Berea shale, which directly overlies the Berea grit, ranges from 15 to 50 feet in thickness, and is separated from the great black shale [Ohio shale] by an interval of 100 to 150 feet, the interval being occupied by the Bedford shale and the Berea grit of Newberry. In northern Ohio the upper boundary of the Berea shale is not well defined. In central and southern Ohio it is sharp and distinct.[3]

In 1888, Dr. Orton described the Berea shale in his account

---

[1] *Proc. Am. Assoc. Adv. Sci.*, Vol. XXX, 1882, p. 170.

[2] *Ibid.*, p. 171.

[3] *Am. Jour. Sci.*, 3d ser., Vol. XXIV, p. 171.

of the "Geology of Ohio,"[1] but added nothing to what has already been cited, and this account was republished in 1893.[2]

Professor Cushing reported the Berea shale in northeastern Ohio, with a thickness of 40 feet overlying 35 feet of Berea grit, near the Pennsylvania line, and farther west in his section through Warren, Trumbull county, 55 feet of Berea shale.[3]

For some years Professor C. L. Herrick studied the Waverly series, and in his general conclusions introduced the term "Berea" or "Transition series," which included the rocks from the base of the Cleveland shale to either the bottom or top of a conglomerate in the upper part of the Waverly, which he called conglomerate I.[4] It is not clear whether this conglomerate was included in the Berea series or not, for on page 100 it is given in this series, but on page 105 it is given in the overlying Kinderhook division. One of the divisions of the Berea series he called the Berea shale, but included in it not only the black shale which Dr. Orton called the Berea, but also the greater part of the overlying Cuyahoga shale as defined by Dr. Orton. The upper 40 feet of shale in the Berea series underlying conglomerate No. 1 was called the Waverly shale.[5]

In a later paper, however, Professor Herrick was not inclined to extend the limits of the Berea shale beyond those of Dr. Orton, for he wrote as follows, under the heading "Berea Shale":

> This term is conveniently applied to the thin band of bituminous shale above the [Berea] grit and perhaps should not be extended (as the writer has done in a previous paper) to the gray and blue shales above. In southern Ohio it varies from fifteen to twenty feet in thickness and is little more than two feet thick at Chagrin Falls.[6]

Mr. W. F. Cooper, who continued the investigation of Professor Herrick on the Waverly series, used the term "Berea shale" in the sense in which it was first used by Professor Herrick; but made two divisions, viz., first, the lower Berea

---

[1] *Rep. Geol. Surv. Ohio*, Vol. VI, pp. 36, 37.

[2] *Ibid.*, Vol. VII, p. 30.

[3] *Proc. Am. Assoc. Adv. Sci.*, Vol. XXXVI, 1888, p. 214.

[4] *Bull. Denison Univ.*, Vol. IV, 1888.

[5] *Ibid.*, pp. 106, 107.

[6] *Bull. Geol. Soc. Amer.*, Vol. II, Jan. 1891, p. 35.

shale, resting on the Berea grit, 180 feet (?) in thickness, capped by the upper Berea shale, 30 feet thick, which was described as "the most fossiliferous zone yet found in the Waverly of Central Ohio."[1] Later, however, Mr. Cooper used the term "Berea shale" in the sense in which it was used by Dr. Orton, for he wrote as follows:

> The Berea shale is immediately over the Berea sandstone. . . . . This horizon has also been called the Waverly black shale, by Andrews, varies in Ohio from 15 to 50 feet in thickness, throughout the line of outcrop, and is an exceedingly persistent and well defined horizon.[2]

In 1889, Dr. Newberry gave the thickness of the Waverly group in northeastern Ohio as about 500 feet, which he stated was composed of the following divisions:[3]

		Average thickness.
1.	Cuyahoga shale	230 feet
2.	Berea Shale	20
3.	Berea Grit	60
4.	Bedford Shale	75
5.	Cleveland Shale	50

He also referred to Professor Hicks' announcement of the discovery of the Cleveland shale in Delaware county, and stated that:

> I think he has found there the Berea shale, which lies immediately above the Berea grit. This latter shale is persistent southward, and is apparently the black shale, so rich in fish remains at Vanceburgh, Kentucky. I suspect the Cleveland shale does not pass south of the line of the Western Reserve.[4]

The above clearly shows that Dr. Newberry abandoned his early idea of the extension of the Cleveland shale across the state, and accepted the later correlation of the Berea shale of northern with the Waverly black shale of southern Ohio.

DISTRIBUTION.

CENTRAL OHIO.

Rattlesnake Creek near Sunbury.—In this account of the distribution of the Sunbury shale across the state we will begin with

---

[1] *Bull. Sci. Lab. Denison Univ.*, Vol. V, 1890, pp. 25, 26.

[2] *Geol. Surv. Michigan*, Vol. VII, Pt. II, 1900, p. 286.

[3] *Monographs U. S. Geol. Surv.*, Vol. XVI, "The Palæozoic Fishes of North America," p. 120.

[4] *Ibid.*, p. 129.

the locality in central Ohio, which has furnished its name, and then describe some of the more important outcrops from there south to northern Kentucky. Returning to Sunbury, its outcrop will then be traced to the north and east nearly to the Pennsylvania line.

The Sunbury shale was named by Professor Hicks in 1878, from exposures on Rattlesnake Creek, on the present farm of Amasa Whitney, about two miles east of Sunbury, Delaware county.[1] If an opportunity remained to select a place for the name of the formation, a much more conspicuous outcrop might be found, but as this has been regularly defined and published it is the writer's opinion that Sunbury shale should be accepted. Professor Hicks described the formation as "a black, bituminous shale containing shells of *Lingula* and *Discina* and spines, scales, and teeth of fishes. But one outcrop of it is known in Delaware county, and that was revealed only by a systematic search of a day and a half."[2] Some three and one-half feet of this shale is shown on the northern bank of Rattlesnake Creek a short distance north of the house of Amasa Whitney. As exposed it is black and argillaceous, rather rotten from weathering, greatly iron-stained between the layers with some lighter colored blotches, and contains iron pyrites. Below this outcrop, at irregular intervals, there are several exposures of the shale on the bank of the creek, and in a loose piece a specimen of a fairly large *Lingula* was found, which was the only fossil secured at this locality. The lower part of the shale, however, in which fossils are generally the most abundant, is not shown here, and the top of the Berea grit forms the bed of the creek a little below the house of Mr. W. P. Swallow. The upper layer of the Berea is greatly iron-stained, contains considerable iron pyrites, and has quite an irregular surface.

A little further down the stream is an outcrop on the southern bank where between two and three feet of thin bedded sand-

---

[1] *Am. Jour. Sci.*, 3d ser., Vol. XVI, pp. 216, 219, 220. Also see p. 71 for a further account of the locality.

[2] *Ibid.*, pp. 219, 220.

stone is shown. It is buff to bluish-gray in color, much of it quite iron stained, of fairly fine grain and somewhat friable. There is no question but that these outcrops just below the house of Mr. Swallow are in the very upper part of the Berea grit.

Rocky Fork.—Dr. Orton noted "an outcrop of black shale on the farm of Lorenzo Taylor, Esq., of Plain township," in the northeastern part of Franklin county, which he stated "may prove to belong to the Cleveland shale."[1] This outcrop has not been seen by the writer, but it is probably in the Sunbury shale, since it is situated about in the line of strike of this formation.

The best exposure of the Sunbury shale in central Ohio is on the banks of Rocky Fork, in Jefferson township, in the eastern part of Franklin county, 2.3 miles northeast of Gahanna. It is well shown on the banks of the creek, both below and above the highway bridge, on the David S. Stagg farm. The first high bank on the eastern side of the creek below the bridge gives a fine exposure of the middle and upper part of the Berea grit, capped by the lower half of the Sunbury shale. The section of this bank is as follows, and it is shown in Fig. 1.

ROCKY FORK SECTION.

No.		Thickness feet.	Total thickness feet.
6.	Soil and drift - - - - - - - - - - -	7	37
5.	*Sunbury* black argillaceous shale, capping the Berea grit, the contact of which is finely shown on the vertical bank. About 8 inches above the base of the shale is a zone of fossils in which *Lingula melie* Hall was obtained - - - - - - -	7	30
4.	Thick stratum of light gray sandstone forming the upper part of the *Berea grit* - - - - - - - - -	6¾	23
3.	Parting of shaly sandstone to shales - - - - - -	....	....
2.	Zone of light gray to bluish-gray sandsone, somewhat irregularly bedded, and lenticular with some shale partings - - -	12	16¼
1.	Shaly sandstone alternating with layers of shale, Berea grit to creek level. - - - - - - - - - -	4¼	4¼

The lower two or three feet of Sunbury shale capping the Berea grit is also shown on the western bank of the creek somewhat above the cliff just described; while at various places on

---

[1] *Geol. Surv. Ohio*, Vol. III, p. 643.

the bank and in the bed of the creek are magnificent examples of ripple marks in the fairly thin layers of Berea sandstone.

Just above the highway bridge is an old quarry in the upper part of the Berea grit, some of the layers of which are bluish in color. Capping the sandstone is the lower two feet or more of the black argillaceous Sunbury shale, and at this locality the clearly shown contact of the two formations may be closely examined. The black shale splits into thin layers, and one of these, a few inches above its base, contains abundant specimens of *Lingula melie* Hall and *Orbiculoidea Newberryi* (Hall), Herrick,[1] together with fragments of fish bones and teeth. Farther up the creek, on the same bank, 8 feet or more of the shale is shown.

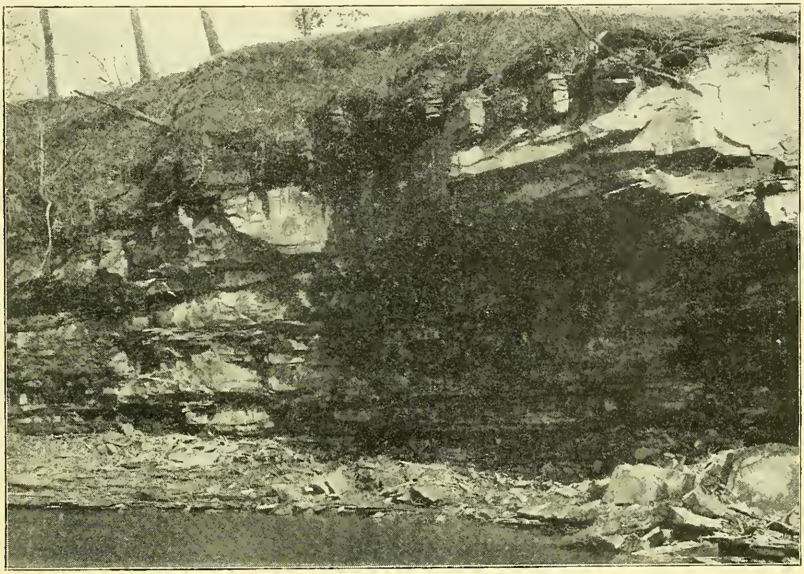


FIG. 1.—Contact of Berea sandstone and Sunbury shale on Rocky Fork, two miles northeast of Gahanna. The thin bedded Sunbury shale is shown in the upper part of the cliff resting on a thick sandstone layer at the top of the Berea.

On the eastern bank of the creek, not far above the highway

---

[1] Mr. Schuchert refers this species to Whitfield's genus of *Lingulodiscina* (*Bull. U. S. Geol. Surv.*, No. 87, p. 261).

bridge is a rock cliff, the lower 5½ feet of which, to the creek level, is the upper part of the Berea grit, while above is 7± feet of the Sunbury shale capped by drift and soil. The contact of the Sunbury shale and Berea grit is also nicely shown in this outcrop.

At this place was formerly a mill known as Ealy's, and this is the locality which was said by Dr. Orton to be the only one in Franklin county where the Cleveland shale of Dr. Newberry or the Waverly black shale of Professor Andrews was known. He stated that "from ten to fifteen feet of this formation are here shown within the compass of an acre."[1]

Some difficulty was experienced in obtaining the thickness of the Berea grit at this locality, and in a former paper the writer has given it as "about 40 feet."[2] South of the bridge, however, the first steep bank on the eastern side of the creek below the one which furnished the above section, apparently gives the base of the Berea grit, and unquestionably its top, so that we probably have the entire thickness of the formation given in this nearly vertical cliff. The Sunbury shale on the bank a little back of the edge of the cliff had not been noticed when the former paper appeared, although the apparent contact of the Berea grit and Bedford shale near the base of the bank was observed. The section of this bank is as follows:

No.		Thickness feet.	Total Thickness feet.
3.	Black argillaceous shale in thin layers; the base of the *Sunbury shale* - - - - - - - - - - - - - -	3	39½
2.	*Berea grit*, the upper part of which consists of fairly massive sandstones, the layers a foot or more in thickness, while the basal part is composed of thin bedded sandstones, and all through the formation shale partings occur at irregular intervals. Below these thin bedded sandstones are grayish shales, so that the entire formation is apparently shown between these two shales - - - - - - - - - - - - - -	33½	36½
1.	Grayish to bluish-gray, somewhat arenaceous shales to the creek level, which are considered as at the top of the *Bedford shale*.[3]	3	3

---

[1] *Geol. Surv. Ohio.* Vol. III, p. 642.

[2] JOUR. GEOL., Vol. IX, 1901, p. 218.

[3] As is well known "Bedford oölitic limestone" has been used as the name of a Subcarboniferous formation in Indiana. The question has arisen whether Bedford

On the western bank of the creek, at the first cliff below the one just described, is a concretionary sandstone, the layer about 1 foot 8 inches in thickness, below which are grayish shales partly covered to the creek level. Above the concretionary sandstone are 7 feet 8 inches of shales, which are mainly argillaceous but become arenaceous at the top. These shales are succeeded by thin bedded sandstones, which are thicker above, showing at one place a conspicuous concretionary layer, and these sandstones are clearly in the Berea. When traced up the creek, however, the lower concretionary sandstone is apparently near the horizon regarded as the base of the Berea in the preceding section, and it is therefore thought to correspond more nearly with the base of the formation than the higher thin bedded sandstones. If this be accepted, however, as the base of the Berea, then there is 7⅔ feet of shale included in the lower part of the formation. In the short distance between these two cliffs a rapid change in lithologic character is indicated and the lower limit of the formation must therefore be regarded as a rather variable line.

Somewhat below this bank is a bend in the creek, where a steep cliff with a conspicuous tree near its edge is shown on the same side of the creek. At this locality the upper part of the Bedford shale is finely shown, as well as the transition into the Berea grit. The section is as follows:

should be retained as the name for the Indiana or Ohio formation, and both views have been pretty fully given in the JOURNAL OF GEOLOGY (see Vol. IX, April–May, pp. 215, 232–36, 267–72). Later the writer referred the matter to the committee on geologic names of the United States Geological Survey, which has been organized for the consideration of similar questions in geologic classification and nomenclature, and the following decision has been communicated by the director, Hon. Charles D. Walcott: "(1) That Bedford rock was used by Owen in 1862 in a *Report of Geological Reconnaissance of Indiana*, 1859–60, p. 137, but the usage is so indefinite as not to constitute a preëmption of the term for stratigraphic purposes. (2) Bedford shale is a term first employed by Newberry in *Ohio Geological Survey Report of Progress*, 1869, p. 29, and this usage should stand. Furthermore, it is understood here that Mr. Cumings has recently proposed to drop the name of Bedford limestone of Indiana, and substitute for it Salem limestone."

No.		Thickness feet.	Total thickness feet.
6.	Soil and drift	6	56½
5.	Grayish sandstone layers, about 1 foot thick, but with some shaly partings. *Berea grit*	13	50½
4.	Arenaceous shales	4	37½
3.	Argillaceous shales	6½	33½
2.	A concretionary layer of sandstone, which is thought to represent the base of the *Berea grit*	1±	27
1.	Argillaceous shales to the creek level; in the lower part are reddish-gray spots which give them a slightly mottled appearance, *Bedford shale*[1]	26	26

In the above section the concretionary sandstone — No. 2 — is regarded as marking the base of the Berea grit instead of the higher sandstones of No. 5, because No. 2 is thought to represent the concretionary sandstone noted on the bank farther up the creek, which was determined by level to correspond approximately with the base of the sandstones on the other side of the creek, where the entire formation is shown.

In the deeply drift-covered eastern part of Franklin county, which is also true of Fairfield county on the east and Pickaway county to the south, there are but few outcrops of the Sunbury shale. Dr. Orton noted its occurrence at one locality in Fairfield county, and his statement was that "it undoubtedly exists in Pickaway and Fairfield counties, though its presence has not been determined in either, except at a point just beyond the Franklin county line, to the south of Canal Winchester."[2]

SOUTHERN OHIO.

Benner's Hill. — In southern Ohio, in Ross, Pike, Scioto, and Adams counties, are numerous outcrops of the Sunbury shale, and its distribution may be readily traced across that portion of the state. In this paper only a few of these outcrops will be described, and they have been selected at some distance from each other in order to fairly represent the character of the formation across the southern part of the state.

[1] An earlier interpretation of this section was given in the JOURNAL OF GEOLOGY, Vol. IX, p. 217.

[2] *Geol. Surv. Ohio*, Vol. III, p. 643.

One of the most interesting sections of the Devonian and Subcarboniferous formations of southern Ohio is that of Benner's Hill, about two miles northwest of Bainbridge, in the southwestern part of Ross county. The section begins on the eastern bank of Buckskin Creek, a short distance below the railroad bridge and house of Mr. George Walley, and follows the steep part of the hill to the bare spot of shale known as Bald Knob, and then runs through the woods to the Walley sandstone quarry and top of the hill.

BENNER'S HILL SECTION.

No.		Thickness feet.	Total thickness feet.
7.	Covered to the highway directly east of the quarry, which crosses about the highest part of that portion of the hill. Loose by the roadside is brownish-red shale, which is apparently from near that horizon. The greater part of this covered slope belongs in the *Cuyahoga shale*	36	490
6.	Black fissile bituminous shale vertical wall of 9 feet on top of the quarry sandstone. *Sunbury shale*, formerly known as the Waverly black slate. The contact between the black shale and the subjacent Berea sandstone is beautifully shown on the vertical wall of the George Walley quarry. The contact is sharp and it makes a conspicuous line	9	454
5.	The upper 7 feet is a massive sandstone layer, which in places does not split into layers. The upper 18 feet of the formation is composed of very massive light gray, generally rather coarse-grained sandstone, with few bedding planes. Below is 13 feet composed of sandstones, the layers of which vary in thickness from 1 to 2½ feet, and alternate with shales. The color varies from bluish to buff and numerous layers of the sandstones in the lower part of the quarry show excellent examples of ripple marks. At the base, sandstones 6 inches or more in thickness alternate with shales; but this portion is partly covered, and a clear line of contact between the sandstones and the underlying Bedford shale is not shown. These sandstones represent the *Berea grit*, and were formerly called the Waverly quarry system	33	445
4.	The interval of the *Bedford shale* is mostly covered; but at the base, near the line of springs, are brownish to buff arenaceous shales. The barometer gave 63 feet for the interval, which is perhaps greater than the actual thickness, since Dr. Orton gave it as 50 feet.[1] This formation was formerly known as the Waverly shales	63	412

[1] *Geol. Surv. Ohio*, Vol. II, p. 645.

3. Probable top of the Ohio shale as indicated by the line of springs, but the upper 7 feet is covered. From the bare summit of Bald Knob to base of shales, 325 feet, nearly all of which is shown by following the run on the lower part of the hill and higher, on its steep western face. The rocks are thin black fissile shales, weathering to a somewhat lighter color, and some of the pieces contain large numbers of *Protosalvinia huronensis* Dawson. The lower 13 feet, as shown in the highway cutting near the base of the hill, is a thin, light buff fissile shale, which weathers to a much lighter color than the shale above, and the weathered pieces are often stained red from iron. Dr. Orton stated that the base of the series was composed of "26 feet of white and blue clays."[1] All of this division is referred to the *Ohio shale*, which in Dr. Orton's section is called the Huron shales,[2] but they probably represent the Huron, Erie, and Cleveland shales of northern Ohio. The thickness of 332 feet is the same in the two sections - - - - 332 349

This formation was named the Ohio black slate by Andrews in 1870, and described as extending from the "Ohio river hills in the vicinity of Rockville, Adams county," northward to the hills at Chillicothe, spreading itself across the upper part of the Scioto valley and "resting upon the Corniferous limestone in the vicinity of Columbus."[3] In 1879 Professor Lesley applied the term Ohio conglomerate to the one occurring at the base of the Pennsylvanian or Carboniferous series in Ohio, stating that the Sharon conglomerate "is undoubtedly part (or the whole) of the *Ohio conglomerate*."[4] While in 1894, Mr. George H. Eldridge apparently named a Cretaceous formation in central Colorado, the Ohio formation evidently, from exposures on both sides of the Ohio creek in the southeastern part of the Anthracite quadrangle.[5] Of course both of these names are clearly synonyms of Andrews's "Ohio black slate," which in later years has generally been shortened to Ohio shale.

[1] *Ibid.*, p. 646.

[2] *Ibid.*, p. 645.

[3] *Geol. Surv. Ohio*, "Pt. II, Rept. of Progress in the Second Dist.," p. 62.

[4] *Second Geol. Surv. Pa.*. Q^2, 1879 (?), Preface, p. 34, and see p. 29. Also see Q^3, 1880, pp. 56 f., 45 f.

[5] *Geological Atlas U. S.*, Folio 9 — Anthracite-Crested Butte Folio, pp. 6, 7. In the legend of the geologic sheets, save one, it is called "Ohio creek formation;" but in the text and on the "Columnar section" the name is given as "Ohio formation."

2. Partly covered slope below the highway; but there are some thin projecting pieces of limestone. This zone probably represents the *Waterlime* or *Lower Helderberg*; but on account of scanty outcrops its correlation was not definitely settled. Above the railroad bridge the Waterlime is quite well exposed on the bank, between the railroad track and the highway. The rock is of a drab color, and some of the weathered layers are very rough. Part of the layers are quite sandy, and some of them are a form of breccia. Fossils occur; *Leperditia* is quite common in some of the layers, a few specimens of *Streptorhynchus hydraulicum* Whitf. were found, and a fairly large Gastropod shell - - - - - - - - - - - - - -	6	17
1. Massive light gray to drab limestone on the banks of Buckskin Creek to water level. A section of a shell, apparently *Pentamerus*, was found, while on the opposite bank of the creek above the railroad bridge imperfect impressions of shells, apparently *Megalomus*, were seen, so that this zone probably belongs in the upper part of the *Niagara limestone* - - - - - -	11	11

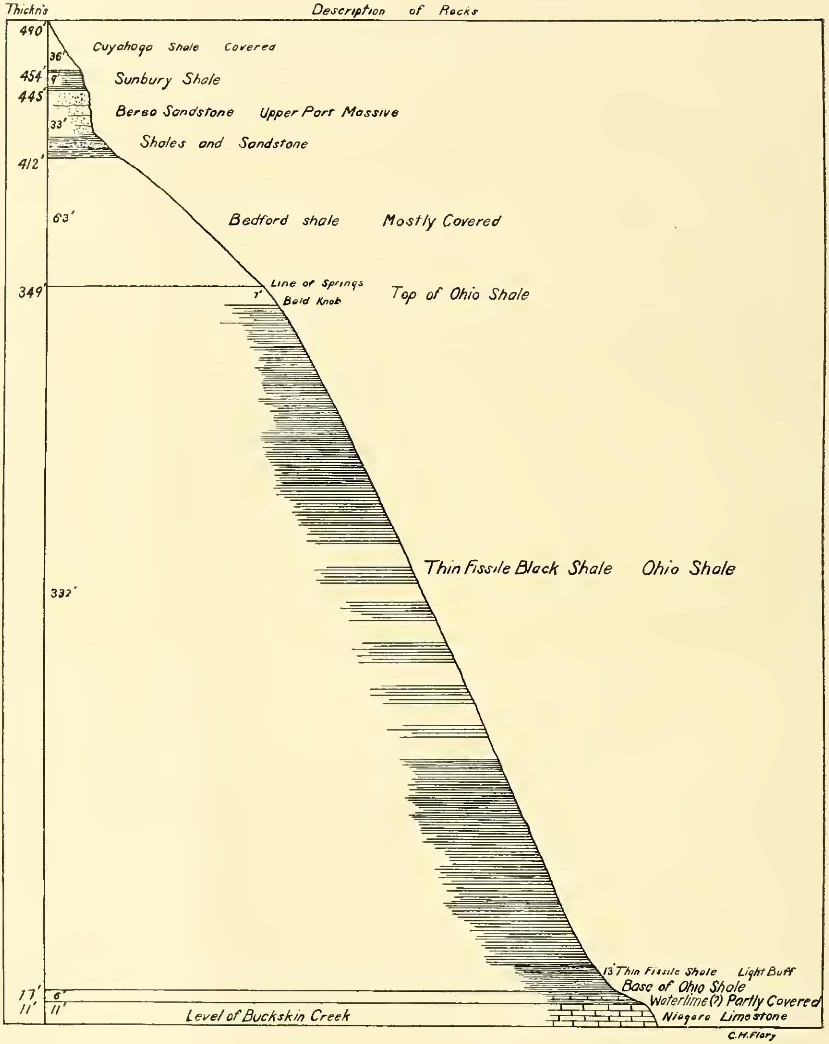
This section was briefly described by Dr. Orton,[1] the total thickness of which he made 500 feet, while in the above section it is 490 feet. He gave the thickness of the Niagara and Helderberg (Waterlime) limestones at the base of the hill as *each* 15 feet in thickness, which is some 10 or 12 feet greater than it can possibly be at this locality. Dr. Orton gave the Huron shales as 332 feet in thickness, the Waverly shales as 50 feet, the Waverly quarry courses as 31 feet, the Waverly black slate as 15 feet, which is probably nearer the actual thickness of the formation than the statement in the above section; still, as a matter of fact, but 9 feet are shown in the quarry, and for the upper beds of Waverly group 42 feet, but it is true that beyond the highway the hill is somewhat higher than at the point where my section terminated. A diagrammatic section of this hill is given in accompanying figure (Benner's Hill Section).

Stony Creek.—The Benner's Hill section is near the western line of Ross county, and the other outcrop in this county selected for consideration is one in the Scioto valley in its southeastern part. Stony Creek is a western tributary of the Scioto river, which it enters near the middle point of the eastern line of Franklin township.

---

[1] *Ibid.*, p. 645.

BENNER'S HILL SECTION



The Canal pike crosses Stony Creek at a point eight miles southeast of Chillicothe and eleven miles northeast of Waverly. A short distance below this highway bridge the viaduct of the Norfolk & Western Railroad crosses the creek, and on its southern bank a few rods above the viaduct is an interesting outcrop of the Sunbury shale, Fig. 2. The following section of the bank was made at this locality:

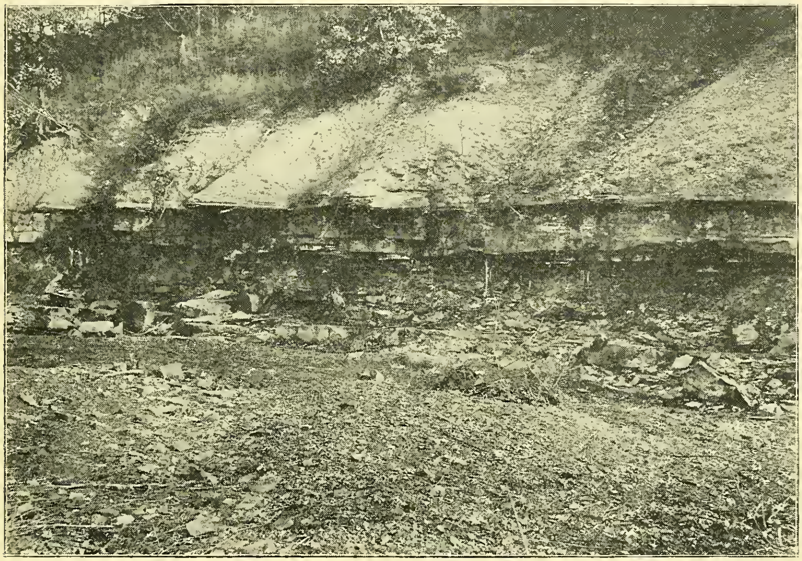


FIG. 2.—Contact of Berea grit and Sunbury shale on Stony Creek, Ross county. The thin, even layers of shale at the base of the Sunbury project beyond the Berea grit.

STONY CREEK SECTION.

No.		Thickness feet.	Total thickness feet.
4.	A projecting ledge of thin bedded brownish sandstone occurs below the highway; the remaining portion of the bank covered to the road - - - - - - - - - - - -	¼	45+
3.	All thin black shale, in no particular respect differing from the Sunbury shale of central and northern Ohio. This outcrop forms the middle part of the bank just below the highway as it goes over the ridge south of the N. & W. viaduct. The *Sunbury shale*		

	with one of the thickest outcrops known in the state. The black shale is also shown by the side of the highway above the cliff as it descends the slope to the northwest	28—	45
2.	Massive sandstone, brown on weathered edge, with a thickness of 1 foot 8 inches. Then thin sandstone at top, olive shales in middle, and thin sandstone at the base, with a total thickness of 1 foot 5 inches. At the bottom a massive, fine-grained sandstone, 1½ feet thick. The total thickness of this zone is 4 feet 7 inches, and it was regarded by Dr. Orton as representing the Waverly quarry courses[1] or *Berea grit.* If this correlation be true, then there is to be noted a remarkable thinning in the formation when compared with the Benner's Hill section or the quarries in the vicinity of Waverly	4½+	17
1.	Bluish to bluish-gray shales, with thin layers of sandstone, to the creek level. Some of the layers of sandstone show fine examples of ripple marks, and one layer about 5½ feet above the base has a thickness of 6 inches. This zone was referred to the Waverly shales by Dr. Orton, who stated that "the uppermost 25 feet of the Waverly shales appear here."[2] The base of this section is at the creek level on the upper side of the viaduct, which is hardly more than 4 feet above the level of the Scioto river, so there is scarcely any opportunity for an exposure of 25 feet of these shales at this locality. It is not improbable if the rocks were exposed to a greater depth at this point that thicker sandstones would be shown and all this lower part of the section might be referred to the *Berea grit.* The thin sandstones with beautiful ripple marks rather support this inference, since similar ripple marks occur so generally in the lower part of this formation and not in the upper part of the Bedford shale	12½	12½

This section was briefly described by Dr. Orton, who reported "twenty-seven feet of the Waverly black slate, the heaviest section of this stratum yet reported in southern Ohio,"[3] which is practically the same as that obtained by the writer.

The bluish-gray shales with thin alternating sandstones are exposed on the banks of the creek above and below the highway bridge, while the lower massive stratum of the Berea grit is shown at the top of the bank immediately east of the bridge.

Another section was measured on the south bank of Stony

---

[1] *Ibid.*, p. 650. [2] *Ibid.*, p. 650.

[3] *Ibid.*, p. 650; also see p. 624, where it is stated that this is "the best section of it to be found in all the Scioto valley."

Creek, about one-half mile above the former, on the Wolf farm, which is as follows:

No.		Thickness feet.	Total thickness feet.
7.	At least 18 feet of thin even black shale is shown; the upper part of which is much weathered and broken and finally concealed by soil. The thin, even layers of the lower part are finely exposed, and there is a sharp and clearly shown line of contact between the shale and the underlying sandstone. *Sunbury shale*	18	29½
6.	Massive rather fine-grained bluish-gray sandstone, at top of *Berea grit*, which has a tendency to split into irregular layers, and in places there are shaly partings. Base of heavy stratum	3$\frac{7}{12}$	11½
5.	Blue to bluish-gray arenaceous shales and thin sandstones	3⅙	7$\frac{11}{12}$
4.	Blue sandstone stratum of variable thickness	½±	4¾
3.	Bluish arenaceous shales and thin sandstones	1¾	4¼
2.	Bluish-gray compact sandstone, which is sometimes concretionary and of somewhat variable thickness	1½	2½
1.	Bluish shales and thin sandstone to bed of creek; the sandstone very much ripple marked	1+	1

It appears to the writer that the first six numbers of the above section may be referred to the Berea grit instead of simply the massive 3½ feet of sandstone—No. 6—immediately below the Sunbury shale. It is true that a considerable part of the rocks below No. 6 are shales; but the sandstones are thicker than in the first section, and this extreme development of shales on Stony Creek is thought to be simply a local phase of the formation. The above section is shown in Fig. —, where the massive 3½ feet of sandstone at the top of the Berea forms a conspicuous layer across the middle part of the halftone, just above which is seen the projecting layer of thin, even-bedded black shale at the base of the Sunbury.

On the east fork of Stony Creek, about one mile above Wolf bank, are ledges of rather bluish-gray sandstone alternating with layers of thin sandstones, which are ripple marked. This is an outcrop of the *Berea grit*, and in the field to the west, and somewhat higher, are the thin black *Sunbury shales*.

Waverly.—The rocks of the Waverly series were named from outcrops in the vicinity of Waverly, to which Professor C. Briggs, Jr., in 1838, gave the name *Waverly sandstone series*,[1] to the rocks

---

[1] *First Ann. Rept. Geol. Surv. Ohio*, p. 80.

occurring between the "argillaceous slaty rock, or shale stratum," now known as the Ohio shale, and the "conglomerate" which lies at the base of the Coal-measures.

In Dr. Orton's description of the geology of Pike county, he termed the shales between the top of the Ohio black slate and the base of the higher massive sandstones the *Waverly shales*,[1] a name apparently proposed by him; while the sandstone which is now known to be the continuation of the Berea of northern Ohio, was named the *Waverly quarry system*.[2]

The old Waverly quarries, formerly operated by Emmett, were mainly on the road toward Pee Pee, and are no longer actively worked. The same sandstone, however, is now quarried along the line of the Ohio Southern railroad up to the Crooked Creek valley to the northwest of Waverly. One of the nearest quarries to Waverly is that of the Southern Ohio Stone Co., on the Ohio Southern railroad, 1½ miles above the Waverly station, or about 2 miles up the Farmersville pike, northwest of Waverly. This quarry has been open some seventeen years, and for a time was worked by the railroad company. The detailed section of the Berea sandstone in this quarry is given below.

SECTION OF THE SOUTHERN OHIO STONE COMPANY QUARRY.

No.		Thickness feet.	Total thickness feet.
14.	*Sunbury black shale*, 2 feet shown in pit above the top of the quarry	2	65
13.	Covered interval of 1 foot 2 inches	1⅙	63
12.	Thin-bedded sandstone at the top of the *Berea sandstone*	2	61⅚
11.	Rather thin sandstone on quarry face, but thickens under cover, and will make quarry stone	5	59⅚
10.	Bridge stone, 22-inch stratum	1⅚	54⅚
9.	Shaly to thin-bedded sandstone	3	53
8.	Good sandstone in three layers, upper course 12 inches, middle one 18 inches, lower 15 inches	3¾	50
7.	Shaly sandstone	$1\frac{5}{12}$	46¼
6.	Good sandstone	1⅚	44⅚
5.	Shaly layers to thin-bedded sandstone; but the greater part of the stratum is concretionary with some shale — the "bowlder layer" of the quarry men	6	43

---

[1] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. I, 1874, p. 619.

[2] *Ibid.*, p. 621.

4. The best stone in the quarry, which is sawed and shipped extensively; the upper course 16 inches and the lower one from 18 to 20 inches in thickness. Base of quarry	3—	37—
3. Course of 32 inches	2⅔	34
2. Good sandstone, which is apparently the base of the *Berea sandstone*	1⅓	31⅓
1. From base of the Berea sandstone covered slope to mouth of well directly below quarry at house of Mr. L. S. Risley. According to Mr. Combs, the top of the Ohio black shale was struck at a depth of from 30 to 40 feet in this well, which gives a thickness from 60 to 70 feet for the Bedford (Waverly) shale. Dr. Orton gave the thickness of the Waverly shales in Pike and Ross counties as 90 feet [1] and it is not improbable that the top of the Ohio black shale occurs at a greater depth in the well than reported above	30	30

The above section gives nearly 32 feet for the thickness of the Berea sandstone, and 60 to 70 feet for that of the subjacent Bedford shale. The general color of the building stone is gray, although sometimes rather buff or even greenish on weathered surface. There are layers showing ripple marks and also bluish to greenish shales, some of which are much iron stained. The general appearance of the stone is quite similar to that of the Berea sandstone in central Ohio.

The slope of the hill above the sandstone is very gradual, and the Sunbury or Waverly black shale does not make conspicuous outcrops; but its occurrence immediately above the sandstone is shown in the small pit above the quarry, where two feet of its lower part is exposed.

On the "General section of the Waverly system in Pike and Ross counties"[2] Dr. Orton gave, as occurring between the Waverly quarries and the Waverly black slate, a zone of "shales with concretions of iron ore" 30 feet in thickness. This zone is apparently not described in the text, where it is stated that the Waverly black slate comes "immediately above the Waverly quarries,"[3] and no indication of this intermediate shale was seen in the sections which were examined by the writer.

---

[1] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. I, 1874, Fig. 1, op. p. 615, and Fig. 2, op. p. 618.

[2] *Ibid.*, Fig. 1, op. p. 615, and Fig. 2, op. p. 618.

[3] *Ibid.*, p. 624.

About 1½ miles farther up the railroad, at Peck, are the extensive quarry and mill of the Waverly Stone Co., which also obtains its stone from the Berea sandstone. There is also a small quarry located on the eastern side of the valley, called Peck's quarry.

Mr. I. Combs, the superintendent of the Southern Ohio Stone Co. has not seen the Waverly brown sandstone, which occurs near the base of the Cuyahoga shales, overlying the Sunbury shale, in the hills bordering Crooked Creek; but the locality east of the river, where it caps the hill on the Gregg farm, is well known to him. He also reported excellent outcrops of it farther north on the eastern side of the river, about one mile below the Omega river bridge. Dr. Orton reported this sandstone as 10 feet in thickness on his section of the "Waverly System in Pike and Ross counties" with 35 feet of blue shales between it and the top of the Waverly [Sunbury] black slate.[1] He correlated it with the stone obtained high in the bluffs on the northern side of the Ohio river near Buena Vista and called it the Buena Vista stone,[2] which correlation is restated in his last account of the geological scale of Ohio.[3]

Buena Vista.—The extensive quarries near the head of an east branch of Lower Twin Creek, some five miles northwest of Beuna Vista, were studied. A tramway extends from the town to the quarries, and a highway may be followed to No. 4 on the tramway, within about one mile of the older quarries, which are no longer worked. On the bank of the creek, just above No. 5 of the tramway, is a good exposure of the upper part of the Ohio shale, which begins at creek level and extends up the bank for 24 feet, when the shales are covered by soil. Two species of *Lingula* were found near the top of these shales, the most common one resembling quite closely *Lingula Williamsana* Girty, while a larger species is also found lower in the bank. A sandstone ledge in the lower part of the Bedford is shown not much farther up the bank.

---

[1] *Ibid.*, Fig. 1, op. p. 615, and Fig. 2, op. p. 618.

[2] *Ibid.*, Fig. 1, op. p. 615, Fig. 2, op. p. 618, and p. 626.

[3] *Ibid.*, Vol. VII, 1893, p. 31.

On the eastern side of the creek at this locality is an old incline, at the top of which is an unworked quarry. The lower part of this quarry shows the thin, black, laminated Sunbury shale, the loose pieces of which are conspicuous on the dump near the top of the bluff, as seen from the creek valley below. Above the Sunbury is olive-colored shale, capped by the Buena Vista quarry stone, in two layers, or "City ledge" as the outcrops of this stratum near Rockville, between one and two miles below Buena Vista, were termed in 1838 by Professor John Locke, in his geological account of Adams county.[1]

Some distance up the tramway from No. 5 is the incline in present use, the foot of which is barometrically 130 feet below the base of the "City ledge" at its top. Perhaps 15 to 20 feet above its base are fairly heavy sandstone layers in the Bedford formation, which, in the Ohio river bluffs, contains much more sandstone than in the central part of the state. The Berea sandstone is shown at the side of the incline near its top, where the top of the formation is marked by a massive stratum, 1 foot 9 inches in thickness, below which are thinner bedded and shaly layers. The Berea is light gray in color and fairly massive, above which in the soil by the side of the incline, are numerous pieces of the Sunbury black shale. From the top of the Berea sandstone on the incline to the base of the "City ledge," or Buena Vista sandstone, opposite the top of the plane is 21 feet. The excavation for the cistern at the head of the inclined plane was made in the Sunbury shale, large quantities of which are shown on its dump.

The Buena Vista stone forms a prominent ledge just back of the top of the plane, and it has been worked more or less extensively for some distance along this bank of the stream toward its head. Not far from the present upper limit of the quarry, the "City ledge" and overlying shales furnished the following section:

---

[1] *Second Ann. Rept. Geol. Surv. Ohio*, 1839 (?), p. 263. The name was given because the stone was extensively quarried and used in the city of Cincinnati (see page 264).

SECTION OF BUENA VISTA FREESTONE QUARRY.

No.		Thickness feet.	Total thickness feet.
7.	Soil	3 ±	24½
6.	Very argillaceous, no grit, olive, bluish and reddish colored shale, some of it mottled	8½	21½
5.	Mottled bluish and reddish argillaceous shale, containing concretions and concretionary layers. In places mainly reddish in color	2	13
4.	Bluish argillaceous, rather compact shale	5½	11
3.	Top of fine-grained massive Buena Vista sandstone or "City ledge." The weathered top of this layer is frequently of rather bluish to greenish tint and covered by a mass of beautiful specimens of *Spirophyton*, the tubes and fronds of which extend down for a few inches into the upper part of this layer	3+	5½+
2.	Greenish argillaceous shale parting	2½ in.	2½+
1.	Lower layer of Buena Vista sandstone; a brownish to bluish-gray, fine-grained massive sandstone which emits a decided petroleum odor when freshly struck. Also frequently of light gray and sometimes reddish-brown tint. Base of the "City ledge," which has a thickness of 5 feet 7½ inches in this quarry. This compact freestone is a valuable sandstone, and in this region it is much more important commercially than the Berea sandstone	2⅓	2⅓

The massive Buena Vista sandstone with the overlying shales are shown in Fig. 3.

The large blocks of Buena Vista sandstone from these quarries, containing numerous specimens of *Spirophyton*, apparently show that these markings are made by worms. Extending down into the stone from the fronds, which occur on or near the top surface of the stratum, at various angles are tubes, some of which are open and others are filled with clayey material. These tubes are apparently the holes in the fine sand in which marine worms lived. Crawling to the surface, and back again and about the opening of the tube, they made the smoothed and grooved space which has been termed the frond, as it was supposed to represent a sea weed buried in the sand.

It is clearly evident that the Sunbury shale (Waverly black slate) extends to the Ohio river, probably with a thickness of between 15 and 16 feet as given by Andrews,[1] above which is 5

---

[1] *Geol. Surv. Ohio*, Pt. II, "Rept. Prog. Sec, Dist." [in 1869], 1870, p. 65; and see his "Section of Waverly rocks from the great Black slate of the Subcarboniferous limestone, as seen on the Ohio river," on "Map showing the Lower Coal-measures."

feet 4 inches of fire clay and blue and drab shale, as given on Andrew's section. His section gives a thickness of 20 feet 9 inches from top of sandstone (Berea) to the base of the "City ledge" (Buena Vista stone), and my section for the same portion of the Waverly is 21 feet, or 3 inches greater, which is a very close agreement when it is remembered that the location of the two sections is two miles or farther apart. Succeeding the zone of fire clay and shale is the Buena Vista stone or "City ledge," in two layers separated by a shale parting of 2½ inches, with a total thickness of 5 feet 7½ inches.

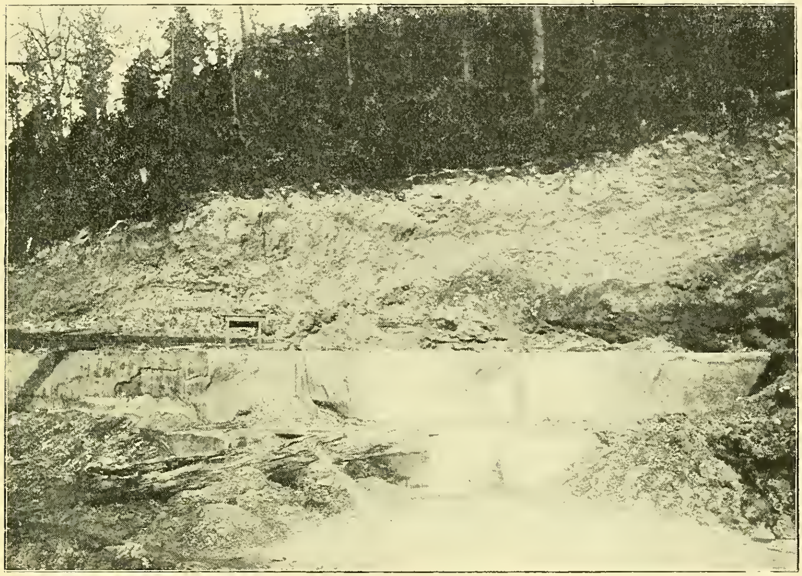


FIG. 3.—The two layers of Buena Vista sandstone and overlying shales on Lower Twin Creek, northwest of Buena Vista.

Professor Locke gave the thickness of the "City ledge" at Rockville as 2½ feet, and stated that it had "a stratum of shale about 15 feet below it," the context showing that he evidently meant the shale had a *thickness* of about 15 feet, "and another of about the same thickness above it." [1]

[1] *Second Ann. Rept. Geol. Surv. Ohio*, p. 264.

The first distinct geographical name applied to the Sunbury shale was the "Waverly black slate," by Andrews, in 1870,[1] who gave its general thickness as 16 feet and its base as 137 feet above the top of the Ohio black slate, on Andrews' "Section of Waverly rocks . . . . on the Ohio river," however, the thickness of the Waverly black slate was given as 15½ feet, and its base as 134 feet above the top of the Ohio black slate.[2] The thickness of the "City ledge" was given by Andrews as 3 feet 5 inches near Rockville and 4½ feet on the Flagg land, probably on Lower Twin Creek,[3] and in 1871, in his "Section along the Ohio river from Adams to Lawrence counties," he reported it as 4 feet thick.[4]

Dr. Orton, in 1882, published a general statement concerning the formations in the vicinity of Buena Vista, in which he stated:

> The Bedford shale is still distinguishable with normal thickness, but carrying a relatively larger proportion of stone than to the northward. The Berea grit is clearly recognizable in the so-called "cliff stone," which has been quite largely worked here. The Berea shale (Waverly black shale) is a constant guide to the true order. The Buena Vista stone makes, as elsewhere, the base of the Cuyahoga shale, which is charged with more frequent freestone beds than to the northward.[5]

Finally, Herrick, in 1891, in his section of the southern exposures of the Waverly near Portsmouth, gave the thickness of the Berea black shale (Sunbury) as 15 feet, below which was from 30 to 40 feet of Berea grit flags.[6]

Vanceburg.—On the Kentucky side of the Ohio river about five miles below Buena Vista is Vanceburg at the eastern end of which is a steep and high hill known as Alum Rock.

---

[1] *Geol. Surv. Ohio*, Pt. II, "Rept. Prog. Sec. Dist." [in 1869], p. 66.

[2] *Ibid.*, "Map showing the Lower Coal-measures."

[3] *Ibid.*, p. 66.

[4] *Proc. Am. Phil. Soc.*, Vol. XI, p. 245.

[5] *Proc. Am. Assoc. Adv. Sci.*, Vol. XXX, p. 174.

[6] *Bull. Geol. Soc. Amer.*, Vol. II, p. 40.

SECTION OF ALUM ROCK.

No.		Thickness feet.	Total thickness feet.
6.	Top of massive sandstone, capping first knob, which lithologically closely resembles the "City ledge" of Buena Vista region, while on top and in the upper part of the stratum are numerous specimens of *Spirophyton* similar to those described in the Lower Twin Creek quarry. The top of this sandstone, however, is 51 feet above the top of the Berea sandstone, while in the Lower Twin Creek it is only 26½ feet, so that it appears somewhat doubtful whether these two exposures are in the same layer. Loose blocks of sandstone containing *Spirophyton* occur at the elevation of 27 feet above the top of the Berea sandstone, and this layer perhaps represents the horizon of the "City ledge" as shown to the northwest of Buena Vista. All of this slope below the massive sandstone at top is covered	38	423
5.	Thin, black, even argillaceous shale, 13 feet shown before it is covered by soil. *Sunbury* (*Waverly black shale*)	13	385
4.	Top of massive *Berea sandstone;* some of the layers thick, light gray in color, rather course grained and weathering brownish. Some of the layers have magnificent specimens of ripple marks. The layer just below the top one is 3 feet thick, and on the top surface are splendid ripple marks	21	372
3.	Perhaps the rocks are mainly gray or greenish to bluish-gray shales, weathering to an iron color; but there are sandstone layers, some irregular or concretionary, often ripple marked, frequently thick, one of them 26 inches, and *Spirophyton* occurs. *Bedford formation*	75	351
2.	Covered. Plenty of yellowish iron stained arenaceous shales in soil. Perhaps all or the greater part of this zone belongs in the Bedford formation	21	276
1.	Black thin layered Ohio shale. Near the top of the shales are a few fossils, as a large *Lingula*. Partly covered slope, but probably all Ohio shale to the level of the Chesapeake and Ohio railroad; 255 feet by the barometer from railroad level to highest outcrop of shale	255	255

The Alum Rock section clearly shows that the Sunbury shale crosses the Ohio river, and has a thickness of at least 13 feet in the vicinity of Vanceburg. It was not followed farther south in Kentucky and at present it is not known how far it can be traced in that state.

NORTHERN OHIO.

From near Sunbury, Delaware county, northward there are no reported surface exposures of the Sunbury shale across Morrow, Crawford, Richland, Huron, and Lorain counties to the western part of Cuyahoga county. As a rule, however, the older formations of this part of the state are deeply covered by drift deposits, so that outcrops are infrequent, and it is not strange that this thin deposit of shale has not been reported. Its continuation, however, appears to be conclusively shown by the records of numerous wells drilled in these counties, in which a black shale of variable thickness was penetrated just above the Berea sandstone. Some of these wells are mentioned below, in all of which the Sunbury (Berea) shale was noted at its proper stratigraphic position, immediately above the Berea grit. At Mt. Vernon, Knox county, the top of the Berea grit is reported at a depth of 470 feet;[1] in Richland county, at Mansfield, it is 640 feet in depth, with 40 feet of Sunbury shale above;[2] at Crestline 113 feet in depth;[3] at Shelby 141 feet,[4] with 23 feet of Sunbury shale on top; at New London, Huron county, 165 feet;[5] at Wellington, in Lorain, 138 feet, above which is reported 30 feet of black shale;[6] and at Belden from 10 to 25 feet of Sunbury shale.[7]

Berea.— Dr. Newberry in his "Report on the geology of Cuyahoga county," stated that at Berea, in the western part of the county, "that portion of the Cuyahoga shale which immediately overlies the Berea grit contains myriads of *Lingula melie* and *Discina Newberryi*,"[8] but there was no suggestion of separating this fossiliferous deposit from the Cuyahoga shale. In 1875 Meek mentioned "the dark shales of Berea" in an explanation of a figure of *Discina* (*Orbiculoidea*) *Newberryi* from that locality, and used the expression "Berea shale."[9]

Quarry No. 6 of the Cleveland Stone Company at Berea furnishes the following section:

---

[1] *Rept. Geol. Surv. Ohio*, Vol. VI, 1888, p. 366.

[2] *Ibid.*, p. 365.

[3] *Ibid.*, p. 303.

[4] *Ibid.*, pp. 316 and 365.

[5] *Ibid.*, p. 440.

[6] *Ibid.*, p. 348.

[7] *Ibid.*, p. 332.

[8] *Rept. Geol. Surv. Ohio*, Vol. I, Pt. I, 1873, p. 185.

[9] *Rept. Geol. Surv. Ohio*, Vol. II, Pt. II, Pl. XIV, explanation of Figs. 1c and 1d.

SECTION OF QUARRY NO. 6.

No.		Thickness feet.	Total thickness feet.
4.	*Erie clay* to top of bank	11	50
3.	Top of *Sunbury* (*Berea*) *shale.* It is mainly a black, quite massive bituminous shale; but some of it as weathered is rather bluish in color. Thin layers contain specimens of *Lingula melie* H., but they are not abundant in that portion of the shale which is exposed at this locality	8⅔	39+
2.	Probably all of this zone is in the *Sunbury shale;* but it is partly covered and the contact with the subjacent Berea grit is poorly shown	3	30½—
1.	Top of the *Berea grit.* A layer from 7 to 16 inches in thickness, and perhaps more, forming the upper part of the Berea sandstone is hard, contains plenty of iron pyrites, is not valuable for stone and weathers into a somewhat shaly layer	27½—	27½—

There are four prominent courses of the Berea grit as worked in this quarry, with the following thicknesses: Course No. 4, including the pyrite layer at the top, 5 feet 4 inches; course No. 3, 6 feet 8 inches; course No. 2, 7 feet 1 inch; No. 1, 6 feet 4 inches. Below this 2 feet of sandstone is shown at the bottom of the quarry without reaching the base of the Berea grit.

In quarry No. 8, adjoining the one just described, they have drilled into the Berea sandstone to the depth of 52 feet, and Newberry stated that in Cuyahoga county it is "something like 60 feet in thickness."[1] In this quarry there is more shaly sandstone at top than in No. 6 and a clay pebbly layer near the top contains a few specimens of *Camarotœchia.* The following section is for the eastern end of the quarry, with the exception of its upper portion which was obtained on the northern bank.

SECTION OF QUARRY NO. 9.

No.		Thickness feet.	Total thickness feet.
4.	*Erie clay* to top of bank	10½	91¾
3.	On the northern wall black shale or grayish-black when weathered	13¼	81¼
2.	Black bituminous shale, some of it with a bluish tint, containing numerous specimens of *Lingula melie* Hall and some of *Orbiculoidea Newberryi* (Hall) Herrick. *Sunbury shale*	11	68

---

[1] *Loc. cit.*, p. 186.

1. Top of *Berea grit.* This course, No. 7, composed of shaly sandstones layers generally thin and containing plenty of iron pyrites; not valuable quarry stone, 5 feet two inches. Course No. 6, 4 feet; course No. 5, 8 feet 4 inches; course No. 4, 7 feet 7 inches; course No. 3, 6 feet 3 inches; course No. 2, 10 feet; course No. 1, 15 feet 6 inches. Floor of the quarry but not the bottom of the grit. Courses 1 to 6 inclusive are all composed of good massive quarry stone with a total thickness of 51 feet 8 inches. When freshly quarried the stone is of light gray color; but on weathered surfaces it is not infrequently stained from the decomposition of iron pyrites - - - - - - - - 57 57

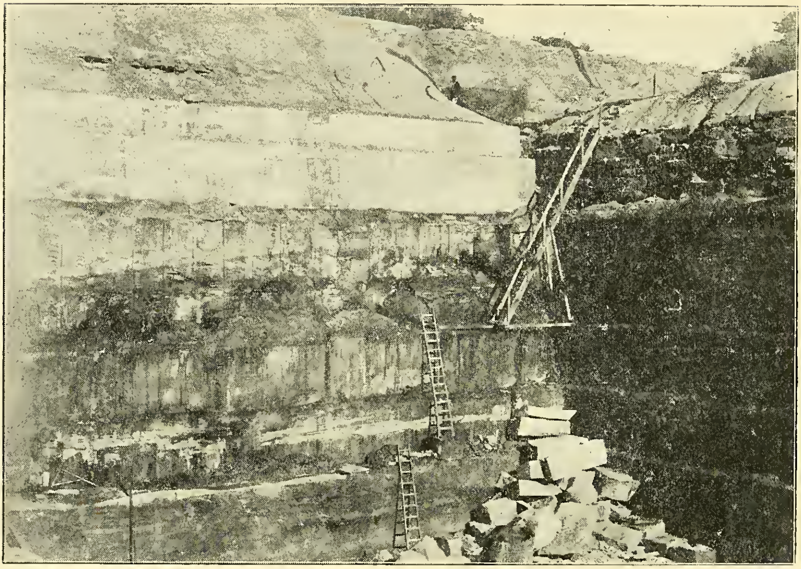


FIG. 4.—Berea grit with superjacent Sunbury shale in quarry No. 9, at Berea.

This section shows that there is not such a marked and sharp lithologic change from the Sunbury to the Cuyahoga shale as is found in the bluffs of the Ohio river or is shown in sections farther east, but a more gradual transition. This quarry is shown in Fig. 4, the greater part of which is the Berea grit, but capped by the Sunbury shale, and fossils are abundant in the zone indicated by the man.

Bedford.— In the vicinity of Bedford, in the southern part of Cuyahoga county, on the banks of Tinker's Creek, are several good vertical sections from the Bedford shale or Berea grit into the Cuyahoga shale. Three of these will be given, and their comparison will show some lithologic variation in a comparatively short distance. The following is a section of the south bank of Tinker's Creek under the bridge of the Akron, Bedford & Cleveland electric road.

SECTION AT THE A. B. & C. ELECTRIC BRIDGE.

No.		Thickness feet.	Total thickness feet.
5.	Gray to bluish-gray shale, with an occasional blackish streak, which breaks into very small pieces as weathered and shown on the upper part of the bank. No fossils were found - - -	10⅚	51
4.	Alternating shales and sandstones of bluish-gray color, the sandstone predominating. *Cuyahoga shale* - - - - -	8¼	40¼—
3.	Thin argillaceous bluish-gray shales splitting into small pieces. At the base a blackish bituminous shale 1 inch in thickness, which splits into thin, smooth layers, and contains *Lingula melie* Hall. In lithologic appearance only the 1 inch of blackish shale at the base of this shale zone resembles the *Sunbury shale* of southern and central Ohio and the eastern part of Cuyahoga county, and this is not as black as typical Sunbury shale. It is probable, however, that the blue color and other characters of this shale are a local variation, and that all of this zone may be referred to the Sunbury shale. If not, then at this locality it has thinned to the 1 inch of black, fossiliferous shale noted at the base of the zone - - - - - - - - - -	5$\frac{5}{12}$	32—
2.	Top of *Berea grit;* massive grayish, rather coarse-grained sandstone - - - - - - - - - -	21½	26½
1.	Shaly to thin-bedded blue sandstone to creek level, all of which is in the Berea grit. There are plenty of ripple marks on the sandstone in the bed of the creek - - - - - -	5	5

Farther down the stream the following section is shown on the eastern bank of the creek a little above the Bedford rolling mills.

SECTION ABOVE BEDFORD ROLLING MILLS.

No.		Thickness feet.	Total thickness feet.
3.	Gray, fine-grained, thin-bedded sandstone, alternating with layers of shale, the sandstone predominating. Base of *Cuyahoga shale* - - - - - - - - - - - - - -	7⅓	35
2.	Thin-bedded argillaceous shales which are mainly of gray color, but passing from blackish-gray to black bituminous shales. At the base *Lingula melie* H. and *Orbiculoidea* occur sparingly. *Sanbury shale* - - - - - - - - - - -	6	27⅔

1.	Massive *Berea grit;* some of the upper layers thin-bedded, partly covered slope to creek level, and only about the upper half of the formation exposed	21⅔	21⅔

The best section of these formations in the vicinity of Bedford, however, is that on the northeast bank of Tinker's Creek, between the Bedford rolling mills and the Cleveland and Pittsburgh railroad viaduct, Fig 5. A dam for an electric light plant is being constructed not far below this locality so that later the lower part of the section may be concealed by water.

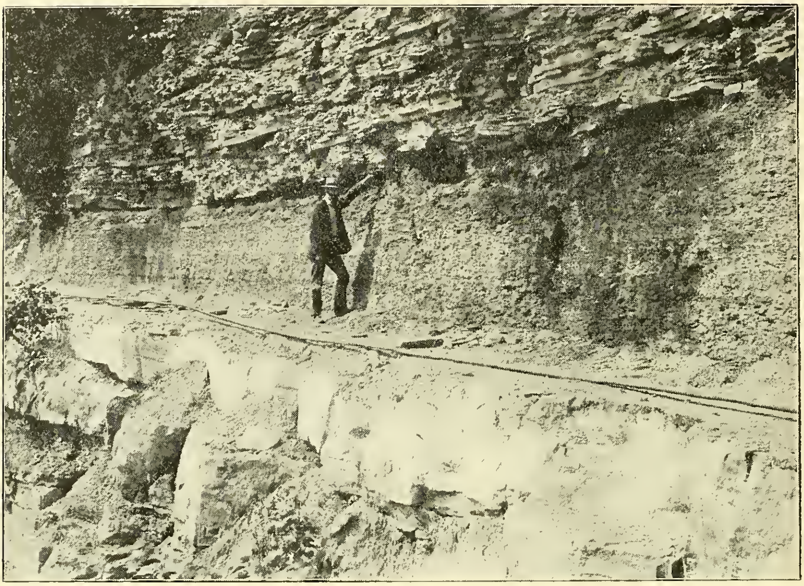


FIG. 5.—Sunbury shale above C. and P. R. R. viaduct, Tinker's Creek, Bedford. The man is standing on top of the Berea grit and indicating with his hand the contact of the Sunbury and Cuyahoga shales. The thin sandstones in the lower part of the Cuyahoga are clearly shown.

SECTION ABOVE THE C. & P. RAILROAD VIADUCT.

No.		Thickness feet.	Total thickness feet.
4.	Mainly thin-bedded, light gray sandstone, with shale partings to top of the bank. At base thin-bedded, light gray, fine-grained sandstone. Base of *Cuyahoga shale*	7½	71—

3. Blackish shale near top of zone. Very fine argillaceous shale which is mainly bluish-gray to gray in color, but with some blackish layers. It is finely shown on the bank above the quarry. *Sunbury shale*	6	63⅓
2. Top of *Berea grit* at top of quarry. Light to dark gray or rusty-brown color, rather harder and finer-grained sandstone than the lower courses, 3⅙ feet. Massive, light gray, coarse-grained grit, often weathers yellowish, 3⅔ feet. Light gray, or frequently weathered to iron color, thin-bedded to shaly sandstone, 3⅙ feet. Massive, light gray, coarse-grained sandstone to grit. Ripple marks occur in lower part, 29⅓ feet	39⅓	57⅓
1. Contact of *Berea grit* and *Bedford shale.* Upper part of Bedford composed of bluish-gray argillaceous shales. Lower shales alternating with thin layers of sandstone, 1 inch or more in thickness, to creek level	18	18

It appears that No. 4 of Dr. Newberry's "Section of strata at Bedford," which he described as a gray shale from four to six feet thick and classed in the Berea grit,[1] is the equivalent of what is called the Sunbury shale in the above sections. Dr. Newberry also included the superjacent zone of thin bedded sandstone (No. 3 of his section) in the Berea. It is the writer's impression that he was in error in this particular, and that the top of No. 5 of his section should be considered as the line of separation between the Berea grit and the overlying formation, now called the Sunbury shale, but in the time of his reports considered as the base of the Cuyahoga shale. The zone termed the Sunbury shale in the above sections is composed of a very argillaceous, thin-bedded shale, mainly gray to bluish-gray in color, with bands of black shale. It appears to the writer that this shale represents the Sunbury shale of central Ohio, but that it has largely lost its black and bituminous character. Remove Nos. 3 and 4 from the Berea grit of Newberry's section and there remains but No. 5 of his section for the Berea, which he described as a "thick-bedded yellow sandstone with ripple marks," 45 feet in thickness; while in the above section we have a thickness of 39½ feet for the Berea. The Sunbury shale of the above section is well shown in Fig. 5, where the man is standing on top of the Berea grit and pointing to the line of contact of the Sunbury and Cuyahoga shales.

---

[1] *Rept. Geol. Surv. Ohio,* Vol. I, Pt. I, 1873, p. 197.

Chagrin Falls.— In the eastern part of Cuyahoga county, on the bank of Chagrin River, above Chagrin Falls, is a fine outcrop of the Sunbury shale. The following section was made at the Goodale quarry opposite the paper mill above Chagrin Falls :

SECTION OF GOODALE QUARRY ABOVE CHAGRIN FALLS.

No.		Thickness feet.	Total thickness feet.
3.	Black, bituminous shale, which weathers on the edge frequently to a rusty color, and is a massive shale under cover. The lower foot of the shale contains immense numbers of *Lingula melie* H. and a smaller number of a large species of *Lingula* and *Orbiculoidea Newberryi* (Hall) Herrick. There are also fragments of fish and plants. The fossils are the most abundant in the lower foot of the shale, but they occur in considerable force for at least 2½ feet above the base, and specimens were collected in the shales at the height of 4 feet. *Sunbury shale* - -	11	20
2.	Top of *Berea grit*. Massive coarse-grained layer, friable rock, easily crumbling in the fingers, 3½ feet thick. At the lower end of the quarry the upper part splits into thin, rather irregular flags, and there is no massive layer at top. Thin bedded to shaly sandstone, part of which makes flagging. The flags show ripple marks, and some of the layers are worthless; 2½ feet exposed - - - - - - - - - -	6	9
1.	Covered to river level - - - - - - - -	3±	3

This is the best locality noted in the Sunbury shale for collecting fossils, and attention was first called to it by Dr. Newberry.[1] The above section is shown in Fig. 6, where the man is standing on one of the layers of Berea grit and indicating with his hand the contact of the Berea and Sunbury shale.

Warren.—Across Lake, Geauga, Ashtabula, and Trumbull counties, there are comparatively few outcrops of the Sunbury shale, and as a rule even the Cuyahoga shale is concealed by drift deposits. On the bank of the Mahoning river, however, above Warren, are excellent outcrops of the Sunbury shale. One of these may be found on the eastern bank below the house of Alfred Fitch, rather more than one-fourth of a mile above the Water Works.

---

[1] *Rept. Geol. Surv. Ohio*, Vol. I, Pt. I, 1873, p. 185.

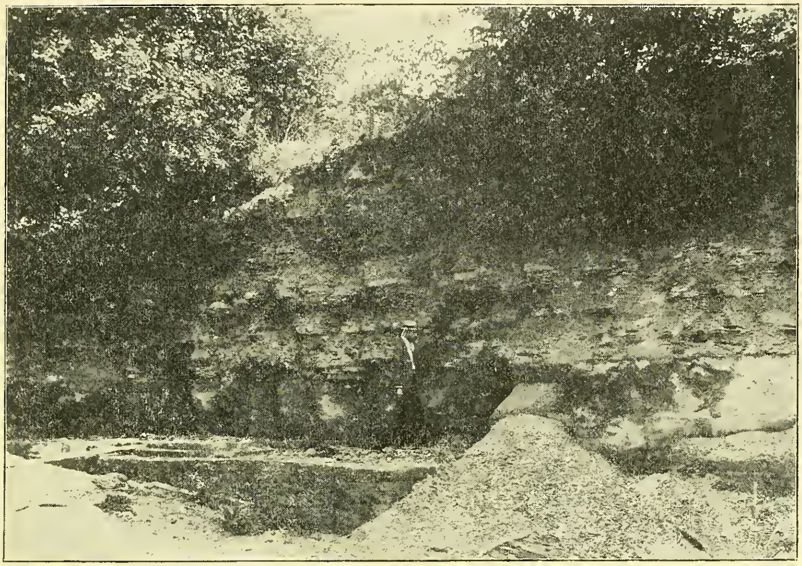


FIG. 6.—Contact of Berea grit and Sunbury shale in Goodale quarry, Chagrin Falls, indicated by the man's hand.

SECTION ON MAHONING RIVER ABOVE WARREN.

No.		Thickness feet.	Total Thickness feet.
5.	Soil and clay		
4.	Sandy layers to sandstone		
3.	Bluish-gray compact sandstone. Base of *Cuyahoga formation*	¾	16¾
2.	Top of shale rather impure and sandy, perhaps in places 1 foot of sandy shale at top. Black to brownish-black shale, some of it very black and compact, in lithologic characters similar to the Sunbury shale. The lower part of the shale contains immense numbers of *Lingula melie* Hall and a smaller number of specimens of another species of *Lingula*. *Sunbury shale*	14	16
1.	Top of *Berea sandstone*. Fairly fine-grained, very uneven bedded sandstone, which contains a large quantity of iron pyrites. A little below, in thinner layers, are numerous ripple marks. The sandstone appears above water on the arch of a small anticlinal fold. At the time it was studied the upper 2 feet of the formation was exposed, while on the river bank, both above and below this locality, the Sunbury black shale runs down to water level	2±	2

On the same bank of the river about ¼ mile below the section just described and a short distance above the Water Works is the following section, the rocks of which are apparently above those of the former section and in the lower part of the Cuyhoga formation.

SECTION ABOVE WARREN WATER WORKS.

No.		Thickness feet.	Total thickness feet.
7.	Soil and till - - - - - - - - - -		
6.	Apparently shale - - - - - - - - -		
5.	Bluish-gray sandstone - - - - - - - - -	¼±	16
4.	Soft bluish-gray, very argillaceous shale - - - - - -	2¾	15¾
3.	Compact layer of bluish-gray, fine-grained sandstone - -	¾±	13
2.	Blackish shales at top containing specimens of *Lingula*. The shales are mainly bluish-black; but contain thin bituminous layers, especially in the upper part, and alternating with the shales are thin layers of bluish sandstone, which are thicker near the base of the cliff, and some are slightly concretionary, weathering to a decided rusty color. Specimens of *Lingula* are numerous in the blackish shales near the top, and some were also collected in the blackish shales near the base of the section - - - - - - - - - -	11	12⅓
1.	At the upper end of the exposure, where the rise brings up the lower rocks, we find that below the shales of No. 2 are coarse arenaceous shales to bluish-gray sandstone, about 1⅓ feet shown. This stratum is apparently the sandstone zone occurring on top of the Sunbury shale. Level of Mahoning river	1⅓	1⅓

The prominent sandstone layer at the southern end of the cliff is 9 feet 10 inches above water level, and 420 feet farther north, at the northern end, 12 feet 4 inches above the water, giving a dip of 2 feet 6 inches for that distance to the southeast or at the rate of 31 feet per mile. This section is considered as in the lower part of the Cuyahoga formation, and shows that its lower shales are blacker than those near the base of the formation in northern and central Ohio, and somewhat similar to those of the subjacent Sunbury shale.

On the western bank of the Mahoning river, 1½ miles from the court house park in Warren, on the farm of Warren Brobst, the anticlinal fold already noted on the eastern bank brings up the Berea sandstone. At the base about four feet of Berea sandstone is shown above low water, which is mainly thin-bedded.

The layers are buff in color, more or less undulating, and some of them have ripple marks. Just above is the black Sunbury shale in the lower part of which are immense numbers of *Lingula melie* Hall, together with a larger *Lingula* which is not nearly so abundant.

Above Edgewater, a mile or more beyond the locality just described, is a rocky bank which shows the following section: At the base a blackish fissile shale, about eight feet in thickness; at the top of the shale is a thin sandstone, above which is another zone of shale, capped by a thin sandstone. The Berea sandstone is not shown at the river level and the exposed shales and sandstones apparently belong to the lower part of the Cuyahoga formation.

M. C. Read wrote the geological report of Trumbull county, and under the description of "the Cuyahoga shale" he stated that:

> In the bed of the Mahoning west of Warren, the abundance of *Lingulæ* and the lithological peculiarities indicate that the stream at this point cuts nearly through these shales, and that the Berea grit is to be found at no great depth below.[1]

From the above statement it is evident that Read did not find or recognize the Berea grit in the Mahoning river above Warren. It is of course possible that he did not visit the locality where the anticlinal fold crosses the river and brings up the Berea so that he did not see the top of the formation, or perhaps the water was considerably higher at the time of his work, and the sandstone was covered.

Mr. Read appears to have been confused regarding the horizon of the Berea grit near the state line, a point which has been elucidated by Dr. I. C. White[2] and Professor H. P. Cushing who identified the formation in the vicinity of Warren. Professor Cushing's statement is as follows: "North of Warren another sandstone appears directly under the black shale [the Sunbury or Berea shale] and is the equivalent of the lowest

---

[1] *Rept. Geol. Surv. Ohio*, Vol. I, Pt. I, 1873, p. 504.

[2] *Second Geol. Surv. Pa.*, Q^3, pp. 60 f., 62, 63 f., and Q^4, pp. 77 f., 85, 86.

sandstone on the state line, of the *Corry* sandstone of Professor White in Pennsylvania, of the Berea of northern Ohio.[1]

Professor Cushing gave a section of the rocks through Warren in which the Berea shale (Sunbury) is given as 55 feet in thickness.[2]

It is evident that he included in the Berea shales the blackish ones which the writer has referred to the lower part of the Cuyahoga formation, for it seems to him that only the 14 feet of black shales exposed on the bank of the Mahoning river, and included between the top of the Berea grit and the base of the overlying 9-inch blue sandstone, are to be regarded as the equivalent of the Sunbury black shale as exposed at the typical localities of Sunbury, and in the bluffs of the Ohio river near Buena Vista.

Dr. Orton stated that "in Trumbull county of northeastern Ohio, the Berea [Sunbury] shale grows very thin and thus the upper quarry courses come down close upon the Berea grit."[3] Later he wrote:

> The Berea shale seems to be reduced in this region [Warren] to a thickness of about 8 or 10 feet. It is, however, well characterized by the Discina and Lingula which belong to the horizon. In many places it is almost entirely composed of these shells.[4]

While in describing the Berea grit in the vicinity of Cortland, 7 miles northeast of Warren, Dr. Orton stated:

> It is always overlain by a thin but very black fossiliferous bed of the Berea shale. An excellent section is furnished in the banks and the bed of Walnut Creek, within the limits of the village of Cortland, and a half-mile below. At the junction of Walnut and Musquito creeks, the flag-rock that makes the upper bed of the Berea is found in the bed of the stream. It is covered by 8 feet of Berea shale, very black and crowded with its characteristic fossils.[5]

Mr. John F. Carll, who described such a large number of oil well sections for the Pennsylvania survey, regarded the Berea

---

[1] *Proc. Am. Assoc. Adv. Sci.*, Vol. XXXVI, 1888, p. 215.

[2] *Ibid.*, p. 214, No. 3.

[3] *Ibid.*, Vol. XXX, 1882, pp. 173, 174.

[4] *Rept. Geol. Surv. Ohio*, Vol. VI, 1888, p. 321.

[5] *Ibid.*, p. 331.

grit as probably identical with the Pithole grit of Venango county, Pennsylvania.[1] Dr. I. C. White included the Pithole grit in his "Oil Lake group," which he described as "composed of the *Corry* and *Cussewago sandstone* and the included *Cussewago limestone* and *shale*,"[2] and stated that the Corry sandstone, which he correlated with the "Third Mountain Sand of Venango,"[3] "passes into Ohio and continues west as Dr. Newberry's *Berea grit* outcrop."[4]

Dr. Orton thought that the Sunbury shales became very thin in Trumbull county, so that the flagging stone near Warren, which he regarded as the equivalent of the Buena Vista stone of southern Ohio and the Sharpsville sandstone of Pennsylvania,[5] came "down close upon the Berea grit." Finally, regarding the correlation, he stated: "I am disposed to believe that the Pithole grit of Pennsylvania, as reported in many borings of the region, consists of this joint product of the two systems" [the Buena Vista and Berea sandstones].[6] Later it was stated that Dr. White's "Sharpsville sandstone is our Buena Vista stone, and his Corry sandstone appears to be none other than the Berea grit."[7]

Orangeville.— This village in the Pymatuning valley on the state line is located partly in Trumbull county, Ohio, and partly in Mercer county, Pa. On the southern bank of the Pymatuning Creek, just below the bridge and dam in Orangeville on the Pennsylvania side, is a bank composed mainly of bluish-gray shales, which gave the following section:

SECTION AT ORANGEVILLE.

No.		Thickness feet.	Total thickness feet.
5.	Dark gray to bluish-gray argillaceous shales which contain some small iron-like concretions - - - - - - -	10½	22

---

[1] *Second Geol. Surv. Pa.*, I3, 1880, pp. 91–97 and I 5, 1890, pp. 94, 97–105.

[2] *Ibid.*, Q4, 1881, p. 91. [3] *Ibid.*, p. 92. [4] *Ibid.*, p. 94.

[5] *Rept. Geol. Surv. Ohio*, Vol. VI, 1888, p. 38, and Vol. VII, 1893 [1895], p. 31.

[6] *Proc. Am. Assoc. Adv. Sci.*, Vol. XXX, 1882, p. 174.

[7] *Rept. Geol. Surv. Ohio*, Vol. VII, 1895, p. 33.

4.	Bluish-gray sandstone weathering to a rusty color, from 6 to 8 inches in thickness - - - - - - - - - - -	½+	11½
3.	Grayish to bluish-gray shales, argillaceous and slightly gritty containing some specimens of *Chonetes* and *Lingula* - -	$4\frac{5}{12}$	$10\frac{5}{6}$
2.	Bluish-gray sandstone which weathers to a rusty color, 5 inches thick - - - - - - - - - - - -	$\frac{5}{12}$	$6\frac{5}{12}$
1.	Rather bluish argillaceous shales, which, near creek level, are more arenaceous and bituminous, containing numerous specimens of *Lingula melie* Hall and *L. cuyahoga* Hall - - -	6	6

All of the above shales weather to a rusty color on exposure, contain fossils, are blacker than those of the lower Cuyahoga shale in the Cleveland region, and in addition contain a much larger number of specimens of *Lingulæ.* It is the writer's opinion that the above shales are in the lower part of the Cuyahoga formation and above the Sunbury or Berea black shale.

These rocks were named the Orangeville shales by Dr. I. C. White, who stated that the name was used "merely for the convenience of avoiding in this report a premature discussion of the question of its identification with the Waverly black shales of Andrews, or lower member of the Cuyahoga shale of Newberry."[1] He described it as: "A group of shales, prevailingly blue, but often rusty or reddish-brown on exposed surfaces, always more or less argillaceous, seldom exhibiting sandy layers more than 6 inches thick; and containing considerable quantities of scattered iron ore balls," with a thickness of about 75 feet at Orangeville.[2] While under the description of Pymatuning township, in which the eastern part of Orangeville is located, is the following account of the cliff below the Orangeville street bridge: "The horizon is *300 feet below that of the Sharon coal,* and therefore under the *Cuyahoga shale.* The upper portion of this exposure consists of reddish-gray shales, interstratified with thin flaggy layers; but down near the creek level the shales begin to grow much finer and darker; and just below the milldam fragments of a dark-bluish fine-grained shale in the waterbed are perfectly filled with *Discina pleurites* and *Lingula melie,* This can hardly be the *Cleveland shale* of Dr. Newberry."[3] In

---

[1] *Second Geol. Surv. Pa.,* Q^3, 1880, p. 63. [2] *Ibid.,* p. 63. [3] *Ibid.,* p. 160.

the succeeding report, Dr. White spoke of the Orangeville shales as "these bottom deposits of the *Cuyahoga formation* of Ohio."[1] Dr. Orton stated that "White's Orangeville shale is an equivalent of our Berea shale."[2]

Mr. W. F. Cooper, in a brief discussion of the Berea shale, states that it "varies in Ohio from 15 to 50 feet in thickness throughout the line of outcrop, and is an exceedingly persistent and well-defined horizon. In northeastern Ohio, near the Pennsylvania line, it lies immediately under the Carboniferous millstone grit; a fact of importance in the development of the Lower Carboniferous of that state, which has heretofore been misunderstood."[3] Mr. Cooper is in error in the above statement regarding the horizon of the Sunbury (Berea) shale, for on the hill and farm of Charles Troutman, about two miles north of Orangeville, the base of the Sharon conglomerate (Millstone grit) is barometrically 270 feet above the level of the Pymatuning Creek in Orangeville, at the base of the cliff of Orangeville shales.

Dr. George H. Girty in recent years has devoted a great deal of time to the study of the Waverly series, and he differs from Dr. I. C. White and Professor Cushing, who correlated the Berea grit with the Corry sandstone of Pennsylvania, in regarding it as "the equivalent of the Cussewago sandstone of northwestern Pennsylvania,"[4] the top of which, according to the *Pennsylvania Reports*, is stratigraphically about 35 feet below the base of the Corry sandstone. Dr. Girty stated: "It is doubtful if the Corry sandstone is represented in Ohio." Dr. Girty further stated that "the Orangeville shale of that region is the basal third of the Cuyahoga shale, in part equivalent to Orton's Berea shale,"[5] in which statement the writer would fully concur, for Dr. I. C. White, in his reference to the outcrops near Warren,

---

[1] *Ibid.*, Q^4, 1881, p. 89, and see p. 90 f.

[2] *Rept. Geol. Surv. Ohio*, Vol. VII, 1895, p. 33.

[3] *Geol. Surv. Mich.*, Vol. VII, Pt. II, 1900, pp. 286, 287.

[4] *Science*, N. S., Vol. XIII, April 26, 1901, p. 664.

[5] *Ibid.*

apparently included the Sunbury shale in the Orangeville shales.[1]

After the above was written the writer learned that a test well was being drilled in Orangeville, Ohio, and he is indebted to Messrs. W. J. Apthorpe and J. D. Burnett, of that town, for information concerning it and samples of the drillings. The mouth of the well is in the creek valley above the State-street bridge, estimated as about 6 feet higher than the milldam, which would make it about 10 feet higher than the base of the shales exposed on the creek bank below the dam. It is reported that the creek alluvium is 17 feet thick in the well and at that depth shale was struck. The first sample submitted to the writer, from the depth of 42 feet, is reported as the first sand struck in the well and from the top of the Berea grit. The sample is composed mainly of light-gray silicious and very micaceous sandstone, with an occasional grain of iron pyrites, and lithologically closely resembles the Berea grit. Mixed with the sandstone chips is an occasional one of black shale, which is evidently from above the sandstone. This light gray sandstone is reported to continue to 122 feet, and a sample from 50 feet and another from between 57 and 117 feet are from a light gray, very silicious sandstone. The sample from 117 to 122 feet is composed of fine light gray to white quartz sand with some grains of iron pyrites and its bottom is thought by Mr. Burnett to represent the base of the Berea grit. Immediately below this, Mr. Apthorpe reports 3 feet of shale ; but the sample from 122 to 164 feet is composed mainly of quartz sand. Mr. Burnett, however, reported that at 122 feet the drill entered a softer sand. The sample from 164 to 170 feet is composed of bluish argillaceous shale with a white streak and bluish-gray or gray arenaceous shale to thin micaceous sandstone. From 170 to 415 feet, the chips are mostly dark gray in color and apparently mainly from arenaceous shale. The data furnished by this well,

---

[1] *Second Geol. Surv. Pa.*, Q^4, p. 90 f., where it is stated that "here also it [Orangeville shale] is darker and even some thin layers bituminous, which goes to support Professor Orton's identification of it with Professor Andrews's *Waverly black slate* of southeastern Ohio."

taken in connection with the barometric section from the level of the Pymatuning Creek and the Sharon conglomerate, on the Troutman farm north of Orangeville, apparently show that in the vicinity of Orangeville there is an interval of about 300 feet between the base of the Sharon conglomerate and the top of the Berea grit. There is some uncertainty as to what should be considered the base of the Berea grit. If the line is drawn at the top of the 3 feet of shale, reported at the depth of 122 feet, then the Berea will have a thickness of 80 feet. The sample, however, from 122 to 164 feet is composed mainly of rather large pieces of quartz sand and is apparently from a massive sandstone. If this lower sandstone be classed in the Berea grit, then it will have a thickness of 122 feet. The well has been drilled to a depth of 1715 feet, and the deeper samples are mainly from bluish to grayish argillaceous shales, together with some from grayish arenaceous shales and thin grayish sandstones, apparently in the Erie shale. The samples showed no indication of the black Cleveland shale, so that it is impossible to give the base of the Bedford or top of the Erie shale in this record.

An examination of Dr. Orton's description of the well records of this region leads the writer to conclude that he referred all the sandstone at this horizon to the Berea grit. Dr. Orton reported the Berea grit "to have a thickness of 100 feet, or even more"[1] in the Mecca oil field to the northwest of Orangeville, in the northern central part of Trumbull county. In the wells near Youngstown, which is southwest of Orangeville, in the northern part of Mahoning county, it is given as from 150 to 160 feet thick "with a thin bed of shale interstratified about half way down."[2] While still farther south in the East Liverpool gas field, in the southeastern corner of Columbiana county, in the Ohio river valley, Dr. Orton stated that "the Berea grit ranges in this territory from 60 to 120 feet in thickness."[3] From a well near Sharon, in the western part of Mercer county, Pa., about seven miles south of Orangeville, the Pennsylvania geolo-

---

[1] *Rep. Geol. Surv. Ohio*, Vol. VI, p. 331.

Ibid., pp. 402, 403.

[3] *Ibid.*, p. 333.

gists have reported a white, sharp sandstone, 75 feet thick, the top of which is 313 feet below the base of the Sharon conglomerate;[1] which Mr. Carll regarded as probably identical with the Pithole grit of Pennsylvania and the Berea grit of Ohio.[2]

CONCLUSION.

It has been shown in this article that the Sunbury shale is in general a well-marked and sharply-defined lithologic division, which extends from Vanceburg, in northern Kentucky, across Ohio to the eastern part of Trumbull county, and perhaps into Pennsylvania. It is usually thin, fissile, black, strongly bituminous, varying in thickness from about 6 to nearly 28 feet. The lower part of the shale is very compact and tough, splitting into thin sheets of considerable size, which are somewhat arenaceous; frequently containing some iron pyrites, and often rich in fossils, especially inarticulate Brachiopods. Near Bedford, in northern Ohio, however, it loses its decidedly black color, and is mainly bluish-gray or blackish-gray, with some blackish bituminous layers. The base of the shale is always sharply separated from the underlying massive Berea grit. At the top, wherever exposed, it is also, lithologically, clearly separated from the overlying Cuyahoga formation, although the line of contact is not so well marked and conspicuous as the one at the base. In northern Ohio, at the base of the Cuyahoga formation, are bluish-gray alternating shales and thin sandstones, while in the bluffs of the Ohio river occur 5 feet of blue to drab fire clay and shale, which is followed by 5 ± feet of brownish to bluish-gray massive Buena Vista sandstone. Perhaps in Cuyahoga county the contact between the Sunbury and Cuyahoga shales is not so clearly defined as in most of the state, while again in Trumbull county and in the eastern part of the state there are bluish-gray to blackish shales in the lower part of the Cuyahoga formation, which resemble somewhat the subjacent

---

[1] *Second Geol. Surv. Pa.*, Q^4, 1881, p. 70; also see I^3, 1880, Atlas, Pl. IV, Fig. 3, where the interval is given as 310 feet; Q^2, 1879, pp. 298, 303; and Q^3, 1880, p. 119.

[2] *Ibid.*, I^3, p. 93.

Sunbury shale. Still it is thought that even in this region the line of division is as sharply and clearly defined as is often the case between two formations. It appears to the writer to be a clearly marked and sharply defined lithologic division. Paleontologically, the lower portion of the shales frequently contains numerous specimens of a few fossils, principally *Lingula melie* Hall and *Orbiculoidea Newberryi* (Hall) Herrick, which may be considered the characteristic species of the formation, although not confined to it, since both species probably continue into the Cuyahoga formation.

Finally, on account of the marked lithologic character of the Sunbury shale, its sharp boundaries, its extensive, although narrow areal distribution, and its stratigraphic importance in the classification of the Waverly series, the writer would regard it as a distinct unit in the geological scale of Ohio.

On the geologic maps, based upon the *United States Topographic Sheets* for southern and central Ohio, it appears to the writer that the Sunbury shale is clearly entitled to be represented by a distinct symbol or color and given the rank of a formation. In the northern counties the shale is not always black and strongly bituminous, and the upper limit is probably not as clearly marked as in the southern part of the state.

In western Pennsylvania Dr. I. C. White has described the Orangeville shales and Sharpsville sandstone, while Professor Lesley used the provisional name of Crawford for the overlying shales,[1] all of which in a general way are synchronous with the Sunbury and Cuyahoga shales of northern Ohio. In the succeeding report Dr. White used the terms Meadville upper shales, Meadville upper limestone, and Meadville lower shales, in place of the Crawford shales,[2] and he writes me:

> The name [Crawford shale] was never used by me nor accepted, because it meant nothing. It was provisionally put in by Professor Lesley without my consent, and the following year when it was found this interval of rocks could be further subdivided in Erie and Crawford counties, it was done, and the name "Crawford shales," which I had never accepted, dropped.[3]

---

[1] *Second Geol. Surv. Pa.*, Q^3, pp. 59 f., 61–63.

[2] *Ibid.*, Q^4, 1881, pp. 83–85.

[3] Letter, March 7, 1902.

The shales at Orangeville are dark to bluish-gray, differing as a rule considerably in structure and color from the Sunbury shale. It is evident that the black shale overlying the Berea grit, reported by Dr. Orton from many wells in northern Ohio as the Berea shale, includes more than that shale, and corresponds to the Orangeville shale of Dr. White. Some geologists believe that the Orangeville shale, comprising all the rocks on the eastern line of the state included between the top of the Berea and the base of the Sharpsville sandstone, is the lithologic unit which ought to be represented on the United States geologic maps of northern Ohio. This is the opinion of Professor H. P. Cushing and Dr. George H. Girty, and is entitled to careful consideration, especially since Dr. Girty writes that the Orangeville shale, Sharpsville sandstone, and Meadville shale "maintain themselves across northern Ohio and appear in Medina county in fairly characteristic aspect."[1]

If the Orangeville shale be accepted as the lithologic unit for mapping in northern Ohio, then the Sunbury shale will become the lower member of the Orangeville formation for that part of the state.

NOTE.—In an article entitled "The Classification of the Waverly series of Central Ohio," published in the JOURNAL OF GEOLOGY, the writer referred to the revised classification of the New York rocks by Dr. John M. Clarke and Mr. Charles Schuchert.[2]

It was intended to state, in the first place, that two principles of nomenclature which had been given, had been imperfectly observed by many geologists in their works on stratigraphical geology. In the second place it was intended to state that, on account of this more precise use of stratigraphic names, it had become necessary to revise even the classic nomenclature of the New York series of formations, in which case it was also found necessary to replace several old and well-known names by new terms. The reference to the revised New York classification was intended as a complimentary one, and as a precedent for similar revision of the classification of other states. These two ideas, however, were expressed in one sentence in a somewhat infelicitous manner which has led to some misunderstanding regarding the real meaning, and therefore the above explanation is made.

CHARLES S. PROSSER.

COLUMBUS, OHIO,
March, 1902.

---

[1] Letter of February 28, 1902.

[2] Vol. IX, 1891, p. 206.

THE VARIATIONS OF GLACIERS. VII.[1]

THE following is a summary of the *Sixth Annual Report* of the International Committee on Glaciers:[2]

RECORD OF GLACIERS FOR 1900.

Swiss Alps.—The retreat of the past few years is becoming more marked. There is but one glacier, the Boveyre (in the Valais), which is certainly advancing; since 1892 it has advanced 113 meters. A smaller number than last year are doubtful, and a larger number are certainly retreating. Reports have been received from eighty-two glaciers.[3]

Eastern Alps.—The Vernagt glacier, in the Oetzthal, continues its remarkable advance, and has gained 150 meters since last year. It has united with its neighbor, the Guslar glacier, and is ploughing up its terminal moraine. The ice is seventy meters thick at the point where the glacier ended in 1895; and its velocity, at one section, where it has been frequently measured, though somewhat less than it was a year or two ago, is still about twelve times as great as it was before the beginning of the advance. Measures on the Hintereis glacier gave a velocity from the middle of July to the middle of September exactly equal to the mean for the year, suggesting a constant rate for all seasons of the year. Of the other glaciers in the same general region some show a slight advance and some a slight retreat. The most easterly glaciers, which are in the Ankogl group, present a remarkable condition; of three observed, one has retreated about three meters in the last two years, and the other two have advanced about twenty meters.[4]

---

[1] The earlier reports appeared in the JOUR. GEOL., Vol. III, pp. 278–88; Vol. V, pp. 378–83; Vol. VI, pp. 473–76; Vol. VII, pp. 217–25; Vol. VIII, pp. 154–59; and Vol. IX, pp. 250–54.

[2] *Archives des sciences phys. et. nat.*, Vol. XII, pp. 56–69, 118–131, Geneva, 1901.

[3] Report of Professor Forel and M. Muret.

[4] Report of Professor Finsterwalder.

Italian Alps.—The glaciers of the eastern Italian Alps show a small retreat; some glaciers southwest of Savoy are retreating more rapidly; but the snow seems to be increasing in the Maritime Alps to the west, and two of the glaciers there have advanced several meters.[1]

Swedish Alps.—The summer of 1900 was very cold, with extremely large snowfalls. The glaciers of Lapland, which were the only Swedish glaciers visited, have not changed since the preceding year.[2]

Norwegian Alps.—According to Schöning, the years when grain has not ripened in Norway were 1600–2, 1632–34, 1685–87, 1695–97, 1740–42. These dates follow pretty closely the dates of cold, damp periods in Europe as given by Brückner, and the dates of advance of the glaciers of the Alps as given by Richter. In Norway, however, it is only for the last of these dates that we have any precise information regarding the variations of the glaciers. In 1742–43 the Nigard (Jostedal) advanced about forty-three meters; in 1748 it began to retreat slowly. Other glaciers showed similar variations. There was, in general, a great advance in the eighteenth century, preceded by a very marked retreat; since then there has been a small retreat on which have been superposed many minor variations. At present the glaciers of Jostedal seem to be advancing.

The glaciers of Jotunheim were, in general, advancing in the summer of 1898; since then they have been retreating.[3]

Arctic regions.—M. Charles Rabot has given a very complete account of the observations which have been made on the glaciers of the Arctics and neighboring regions, with full references to the literature, which will be of great service to future observers. His general results as to the variations of these glaciers are:

1. Before the eighteenth century, the glaciers were much less extensive than they are today, and this minimum lasted for several centuries.

---

[1] Report of Professor Porro.

[2] Report of Dr. Svenonius.

[3] Report of Dr. Oyen, which is condensed from a very detailed account of the glaciers of Norway published in English in *Nyt Magazin for Naturvidenskaberne*, Vol. XXXIX, pp. 73–116, Christiania, 1901.

2. During the eighteenth century an enormous advance took place, greater than an ordinary variation. The glaciers invaded territory which they had never occupied during the present [geological] period. This advance was general over all the northern hemisphere.

3. During the nineteenth century the variations have not been uniform. In some regions there has been a considerable advance followed by a slight retreat; whereas, in others, the glaciers, after remaining at a maximum up to the early part of the century have since experienced a small diminution. Nowhere has the retreat been so great as in the Alps during the last fifty years.[1]

Spitzbergen.—Baron de Geer has made a map of the southern and central parts of Spitzbergen which gives an excellent idea of the large glaciers of that region. Professor Nathorst has also described and figured some of these glaciers.[2]

Greenland.—The Swedish expedition of 1899 made a large map of northeastern Greenland; which shows a great number of glaciers, including the Waltershausen which has a breadth of 13 kilometers where it ends in the fiord. Dr. Steenstrup has described a number of small glaciers occupying depressions on the mountain sides on the western coast, which are frequently entirely covered with débris; they seem to be the remnants of a greater glaciation.[3]

Canada.— All the glaciers observed continue to retreat at an increasing rate. The Victoria glacier (Alberta) has diminished slightly. Its velocity measured at two points amounts to 130 feet per year. The Asulkan glacier (B. C.) has retreated 24 feet; the Illicillewaet has retreated 64 feet and has become thinner and

---

[1] "Les Variations de Longueur des Glaciers dans les régions arctiques et boréales," *Archives des sciences phys. et. nat.*, Geneva, 1897, 1899, and 1900. These papers were more fully reviewed in *Science*, December 13, 1901. It is interesting to note that the same order of events has been followed by the glaciers of southeastern Alaska, namely, a long period of small extension, then a short period of great advance, and finally a general retreat, which has been going on for the last hundred years or more. "Studies of Muir Glacier," *Nat. Geog. Mag.*, 1892, Vol. IV, pp. 38, 39. "Glacier Bay and Its Glaciers," *Sixteenth Ann. Rept. U. S. Geol. Surv.*, 1896, pp. 438–40.

[2] G. DE GEER, *Om gradmatningsnatels framförande öfver södra om mellersta Spitzbergen*, Ymer, 1900; A. G. NATHORST, *Twå somrar i norra ishafvet*, Ymer, 1900.

[3] Report of Professor A. Nathorst.

narrower. About 1,500 feet from the end a velocity of about 194 feet per year was measured.[1]

Caucasus.— A number of glaciers in the southeastern part of the chain are retreating, and a number of glacial lakes have been discovered there. The glaciers of the central part of the chain are also found to be retreating. Two glaciers on Mt. Ararat give evidence of retreat.

Siberia.— Professor Sapojnikov has published a finely illustrated book on "The Katoun River and its Tributaries" (Tomsk 1901) in which he gives a detailed account of the glaciers draining into that river. Some of the glaciers he has mapped, others he has only photographed. They are all retreating.

Turkestan.— A number of glaciers have been recently discovered in Turkestan, all of which give distinct evidences of being in retreat.[2]

Himalaya.— The grèat glaciers of Kanchinjanga are from 15 to 17 miles long, and descend to about 13,000 feet above sea level. They are slowly retreating. The Anglo-Indian surveyors formerly restricted the name glacier to the clear ice between the névé fields and the lower moraine-covered portions; many erroneous ideas regarding these glaciers have thus been introduced.[3]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1901.[4]

The narrative and general papers of the Harriman Alaska expedition have been published in two handsome volumes, which contain many excellent illustrations of the glaciers. The general description of the glaciers is written by Mr. John Muir, and he notes that at the time of his first visit in 1879, the two branches of the Grand Pacific glacier and the Johns Hopkins glacier were united and presented a single ice-front; the Hugh Miller and the Charpentier glaciers were also united at that time. He estimates

---

[1] Report of Messrs. G. and William S. Vaux, Jr.

[2] Report of Professor Mouschketov.

[3] Report of Mr. D. W. Freshfield.

[4] A synopsis of this report will appear in the *Seventh Annual Report of the International Committee.* The report on the glaciers of the United States for 1900 was given in the JOUR. GEOL., Vol. IX, pp. 252–54.

that the Hugh Miller and the Muir glaciers have receded about two miles in the last twenty years; the Grand Pacific and the Johns Hopkins about four miles; and the Geikie, Rendu, and Carroll from seven to ten miles.

Glacier Bay, Alaska, remains so full of floating ice resulting from the earthquake of September, 1899, that steamers were unable to approach Muir glacier last summer. However, on December 31, 1901, one of the steamers made a special effort to approach the glacier and succeeded in reaching a point about a mile from the former ice wall. The captain of the steamer reports that from this point onwards the inlet was closely packed with large bergs, and that the true end of the glacier could not be distinguished. The shores of the inlet were thickly covered with large stranded icebergs fifty or sixty feet high.

Last summer the author visited the glaciers of Mt. Hood and Mt. Adams. These two volcanic cones in the northern part of the Cascade Range support eight and nine glaciers respectively. The heights of the lateral, and in some cases of the terminal, moraines show that the glaciers have been larger at no distant date, and that they are now retreating. Some of the moraines are still underlain by ice. But few of the glaciers occupy valleys; many of them lie on the mountain slopes supported by their lateral moraines, and it is evident that they have eroded their beds very little. Stations were established at the ends of several glaciers, and future variations will be shown by photographs to be taken from these stations.

HARRY FIELDING REID.

GEOLOGICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
February 26, 1902.

REVIEWS.

The Carbonic Anhydride of the Atmosphere. By PROFESSOR E. A. LETTS, D.Sc., Ph.D., and R. F. BLAKE, F.I.C., F.C.S. (Plates XVI to XVIII). *The Scientific Proceedings of the Royal Dublin Society*, 1900, Vol. IX (N. S.), Part II, pp. 107–270.

THE memoir is divided and separately treated in two parts, the results of which can best be summarized under each division. The extensive review and criticism by the authors of the literature on the amount and causal distribution of atmospheric carbonic anhydride added to the widespread importance of this constituent in aiding certain geological processes, warrant a detailed review of this very valuable paper.

PART I.

Section I is devoted to the "Introduction and Methods of Determination." The first demonstration of the existence of carbonic anhydride in the air was by Dr. Black, of Edinburgh, probably between the dates 1752 and 1754. Many different processes have been employed since De Saussure's time (1796) to determine atmospheric carbonic anhydride, but only the more important ones are considered in this paper. The authors state that with the exception of several methods based on the physical properties of gases, all the processes depend on the employment of an alkali or alkaline earth as an absorbent; and the amount of carbonic anhydride absorbed is determined by one of several methods, among the most important of which are: (1) increase in the weight of the absorbing apparatus; (2) determination of the excess of the absorbent; (3) liberation and measurement of the absorbed carbonic anhydride. A rather extended review of the work of numerous investigators following these methods, in which the more essential points in each method as developed by the individual worker, are brought out and discussed in a brief manner.

Section II is a description of "The Authors' Experiments on Pettenkofer's Process as Modified by Them." A set of determinations made by the authors of carbonic anhydride in the air of a weaving shed in a linen factory at Belfast, in which the use of the Pettenkofer method failed to give concordant results in duplicate determinations, led to the investigation of this method by the authors. The method finally employed is described in considerable detail, including the preparation of reagents, and the apparatus used are figured. A large number of tests were made on artificial mixtures and subsequently on samples of air collected in the rooms and the grounds of Queen's College, Belfast. The results are recorded in tabular form.

Section III closes Part I of the memoir, in which "The Authors' Experiments on the Action of Baryta Water on Glass and on Silica, and the Disturbing Effect of Soluble Silicates on the Delicacy of the Phenol-Phthalein Colour Reaction," are discussed.

The results obtained are of special interest. The experiments with glass were made on the greenish-white glass of Winchester quarts bottles, using a dilute solution of baryta water of known strength. 1^{cc} of the baryta water is equivalent to 0.1^{cc} of CO_2 at N. T. P. The quantitative results for different time exposures are:

After 48 hours - - - - -	0.0021	gram of glass.
" 72 " - - - -	0.0025	" "
" 72 " - - - - -	0.0050	" "
" 98 " - - - -	0.0062	" "
" 98 " - - - - -	0.0098	" "

The action of alkalies on glass has been investigated previously by a number of workers, and the results here obtained by the authors are in accord with those of previous investigators in showing the very appreciable effect in a short time with very dilute solutions of the alkali, which increases with the time exposure.

It is of interest here to compare Emmerling's results obtained with boiling weak solutions of caustic potash (400^{cc}) in a flask of 600 to 700^{cc} capacity, whose loss in weight per hour was found to be:

0.25 per cent KOH - - -	0.0115	gram of glass per hour.
0.025 " " " - - -	0.0070	" " "
0.005 " " " - - -	0.0027	" " "

In order to ascertain the exact nature of the action of the baryta water on the glass, a given amount of the $Ba(OH)_2$ solution of variable but known strength was introduced into the stoppered bottles and allowed to remain for a given number of days, when the solution was carefully removed and analyzed by the authors. The results follow in tabular form.

	SiO_2	Al_2O_3 Fe_2O_3	CaO	Alkaline sulphates.
Weak baryta solution.....	0.0045	0.0009	None	0.0024
Stronger " "	0.0094	0.0012	None	0.0009
'Percentage composition of the glass used.........	69.95	2.57	17.21	Alkalies as Na_2O 10.27

The authors' conclusions regarding these results are stated by them as follows:

1. A weak baryta solution acts with relative rapidity on the glass of the Winchester quarts (and probably exercise an appreciable action on most varieties of glass), dissolving silica and alkalies, and smaller quantities of alumina and ferric oxide, but no lime.

2. A stronger solution dissolves more silica but less alkalies, about the same amount of alumina and ferric oxide, and also, as in the previous case, no lime.

An appreciable effect is shown by the authors in the titration of $Ba(OH)_2$ after remaining in contact with the glass; and also on the presence of alkaline or soluble silicates on the delicacy of the phenolphthalein color reaction during titration with an acid.

Similar tests conducted on silica with a weak solution of baryta water indicated a similar action as the glass. Some very interesting quantitative results are recorded.

PART II.

Part II is treated in two sections, and makes up the bulk of the memoir. More than twice the space is given to it (106 pages exclusive of the appendices and bibliography) than is allotted to Part I, which is disposed of in 50 pages. Part II consists of a review and criticism of all authentic and trustworthy data collected from all sources and arranged in tables, which bear on the amount and distribution, and the factors controlling the distribution of carbonic anhydride in the atmosphere under varying conditions. It is more than an ordinary compilation in that the data are discussed fully but briefly and the conclusions warranted are concisely stated. It is not possible to make entirely clear the full value of this part of the report in a review, but that an invaluable service has been rendered by the authors will appear from the following general summary:

Section I considers the amount of carbonic anhydride in the atmosphere. After discussing the effects of a permanent increase and decrease in the present amount of CO_2 in the atmosphere on plant and animal life, and the several theories advanced to account for the source of CO_2 to permanently augment this amount, a table showing the amount of CO_2 in 10,000 volumes of air is given.

The arrangement of the table from left to right includes a number of columns under the following headings: "Date of Observation;" "Observer;" "Locality;" "Number of Observations;" "CO_2 in 10,000 volumes of air, including mean, maximum, and minimum;" "Variation, including absolute and percentage;" "Author." The tabulation vertically is in the order of the date of observation, beginning with the earliest (1797) and ending with the most recent (1897). It includes 124 entries, the largest number of observations included in any single entry being the mean of 566; and the number of observations recorded in the table cover a period of 100 years.

A perusal of the figures indicates that the earliest workers obtained an amount vastly too large, accredited by the authors to the methods used. In 1812 Thenard originated a method which yielded results quite close to the present ones. From this time until about the year 1870 the average normal amount of this constituent in the atmosphere was given at approximately 4 in 10,000 volumes, an amount which is at least 25 per cent. greater than that shown at present in fresh air away from cities and towns, approximately 3 in 10,000 volumes.

Section II discusses the "Causes of Variation." In attempting to review and criticise the variations in the amount of carbonic anhydride in the atmosphere, the authors justly appreciate the difficulties encountered, and they state that "not the least of these is to correctly appraise and estimate the value of the evidence brought forward in support of the different contentions which have been raised from time to time in this matter." Only a little study of the work of previous investigators is sufficient to convince one that it has taken nearly a century for chemists to correctly estimate the average amount of this constituent in the air. The figures have been reduced from 100 to 200 volumes of CO_2, in case of the earliest workers, to 3 volumes in 10,000 volumes of air in recent investigations. Two opposite views have been held concerning the variations, championed by De Saussure and Gay Lussac. A statement of these two opposing views can best be summed up in the words of the authors.

> According to the first of these [De Saussure], considerable variations in the amount of atmospheric carbonic anhydride occur, of a more or less lasting or permanent nature, caused by natural agencies such as the seasons, influence of vegetation, the direction and force of the wind, humectation and desiccation of the soil, day and night, etc.
>
> Gay Lussac, on the other hand, was of opinion that owing to the continued movements of the air, both horizontally and vertically, practically uniform distribution or diffusion of the carbonic anhydride occurs. It must be at once granted, from the evidence which has since been forthcoming that Gay Lussac's opinion is correct to the extent that the variations are much less than De Saussure and others of his school believed and that the average amount of atmospheric carbonic anhydride is much the same under the most diverse conditions of weather, locality, season, etc.

The authors state, on the other hand, that variations of a lasting kind do occur, amounting to at least as much as 10 per cent. of the total quantity.

Variations in the atmospheric carbonic anhydride are discussed by the authors under the following headings: (*a*) Locality and local effects. (*b*) Day and night. (*c*) Influence of vegetation. (*d*) Influence of atmospheric precipitates; (1) fog and mist; (2) rain and snow. (*e*) Influence of wind. (*f*) Influence of the seasons. (*g*) Influence of cloud and sun. (*h*) Influence of height.

The figures obtained by various investigators bearing on each one of the above headings are brought together in tabular form, reviewed and criticised, and conclusions when warranted are deduced.

While the subject of variation of atmospheric carbonic anhydride has been one of long-continued investigation and a wealth of figures accumulated, the results are lacking in uniformity, and more often have been carelessly obtained, and are therefore unreliable, and very often lead to opposite conclusions. Much remains to be done in the way of careful and uniform observation and determination by reliable and painstaking workers before definite conclusions may be looked for. From the mass of figures given by the authors the tendency, however, is certainly strongly in favor of Gay Lussac's opinion, that is, the distribution of atmospheric carbonic anhydride is more uniform and the variations not so great as was formerly held by many.

The memoir concludes with two appendices and an extensive bibliography. Appendix I is entitled "On Ground Air and its Relations to Atmospheric Carbonic Anhydride," in which some very interesting figures are given and important conclusions drawn. Appendix II is on "A Comparison of the Results of Determinations of Carbonic Anhydride by Pettenkofer's Original Process, and the Method proposed by Professor Letts and Mr. Blake, and on the Errors incidental to Pettenkofer's Process." By William Caldwell.

The bibliography contains 305 entries, proportioned as follows: German 128, French 98, and English 79.

THOMAS L. WATSON.

DENISON UNIVERSITY,
Granville, O.

Om de Senglaciale og Postglaciale Nivåforandringer I Kristianiafeltet (*Molluskfaunan*). By W. C. BRÖGGER. Separaftryk af Norges geologiske undersögelse No. 31. Kristiania, 1901.

THIS volume concerns itself primarily with the study of the faunas of Pleistocene time in the vicinity of Christiania, and with the changes of level which the character and distribution of these faunas indicate.

The conclusion is reached that the deep sea bottom adjacent was something like 2600^{m} higher than now when the great ice sheet was on, this inference being based on the existence of shallow water fossils at great depths in the "Norwegian sea."

At the end of the last interglacial epoch the land is thought to have been some 100^{m} higher than now, and that this epoch of elevation continued into the time of the last ice covering. As the ice of the last epoch began to melt, the land began to sink, the subsidence continuing for some time after the retreat of the ice began. At the time of the formation of the outermost moraines, the land was 100^{m} to 125^{m} lower than now. This was the time of the deposition of the older and younger yoldia clays and of the older arca clay. While the ice retreated to the second series of moraines, subsidence continued until the land was 150^{m} to 160^{m} below its present level, when the outermost moraines of the second series were formed, and 180^{m} to 185^{m} below its present level during the formation of the innermost moraines of the same series. There was further sinking as the ice receded to its third halting place, and at that time the land stood about 200^{m} below its present level at Christiania. Just before the moraines of the third set were made, the younger arca clay was deposited. Still later the land sank somewhat more, while the ice receded to what is called its "epiglacial station;" that is, to its fifth halting place. By this time the land had sunk to about 240^{m} below its present level. Subsidence then gave place to uplift.

Both the subsidence and the re-elevation are thought to have affected the peripheral parts of the land first, and to have extended progressively toward the center.

The author holds the view that the ice disappeared first from the highlands of Norway, and that the higher parts of central Norway were nunataks at the time of the formation of the first moraines, and that the ice was so thin as to fill only the valleys in the peripheral parts of south Norway at the time of the second series of moraines, while during the time of maximum subsidence the ice filling the Mjosen valley is thought to have found its upper limit about 480^{m} above sea level.

The molluscan faunas of the clay beds of glacial age indicate that the climate was progressively ameliorating from -8 C., or -9 C., at the time of the formation of the outermost moraines, to $+2$ C. at the time of maximum subsidence. The name "Christiania Period" is proposed for the time of sinking.

The shell banks and clay beds deposited during the rise of the land indicate by their character and distribution that the rise commenced in some places sooner than in others, and that it proceeded at unequal rates in different places.

The volume also includes a study of the postglacial and recent faunas. The division between the postglacial and recent is placed at the time when the elevation after the subsidence had attained 40 per cent. to 66 per cent. of all that has taken place in the Christiania region. The distribution and the character of the faunas of postglacial and recent times show that the rate of rise has been inconstant and that progressive amelioration of the climate has accompanied the elevation. The climate at the present time is, however, cooler by about 2° C. than that which obtained while the youngest of the so-called postglacial faunas lived.

An English summary at the end of the volume makes the author's conclusions available to those who do not read the Norwegian language.

R. D. S.

Geology and Water Resources of the Southern Half of the Black Hills and Adjoining Regions in South Dakota and Wyoming. By N. H. Darton. From the Twenty-first Annual Report of U. S. Geological Survey, Part IV.

In his report on the geology of the southern half of the Black Hills, Mr. Darton has given us not only a revision and elaboration of the facts previously known about that interesting region, but has added many which are new and important. The formations which he recognizes in the area are included in the following section :

Pleistocene - -	River gravels and alluvium.	
Tertiary - - -	Oligocene—White River beds (unconformity).	
Upper Cretaceous -	Laramie.	
	Fox Hills.	
	Pierre shales.	
	Niobrara chalk.	
	Benton	Carlysle.
		Inoceramus limestone.
		Graneros shale.
	Dakota sandstone.	
Lower Cretaceous -	Fuson.	
	Minnewaste limestone.	
	Lakota sandstone (unconformity).	
Jurassic - - -	Beulah shales.	
	Unkpapa sandstone.	
	Sundance (unconformity).	
Triassic (?) - -	Spearfish Red Beds.	
Permian - - -	Minnekahta limestone.	
	Opeche.	
Upper Carboniferous -	Minnelusa.	
Lower Carboniferous -	Pahasapa limestone.	
	Englewood limestone (unconformity).	
Cambrian - - -	Deadwood sandstone and conglomerate.	
Algonkian - - -	Crystalline schists and granites.	

Many of these names are new, and the significance of a few of the older ones has been altered, owing to the better information which the author has gathered regarding fossils and uncomformities.

Although the report deals not only with the geologic history of the Black Hills, but with structure, hydrography, and resources of the region as well, a résumé of the first topic only is here given.

Too little is known of the pre-Cambrian condition of the Black Hills to permit a discussion of it at present. The rocks of that age are a complex system of granites and schists which will require careful study for interpretation. The area was land during early and middle Cambrian times, but toward the close of the period the sea advanced, covering most and perhaps all of the area. The Potsdam or Deadwood sediments were largely derived from the Algonkian Crystalline rocks, as evidenced by the local material contained in the basal Cambrian conglomerate. The Ordovician beds known in the northern Black Hills are not found southward, and both Silurian and Devonian are likewise absent. As to whether the region was land during those three periods or was alternately elevated and submerged, the erosion during the times of elevation being sufficient to remove all the sediments deposited during the periods of submergence, can only be conjectured. The unconformity between the Cambrian and the Carboniferous is inconspicuous.

From the early Carboniferous on through the Trias, sedimentation seems to have been continuous. During the Lower Carboniferous the region was the scene of limestone deposition in an open interior sea. Probably there was no considerable land mass in the vicinity until the Upper Carboniferous. At this time islands are believed to have existed in the neighborhood of the Laramie Mountains of Wyoming, and they probably furnished the clastic material of the Minnelusa formation. Late in the Carboniferous or early in the Permian (the lack of fossils in the Opeche beds prevents a definite location of the horizon) the waters of the area appear to have been inclosed seas, and to have suffered temporary reduction by evaporation in an arid climate. Red clays, interstratified with thin seams of gypsum, indicate such conditions. Mr. Darton was so fortunate as to find a few Permian fossils in the comparatively barren Minnekahta limestone, thereby showing with reasonable certainty that the Permian sea extended farther north and east than was previously supposed. The Spearfish Red Beds are classed as Triassic because of their stratigraphic relation to the Permian and to the Jurassic, and because of their lithologic resemblance to Triassic formations elsewhere in the Western United States. They are almost devoid of fossils. During this period, as in the early Permian, we may suppose that the region about the Black Hills possessed an arid climate and was covered by saline lakes, in which gypsum and red clays were deposited.

The unconformity between the Red Beds and the marine Jurassic doubtless represents an epoch of erosion during the early part of the Jurassic. The Sundance, Unkpapa and Beulah formations belong rather to the later part of the period, and doubtless owe their origin to the great gulf which entered the United States from the northwest at that time. Another period of emergence without distortion of the strata followed the exclusion of this gulf, and no surely marine formations were deposited in the region until after the Dakota epoch of the Cretaceous.

The Lakota, Minnewaste, and Fuson formations were formerly not separated from the Dakota group, but they are now segregated on the testimony of the plant remains contained in the Lakota sandstone. The local unconformities and beds of coal in the Lakota indicate a condition of slight crustal oscillations near sea level. Marine fossils have not been detected in any of the Lower Cretaceous formations nor in the Dakota. The land was probably low, and frequently inundated by lakes, or brought to a marshy condition.

By the beginning of the Benton stage the great interior sea of the Cretaceous had spread over the plains, and in it sediments continued to be deposited until near the close of the period. The prevalence of fine clastic sediments was interrupted by temporary depositions of chalk and limestone in clear open waters. The retreat of the interior sea beginning in the Fox Hills stage was probably completed during the Laramie, a large part of the latter formation being non-marine. Although the Laramie beds do not occur in the Black Hills, they are now upturned like the older beds upon the west side of the uplift, and it is probable that they originally covered the whole of it.

The Black Hills dome was probably uplifted very early in the Eocene. During that epoch it was truncated and fashioned into its present general form. That many of the larger valleys date from that time is proved by the existence of Oligocene deposits even in their deeper portions.

In the Oligocene epoch a great lake is supposed to have partially surrounded the Black Hills and spread far up on their sides, leaving the Dakota hog-back ridges isolated as off-shore islands. In support of the view that the beds are lacustrine the author cites the horizontal continuity of the beds, the fine assortment of the material, and the existence of thin beds of limestone. Although much of the formation has been removed by subsequent erosion, its former extent is roughly indicated by outlines and by a superposition of drainage which allowed many Eocene valleys to drain northward through Neocene cañons cut across the old divides. After the Oligocene no extensive sediments were deposited in the Black Hills. A further uplift of several hundred feet produced a tilting toward the northeast which gave the advantage of gradient to the streams on that side of the uplift and induced frequent captures of the headwaters of the more southerly creeks.

No traces of glaciation have as yet been found in the hills.

E. B.

SUPPLEMENTARY NOTE TO CHARLES S. PROSSER'S PAPER ON "SUNBURY SHALE OF OHIO."

A layer of concretionary sandstone mentioned in the sections on Rocky Fork, Franklin county, showing the lower portion of the Berea grit and the upper part of the Bedford shale, according to latest observations probably belongs in the upper part of the Bedford shale. In this case the concretionary layer, No. 2, of the section of the cliff below the tree on the farm of John Augen is not to be regarded as the base of the Berea sandstone, but in the Bedford shale, while the Berea begins with No. 5.

C. S. P.

RECENT PUBLICATIONS.

—American Paleontology, Bulletin of, No. 14. April, 1902 (Harris Co. Cornell University, Ithaca, N. Y.)

—AMI, H. M. Bibliography of Canadian Geology and Paleontology for the year 1900. [From the transactions of the Royal Society of Canada. Second series, 1901–2. Vol. VIII, Sec. IV, J. Hope & Sons, Ottawa.]

—ANDERSON, WM. First Report of the Geological Survey of Natal and Zululand. Surveyor General's Department. [P. Davis & Sons, Pietermaritzburg.]

—AGASSIZ, ALEXANDER. An Expedition to the Maldives. [From the American Journal of Science, Vol. XIII, April, 1902.]

—BANKS, NATHAN. Papers from the Hopkins-Stanford Galapagos Expedition, 1898–99. VII. Entomological Results (6): Arachnida. With field notes by Robert E. Snodgrass. [Proc. Washington Acad. of Sci. Vol. IV, March 27, 1902.]

—BARRELL, JOSEPH. The Physical Effects of Contact Metamorphism [From the American Journal of Science, Vol. XIII, April, 1902.]

—BEEDE, J. W. Invertebrate Paleontology of the Red-Beds. [Advance Bulletin of the First Biennial Report of the Geological Survey of Oklahoma, April, 1902.]

—DARTON, N. H. Preliminary List of Deep Borings in the United States. Part I (Ala.–Mont.); Part II (Nebr.–Wyo.). [Dept. of the Interior Water Supply and Irrigation Papers of the U. S. Geol. Surv. Nos. 57 and 61, Washington, 1902.]

—ECKEL, EDWIN C. The Classification of the Crystalline Cements. [From the American Geologist, March, 1902.]

—FOLSOM, JUSTUS WATSON. Papers from the Harriman Alaska Expedition. XXVII. Apterygota. [Proc. of the Washington Acad. of Sci. Vol. IV, pp. 87–116. March 27: 1902, Washington, D. C.]

—HOLST, NILS OLAF. Några Subfossila Björnfynd. Sveriges Geologiska Undersökning, Stockholm, 1902.

—HALLOCK, CHARLES. The Ancestors of the American Indigenes. [From the American Antiquarian. Vol. XXIV, No. 1, Jan. and Feb., 1902.]

—KAHLENBERG, LOUIS. Instantaneous Chemical Reactions and the Theory of Electrolytic Dissociation. [Reprinted from the Journal of Physical Chemistry, Vol. 6, No. 1, p. 1, January, 1902.]

—LEE, WILLIS T. The Areal Geology of the Castle Rock Region, Colorado. [From the American Geologist, Feb., 1902.]

—MICHELSON, ALBERT A. The Velocity of Light. [The Decennial Publication, University of Chicago Press, 1902.]

—O'HARA, CLEOPHAS. The Mineral Wealth of the Black Hills. [South Dakota School of Mines Bulletin No. 6. Dep't. of Geology. Rapid City, S. Dakota, 1902.]

—PENCK VON, ALBRECHT and RÜCKNER, EDUARD. Die Alpen in Eiszeitalter (mit mehreren vollbildern in autotypie, 2 farbigen profil-tafeln sowie zahlreichen text-illustrationen). [Gekrönte Preisschrift Lieferung 2. Chr. Herm. Tauchnitz, Leipsig, 1902.]

—RIGGS, ELMER S. The Fore Leg and Pectoral Girdle of Moroscaurus—with a note on the genus Camarosaurus. [Publication 63, Field Columbian Museum, Geol. series, Vol. I, No. 10, Chicago, 1901.]

—The Dinosaur Beds of the Grand River Valley of Colorado. [Publication 60, Geol. series, Vol. I, No. 9, 1901.]

—WOODWORTH, J. BACKUS. Pleistocene Geology of portions of Nassau County and Borough of Queens. [New York State Museum, Bull. 48, New York, 1901.]

—WALCOTT, CHARLES D. Outlook of the Geologist in America. [Bulletin of the Geol. Soc. of Am. Vol. XIII, pp. 99–118, Rochester, Feb., 1902.]

THE

JOURNAL OF GEOLOGY

MAY–JUNE, 1902

THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.[1]

CONTENTS.

Part I.—INTRODUCTION.

VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

Linnæus; Development of mineralogy; Foundations of petrography; Werner's classification of rock formations.

DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

Abbé R. J. Haüy, 1801; John Pinkerton, 1811; Alexandre Brongniart, 1813; P. L. A. Cordier, 1815; John Macculloch, 1822; Karl Cæsar von Leonhard 1823; Alexandre Brongniart, 1827; Systems of von Leonhard and Brongniart compared.

Investigations into the Chemical Composition of Rocks; Classification by Feldspars; Influence of genetic hypotheses; Geological classifications.

Carl Friedrich Naumann, 1850, 1858; Bernhard von Cotta, 1855, 1862; Ferdinand Senft, 1857; J. Reinhard Blum, 1860; Justus Roth, 1861; Th. Scheerer, 1864; Ferdinand Zirkel, 1866; Ferdinand von Richthofen, 1868.

Cordier's System and its Influence; H. Coquand, 1858; Archibald Geikie, 1872,

Part II.—Beginning of the Microscopical Era; Ferdinand Zirkel, 1873; A. von Lasaulx, 1875; H. Rosenbusch, 1877; Foqué and Michel Lévy, 1879.

---

[1] An abstract of this review was delivered as a retiring presidential address before the Geological Society of Washington, December, 1900.

Samuel Allport; Clarence King, 1878; M. E. Wadsworth, 1884.

J. D. Dana, 1878; Karl A. Lossen; H. Rosenbusch, 1887; H. Rosenbusch, 1896.

Justus Roth, 1883; E. Kalkowsky, 1886; J. J. Harris Teall, 1886–1888.

Franz Schröckenstein, 1886, 1897; H. O. Lang, 1891; F. Loewinson-Lessing, 1890, 1897; A. Osann, 1900, 1901.

Ferdinand Zirkel, 1893–1894; H. Rosenbusch, 1898; Johannes Walther, 1897.

SUMMARY.

Part I.

INTRODUCTION.

THE systematic and descriptive science of rocks — petrography — is a product of the nineteenth century. One hundred years ago the distinction had not yet been drawn between the rock and the geological formation or terrane, and many dense rocks were still included among minerals and described as such. With the discrimination between stratigraphic units and rocks proper the science of petrography became outlined, but did not at first receive a name. For some time after the proper scope of the science was clearly defined its development was rapid, and in certain later periods there have been notable advances, due to the invention of some new method of research or to the stimulation afforded by discoveries in some closely allied branch of science.

For the last thirty years or more research in all directions has added greatly to our knowledge of rocks, through the adaptation of the microscope to their study, improved methods of chemical analysis, and a vast store of accurate field observations of occurrence and relationships. But the systematic part of the science has not kept even pace, and does not adequately express the knowledge of the day. This lagging behind on the part of the classificatory branch of petrography is most natural, and similar conditions have existed in various epochs of the past. It is due partly to the necessity for a thorough consideration of the store of new information concerning rocks before its true bearing upon classification could be correctly appreciated, and partly to prevailing differences of opinion as to the relations of petrography to the broader science of rocks — petrology.[1]

At the present time students in many parts of the world, dissatisfied with existing petrographic systems, are turning their attention to classification, and are attempting to apply the newly acquired knowledge, with or without the aid of theoretical considerations, to the construction of improved systematic arrangements of rocks. In view of this situation it has seemed appropriate to present at this time a review of the development of systematic petrography. An understanding of the steps taken in bringing the science to its present condition must certainly be useful to those who would assist in causing important advances in the future.

In this review no attempt will be made to give a complete historical sketch of petrography, but rather to study in a somewhat critical way the course of development through which the science has passed, to analyze the more important contributions to its advancement, and especially to examine the principles nominally applied in formulating schemes of classification and to test the methods of application as to their logical directness and consistency. From some cause the existing systems are commonly regarded as unsatisfactory and inadequate, and this condition indicates either that the principles of classification have not been wisely chosen or that they have been incorrectly applied.

That the standpoint of the reviewer may be clear, it may be

---

[1] The terms "petrology" and "petrography" have been so widely used in various senses that the writer wishes to urge an agreement among students of rocks to apply each in future in accordance with the scope implied in its etymology. On this basis the broad science or treatise of rocks is manifestly *petrology*, and the descriptive, systematic science, leading to the nomenclature of these objects, should be *petrography*. This usage corresponds to the definitions given in the "Lexique Pétrographique" prepared by F. Loewinson-Lessing, with the co-operation of many other petrographers, published in the *Compte Rendu of the Eighth International Congress of Geologists* (Paris).

well to state the principles which have guided him in his analysis of systematic propositions :

1. A systematic classification of rocks has for its object the arrangement of all rocks in groups according to a method, producing a regular subordination of parts. While in all classifications the groups must possess certain chosen characters in common, the system is natural or artificial according as the groups express community of fundamental, important characteristics, or of comparatively unimportant properties, chosen for convenience only.

It is commonly admitted that rocks are incapable of truly natural classification, but that the nearest possible approach to a natural system is to be desired. It is, therefore, important to scrutinize systematic propositions to see if their factors of classification have a fundamental connection, making the sequence of divisions natural in desirable degree. Each factor applied should have important natural relations to those preceding and following it in construction of the system. The writer thus believes that the classification of systematic petrography should be a *hierarchical classification*, in distinction to the *cross-classification* necessary in petrology.

2. A systematic classification must be logical in construction. Whatever principles or criteria the architect of a system may adopt, he must be logically consequent and consistent in their application, else his structure is weak, and must fall.

3. It is unscientific to use an assumption which is known to be untrue as a basis of classification.

4. An adequate system of petrography must be stable and comprehensive. In order to fulfil these requirements it must be based upon knowledge, not upon theory or hypothesis ; it must be created for *all rocks*, known or unknown, of the characters now understood ; its framework must be capable of change in detail without injury to the structure as a whole.

5. The use of ignorance concerning the constitution of some rocks as a factor for their classification is no longer permissible.

If, in the comments to be made upon various systems, it appears to the reader that those of the present day are more severely criticised by the writer than those of earlier periods, it must be remembered that such a discrimination is natural and just. With greater knowledge of rocks, and with the experience of earlier systematists to guide him, the petrographer of the present day should be able to present a classification freer from defects than any proposed by his predecessors. It is the writer's aim to avoid all personal animus in discussion of the existing systems of classification.

Petrography may be concisely defined as the systematic classification of rocks. But if the principal handbooks of today be referred to, it will be found that it is a matter of supposed mutual understanding, rather than of precise statement, as to what constitutes a rock. It is commonly said that rocks are masses of geological importance in the constitution of the earth, but no very serious attempt is made to define what is of importance, or to discuss what treatment shall be given to substances excluded under such a definition. For the purposes of this review, it will be sufficient to define rocks as the *substances constituting* masses of geological importance, recognizing that geological units of mass are not necessarily units in constitution, and may change in material character from place to place. It is the task of petrography to furnish a systematic arrangement of these natural objects and a corresponding nomenclature. The geologist may wish to consider rocks from many different standpoints, each requiring a more or less special grouping and appropriate terms to express the observed or assumed relationships, and such groupings may be apart from systematic petrography.

VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

The category of rocks as understood today is somewhat different from the categories conceived to be the subject-matter of petrography in various epochs of the past. The early history of petrography is therefore in large degree a history of the differentiation of the sciences dealing with various categories of the mineral kingdom — mineralogy, stratigraphic geology, and petrography. But while a complete review of the subject must note the origin and application of the ideas by which this differentiation was brought about, it is more particularly the object of this retrospect to trace the development of classification, beginning with the time when it was first sought to distinguish a group of objects even approximately corresponding to rocks as at present understood. A brief consideration of the earlier stages is, however, necessary to a clear understanding of the conditions existing in the first decade of this century.

Linnæus.— Certain gems and ornamental stones were known to the ancients by names which they bear to this day; but no attempted classification of the mineral kingdom prior to the time of Linnæus, in the middle of the eighteenth century, need be considered at this time, nor is the system of Linnæus of much importance except for the framework of the classification he proposed for the mineral kingdom, the same which he applied with so much greater success to the organic world. It has been said of Linnæus that he had a talent amounting to a genius for the arrangement of natural objects according to system; that "He found biology a chaos; he left it a cosmos." But he extended his *Systema Naturæ* to cover the inorganic world from a logical desire to reorganize the entire field of natural history, rather than from an intelligent knowledge of rocks and minerals.

In the Linnæan system the first grand division of the mineral kingdom is into Petræ, Mineræ, and Fossilia; but an examination of the substances arranged under these heads shows that the system expresses great ignorance as to the character and relations of many objects classified. Doubtless the followers of Linnæus, who were many and enthusiastic, were stimulated to much research as to the character of rocks and minerals, in their efforts to arrange them within the system of their master; but the most visible effect of the Linnæan system was to furnish a theme for controversial debate and argument for a century to come. The attempt to force inorganic substances into the same scheme of species, genera, etc., provided for plants and animals was warmly advocated on the one hand, and as fervently denounced on the other.

Development of mineralogy.—The latter half of the eighteenth century witnessed great advances in knowledge concerning the materials of the earth's crust, and toward its close there began to crystallize out of that knowledge the three sciences of mineralogy, geognosy, and petrography, although the latter was long unnamed.

With more and more accurate information as to the constant chemical composition of minerals, and under the influence of Haüy's brilliant conception of molecular structure and crystal form as attributes of these substances, mineralogy rapidly advanced to its place as a definite branch of science. Its subject-matter grew more and more homogeneous by a process of exclusion, as it became clear that many composite or impure substances had been erroneously classified with minerals. But the mineralogist of this period of development had little interest in and paid little attention to the heterogeneous aggregate of objects rejected from his category. Nevertheless mineralogists considered rocks as so plainly forming an appendix to mineralogy that they set up schemes for their classification based almost wholly upon mineral composition.

Foundations of petrography.— While mineralogy was thus developing on definite lines, the students of the mineral masses observed to have wide distribution in the earth were building up a vastly more complex science. By the careful researches of Pallas, de Saussure, von Buch, von Humboldt, Werner, Smith, Macculloch, and many others, the generalizations upon which stratigraphic geology is based were being formulated. The facts of an order in the superposition of strata were established in several localities and the genius of Werner was devoted to the framing of hypotheses explaining the observations made and providing for the extension of generalizations to the rock masses of the globe.

The foundations of petrography were laid in this period, the term rock (*roche*, *Gestein*) was frequently employed, and works termed classifications of rocks were published before the nineteenth century began. Thus in 1787 appeared Karl Haidinger's *Systematische Eintheilung der Gebirgsarten* (Vienna) and A. G. Werner's *Kurze Classification und Beschreibung der verschiedenen Gebirgsarten* (Dresden). The former essay, though awarded a prize by the St. Petersburg Academy of Sciences, appears based upon a superficial knowledge of rock masses when compared with the Wernerian arrangement. In these and other contemporaneous systems it is plain that the geological formation was not distinguished from the rock, as we now use these terms, and hence there was no true petrographical scheme at this time.

Werner's classification of rock formations.—Werner devoted much careful study to the mineral composition and general characteristics of rocks, and often described them in appropriate and precise terms. He distinguished between *simple* and *compound* rocks, and recognized that in many cases certain minerals were to be considered as *accessory* as compared with other *essential* constituents. Perhaps more than any other geologist he laid the foundations of *descriptive* petrography, but his systematic arrangement was so predominantly devoted to expressing a supposed order of superposition of rocks in the earth that it was rather a crude stratigraphic scheme than a classification of rocks which he presented. This will be clear from the outline given below.

Werner applied the term "formation" to masses of a certain character originating under certain conditions and perhaps recurring at various times in the history of the earth. Formations were grouped according to the great periods of their origin. He distinguished:

1. Primitive formations (*Das Urgebirge*): Under this head are found granite, gneiss, mica schist, clay slate, limestone, quartzite, porphyry, pitchstone, serpentine, and many other formations.

2. Transition formations (*Das Uebergangsgebirge*): Here were placed clay slate, graywacke, greenstone, gypsum, etc. The oldest fossils were supposed to occur in these rocks.

3. Stratified formations (*Das Flötzgebirge*): In this division are found sandstone, stone coal, marl, rock salt, various limestones, chalk, basalt, amygdaloid, and other formations.

4. Alluvial formations (*Das aufgeschwemmte Gebirge*): Here occur sand, clay, gravel, etc.

5. Volcanic rocks (*Vulkanische Gesteine*): This includes only lavas and ejectamenta of volcanoes, with several pseudovolcanic substances.[1]

The great majority of igneous and metamorphic rocks, as we now term them, were believed by Werner to be of aqueous origin, and were treated as such. In Werner's mineralogical system many rocks also found a place, as appears in von Kobell's statement of his system as it was in 1798. For example, under the clay family (*Thongeschlecht*) are included, among others, pitchstone, clay slate, basalt, wacke, clinkstone, lava, and pumice.[2]

DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

At the beginning of the century, then, the attempts at the systematic classification of rocks were progressing on two very different lines. On the one hand the mineralogist, treating rocks as an appendage to mineralogy, was arranging them primarily by their mineral constitution, as far as he could determine it, and was for the most part uninfluenced by considerations of geologic origin or occurrence. His system was founded upon the most obvious characteristics of the objects in question.

On the other hand, the geologist was hampered by his efforts to arrange in one system geological terranes (formations) and rocks proper. He could not logically apply any criterion throughout the system, and was most inclined to use geological occurrence and theoretical considerations of origin.

The geologist's early classifications of rocks were naturally more complicated and less logically and consistently carried out than the schemes of mineralogists, and were correspondingly

---

[1] This general statement of Werner's elementary system I have taken principally from A. VON ZITTEL'S *Geschichte der Geologie und Paleontologie*, 1899, p. 89.

[2] F. VON KOBELL, *Geschichte der Mineralogie*, 1864, p. 165.

less satisfactory. But no classification of this period could have been really adequate, because the chemical and mineralogical compositions, as well as the origin, of many rocks were unknown, and only modern methods of research have permitted the assignment of a large number of types to their proper relationships.

Abbé R. J. Haüy.—The first systematic arrangements of rocks to be of much importance to the science of petrography as now understood were evolved in Paris, and the controlling idea of these systems has dominated French petrography for a century, and is evident in all systems to some extent.

The Abbé R. J. Haüy was professor of mineralogy at the Museum of Natural History in Paris and in charge of its great cabinet of minerals. As already mentioned, his conception of molecular structure and its relation to crystal form had placed mineralogy within its proper sphere. In 1801 he published the first edition of his classic work "*Traité de minéralogie*," in four octavo volumes, with a fifth of quarto-size containing eighty-seven plates, filled for the most part with figures of crystals. This treatise is evidence at once of the advanced state of mineralogy and of the non-existence of anything worthy of being termed a science of rocks, in France, at this time. The quarto-volume of the *Traité* contains a tabular view of Haüy's "Distribution Méthodique des Minéraux." To this elaborate system of minerals are added two short appendices presenting an arrangement of rocks. One is headed "Agrégats des différentes substances minérales," the other, "Produits des Volcans." That the arrangement of rocks had not received much thought from Haüy at this time is clear from the imperfect scheme presented and from the fact that it was not until 1811 that Haüy addressed a letter to Leonhardt's *Taschenbuch für Mineralogie*, saying that he had conceived the idea of classifying rocks mineralogically ("J'ai conçu l'idée de classer cette suite (des roches) minéralogiquement").

Haüy was not a geologist, and his system must be judged in the light of the circumstances under which it was constructed. These are trenchantly characterized by Lossen in his comment that "the idea of mineralogical classification, of this great contemporary of Werner, did not spring from a wealth of geognostic observations; his letter [above referred to] was not dated from the central plateau of France, from Vesuvius, from the Rhone Valley, or from Predazzo, as were the classic letters of Leopold von Buch at an earlier day, but from the mineralogical cabinet in Paris.[1] Furthermore, the enlargement of the halls allotted to the collections and the consequent rearrangement of the latter was the immediate inspiration of the idea. Haüy's system is therefore characterized by Lossen as cabinet specimen petrography.

The writer does not know whether or not Haüy's revised system was actually published prior to the appearance of the second edition of his *Traité de minéralogie* in 1822. As there presented, it expressed at least ten years' development under the idea announced in 1811. Its principal feature is: a subdivision of rocks into classes, orders, genera, species, varieties, and modifications. Five classes of rocks are distinguished, viz.: (I) Stony and saline; (II) Combustible nonmetallic; (III) Metallic; (IV) Rocks of an igneous origin according to some, aqueous according to others; (V) Volcanic rocks. This grand division is clearly not logical or consistent. General, chemical, and physical properties and mode of origin are all arbitrarily applied. The stony appearance used to produce the first class is recognized as possessed also by the questionable igneous rocks of the fourth class, and is the first factor used for their further subdivision. A "schist inflammable" is included in the first class in spite of the property applied to produce the second class. Except for the class of metallic substances Haüy's category of rocks is similar to that now recognized as the subject-matter of petrography; that is, he did not include with them geological formations, as did many of his contemporaries.

The inconsequent construction of this system appears also in

---

[1] K. A. Lossen. "Über die Anforderungen der Geologie an die petrographische Systematik." *Jahrbuch der königl. preuss. geolog. Landesanstalt und Bergakademie*, 1883.

the factors used to produce three orders under the first class, viz.: (I) Phanerogenous ("phanerogène"); (II) Adelogenous ("adélogène"); (III) Conglomerate. The rocks of the first order are made up of definite mineral species, and their composition is apparent. The composition of those of the second order is not apparent to the naked eye, and it is assumed that portions of them do not belong to mineral species. Further, it is stated that some of them are clastic; but why these are not placed in the third order, which is defined as containing rocks composed of cemented particles of older rocks, is not discussed.

The "cabinet petrography" of the mineralogist, as Lossen characterized it, is still more evident in the formation of genera, which in the first class, embracing the largest number of rocks, are named after minerals. The first genus is Feldspar, including not only rocks consisting mainly of feldspar, but also granite, syenite, pegmatite, protogine, gneiss, etc. Similarly, diorite is a species under the genus Amphibole. Haüy's system has always been criticised as giving entirely undue weight to certain minerals; but unnatural as is his scheme in that respect we have the same idea with us today, although it is no more logical now than it was a hundred years ago.

The criteria used in subdividing genera and species in Haüy's scheme are mainly those deemed of *primary* importance by later authorities. The *simple* and the *composite* are the leading heads under the genus, and structure is used to form varieties or modifications under the species.

John Pinkerton, 1811. — In 1811 there appeared in London a pretentious work of 1200 pages entitled: *Petralogy, a Treatise on Rocks*, by John Pinkerton, an Englishman. The author was an eccentric character, whose claim to renown rests rather on his historical researches than on his *Petralogy*, for he clearly had little conception of the objects under discussion in that work. The greater part of Pinkerton's energy was directed to a quaint and prolix argument against the tendency of the time to classify mineral substances in the same manner as animals and plants. His *bête noire* was the mineral *species*, for he insisted that the essential element of the species in the animal or vegetable kingdom was its power to "produce a similar progeny."

> Dr. Jameson tells us [remarks Pinkerton] that there is in fact but *one* species in mineralogy, namely, the globe; but even this may be doubted till it shall have produced another, at least as round and as wicked.

Admitting as appropriate the fundamental division of natural history into three kingdoms, the animal, vegetable, and mineral, Pinkerton ingeniously draws a distinction.

> In the two former [he remarks] the kingdom consists of living subjects, who, of course, may be well considered as divided into classes, orders, genera, and species; but in the mineral kingdom the territory alone constitutes the subject of discussion.
>
> But the very term mineral kingdom may of itself lead to a new and more proper nomenclature; for as a kingdom may be regarded as either vivified with animal and vegetable life, or as an inert tract of country, with certain geographical, chorographical, and topographical divisions; so the latter point of view can alone apply to mineralogy, while the former belongs to zoölogy and botany.
>
> What is more usual than the division of a kingdom into provinces, districts, domains, etc.? I would propose, therefore, in the present advanced state of the science, that the mineral kingdom be considered as divided into three Provinces:
>
> 1. Petralogy, or the knowledge of rocks, or stones which occur in large masses.
> 2. Lithology, the knowledge of gems and small stones.
> 3. Metallogy, or the knowledge of metals.
>
> Petralogy, a Province of mineralogy [is then] divided into twelve *Domains*; of which the first six, being distinguished by the substances themselves, may be called *substantial*; while the remaining six, being distinguished by circumstances or accidences of various kinds, may be called *circumstantial* or *accidential*; but this last division is of little moment.

The six "substantial" domains of Pinkerton are:

1. The Siderous, in which iron predominates.
2. The Siliceous.
3. The Argillaceous.
4. The Magnesian.
5. The Calcareous.
6. The Carbonaceous.

The "accidential" domains are:

7. The Composite.

8. The Diamictonic, "in which substances are mingled."
9. The Anomalous, "or those which contradict the common order of nature."
10. The Transilient.
11. The Decomposed.
12. The Volcanic.

This outline will indicate sufficiently that the *Petralogy* has no real importance to the present review. Pinkerton does not appear to have been taken seriously by his contemporaries, as there is little or no reference to his elaborate system in succeeding publications of his countrymen.

Alexandre Brongniart, 1813.—In 1813 Alexandre Brongniart[1] published a *Classification minéralogique des roches mélangées.* The writer has not seen the original, but von Leonhard gives a tabular view of the scheme proposed by Brongniart, which shows it to have been crude, and not worthy of special discussion here, because of the much more elaborate and mature work by this author issued a few years later, to which some space must be given. But comparatively crude as this outline was, it gave much evidence of the logical mind of its author.

P. L. A. Cordier, 1815.—Contemporaneously with the constructive labors of Haüy and Brongniart, another French master was also struggling with the same problem. It is to the painstaking researches of P. L. A. Cordier that we owe the first great step in deciphering the composition of volcanic and other rocks of such fine grain that their constituents could not be recognized by the simple methods of examination then in use. He instituted chemical, microscopical, and mechanical researches of much ingenuity, and arrived thus early at the conclusion that volcanic rocks were made up of known minerals in microscopic crystals or grains, and of glass, which he believed contained the same elements. In 1815 Cordier presented to the Academy of Science in Paris the results of his investigations in an important work upon the substances composing volcanic rocks.[2] The

---

[1] *Journal des Mines*, Vol. XXXIV.

[2] P. LOUIS CORDIER, "Mémoire sur les substances minérales dites *en masse*," etc., followed by "Distribution méthodique des substances volcaniques dites *en masse*,"

classification of volcanic rocks accompanying his memoir was limited to the few surface lavas then known and the tuffs and ashes. He had the idea that either feldspar or pyroxene predominated in all cases, and hence the first division was into feldspathic and pyroxenic rocks. Texture was the main property applied for further subdivision.

John Macculloch, 1822.—The third decade of the century witnessed the publication of several important essays in rock classification. The first of these was by John Macculloch, and was entitled *Geological Classification of Rocks, with Descriptive Synopses, Comprising the Elements of Practical Geology*, issued in London, 1822. Macculloch's work is called "a classification of rocks," but it is really a classification of rock formations, as we should now express it. It is an attempt at stratigraphic geology without recourse to fossils. Its foundation was a knowledge, which was very thorough for the time, of the rocks of a limited area, and the assumption that the same rocks must, in general, occur in all parts of the world in the same sequence and relations as in the British Isles. In discussing the basis of his scheme he says:

> In considering the different plans on which a classification of rocks might be constructed, he (the author) was, without hesitation, led to adopt one founded on the geological relations and positions of rocks in nature . . . . the basis of the arrangement is virtually the same as that adopted by Werner.

Macculloch thought that all rocks might be placed in a few groups, distinguished by certain prevailing mineral characters.

> It will be further seen [he says] that these different groups are also in a great measure distinguished in nature by certain general or geological relations, more or less constant and perfect.

The arrangements according to mineral characters and geological relations were believed to coincide.

The attempt to use fossils as criteria of the age of rock formations, which was then being made by the Germans, did not appeal to Macculloch. He is said to have been jealous of the

---

Journal de Physique, 1815–1816. Both memoir and table of classification were reprinted by D'Orbigny in 1868, in his work *Description des roches*, etc., which gave the system of Cordier as elaborated at the time of his death, in 1861.

rapidly developing science of palæontology. In his opinion fossils were not well enough known, as to their kinds or their distribution, to be used as factors in classifying rocks as to their geological position. He says, however, that he looks forward to the time "when a system of organic mineralogy will be formed."

With regard to his system Macculloch remarks:

> The classification is simple; all rocks being referred to a primary and a secondary class, and a smaller division being formed of those which are found in both. The substances which cannot be referred to the latter class, from their more recent origin are considered separately in an *appendix;* and a similar expedient is adopted for the volcanic rocks.

"Primary" means to Macculloch anterior in date to the secondary; and "secondary" means later than the primary. Each class is divided into two divisions, the *Stratified* and the *Unstratified.* "As these subdivisions," remarks the author, "have not yet been introduced into any of the arrangements of rocks, they will each require some explanation."

The result of Macculloch's scheme is expressed in the following tabular arrangement of rocks:

PRIMARY CLASS.

Unstratified.

Granite.

Stratified.

Gneiss.
Micaceous schist.
Chlorite schist.
Talcose schist.
Hornblende schist.
Actinolite schist.
Quartz rock.
Red sandstone.
Argillaceous schist.
Diallage rock.
Limestone.
Serpentine.
Compact feldspar.

SECONDARY CLASS.

Stratified.

Lowest (red) sandstone,
Superior sandstones.
Limestone.
Shales.

Unstratified.

Overlying (and venous) rocks.
Pitchstone.

OCCASIONAL ROCKS.

Jasper.
Siliceous schist.
Chert.
Gypsum.
Conglomerate rocks.
Veinstones.

Appendix.

Volcanic rocks.
Clay, marl, sand.
Coal.
Alluvia.
Lignite.
Peat.

If we examine this table, it is seen that Macculloch was not able to carry out consistently the application of the factors adopted. This is most conspicuously the case with the "overlying (and venous) rocks" placed in the unstratified division of the secondary class. These overlying rocks were, in fact, recognized as later than the secondary rocks in many cases. They are mainly what we should call intrusive igneous rocks, found cutting other rocks, and of the real age of which Macculloch confessed that he had little evidence. He was ignorant of the composition of aphanitic or felsitic rocks, and they receive no consistent treatment at his hands.

Macculloch is credited with having been a keen observer and with having made truly great contributions to stratigraphic geology. But he does not appear to have conceived of the distinction between a geological formation and a rock. There are in his book many phrases, such as the title of the work itself, and statements scattered through it, which are couched in the language of today, but have very different significance at this time. It is interesting to apply many of his remarks concerning the condition of the systematic science of rocks, as understood by him, to the petrography of today.

Karl Cæsar von Leonhard, 1823.—In 1823 appeared a truly epoch-making work, the *Charakteristik der Felsarten* by Karl Cæsar von Leonhard, professor at the University of Heidelberg. This is, in fact, the first fairly consistent treatise upon rocks. It is founded upon an exceptionally accurate knowledge of the objects classified, and with advanced ideas as to the true relations between geognosy proper and the descriptive science of rocks. Yet von Leonhard did not give his science a name, and presents it as a part of geognosy.

Von Leonhard says that his object is to present all facts bearing upon the *character* of rocks, an aim expressed in his chosen title. He points out that a discussion of the stratigraphic relations of rocks must be preceded by an accurate statement of their nature. Rocks are defined as the mineral masses of more or less considerable extent in the crust of the earth. It is recognized that, from the standpoint of geognosy proper, only those masses can be considered important the extent of which is so considerable that general laws as to their relations and distribution may be discerned. Yet it is pointed out that there are other masses of subordinate or abnormal occurrence which may have a wide distribution, though occupying no position peculiar to themselves, and that these masses are important when arranged by their characteristics. Stratigraphic geology and petrography are thus fairly outlined, though no definite proposal for their separation is made.

The classification presented by von Leonhard has many features which are preserved in modified form in the German systems of today. Like all early systems, however, the primary division is arbitrary, and drawn upon no definitely stated principle. Four divisions are established: (1) Heterogeneous rocks, (2) Homogeneous rocks, (3) Fragmental rocks, (4) Loose rocks, while coals are placed in an *appendix*. For subdivision, structure is used as the basis, the granular, schistose, porphyritic, dense, and glassy groups being established in some of the main divisions. These terms are used with nearly the meaning we now attach to them. The principal anomalies of association in the arrangement arise from the throwing together of igneous and sedimentary rocks in certain groups, and from the inconsequent way in which von Leonhard met the difficulty of dealing with the more or less dense rocks, the composition of which could not then be ascertained. These were mainly of igneous origin, and not stratigraphic units, and there was no proper place for them in the system. They were treated as a group by themselves under the Homogeneous rocks, with the heading, "Rocks (apparently homogeneous) which are not to be regarded as minerals" ("Nicht als Glieder oryktognostischer Gattungen zu betrachtende—scheinbar gleichartige—Gesteine"). Here we find trachyte, aphanite, serpentine, basalt, pitchstone, obsidian, and various schists. Von Leonhard realized more or less clearly that most of these rocks would some day be found to be complex in character, and he therefore appreciated that his treatment of them was a makeshift. Twelve years later, in his *Lehrbuch der Geognosie und Geologie*, he raised the *apparently homogeneous* rocks to an equal rank with the heterogeneous and homogeneous divisions.

Von Leonhard was unquestionably the foremost petrographer of his day, sharing with Alexandre Brongniart the honor of first placing the classification of rocks upon a firm basis as a systematic science. He had been called to Heidelberg but a few years before this work was issued, finding there perhaps the largest collection of rocks then in existence. He had also visited Paris and studied the great collection of the Museum of Natural History as arranged by Haüy. Von Leonhard also belonged to the group of German geologists who, with Smith and Macculloch in England, and a few elsewhere, were engaged in placing stratigraphic geology upon a sure foundation. He did not himself develop the distinction, clearly foreshadowed in his work, between the geological formation and the rock.

A critical examination of the system contained in the *Charakteristik* shows that von Leonhard actually applied as his first criterion the distinction between massive and clastic rocks, as we should express it, though he may not have realized it. Next he applied the idea of homogeneity and its opposite. But the notable feature is the prominence given to structure and the close approximation of some of his definitions to ones in current use. It was the first time structure was assigned so prominent a rôle in a system of rocks. Mineral composition followed structure, and was applied quite reasonably.

The system of von Leonhard is specially noteworthy as the work of a German, for in it he breaks away from the influence of the Wernerian school. This was doubtless to some extent the result of a visit to Paris, but while building upon the characteristics of rocks he did not give to mineral composition the completely dominating place which it held in the French systems. Von Leonhard rejects the biological framework of classes, orders, genera, and species as quite inapplicable to rocks, since they lack individuality.

Alexandre Brongniart, 1827.—The *Classification et charactères minéralogiques des roches homogènes et hétérogènes*, by Alexandre Brongniart, published in 1827, marks the next important step in the development of petrography. This admirable little book of only 144 pages contrasts markedly with other voluminous works of its period. It is concise in statement, and presents a clearly conceived and logically worked out system.

In the introduction we find minerals, rocks, and geological terranes distinguished and defined. *Minerals* are species or varieties determined by the laws of mineralogy; *rocks* are the same substances considered in their masses and as entering into the structure of the globe; *terranes* are assemblages of several rocks, considered as having been formed at about the same epoch. Brongniart pointed out that there were two ways of looking at rocks—as to their composition, and as to their occurrence. He held that geognosy was not strictly a classification of rocks; that to arrange rocks by occurrence and describe them in that order involved many digressions from the discussion of relationships; that rocks formed at different times must then be referred to as many times as they occurred; that the same name would be given to different substances formed at the same time; and, finally, that classification by occurrence involved the use of hypotheses where knowledge was lacking. All these troubles should be avoided, in his opinion, by classifying and naming rocks upon mineralogical composition and independently of occurrence. The treatment from the latter standpoint could then follow naturally.

The system of Brongniart is a mineralogical classification with the aid of the exterior characters. His divisions are styled classes, orders, genera, and species. There are but two classes, viz.: (1) "Roches homogènes ou simples ;" (2) "Roches hétérogènes ou composées." In this respect Brongniart is more logical than von Leonhard. The *Homogeneous rocks* are defined as those that *appear to be so* to the naked eye. There are two orders under the class of *Homogeneous rocks*, namely: (1) "Roches phanérogènes (of distinct known mineral species); (2) "Roches adélogènes" (of unrecognizable constitution). This division is logical enough, but it is based on a criterion of primary value which is clearly applicable to *all* rocks. The result is that under Homogeneous rocks are included, in the second order, a number of substances, including clays, dense schists, trap, basalt, and other igneous rocks, of really heterogeneous character.

The Heterogeneous rocks are also divided into two orders: (1) "Les roches de cristallisation; (2) Les roches d'agrégation." This distinction really introduces the factor of conditions of origin, which fact Brongniart seemingly did not recognize, as he makes no comment upon it.

When it comes to finer subdivision we find that this system is almost purely mineralogical, as its title claims. Structure is relegated to a very subordinate rôle, wherever it is convenient to apply it.

Systems of von Leonhard and Brongniart compared.—If we now review the construction of the systems proposed by von Leonhard and Brongniart, which may be taken as the real starting point of systematic petrography, we find that both resorted at once to an expedient which expressed the fact that in their day the composition of many rocks was unknown. And the principal inconsistencies of the two arrangements came from their treatment of the aphanitic rocks of all kinds throughout the schemes. But we must admit that these substances could not be correctly classified by composition so long as their character was so nearly unknown.

Both these masters relied mainly on *mineral composition*, but von Leonhard advanced *structure* also to a prominent place. Both declared that the system and nomenclature of rocks should be founded upon *characteristics*, and that the various treatments rocks must further receive from the geologist would be facilitated rather than retarded by such an arrangement. Brongniart made a suggestion, apparently unconsciously, in subdividing Heterogeneous rocks, that geological conditions of origin might serve as a practical basis in classification ; but he made only limited application of that factor, and does not appear to have grasped the broader meaning of his own proposition.

After von Leonhard and Brongniart had placed petrography upon a firm basis, no great advance was made in the systematic part of the science until the middle of the century. The cause of the unsatisfactory elements in the early schemes was recognized to lie in the ignorance concerning the character of many rocks, and a large number of investigators devoted themselves to the study of the composition of rocks on the one hand and to their geological relations on the other. While the object of this review is to trace the application of principles or of knowledge in classification rather than to follow the course of investigation, it is necessary to refer briefly to the studies made during the second quarter of the century, noting the use of new knowledge in system.

Investigations into the chemical composition of rocks.— Among the characters of rocks not taken into appropriate account in the first systems, by far the most important is *chemical composition.* But from the beginnings under Cordier more and more attention was paid to chemical investigation, until other things became quite subordinate. First, qualitative test was applied, then partial analysis, and finally bulk analysis. Chemical research was naturally applied with most valuable results to the denser rocks, chiefly of igneous origin, and in this way, with ever-extending field investigation, it was found that these substances were vastly more complex, more varied in character, and much more common than had been supposed. From these causes the petrography of igneous rocks grew to be the principal part of the science instead of being relegated to an "appendix," as had been done at an earlier day.

The chemical analysis of igneous rocks was mainly directed to a determination of their mineral constituents and to the question as to whether the various oxides were present in simple or constant proportions or not. For the latter inquiry the ratio of the oxygen contained in the silica to that of the bases, taken together or in groups, was calculated and comparisons instituted. G. Bischof set up as a means of comparison the so-called "oxygen quotient," obtained by dividing the total oxygen of the bases by that of the silica, as shown in the analysis of any given rock. That the faulty analyses of the time could not in any case have yielded trustworthy evidence of stoichiometric or constant proportions of the constituents is now clear; but even with the imperfect analyses the complexities of the problem were such as to lead nearly all chemical students of rocks to abandon attempts to deduce chemical formulæ or simple ratios for them.

For many years chemical investigations were necessary in determining the approximate mineral composition of many rocks, and important discoveries were undoubtedly made; but it is pathetic to recall the years spent in hard labor by many of the foremost men of their time in endeavoring to work out the mineral composition of fine-grained or aphanitic rocks from incorrect or inadequate bulk analyses, and with very imperfect knowledge of the constitution of some rock-making minerals. Abich, Bunsen, von Waltershausen, Bischof, Scheerer, Roth, Streng, Delesse, Haughton, and many others devoted much time to this research without what appears to us, at this time, to have been commensurate results.

Classification by feldspars.—The principal effect of this chemical work upon petrographic classification appears to have been to perpetuate the mistake of giving an undue importance to the feldspars as rock constituents. As different kinds of feldspar were recognized by chemical analysis, largely through the researches of Gustav Rose, a further mistake was made. It was for a time thought that orthoclase (or potash feldspar), albite, oligoclase, labradorite, and anorthite were the only feldspar species entering into rocks, and that they did not occur to any great extent in association. Hence, after setting up a great division of *feldspathic rocks*, the logical method for subdivision was according to the kinds of feldspar present. This was thought to be the more surely a correct principle, since its application seemed to produce groups nearly coinciding with those previously recognized, but less sharply defined.

Perhaps the first to advocate the use of feldspars in this way was Hermann Abich, in 1841.[1] Abich viewed magmas as basic, neutral, or acid silicate solutions of a great range in specific gravity. As the known feldspar series presented also a wide range in silica and in specific gravity, it seemed to him certain that there must be a definite relation between the silica content of a given magma and the feldspar which could crystallize out of it. It therefore seemed to him possible to use the various feldspars for the classification of endogenous (or eruptive) rocks very much as fossil remains were used in sedimentary rocks. For the next twenty-five years a sharp division according to feldspars was advocated, in systems to be reviewed; and it required the application of the theory of isomorphous mixtures to feldspars, the polarizing microscope, and modern methods of mechanical and chemical analysis, to demonstrate the true distribution of feldspars in rocks, and the thoroughly artificial nature of this arrangement.

Influence of genetic hypotheses.—The connection of chemical composition of igneous rocks with theories as to the origin of the differences in composition of magmas and the use of the genetic conception in classification forms an interesting chapter in the history of systematic petrography. Yet the application of this genetic idea led at first only to a broad and ill-defined

---

[1] H. ABICH, *Geologische Beobachtungen über die vulkanische Erscheinungen und Bildungen in Unter- und Mittel-Italien*, Braunschweig, 1841.

proposition in classification which does not require full discussion in this place. Reference is had to Bunsen's hypothesis of two fundamental magmas — the trachytic and the pyroxenic — mixtures of which were supposed to produce all igneous rocks.[1] From the systematic standpoint Durocher's hypothesis had the same result, though differing somewhat from Bunsen's in the physical origin of the magmas. Durocher (1857) carried out a chemical division of igneous rocks on his hypothesis, forming the *acid*, *hybrid*, and *basic* groups.[2] Th. Kjerulf[3] (1857) proposed four chemical groups: *acid*, *neutral*, *basic*, and *ultra-basic*, and various authors recognized the grand division of *acid* and *basic*. Such divisions, when closely connected with hypotheses, have had more influence upon the geologist than upon the systematic petrographer; for it was quickly found that, although the fundamental idea might be near the truth, the theory was too imperfect (or narrow) to explain the observed range in chemical composition of igneous magmas. The broad chemical distinction, considered merely as a recognition of the observed range in composition of rocks, was not given sufficient precision to be of much value in system.

Geological classifications.—During these years of patient research, especially into the composition of igneous rocks, geologists were making important contributions to the broader phases of classification. As a knowledge of occurrence, relation, and modes of formation of rocks increased many different factors were tested as to their applicability to the formation of systematic arrangements. Soon the numerous geological standpoints from which rocks might be viewed and classified led to a great many schemes for their arrangement, and much confusion existed. This condition continued until the geologist separated the systematic classification of rocks from various other arrange-

---

[1] R. Bunsen, "Ueber die Processe der vulkanischen Gesteins-bildungen Islands," *Poggendorf's Annalen*, etc., Vol. LXXXIII, 1851, pp. 197–272.

[2] J. Durocher, "Essai de pétrologie comparée," etc., *Annales des Mines* (5) Vol. XI, 1857, p. 217.

[3] *Nyt magazin for naturvidenskaberne*, Vol. IX, 1857, p. 294.

ments of which these bodies were found capable. Certain geologists, as, for instance, De la Beche in England, had, at an early day, very clear and logical ideas as to the principles which must control classification. In the third edition of his *Geological Manual*, issued in 1833, is the sentence: "Classifications of rocks should be convenient, suited to the state of science, and as free as possible from a leading theory." In accordance with this principle, De la Beche divided all rocks (including formations) into *stratified* and *unstratified*, "independent of the theoretical opinions that may be connected with either of these great classes of rocks." The stratified rocks were then subdivided into "superior or fossiliferous" and "inferior or non-fossiliferous." By this logical division De la Beche at once secured classes or subclasses corresponding well to those now called igneous, metamorphic, and sedimentary.

Carl Friedrich Naumann, 1850, 1858.—Without attempting a complete history of the introduction of each factor into classification, we will now consider the system of Carl Friedrich Naumann, the great Saxon geologist, as of much importance in presenting *a new mode of treatment.* The first edition of his *Lehrbuch der Geognosie* appeared in 1850, the second in 1858. Naumann was a great systematist; he viewed rocks from many standpoints, and from each constructed a peculiar scheme of treatment. Thus one section of the *Geognosie* was called "Petrographie oder Gesteinslehre," defined farther as a branch of "Chthonographie oder die Geognosie im engeren Sinne des Worts." This is the first use of *petrography* of which I have knowledge. It is used in the sense of petrology, as the latter term is now commonly applied in America.

Naumann not only gave the comprehensive science of rocks a special name, but he established within it six divisions, namely:

A. Hylology, a discussion of the constituents of rocks.

B. Histology, on texture and structure of rocks.

C. Morphology, a classification of forms of occurrence.
D. Synopsis, or the systematic descriptive science.
E. Petrogeny, a discussion of the genesis of rocks.
F. Allo-osology, the science of the alteration of rocks.

Under this elaborate framework rocks were grouped in many ways. They were considered as minerogenous, zoögenous, or phytogenous, according to origin of materials; as crystalline, clastic, dialytic, or amorphous, depending on character of the constituent grains; as simple or composite; in another view as phanomeric or cryptomeric, and so on.

But when it came to the systematic arrangement of his "Synopsis" Naumann was at sea. He himself called it an *attempt* at a grouping of rocks—"Ein Versuch einer Gruppirung der Gesteine"—and plunged without discussion of principles into the description of rocks under a scheme of classes, orders, families, and lesser divisions.

In the first edition of the *Lehrbuch*, Naumann divided all rocks into three classes, namely: (1) Crystalline rocks; (2) Clastic rocks; (3) Rocks which are neither crystalline nor clastic.

It was explained that the groups of amorphous, zoögenous, and phytogenous rocks are scarcely co-ordinate in importance with the crystalline and clastic divisions, so they were united in the third composite class. In the descriptions of the Synopsis, however, the amorphous (hyaline and porodine) rocks were considered in connection with the rocks of the other two classes to which they are related in composition.

In the second edition but two classes were recognized, embracing all rocks: (1) Protogenous (original); (2) Deuterogenous (derived). Naumann gave no discussion of the basis upon which he made the change.

In both editions Naumann leaves the manner of subdividing classes to the reader to make out for himself. In the class of original rocks are six orders, viz.: (1) Ice, (2) Haloid rocks, (3) Quartz rocks, (4) Silicates, (5) Ores, (6) Coal. Families are produced within these orders by mineral composition. Structure, texture, and other properties are occasionally used for minor unnamed divisions. After the elaborate preparation for this arrangement, it must be confessed that Naumann failed utterly to produce a system worthy of the name. No logical and consequent application of principles can be found in his Synopsis.

The great value of Naumann's work lies in the clear setting forth of the scope of the *general science* of rocks, independently of their formal or historical relations to the earth. He outlined the divisions under the broad science, and showed the proper position of the purely systematic and descriptive branch. He illustrated clearly how many arrangements or groupings of rocks are natural and necessary from the geologist's standpoint, and evidently understood that he could not introduce all these considerations into the construction of one system of classification.

In the development of petrographical system, Naumann's analysis of the broad science was of great importance. For many years the primary classification of rocks, leading to an arrangement for purposes of description, followed some of the various ways set forth by him. And even at the present day we find H. Credner, a successor of Naumann in the university at Leipzig, presenting rock descriptions in his well-known *Elemente der Geologie* under a framework very similar to that of the *Lehrbuch der Geognosie*. Whatever the choice of criteria adopted by individuals from among the alternatives presented by Naumann, very similar, if not identical, major divisions were formed.

Bernhard von Cotta, 1855, 1862.—Almost contemporaneously with Naumann's *Geognosie* appeared several other treatises on rocks by German authors of note. *Die Gesteinslehre*, by Bernhard von Cotta, was first published in 1855, and its second edition in 1862, the latter being translated into English and serving for years as a standard work.

The first edition of the *Gesteinslehre* professes to be merely a description of rocks, and the arrangement or order in which the various kinds are presented is stated to be one of convenience only. Von Cotta's point of view was that, as rocks are simply aggregates of mineral particles, one kind grading into another, and as they are of different modes of origin, there can be no species comparable to those of plants, animals, or minerals, and hence a classification, properly speaking, is an impossibility. Reviewing the various characters of rocks as to their application in nomenclature and description, this author touches on some fundamental points with noteworthy discrimination. This is particularly true with regard to his remarks on the availability of texture for purposes of classification. Noting that it is the most easily distinguished character of rocks, and that it had been used as a primary factor in classification, he pointed out that chemical and mineral composition were more fundamental, and that there was nothing so intrinsically important in texture that differences in that respect should be allowed to separate things otherwise alike.[1] It seemed to him better to name the rock from its mineral composition, and for textural varieties to add expressive terms.

In this first edition of the *Gesteinslehre*, von Cotta introduced no geological factor into his adopted arrangement. He treated all rocks in the following groups, which were purely for convenience :

1. Basaltgesteine.
2. Grünsteine und Melaphyre.
3. Trachyte.
4. Porphyre.
5. Granite und Gneisse.
6. Glimmerschiefer.
7. Thongesteine.
8. Kieselgesteine.
9. Kalksteine und Dolomite.
10. Gypsgesteine.
11. Verschiedene Mineralien als Gesteine.
12. Eisengesteine.
13. Kohlen.
14. Trümmergesteine.

In the second edition of the *Gesteinslehre*, issued in 1862, while still claiming rocks to be incapable of true classification by inherent characters, von Cotta makes a noteworthy advance toward a systematic arrangement by grouping them primarily according to geological mode of origin. As further factors he uses, in certain classes, broad chemical distinctions and form of occurrence. His general scheme is as follows :

---

[1] "Genau genommen ist indessen die Textur gar nichts so wesentliches, dass sie veranlassen könnte, wegen ihrer Ungleichheit zwei Gesteine ungleich zu nennen, wenn sie übriges gleich sind."—*Gesteinslehre*, p. 22, 1855.

- I. Eruptive rocks, probably all originating through consolidation from a molten condition.
  - 1. Poor in silica, or Basic.
    - *a*. Volcanic.
    - *b*. Plutonic.
  - 2. Highly siliceous, or Acid.
    - *a*. Volcanic.
    - *b*. Plutonic.
- II. Metamorphic crystalline schists, probably all derived from sediments, yet resembling eruptive rocks in mineral composition.
- III. Sedimentary rocks.
  - 1. Argillaceous.
  - 2. Calcareous.
  - 3. Siliceous.
  - 4. Tuffs.

To these three clearly defined groups was added an appendix of rare rocks or those of problematic origin. Here were included many quartzose rocks, coals, iron ores, serpentine, etc.

The eruptive rocks were considered as derived from molten magmas; the broad chemical distinction was made with Bunsen's law in mind, but not directly as its expression; the volcanic and plutonic rocks were separated purely on the basis of occurrence; the further subdivision was by general mineral composition, and texture was used as subordinate to it. It is worthy of special note that von Cotta expressly pointed out that geological age was not involved in the distinction between the volcanic rocks and the plutonics. He considered that the older volcanics had been largely removed by erosion, and that the younger plutonics had not yet been laid bare.

Ferdinand Senft, 1857.—In 1857 appeared an elaborate work by Ferdinand Senft, with the title (translated) *Classification and Description of Rocks, Founded upon their Mineral Constitution, Chemical Composition, and Structure.*[1] This treatise, which received the Demidoff prize (St. Petersburg), is mainly notable for its elaborate attempt to apply chemical factors in details of classification.

---

[1] "Classification und Beschreibung der Felsarten, gegründet auf ihre mineralogische Beschaffenheit, ihre chemische Zusammensetzung und ihre Structur," Breslau, 1857.

In this work Senft gives detailed tables for the determination of rocks, the first of which presents the following general scheme of classification :

A. Inorganic rocks ("Anorganolithe").
  I. Crystalline.
    1. Simple.
    2. Composite.
  II. Clastic.
    a. Indurated.
      1. Pseudoclastic.
      2. Hemiclastic.
      3. Holoclastic.
    b. Unconsolidated.
      1. Gravel, sand, etc.
      2. Soil ("Erdkrumer").
B. Organic rocks.

Curiously enough Senft's discussion of principles of classification begins with the consideration of the means for subdividing the smallest divisions of this table, which he calls "Classes."

Senft believed that rocks of these classes should be further arranged by their characters. Reviewing these, he points out the great difficulties in so classifying them, owing to the fine grain, variable composition and texture of many kinds. The facts lead him to assert that the main systematic divisions, such as orders, groups, etc., cannot be founded on structure (Gefüge) or other outer habit of the rocks, because the former factor would at once separate similar things, and the latter bring different things together. Mineral composition would be the best basis for arrangement were it not for the fact that, in the fine-grained or aphanitic rocks, chemical tests are necessary to determine the mineral components. As it is, the chemical relation of rocks — and especially of the crystalline — to certain solvents affords the only safe means by which rocks can be classified. This factor of solubility is actually applied to the formation of orders, suborders, and groups under the classes provided by the scheme already outlined. Senft is, however, not fully consistent, for the first division of the class of composite crystalline rocks is on mineral composition, into the two orders: (1) Alabradorites (rocks free from labradorite, generally rich in quartz, and never containing augite); (2) Labradorites (rocks characterized by labradorite and free from quartz and orthoclase). These were subdivided into nine groups, according to the action of hydrochloric or sulphuric acid upon the rocks. For further details of this unique and highly artificial system the reader must be referred to the original work.

J. Reinhard Blum, 1860.—Shortly after the treatises of Naumann, von Cotta, and Senft, there was published the *Handbuch der Lithologie oder Gesteinslehre*, by J. Reinhard Blum.[1] This work is but little more than a descriptive handbook, with slight discussion of principles of classification, and in it no original contribution to the systematic science was made. The main divisions of the work are as follows:

- I. Crystalline rocks.
  - A. Homogeneous.
    - *a.* Granular.
    - *b.* Schistose.
    - *c.* Porphyritic.
  - B. Heterogeneous—with three structural divisions.
- II. Clastic rocks.
  - A. Cemented.
  - B. Not cemented.

The further division of crystalline rocks is by mineral composition.

Justus Roth, 1861.—Among the students of the chemical composition of igneous rocks none has rendered greater service than Justus Roth, who, in 1861, published his *Gesteinsanalysen, in tabellarischer Übersicht und mit kritischen Erläuterungen.* Upon the basis of nearly a thousand analyses available at that time, Roth undertook to ascertain whether chemical composition gave in itself a practical ground for the classification of igneous rocks. As a basis for comparison of analyses Roth selected the oxygen ratio, *i. e.*, the ratio of the oxygen of the acid radical, SiO_2, to that of the bases, RO (including R_2O) and R_2O_3, and obtained

---

[1] *Erlangen*, 1860, pp. 356.

the oxygen quotient (originally proposed by Bischof) by dividing the oxygen of the bases by that of silica.

Comparing all available analyses in this way Roth recognized that no simple chemical relations existed between different rocks, and that chemical formulæ were therefore useless; that rocks of different mineral composition fell in the same chemical division; that chemical and mineral arrangements of rocks could not coincide; that a purely chemical arrangement would separate things closely related on geological and mineralogical grounds; and that a mineralogical arrangement must be connected with structure and texture. In this dilemma Roth chose to arrange igneous rocks primarily by their kinds of feldspar and the presence or absence of quartz. He admits that pyroxene or amphibole might be used in the same way, but considers feldspar much preferable because of its greater abundance and easier determination. The scheme of classification presented by Roth is as follows:

I. Orthoclase rocks (often containing some oligoclase).
  A. With quartz (*i. e.*, more siliceous than orthoclase).
    1. Granite.
    2. Gneiss.
    3. Felsite porphyry.
    4. Liparite.
    5. Syenite.
  B. Without quartz.
    1. Orthoclase porphyry.
    2. Sanidine trachyte.
    3. Sanidine-oligoclase-trachyte.
    4. Phonolite.
    5. Leucitophyre.
II. Oligoclase rocks.
  A. With hornblende.
    1. Diorite.
    2. Porphyrite.
    3. Amphibole andesite.
  B. With augite.
    1. Oligoclase-augite-porphyry.
    2. Melaphyre and spilite.
    3. Pyroxene-andesite.
    4. Nephelinite.
    5. Haüynophyre.
III. Labradorite rocks.
    1. Labradorite-porphyry.
    2. Gabbro.
    3. Hypersthenite.
    4. Diabase.
    5. Dolerite.
    6. Normal pyroxenic rock (Bunsen.)
    7. Basalt.
IV. Anorthite rocks.
  A. With augite — eukrite.
  B. With hornblende.

This arrangement attempts no expression of a relation between chemical and mineral composition; it assumes constant presence of feldspars in some amount in all rocks, and also certain characteristic associations of minerals. It indirectly recognizes structure and geological age as factors in classification. Roth believed that the classification by mineral components outlined certain combinations or associations as central points of notably frequent and widespread occurrence, about which the rocks of other combinations and of comparative rarity must be grouped. While expressing the idea that not only the kind but the amount of various minerals might be considered in a mineral classification, he confined his own adaptation of this idea to the recognition of *essential* and *accessory* constituents, in certain cases, and with no definite plan.

Th. Scheerer, 1864.—Shortly after the appearance of Roth's tables of rock analyses, a proposition for the general classification of igneous rocks upon a chemical basis was published by Th. Scheerer.[1] This proposition is notable as representing the views of one of the men who, in the preceding decade, had devoted much time and labor to the bulk analysis of rocks. Unlike Roth, who had come to the belief that no simple and persistent chemical formulæ or ratios could be set up for igneous rocks, Scheerer was convinced that he had found such formulæ, and that all silicate rocks could be referred to nine comparatively simple chemical types.

Upon the basis of earlier investigations of the gneisses of the Saxon Erzgebirge, Scheerer had come to the idea that all of them could be considered as mixtures of three magmas, represented in nearly pure form in three prevalent gneisses of the region, namely: the "Rother Gneiss," "Mittlerer Gneiss," and "Grauer Gneiss," the composition of which might be expressed in simple formulæ, given below. The visit to the Fassathal was made to test the general applicability of this threefold division to other highly siliceous rocks, and to gather from the numerous basic rocks of that region material for chemical

---

[1] "Vorläufige Bericht über krystallinische Silikatgesteine des Fassathales und benachbarter Gegenden Südtyrols," *Neues Jahrbuch für Mineralogie*, etc., 1864, pp. 383–411.

investigations which might show the feasibility of classifying all rocks in a similar manner.

Upon scrutiny of his material and study of analyses of rocks from other localities, Scheerer was persuaded that all highly siliceous igneous rocks could be referred to the three magmas represented by the Saxon gneisses above mentioned, or to mixtures of these magmas. The intermediate and basic rocks he believed could in a similar manner be assigned to six definite chemical types, and in the cited publication Scheerer outlined this chemical classification.

Scheerer's system expresses the idea that the molten material below the solid crust is arranged by specific gravity in zones, each of quite simple stoichiometric composition. He further believed that the upper, more siliceous magmas were first erupted, and the basic ones in late geological periods. From this cause the earliest rocks might be supposed to represent the fundamental magmas more nearly than the basic ones, since the latter magmas must have passed through rocks of varied constitution in reaching the surface, and, therefore, suffered much modification through the fusion and assimilation of fragments torn loose in ascending.

The nine chemical types of Scheerer were arranged in three groups, and named from rocks deemed to represent them in purest form.

	Oxygen Ratio $SiO_2 : RO + R_2O_3$ (= 1).	Oxygen Quotient.	Mean silica Percentage.
PLUTONITES:			
Upper = "Rother Gneiss"	4.50	0.222	75
Middle = "Mittlerer Gneiss"	3.75	0.267	70
Lower = "Grauer Gneiss"	3.00	0.333	65
PLUTO-VULCANITES:			
Upper = Quartz-bearing syenites	2.67	0.375	63
Middle = Syenite	2.33	0.429	60
Lower = Melaphyre	2.00	0.500	55
VULCANITES:			
Upper = Augite-porphyry	1.50	0.667	48
Middle = Common basalt	1.33	0.750	42
Lower = Basic basalt	1.00	1.000	36

The "Rother Gneiss" corresponded to Bunsen's "normal trachytic" magma, and the augite-porphyry to the "normal pyroxenic" magma.

The primary divisions of Scheerer are obviously very nearly the same as Durocher's acid, hybrid, and basic groups. The types themselves seem to have been established under the control of a genetic theory, and contrary to the evidence afforded by the tables of rock analyses published by Roth three years before the appearance of Scheerer's proposition. The latter does not refer to the conclusions reached by Roth, which were so directly opposed to his own.

Ferdinand Zirkel, 1866.—Shortly after the works by Roth, von Cotta, and Scheerer there appeared (1866) a work which may be taken as well representing the stage of development of petrographic system in Germany at the beginning of what may be called the era of the microscope. This work is the *Lehrbuch der Petrographie*, by F. Zirkel, who was to be one of the master spirits of following decades.

This treatise was, and, indeed, still is, a mine of useful information to the student, and its contribution to the systematic science was of much influence. Zirkel's elementary scheme of classification is the following:

A. Original crystalline rocks ("Ursprüngliche krystallinsche").
I. Simple rocks ("Einfache Gesteine").
II. Composite rocks ("Gemengte Gesteine").
    1. Composite crystalline-granular and porphyritic rocks ("Gemengte krystallinisch-körnige und Porphyr-Gesteine").
    2. Composite crystalline-schistose rocks ("Gemengte krystallinisch-schieferige Gesteine").
B. Clastic rocks ("Klastische Gesteine").

This arrangement has elements drawn from various sources. In the grand division into original and clastic (secondary) Zirkel followed Naumann, but returned to von Leonhard for the criterion of the second order. In rejecting von Cotta's system, based on mode of origin, Zirkel remarked that this plan would be highly satisfactory were it not founded upon hypothetical considerations. He secured divisions closely corresponding to von Cotta's eruptive, sedimentary, and metamorphic classes by roundabout means.

In his arrangement of original simple rocks, Zirkel practically followed Naumann.

In the *Lehrbuch* igneous rocks were given the greatest attention. They were brought together in one group by applying three factors at once, as *composite crystalline-granular and porphyritic rocks.* In practice the noncrystalline or vitreous rocks were also included here. This inconsequent proceeding was necessary to bring the eruptive or igneous rocks together, a fact demonstrating that the chosen method of primary subdivision was logically incorrect. The first subdivision of this group was by relative age into the *Older* and *Younger* rocks, a distinction which Zirkel himself recognized was highly artificial.[1] He pointed out that rocks of certain characters had actually received different names, according to age, although the time factor had not been used in their systematic arrangement ; and he chose to be logical in application of that factor, to agree with usage, rather than to eliminate the duplicate terms. Had he chosen the latter alternative it is safe to assert that much of the still existing confusion from unnecessary duplicate rock names might have been avoided.

In further systematic subdivision mineral composition and texture were used in ways which have been followed more or less closely by many petrographers to the present time. Following Roth and others it was first determined to consider all rocks of the groups in question as *feldspathic* or *non-feldspathic.* Feldspathic rocks were held to include all in which feldspars or feldspathoids were present in appreciable amount. By this course two very unequal divisions were created and the qualitative element of mineral composition was confirmed in its position of dominance over the quantitative, which has had such unfortunate influence upon systematic petrography to this time.

The plan of forming a great group of feldspathic rocks may have appeared to be desirable on account of the belief, long since

---

[1] *Lehrbuch*, Vol. I, pp. 446, 447.

shown to be erroneous, that four kinds of feldspar, namely, orthoclase, oligoclase, labradorite and anorthite, seldom occurred together, and therefore might be used to characterize four great series of rocks. The feldspathoids were used to define another large series.

It appears that in this proposition to use qualitative mineral composition as a leading factor in classification, as in that to apply the age distinction, Zirkel merely gave definite expression to the growing usage of the time, which was practically found in other systems, though not so clearly avowed as a principle. The effect of his proposition to apply geological age and this qualitative element of mineral composition as leading factors in the systematic arrangement of the rocks we now term igneous was peculiarly unfortunate, because this invaluable work of reference was issued at the beginning of the era in which petrographers were to be so busily engaged in the microscopical study of rocks that they had no time for systematic work. In the flood of descriptive literature of the succeeding decade these propositions were adopted almost of necessity. The students from all lands who flocked at this time to Germany to study under Zirkel and other masters, carried the system back to their respective countries, giving it quickly a world-wide usage.

Ferdinand von Richthofen, 1868.—Shortly after the appearance of Zirkel's *Lehrbuch* a philosophical discussion of the classification of igneous rocks, as viewed from the geologist's standpoint, was published by the distinguished German traveler and geologist, Ferdinand von Richthofen. This essay was written and published during an extended visit in the United States, under the title "Principles of the Natural System of Volcanic Rocks."[1]

Von Richthofen calls systematic petrography "the most intricate branch of descriptive natural science." He characterizes the earlier systems as artificial, because based upon the idea "that classification should be made dependent on one certain principle previously assumed as the point of issue." The prin-

---

[1] *Memoirs presented to the California Academy of Sciences*, Vol. I, pp. 39–133, 1868.

ciples especially named as used in this way are, crystalline texture, lack of stratification, predominance of silicates, etc. To von Richthofen it appeared that the exact mineral composition of rocks as a basis for their classification had become possible after the investigations of Gustav Rose on the feldspars, and that by this means petrography had been brought out of a chaotic state. While acknowledging, therefore, the high value of mineral composition as a basis for classification of igneous rocks, von Richthofen considered that its exclusive application had grouped rocks geologically far separated, and distinguished rocks geologically closely connected, which seemed to him a fundamental error.

The "natural system" of igneous rocks proposed by this author was based upon the Bunsen law of two fundamental magmas, and upon what he considered to be demonstrated facts of a broad correlation between developed texture and age of igneous masses, and of an order of succession of magmas in the history of the earth. By using "eruptive" as a collective term for all rocks under discussion, he implied the adoption of geological mode of origin as the first principle in classification. Von Richthofen remarked that Bunsen's law might have to be revised, "but no change of its principles may ever be expected, as an overwhelming amount of evidence has accumulated in support of its essential tenor." Texture is used by von Richthofen as the second principle in system to produce three classes of eruptive rocks: granite, porphyritic, and volcanic. He says that the conclusion appears to him to be justified "that the three great classes of eruptive rocks are geologically separated and represent three successive and distinct phases of the manifestation of subterranean agencies." The granites of the Sierra Nevada, with which he had personally become familiar, forced von Richthofen to admit that in some parts of the world the ancient granitic and porphyritic eras were succeeded by later eras of the same rocks, within the Mesozoic, but he believed that the volcanic era began with the Tertiary, both in Europe and America. The old lavas of the British Isles, known since the early decades of the century, were either disregarded or overlooked by him.

Mineral composition was regarded by von Richthofen as "essentially dependent on the chemical composition," and was used by him as "more articulate" than the latter, in the construction of his scheme. The outline of von Richthofen's systematic arrangement is as follows:

Eruptive Rocks:
- Class I. Granitic Rocks.
    - Orders: 1, Granite; 2, Syenite; 3, Diorite; 4, Diabase.
- Class II. Porphyritic Rocks.
    - Orders: 1, Felsitic Porphyry; 2, Porphyrite; 3, Melaphyr; 4, Augitic Porphyry.
- Class III. Volcanic Rocks.
    - Orders: 1, Rhyolite; 2, Trachyte; 3, Propylite; 4, Andesite; 5, Basalt.

The further mineralogical variation of rocks was expressed in families under each order.

In this system three principles were applied: (1) Mode of origin; (2) A supposed fact of correlation between age and texture; (3) Chemical composition as represented in mineral composition, and practically expressing the author's belief in the Bunsen law.

While von Richthofen's system was not followed in its details by petrographers, some space has been given to it here because of its influence upon many geologists, perhaps especially in the United States, and because it illustrates so clearly the perils of introducing genetic ideas into the systematic classification of igneous rocks, even when those ideas are believed to be established as laws.

It may be mentioned here that von Richthofen enunciated practically the same views in his *Führer für Forschungsreisende*, issued in 1886.

Cordier's system and its influence.—Turning now to France, before taking up the essays at classification made during the era of the microscope, it appears at first thought strange that for thirty years after Brongniart's classic work no important advance was made in the systematic classification of rocks in that country. And when a very significant advance was made, it appears not to have been recognized. The master spirit of French petrography during this period and until his death was P. L. A. Cordier. He was engaged until the end in carefully elaborating his system of classification, which was presented in lectures and applied to the great collection of the Museum of Natural History in Paris. Cordier does not seem to have published his classification himself, but it was made known by his associate, Charles d'Orbigny, in the *Dictionnaire universel d'histoire naturelle*, article "Roches," and others, Paris, 1842–1848; and in the volume *Description des roches*, etc., edited from the manuscript and lectures of Cordier, published in Paris, 1868, seven years after his death.[1]

The stagnation in systematic petrography in France during this period may be referred to two causes: First, the inherent weakness of Cordier's system; and, second, the traditional custom prevailing in France which gives to the recognized master in any branch of science a strongly dominant influence, which few are willing to openly oppose.

The weakness of Cordier's system came chiefly from the fact that it was, like that of Haüy, based too largely upon the convenient arrangement of cabinet specimens. Viewing rocks simply as aggregates of minerals, they were studied in detail, and their broad relationships were ignored, as belonging wholly to geology. In 1848, only two years before Naumann issued his philosophical analysis of petrography, and 33 years after Cordier published his own first scheme for the arrangement of volcanic rocks, his comprehensive system was announced by D'Orbigny, in the cited article of the *Dictionnaire universel*, etc., to have the following features:

Its fundamental idea was that the classification of rocks should be grouping of *species*, not a subdivision of the grand category of rocks. The species, based upon composition, was

---

[1] At an earlier date it was translated into German by Kleinschrod, in *Jahrbuch für Mineralogie*, 1831, p. 17.

regarded as a nearly constant mixture of certain elements and as characterized by a certain structure. Species were supposed to be much more numerous than the unimportant transition types—"roches du passage."

The rock species was determined almost solely on mineralogical grounds. Geological origin and occurrence were used merely as appropriate elements in the description of the species—stating its *habitat*, so to speak.

Species were grouped in genera according to the state of aggregation, as explained below. Orders were based upon the power of the eye to distinguish the character of the rock. The most important of the still larger groups, the family, was formed in most cases upon the *predominant mineral present*, and the families were grouped upon an indefinite chemical basis, in four classes, namely:

Class 1. Earthy rocks (roches terreuses).

Class 2. Saline or acid non-metalliferous rocks (Roches salines ou acidifères non métalliques).

Class 3. Metalliferous rocks (Roches métallifères).

Class 4. Combustible non-metallic rocks (Roches combustibles non métalliques.

Predominance of one mineral constituent, the quantitative factor applied to form families, the most important of divisions aside from the species, was assumed to mean: (1) more than half where two constituents were concerned; (2) more than one-third where three constituents were present, and so on. In complex rocks it was naturally difficult of application and was almost impossible in aphanitic rocks. Moreover, it was not adhered to strictly, as pointed out by D'Orbigny in regard to basalt, which was referred to the pyroxenic family although feldspar might really predominate over pyroxene. As D'Orbigny naïvely remarks: "But it is this latter substance which gives its character to the rock" (Mais c'est cette dernière substance qui donne son caractère à la roche).

The elaborate system of Cordier may be illustrated by the following section, giving the subdivisions within the feldspathic family:

Class I. Earthy rocks (Roches terreuses).
  First family, feldspathic rocks (Roches feldspathiques).
    1. Order. Phaneromeric — of which the constituents are visible to the naked eye (Phanérogènes dont les éléments sont visible a l'œil nu).
      1. Genus. Aggregates (agrégées).
        Species: (1) harmophanite, (2) leptynite, (3) gneiss, (4) pegmatite, (5) granite, (6) syenite.
      2. Genus. Conglomerates (Conglomérées).
        Species: (1) feldspathic breccia, (2) feldspathic conglomerate, (3) feldspathic grit and sandstone.
      3. Genus. Unconsolidated sands, etc. (Meubles).
        Species: (1) Feldspathic sands and gravels (sables et graviers feldspathiques), (2) pebbles and débris of feldspathic rocks (galets et débris de roches feldspathiques).
    2. Order. Aphanitic — wholly or partially (Adélogènes en tout ou en partie — dont le volume des parties est en totalité ou en partie invisible).

Other families of earthy rocks are named after pyroxene, amphibole, garnet, hypersthene, diallage, talc, mica, and quartz. An inconsequent element in the construction of the system, found in various places, is illustrated in the eleventh family, vitreous rocks, introducing a new factor while stating that the rocks in question are *feldspathic*.

The great majority of known igneous rocks are assigned by this system to the aphanitic (adélogène) orders of the various families, because their constitution is not wholly determinable by the naked eye.

The system of Cordier was the system of France for years after his death, in 1861, and was published in elaborate form by D'Orbigny in 1868.[1] In all essential particulars the system had remained unchanged. At the beginning of the chapter upon the principles of classification is the declaration: "The description of rocks requires in advance: (1) the formation of species; (2) their classification" (La description des roches exige avant tout: 1° l'institution des espèces; 2° leur classification). There is so

---

[1] CHARLES D'ORBIGNY, *Description des Roches, ete.* Rédigé d'après la classification, les manuscrits inédits, et leçons publiques de P. L. A. Cordier. Paris, 1868.

little new in the construction of the system that no further analysis of it seems necessary.

No influence of Cordier's principles can be detected in modern systems for the classification of rocks. The importance of his system from the standpoint of this review lies in the retarding influence it exerted for several decades over the development of the science in the country where Brongniart had laid such logical foundations. But it seems to the writer that it was after all not so much the inherent weakness of Cordier's system as it was his domination over the thought of his countrymen, to a degree possible only in France, that retarded progress for so long. It is significant to recall that D'Orbigny's last presentation of the system appeared two years later than the *Lehrbuch* of Zirkel, but far more so to note, in confirmation of the opinion just expressed, that it was published eleven years after an important treatise on rocks, issued in Paris by a French geologist of renown, presenting a broad and logical view of petrographic system, which was not even referred to by D'Orbigny.

H. Coquand, 1858.—In 1858 there was published in Paris a work by H. Coquand, the title of which, translated, is as follows: *A Treatise on Rocks, Considered from the Point of View of Their Origin, Their Composition, Their Occurrence, and Their Use in Geology and Industry.* This book has over four hundred pages, and contains a classification of rocks very different from any earlier or contemporary scheme, but it has received very little recognition in spite of its merits. Coquand was professor of mineralogy and geology in the College of Besançon. Possibly he did not belong to the distinguished coterie of Parisian geologists, and in that case the fact that he should come out with a system full of originality, strongly opposing that of Cordier, who was still alive, may have been regarded by his contemporaries as such a flagrant violation of unwritten law that the only course open to them was to ignore his proposed scheme of classification.

The title of Coquand's treatise shows at once how completely he had broken away from the traditions of his countrymen. His classification has little in common with other French systems, and, if not wholly original, one must suspect the dominant influence of Naumann's views. Its main outlines are as follows:

Three families of rocks are recognized:
- I. Igneous rocks.
- II. Aqueous rocks.
- III. Metamorphic rocks.

Igneous rocks are divided into three groups:
1. Granitic (in the sense of granular).
2. Porphyritic.
3. Volcanic.

Aqueous rocks into three groups:
1. Chemical deposits.
2. Mechanical deposits.
3. Carbonaceous rocks, of vegetable origin.

Metamorphic rocks into three groups:
1. Crystalline schists.
2. Those of chemical origin.
3. Those of mechanical origin.

It will be seen that this system is in its outline wonderfully like many of recent years in its logical use of factors in construction, and in the order of their application. In further subdivision, finally producing species, Coquand was less fortunate, being governed still by the mineralogical idea too closely. Probably he was much less fitted for the descriptive task than Cordier, who doubtless surpassed him in intimate knowledge of the detailed characters of rocks as cabinet specimens; but he certainly possessed a logical mind, and grasped far better than his contemporaries the relations of petrography to geology.

Archibald Geikie, 1872.—Turning to the literature of other countries during this period, it is evident that systematic petrography was developed as a science almost wholly through the labors of workers in Germany and France. Prior to the microscopical era, soon to be considered, practically no special students of this subject appeared in either Great Britain, America, or in other countries. Aside from the discussions of geologists, like De la Beche, already mentioned, there was in Great Britain no important contribution after the time of Macculloch. The conditions in that country up to 1870 may be summarized by the statements of Archibald Geikie, in 1872, in the *Students' Manual of Geology*. He there says: "There is as yet no good English treatise on petrography, or the classification and description of rocks." In this work all rocks are first classified "under the four great heads of igneous, aqueous, aerial, and metamorphic, according to the nature of the agencies by which they have been brought into their present state and position." "Igneous rocks without exception are composed of minerals which are silicates. These minerals may be said to belong to two great classes: silicates of magnesia and silicates of alumina," each combined with other bases. "The felspars are the bases of all truly igneous rocks, those in which no felspar or mineral of that type is present being very few and unimportant, even if they exist at all." Here we see the proposition made by Zirkel stated in extravagantly positive terms.

Igneous rocks are divided into volcanic, trappean, and granitic, with crystalline and fragmental subdivisions under the first two. The trappean class is vague and "of convenience only." In the volcanic class the law of Bunsen is practically recognized and two groups established: "the trachytes, or felspathic or acidic group," and "the dolerites, or pyroxenic or basic group." Similar groups are formed under the trappean class. The granitic class embraces only granite and syenite.

WHITMAN CROSS.

(To be continued.)

NEOCENE DEPOSITS OF THE KLAMATH REGION, CALIFORNIA.

Description.— In the Klamath region west of the Sacramento River, chiefly in Trinity county, there are several deposits of alluvial gravel and sand which seem to correspond to the auriferous gravels or "high-level channels" of the Sierra Nevada region. They were first mapped in 1892 by Diller[1] as Neocene deposits, and correlated with the Ione formation. Four separate areas are known within Trinity county, one in the old valley of Trinity River between Trinity Center and Junction City, another in Hay Fork valley, the third in Indian Creek valley, and the remaining one in Hyampour valley. Doubtful remnants may occur near Lowden's ranch and Big Bar on Trinity River.

These deposits occur in valleys of erosion, trenched deeply into the hard metamorphic rocks. The distinguishing characteristics of the old or Neocene valleys are (1) their great width compared with the Pleistocene valleys; (2) their flat bottoms; (3) their abrupt termination at both ends; and (4) their usually containing remnants of Neocene channel deposits. The writer is familiar with three of these valleys and will describe them in some detail.

Scott valley, in Siskiyou county, has a length of about twenty miles and an average width between three and four miles. Its direction is north-south and it lies between parallel ranges of mountains of which that on the west consists of very resistant formations, including micaceous quartz, schist, serpentine, and granodiorite, and attains a general elevation above the valley of four thousand feet. The range on the east is not nearly so high, owing to the formations composing it being the rather soft slates of the Devonian and perhaps Carboniferous. The valley itself is trenched largely into these slates, but reaches serpentine and the older schists beneath them. Undoubtedly the unusually great

---

[1] *Fourteenth Annual Report of the U. S. Geol. Surv.*, Pl. XLV.

width of this valley is due to the rather soft nature of the formations, but the fact remains that all other valleys of this region carved into the same formations are relatively narrow and have the gulch form, which, in the Klamath region, is the characteristic of the Pleistocene valleys.

Scott valley terminates as abruptly at the northern or downstream end as at the other, and Scott River drains it through a narrow gorge which is only partly explained by the hardness of the formations cut into. This valley has no known Neocene remnants, as its floor is so elevated (about three thousand feet above the sea) that subsequent erosion may have completely removed them. Its identification as Neocene rests on its large size and its abrupt termination at both ends.

The Hay Fork valley, in southern Trinity county, has a length of about eleven miles and an average width between one and two miles. Its course is a little south of west, or obliquely across the strike of the formations, which here occur in parallel belts as they have been folded and faulted. The strata of the metamorphic rocks stand at a high angle, usually approximating to the vertical. The flat floor of the valley has an altitude at Hay Fork village of about 2,200 feet above tide and the surrounding mountains rise to an average height of about 4,000 or 4,500 feet above the sea. The valley is, therefore, quite a deep trench and a prominent feature of the topography. Its walls are comparatively steep. The form of the valley shows distinctly that it is the result of ordinary stream erosion. There would be nothing remarkable about this valley if it were not that it is the only one of the kind in that portion of the country. All the neighboring valleys are relatively narrow and of the gulch type. Hay Fork stream enters the valley on the south about four miles from its eastern end, coming out of a narrow, gorge-like valley. Above this point the Hay Fork valley is occupied by an insignificant stream which seems out of place in the large valley. As there is nothing in the structure to explain the great contrast in size and shape of the valleys, we naturally conclude that the broad Hay Fork valley belongs to a separate and older system.

To what extent this valley may have been filled up by alluvial action we do not know, as, since its elevation, erosion has nearly reopened it, and the Neocene deposit within it appears merely as a small remnant. It seems to be continuous from end to end, and back of Hay Fork village forms a sort of terrace, occupying the north half of the valley and rising about sixty feet above the present stream level. It consists chiefly of layers of fine gravel and sand, indicating ordinary alluvial action. Near the upper end of the valley, interstratified with the gravel, I have found at least one bed of a white chalky material which seems to be rhyolite tuff, and Anderson reports this material from other parts of the formation. Near the lower end of the valley, where the deposit of gravel occurs in the bed of Hay Fork Creek, the stream exposes layers of lignite. It is the presence of this impure coal and the supposed tuff which postulate a pre-Pleistocene age for the deposit and the valley in which it occurs.

Hay Fork valley is terminated at the western or downstream end by a sudden narrowing of the valley of the Hay Fork Creek, which drains the old valley through a deep rocky gorge (said to be a veritable cañon), not to be explained by an increase in that direction in the resistant properties of the metamorphic formations.

Before discussing the Neocene deposit of the Trinity River, which is in many respects the most interesting and instructive of these old river channels, it will be necessary to direct attention to one of the most salient points in the later history of this region. This is the abandonment by the Trinity River of its original course, between Trinity Center and Junction City, and the excavation by it of a new valley roughly parallel to the old, and distant from it on the average about five miles. The new course is southeast of the old, on the outer side of a curve and consequently considerably longer than the original course. The two valleys are separated by a rock ridge of no mean height. The new valley is comparatively narrow and of the gulch type, although its floor in places has a width of one-fourth to one-half mile.

Now, on the direct line between Trinity Center and Weaverville, and thence to Junction City, there is a distinct basin or broad valley, three or four miles in average width, and partly floored by another of the Neocene River deposits. The general altitude of this basin is toward the north, about 3,500 feet above the sea, or 1,300 feet above neighboring portions of the present Trinity River. Examined in detail, the present floor of the basin is found to be quite uneven. Since the abandonment of this course by the Trinity River, streams which issue from the high mountains on the west, and formerly joined the main river in the basin, now continue across it and transect the rock ridge beyond, and have cut cañons or narrow valleys in the floor of the basin. A large part of the surface has been reduced much below the original level. So far as the channel deposit is concerned, only two limited portions of it are regarded as preserving essentially the original surface.

On the west of the basin rise abruptly to altitudes of seven and eight thousand feet, the bare rugged peaks of the Sierra Costa Mountains. The Trinity range on the east is much lower, and it is difficult to fix the original line between the basin and these mountains.

The old channel deposit is continuous from a point about one mile south of Swift Creek to the La Grange hydraulic mine on Oregon Mountain, between Weaverville and Junction City, a distance of twenty miles. It lies along the western edge of the basin, at the foot of the high mountains. Northward from Weaverville, it is known through its exposure on the sides of the deep transverse valleys, to occupy a deep valley about one mile in average width, and having remarkably steep walls, a veritable cañon. This cañon seems to be an old valley of erosion, which was completely filled with alluvial gravel and sand, giving the Neocene deposit a great thickness, which is one of its remarkable features.

We have no data for determining the actual thickness of the deposit, but we can fix upon a mininum in the latitude of Buckeye Mountain, a few miles northeast of Weaverville. Buckeye

Mountain is a ridge of gravel transverse to the course of the channel. Close by on the north, Stewart's Fork River has cut a valley across the old channel to the depth of 1,600 feet, without reaching the bottom of the gravel. On the southwest, a well in Weaverville is said to have penetrated over 600 feet of gravel and sand before reaching the metamorphic rocks. At least 1,000 feet in thickness of the deposit was removed in the erosion of Weaver basin. A thickness of the old channel deposit of 1,600 feet is a very conservative estimate. On Oregon Mountain the La Grange mine exposes 500 feet in depth of these gravels. North from Stewart's Fork several streams, Stope Creek and the East Fork of Stewart's Fork, have cut transverse valleys through the old channel to a depth exceeding 500 feet, and have not reached its bottom. That its thickness is abnormally great for an alluvial deposit needs no further evidence.

Lithologically, the formation is just an ordinary river gravel, irregularly stratified in the manner common to such deposits. The pebbles, cobbles, and small bowlders are very plentiful, and have been derived from the metamorphic rocks of the neighborhood. The predominating species in any section is that of the bordering terrane. Below the zone of oxidation the color is a deep blue, but higher, yellow and buff predominate, and at the surface there is a deep staining of bright red. There is much clay among the gravel, in places gathered into separate layers.

At the mouths of certain valleys which issue from the high mountains on the west, as, for instance, Stope Creek and the East Fork of Stewart's Fork, northwest of Minersville, after the completion of the main deposit, it was covered by alluvial fans remarkable for the immense bowlders, largely of granodiorite, which are thickly packed in them. So old are these deposits that all the bowlders are decayed, and a ditch or a fresh natural section, as a recent landslide, shows merely their outlines, and never a projecting rock — that is, the bank is smooth, like a clay or sand bank. On the main channel deposit near its original surface, there are no bowlders or cobbles scattered about, all having disappeared by decay, but deep in the formation the cobbles are comparatively fresh.

The age of this deposit is considered to be the same as that of the Hay Fork, Indian Creek and Hyampour, because it is of similar lithologic character, occupies a similar valley, and has suffered great erosion since its abandonment by Trinity River. No coal is known from this area, and no tuffs have with certainty been discovered in it. No bones or fossil plants have yet been reported from it. However, it has not been closely examined for them, and even the tuff may occur and have escaped notice.

Conditions of accumulation. — Several interesting problems are presented by the old Trinity River deposit. What were the conditions which caused the accumulation of 1,600 feet of alluvial gravel and sand? Why did the river abandon its old course and cut a new valley on a longer course?

Let us first inquire into what fixed the site of the old valley. The abrupt southeastern face of the Sierra Costa Mountains on the west side of the old Trinity valley has the appearance of a degraded fault scarp. After long consideration of the matter, I have concluded that while there may be an old fault on this line, it has had very little influence on the present topography. It is along this line that the resistant serpentine and granodiorite of the higher mountains meet the rather soft and easily eroded Bragdon slate and the Clear Creek volcanic series, the Mesozoic representatives in this region. The mountains on the west are high because the rocks are very resistant, and those on the east are low because the rocks are softer. Along the junction between the two areas was a line of unusual weakness, perhaps because of an old fault, and that controlled the Trinity River between Trinity Center and Weaverville. In the course of time the river varied somewhat from the fault(?) line, and at one place cut its deep cañon entirely on the serpentine side of the line. This strengthens its interpretation as a valley of erosion.

The accumulation of 1,600 feet of gravel and sand by river action could have occurred under one of only two conditions; either a depression of the land to a lower level relatively to sea level, or the local sinking of an orographic block bounded by faults, such as Professor Whitney adduced in explanation of Yosemite Valley. Dr. A. C. Lawson has called to my attention that in Europe, particularly in Germany, there are depressed areas of no great width which clearly have resulted from a "dropping out of the bottom," as we may say. The flat bottoms, steep walls, and canoe shape of the valleys occupied by the Neocene deposits in Trinity county seem to favor this theory, but against its adoption I have the following objections :

1. Outside of the four or five Neocene valleys already mentioned, there is no evidence in Trinity county of Neocene or later faulting. We know there have been gentle disturbances, broad arching of the strata, but no general breaking up of the rocks. The faulting would have to be strictly localized or confined to these valleys. Where the faults intersected at the corners of these valleys they must have terminated abruptly, not gradually dying out as is the habit of faults.

2. The valleys trend in different directions, so that there could be no regularity in the system of dropped fault-blocks, as there usually is.

3. The old Trinity valley is rather too crooked, and the crooks are not systematic enough to fit into such a scheme of dropped fault blocks.

4. The coarse character of the deposit throughout the Trinity area shows that the valley was kept filled up to a river level during a progressive sinking, and had there been a sinking of the rock floor relative to the walls, the gravel deposit should in its lower portions be much disturbed and bent up along the borders, a structure which has not yet appeared in the deepest natural or artificial excavations.

5. But the strongest objection of all lies in the fact, which may be particularly observed in the case of the old Trinity valley, that these valleys do show the influence on their width of the varying resistant properties of the formations traversed. The northern portion of the old Trinity valley is narrow (averaging one mile) because it is trenched into serpentine and the

Clear Creek volcanic series, both relatively resistant. In the Weaver basin it entered an area of the Abrams mica schist, which observation elsewhere has shown to be one of the less resistant formations, and here the valley widened out to three and four miles. When it entered the much harder hornblende schist west of Weaverville, it contracted very rapidly to less than one mile. I do not see how we can get around this evidence that this is a simple valley of erosion, and not a depression resulting from the sinking of a fault block.

The other hypothesis has an objection also. It is another unusual feature of these Neocene valleys that they had few tributaries. Probably the small streams came down from the uplands in short cañons with steep gradients. Pleistocene erosion, in developing the gulches, has largely obscured these earlier ravines. Outside of the Sierra Costa range it was a region not unlike that of the Sierra Nevada today, with the smaller streams flowing in shallow valleys on the uplands, and only the trunk streams in deep cañons. The topography seems to have been young, so far as that particular cycle of erosion was concerned. Naturally we would suppose that all the streams were flowing far above a baselevel of erosion, but in the flat bottoms of the old valleys and their width of nowhere much less than a mile and in places as much as four miles, we seem to have evidence that the trunk streams at least were approaching a baselevel of erosion. I will acknowledge that there is something apparently contradictory and unnatural about this, and I am unable to give a satisfactory explanation of it. However, if the Neocene valleys are the product of erosion, the fact remains that some deep cañons were excavated beneath the general level of the country. The evidence seems to me to indicate a sharp uplift of most if not all of the Klamath region in the Neocene, preceding the accumulation of the old channel deposits. The elevation may have had a maximum of several thousand feet in Trinity county and probably died out to zero on the borders of the Klamath province.

Following this elevation there seems to have been a slow subsidence of the same area, to enable the old channel deposits to accumulate to such great thickness in the wide cañons of the trunk streams. It is only in the Trinity valley deposit that a great thickness is seen, but there are no reasons for believing that similar accumulations were not made in the other valleys. The preservation of the deposit in Trinity valley has been especially favored because the main stream abandoned the valley, which was not the case in the other valleys. It is probable that all the Neocene valleys were filled with alluvial deposits up to a certain baselevel plane and since largely reopened by erosion, a history which Lawson has shown to be duplicated in the Salinas valley in the southern Coast Ranges.[1]

If we will take our stand on the summit of the low mountain range just west of the Trinity river at Bragdon, we will get a fair idea of the condition of the surface at the close of deposition of the old channel deposit. We overlook the Neocene basin for miles to the northward and southward. We see that two limited areas apparently represent the original surface of the alluvial deposit. Some miles to the southward the summit of Buckeye Mountain appears, where it is composed of the river gravel, as a ridge with perfectly even crest-line, but sloping toward the east-southeast at a regular and low angle, estimated at about one hundred feet per mile. The altitude is 3,800 feet.

A little north of west from us, and distant only a few miles, another apparent remnant of the original surface forms a sort of plateau, only very slightly trenched by erosion, and known as the Greenhorn Flats. The elevation is about the same as Buckeye Mountain, and there is a distinct slope toward the east-southeast at a regular rate of about the same degree as the other remnant. The conviction is forced on the observer that the entire deposit north of Weaverville has been tilted toward the east-southeast at the rate of about one hundred feet per mile, and the suspicion is raised that this tilting was so rapid that the Trinity River could not maintain its old course by down-cutting

---

[1] *Bulletin of the Department of Geology, University of California*, Vol. I, p. 154.

into the gravel, but was forced on to the metamorphic rocks to the eastward, and so came to trench its new valley.

If we will project the reconstructed surface of the gravel deposit toward the east, we will find that it about intersects the general summit level of the ridge of metamorphic rocks between the old and the new courses of Trinity River. Beyond the new valley we will find no elevation prominently reaching above this plane until we get well up toward the summit of Trinity Mountain. As there is no evidence of faulting since the accumulation of the Neocene gravels, it is evident that at the completion of the river deposit, when its surface had reached that now represented by Buckeye Mountain and the Greenhorn Flats, the alluvial plain was bordered on the east by a low, flat belt of country, five and perhaps in places ten miles wide, a local baselevel of erosion. It is not certain that this was a perfect flat all over; indeed, it is probable that it was a series of broad valleys in which flowed the tributary streams, separated by low, smooth, in places indistinct, divides.

Certainly, the country for some miles east of the old channel was low enough to enable Trinity River to rapidly migrate across it until it had reached a distance of three to seven miles from the old course, when the vertical component of the uplift became the controlling factor, and the river simply stopped migrating and cut down into the underlying metamorphic rocks.

It is presumed that the uplift of the Klamath region was general throughout the province, but the amplitude varied. The country was bowed up into one or more great arches without faulting, except possibly on the northeastern and southwestern borders of the mountain system. From the group of high mountains west of the old Trinity valley to the present Sacramento valley near Redding, I regard as the eastward slope of one of these great arches. Between Redding and Shasta there are traces of an old peneplain[1] earlier in age than that on which the Red Bluff gravels lie, and this I would correlate with the late Neocene baselevel developed on the east border of

[1] Jour. Geol., Vol. II, pp. 34, 35.

Trinity valley. The former rises from six hundred to about one thousand feet above the sea in less than three miles. Projecting this plain westward and the tilted baselevel of Trinity valley eastward until they intersect, we would find that nearly all of the gulches lie below this level, while the mountain tops which reach above it have a more subdued and older-appearing topography.

Completed baseleveling was only effected on narrow strips on the border of the Sacramento valley and on the east border of the Trinity valley. The country between was quite undulating, and contained rounded mountains reaching elevations of 1,000 and even 2,000 feet above the neighboring baselevel. These residuals were of the same category as those in the McCloud-Pit projection of the Klamath mountains, which may be shown to rise as monadnocks above an uplifted baselevel, represented by Bagley Flat.

At the Big Bend of Pit River and along Kosk Creek, a northern tributary, the Ione sandstone, as identified by Diller[1] is strongly developed, having a probable thickness of about six hundred feet. It dips easterly at a low angle, and passes under the lavas of the Lassen volcanic range. On the west, the surface of the metamorphic rocks of the Klamath region, here chiefly Jurassic in age, come out from under it and rise to the westward at about the same angle as the eastward dip of the sandstone. The Ione pebbles are scattered over this slope to a distance of several miles from the present Ione escarpment. This slope represents the pre-Ione surface of the Klamath region, and consequently is not the equivalent of the latest stage of the Sierra Nevada peneplain.

On the north side of Pit River, west of Cañon Creek, there is a high terrace known as Bagley Flat. It is a shelf cut into the slope of the Klamath mountains. Its present altitude is about 2,750 feet, or 1,200 feet above Pit River. It corresponds in height with the lava plain on the south of the river, but instead of being a constructional plain of sandstone overlaid by andesite, it is a baselevel of erosion. The Neocene lava occurs as rem-

---

[1] Lassen Peak Folio of the *Geologic Atlas of the United States.*

nants on this shelf, fixing its age as that of the andesite eruption. I regard it as a sort of coastal plain of erosion, baseleveled by the body of water in which the Ione sandstone was deposited. After the Ione formation was completed, the andesitic lava flowed over the sandstone area and lapped over on to this narrow coastal plain. This andesite, from its lithologic character and from its relations to the underlying Ione formation and an overlying basalt,[2] may be correlated with the andesitic tuffs and lavas partly burying the Sierra Nevada peneplain. Hence, Bagley Flat is the equivalent of the Middle Pliocene peneplain of the Sierra Nevada region.

Back of Bagley Flat, two mountains, Bagley Mountain and another unnamed, rise rather steeply to altitudes respectively of 4,437 and 3,905 feet, and were monadnocked on the baselevel of the Middle Pliocene to the extent approximately of 1,600 and 1,100 feet. West from here, as far as the Sacramento River, the Klamath mountains consist of a group of peaks, of which these two mountains are members. While the general surface slopes to the south and the peaks reach altitudes of 4,000 to over 6,000 feet, there is not sufficient uniformity in their height to suggest a dissected peneplain. These peaks have the aspect rather of monadnocks, and the relation of several of them to Bagley Flat shows that they belong to the same category as the monadnocks of the Sierra Nevada region. This portion of the Klamath region was nearly all residual, baseleveling only being effected on a narrow strip around the head of the Sacramento valley. It is a significant fact that the Klamath mountains rise much more abruptly on the side of the great valley than do the Sierra Nevada Mountains. This is beautifully exemplified by a view toward the north from Redding, where Bear Mountain and other peaks in the vicinity appear to rise sharply from the plain.

A view toward the southeast from Brock Mountain shows a number of flat-topped ridges bearing a marked resemblance to eastern dissected peneplains, but this is quite local, and I do not know its significance. If any older peneplain than the Middle

Pliocene of the Sierra Nevada region was developed in this region, it has been completely destroyed by erosion, and is not identifiable, while, as already intimated, the Middle Pliocene baselevel did not penetrate far from the border of the present Sacramento valley. In general, we may say, the present topographic features are older than those which dominate the Sierra Nevada country.

The nearest approach to the development of a late Neocene peneplain in Trinity county was effected at the close of deposition of the Neocene gravels. The surface of the alluvial deposits rose by aggradation and the neighboring rock surface sank by degradation, until at the close of the epoch the two planes met. This is precisely the same relation that exists between the auriferous gravels and the peneplain of the Sierra Nevada region, indicating that we are treating equivalent and contemporaneous events. So confident am I that this is true that I am inclined strongly to accept the Neocene baselevel of the region under discussion as a datum plane of the same value as the Sierra Nevada peneplain, consider its maximum development of rather late Pliocene age, and base upon it speculations as to the ages of all other physiographic features in the province.

The Sierra Costa Mountains rose above the Neocene baselevel to elevations of three to five thousand feet, and had a topography similar in its larger features to that of today. The higher valleys of these mountains are essentially the valleys of the Neocene. They are commonly called "cañons" by the miners, because they have relatively broad floors and very steep walls. Part of this cañon-like form is due to glaciation, but more is preglacial in its origin. The work of the glaciers was short and confined to a removal of talus from the foot of the precipices, to the smoothing of inequalities, and to the filling of the deeper portions of the valleys by drift débris.[1] Beyond the ends of the glacier sites, the same broad valleys continue at the same level, but this fact is obscured by the Pleistocene erosion of deep gulches in the bottoms of the older valleys, the slopes of which

---

[1] JOUR. GEOL., Vol. VII, 1899.

later system of valleys often coalesce with the slopes of the older valleys so as to make the whole trench, perhaps five thousand feet in depth, appear as the work of a single cycle of erosion. Usually, however, there is a shoulder high up on the slopes which is not always explained by the structure or by landslides, and the concurrence of a series of these shoulders at about the same elevation on both sides of one of these valleys raises the suspicion that they represent the bottom of the Neocene valley.

So far as is now known the Sierra Costa range is the only portion of the Klamath region or indeed of any part of northern California which possessed a rugged, sierra-like topography during the late Neocene, and it should be awarded the distinction of being the oldest prominent mountain range within the state, unless such exist south of the Tehachapai range.

Correlation.— Rhyolite tuff has been found by Diller in the Indian Creek basin, and I believe also in Hyampour valley, and by Anderson and the writer in Hay Fork valley. The first investigator thought the material had been showered over the hills as fine ashes and then carried down into the streams, and thus became interstratified with the alluvial gravels. It was largely because of the presence of this tuff that he provisionally correlated the Neocene gravels in Trinity county with the Ione formation. At the same time he recognized the possibility that the tuff may have been derived from the group of volcanoes in the Coast Range region, in Lake county, and may not belong to the epoch of rhyolitic extrusions in the Sierra Nevada region.

The latter represent a distinct epoch of the period of vulcanism, and this rhyolite epoch was contemporaneous with the accumulation of the auriferous gravels proper or high-level channels. The latter are now thought to be the chronologic equivalent of the San Pablo formation, presumably of Lower Pliocene age. If the rhyolite tuff of the Klamath region was derived from the Sierra Nevada or Lassen Peak volcanoes, it would imply that the tuff-bearing portion of the Neocene gravels is probably Lower Pliocene in age. The presence of lignite in the Hay Fork and Hyampour valleys also favors this correlation, for lignite is very characteristic of the Ione formation, another supposed equivalent of the San Pablo formation.

However, it seems to the present writer more probable that the rhyolite tuff was derived from the Lake county volcanoes. There is a great mass of tuff in the upper end of the great valley, extending west of the Sacramento River, and clearly referable to the Lassen Peak volcanic range as a source, but it is andesitic in character. None of this reached the Trinity county basins so far as I am aware. The occurrence of the rhyolite tuff in the southern part of Trinity county alone seems to imply that it was showered from the south and not from the east. Strong winds come oftener from the direction of Lake county than from that of the Lassen Peak range.

I am informed that the volcanic series of Lake county is essentially Middle Pliocene in age, being apparently the equivalent of the Berkeleyan series. About the close of deposition of the San Pablo sandstone, rhyolitic ashes seem to have been widely showered over the northern Coast Range region, and it is probable that at this time similar material reached the Trinity county basins.

Whether we refer the source of the tuff to the Sierra Nevada Lassen Peak or to the Lake county volcanoes, we arrive at virtually the same result in the matter of the probable age of the tuff-bearing portion of the Neocene gravels of the Klamath region, namely, about the time of transition from the Lower to the Middle Pliocene.

The lignite and tuff are found near the rock-floor of the old Neocene valleys, and simply tentatively fix the age of the lower portion of the gravel series. The accumulation of the gravel continued until the inception of the profound orographic disturbance to which the Pleistocene valleys are due. In a separate paper it is hoped to show that the latter are equivalent to the Sierran valleys of the Sierra Nevada province, and that the orographic disturbance referred to in this paragraph was that which terminated the Pliocene and inaugurated typical Quaternary conditions in California. It is, therefore, reasonably certain that the upper portion of the Neocene gravels of the Klamath region represents the Upper Pliocene. In short, the alluvial filling of the Neocene valleys is probably the chronologic equivalent of the whole of the Coast Range Pliocene series, with its San Pablo, Berkeleyan, and Merced divisions.

I have correlated in a general way the Neocene baselevel of the Trinity valley with the peneplain of the Sierra Nevada region, but this requires some qualifications. The latter was developed in early Pliocene time and largely buried under andesite lava and tuff during the Middle Pliocene time. Then it was slightly disturbed and partly resurrected by erosion during late Pliocene time. In the Klamath region there were deep cañons in the earlier portion of the Pliocene period, and the Neocene baselevel reached its stage of maximum development at about the close of the period. Then came the great uplift which terminated low-level conditions in both provinces.

OSCAR H. HERSHEY.

BERKELEY, CALIF.,
February 7, 1902.

NOTE ON THE CARBONIFEROUS OF THE SANGRE DE CRISTO RANGE, COLORADO.

THE detailed section given below was taken at the crest of Sangre de Cristo range, directly west of Trinidad, Colo., between the sources of the Middle Fork and the North Fork of the Purgatory River. The Sangre de Cristo range reaches a maximum elevation in this region of 14,079 feet, in Mt. Culebra. From this peak northward the crest of the range descends gradually to an elevation of about 9,300 feet at Veta Pass, thence rises again to Sierra Blanca — 14,413 feet — the highest peak in Colorado.

The crest of the Sangre de Cristo range is composed for the most part of coarsely crystalline rock flanked by sedimentaries. At the point where the section was taken the crystallines of the crest pass gradually beneath the surface, giving place to the sedimentary formations. From this point northward for a considerable distance the crest of the range is composed mainly of strata having a northeastward dip (see Hayden's *Atlas of Colorado*). Mr. Endlich maps a considerable portion of the sediments as Lower Carboniferous; but the greater part, including the barren red sandstones, which are several thousand feet thick in this region, is mapped as Upper Carboniferous. The red sandstones are obviously a part of the Red Beds, whose wide distribution in the mountain region is well known, but whose age is still a matter of doubt.

It was in the hope that some light might be thrown upon the age of certain isolated remnants along the eastern slope of the mountains that I took the trip to the fossil-bearing series at the crest of the range. In place of the Lower Carboniferous series which I had expected, I found the Upper Carboniferous series reported in the accompanying section. This section was taken in a cañon near the southern limit of what Mr. Endlich mapped as Lower Carboniferous. To the north of this point the series attains a somewhat notable thickness, due mainly to the presence of strata younger than those represented in the section. Nearly all the layers of the section are more or less fossiliferous, but the most productive horizons are about 150 feet from the base. The 28-foot shale yielded thirty species. Some of these species were found at each of the horizons collected from. The lower 100 feet yielded few fossils, but none were found which could be referred to the Lower Carboniferous.

My collections were submitted to Dr. Stuart Weller, who very kindly identified the species for me and furnished the following lists: Zaphrentis sp. undet., Orbiculoidea convexa Shum., Orbiculoidea missouriensis Shum., Chonetes mesoloba N. & D., Productus longispinus Sow., Productus costatus Sow., Productus cora D'Orb., Spirifer cameratus Morton, Spirifer rockymontana Marcou., Reticularia perplexa McCh., Seminula argentea Shep., Aviculopecten carboniferus Stev., Astartella concentrica McCh., Nucula ventricosa H., Nuculana bellistriata Stev., Pelecypod (genera and sp. undet.), Bellerophon percarinatus Con., Bellerophon carbonarius Cox., Bellerophon montfortianus N. & P., Bellerophon sp. undet., Rotella verrucelifera White, Soleniscus brevis White, Soleniscus sp. undet., Sphaerodoma texana Shum., Sphaerodoma sp. undet., Trachydomia wheeleri Swall. var., Naticopsis altonensis McCh., Naticopsis altonensis var. gigantea M. & W., Pleurotomaria perizomata White, Pleurotomaria (several small species undet.), Murchisonia copei White, Orthoceras sp. undet., Syringopora sp., Campophyllum torquium Owen, Straparolus catilloides Con.

A few fossils were found as loose fragments and their horizons not determined. They are as follows: Derbya crassa M. & H., Hustedia mormoni Marcou., Allorisina subcuneata M. & H., Schizodus wheeleri Swall., Bellerophon (large sp. undet.), Temnocheilus winslowi M. & W., Phillipsia sp., large fish spine.

A small collection was also obtained from the western slope of Veta Pass, five miles above Placer. The section here is composed of sandstones, limestones, shales, and conglomerates similar to the section north of Mt. Culebra. The following species were found: Zaphrentis sp., Orbiculoidea sp., Derbya crassa M. & H., Chonetes granulifera Owen, Chonetes mesoloba N. & P., Productus nebrascensis Owen, Productus costatus Sow, Spirifer cameratus Morton, Reticularia perplexa McCh., Seminula argentea Shep., Hustedia mormoni Marcou, Aviculopecten occidentalis, Astartella concentrica McCh., Schizodus Wheeleri, Swall., Bellerophon percarinatus Con., Bellerophon inspeciosus White? Soleniscus sp., Conularia? sp., Orthoceras sp.

SECTION TAKEN AT THE CREST OF THE SANGRE DE CRISTO RANGE, BETWEEN MIDDLE FORK AND NORTH FORK OF THE PURGATORY RIVER.

FEET.	
10	Hard quartzitic conglomerate.
5	Dark shale.
2	Limestone, fossiliferous.
12	Red sandstone, with bands of red shale and irregular masses of limestone.
4	Greenish argillaceous sandstone.
18	Pink sandstone, argillaceous above, conglomeratic below.
4	Fossiliferous limestone.
10	Deep red sandsone, conglomeratic at the base, shaly near the top.
20	Limestone, arenaceous near the base.
13	Massive, light-colored grit, coarse and conglomeratic.
6	Banded sandstone and limestone intimately commingled. The limestone is often in more or less rounded masses. Irregular beds of gravel occur in places.
3	Nodular limestone.
8	Massive limestone.
3	Shale with limestone nodules.
23	Massive limestone.
20	Coarse sandstone, conglomeratic in the lower half.
8	Massive grit (local unconformity).
10	Calcareous shale, passing to black shale, with limestone nodules near the top.
15	Fossiliferous limestone with sandstone layers. Cup corals abundant.
6	Massive limestone.
8	Shale.
2	Coarse grit.
10	Sandstone with large nodules and irregular masses of limestone.
25	Shale with bands of sandstone and limestone.
4 to 12	Banded limestone.
28	Soft black shale, fossiliferous.
9	Coarse grit.
6	Black shale.
2 to 20	Coarse grit, conglomeratic in places.

45 Dark shale, with limestone nodules and thin seams of sandstone; runs to massive limestone in places; becomes red and arenaceous near the base.

7 Coarse grit.

10 Dark red shale, with nodules and irregular masses of limestone.

4 Limestone.

12 Red to black micaceous shale, with bands of sandstone near the base, and limestone nodules near the top.

10 Coarse grit.

? Red grit and conglomerate.

Crystalline rocks of the mountains.

WILLIS T. LEE.

TRINIDAD, COLO.

GLACIAL PHENOMENA IN THE ADIRONDACKS AND CHAMPLAIN VALLEY.

INTRODUCTION.

THIS paper was undertaken at the suggestion of Professor J. F. Kemp, of Columbia University, to whom the writer is indebted for much valuable assistance. The data on striæ were gathered from all possible sources — from the published reports of the New York state museum, from the field notes of Professor Kemp,[1] from the notes of Professor Cushing in the north and west, and from those of the writer in the south. Especial thanks are due to Dr. Cushing for the information thus furnished. The study of the Pleistocene history of the Adirondacks has been fragmentary, and will be subject to much elaboration in the future. The purpose of the present paper is the correlation of such facts as are known from the writer's observation and from the work of others, and the interpretation of these facts in their bearing on the erosion history of the region. Especial thanks are also due to Professor Kemp for assistance with the map.

TOPOGRAPHIC RELATIONS OF THE ADIRONDACK REGION.

The Adirondacks form the most conspicuous topographic feature of northern New York. Within this area of about ten thousand square miles are some dozen peaks which rise to altitudes of approximately five thousand feet. The valleys between these highest mountains are deep and narrow, their bottoms being about two thousand feet above the sea. This central mass of high peaks is composed entirely of anorthosite ; surrounding it are lower gneissic peaks of two to three thousand feet in altitude, with gentler outlines and broader intervening valleys. Towards the southwest this gneissic area stretches for some miles as a plateau, with undulations caused by old valleys, now largely drift-filled. Surrounding this crystalline area is a plain cut on

---

[1] Used by permission of the director of the United States Geological Survey.

gently dipping Palæozoic rocks and sloping eastward to Lake Champlain, northward to the St. Lawrence, westward to Lake Ontario, and southward to the Mohawk. The central peaks, of which Marcy is the highest, lie about thirty miles west of Lake Champlain and one hundred miles south of the St. Lawrence.

GLACIAL PHENOMENA.

General relations of the region to the direction of ice movement.—The region lies 250 miles north of the terminal moraine on Long Island, and is thus well within the limits of the last continental ice sheet. It is interesting to determine the effect upon the direction of ice movement of this enormous mass of rock across its path, and what effect the ice left upon the region thus traversed. As is well known, the ice in the last glacial epoch was differentiated into lobes which conformed more or less closely to pre-existing valleys.[1] One such lobe lay in the Hudson and Champlain valleys, its axis in the southern part corresponding, not to the Hudson valley, but to the broad valley west of the Palisade Ridge.[2] Another lobe lay to the westward, presenting a fringed margin in the shape of local glaciers in the Finger Lake region, its upper portion coming in a broad stream from the upper St. Lawrence valley. These two valleys intersect slightly northeast of the Adirondacks. The prevailing direction in the St. Lawrence valley being southwest, it follows that these two streams must have separated near the point of junction of the two valleys.[3]

The dispersion of ice from northern Canada seems to have taken place from several centers.[4] Eastern Labrador was one such center, ice moving out from it in all directions. Glacier ice seems to show a general tendency to choose broad, open valleys

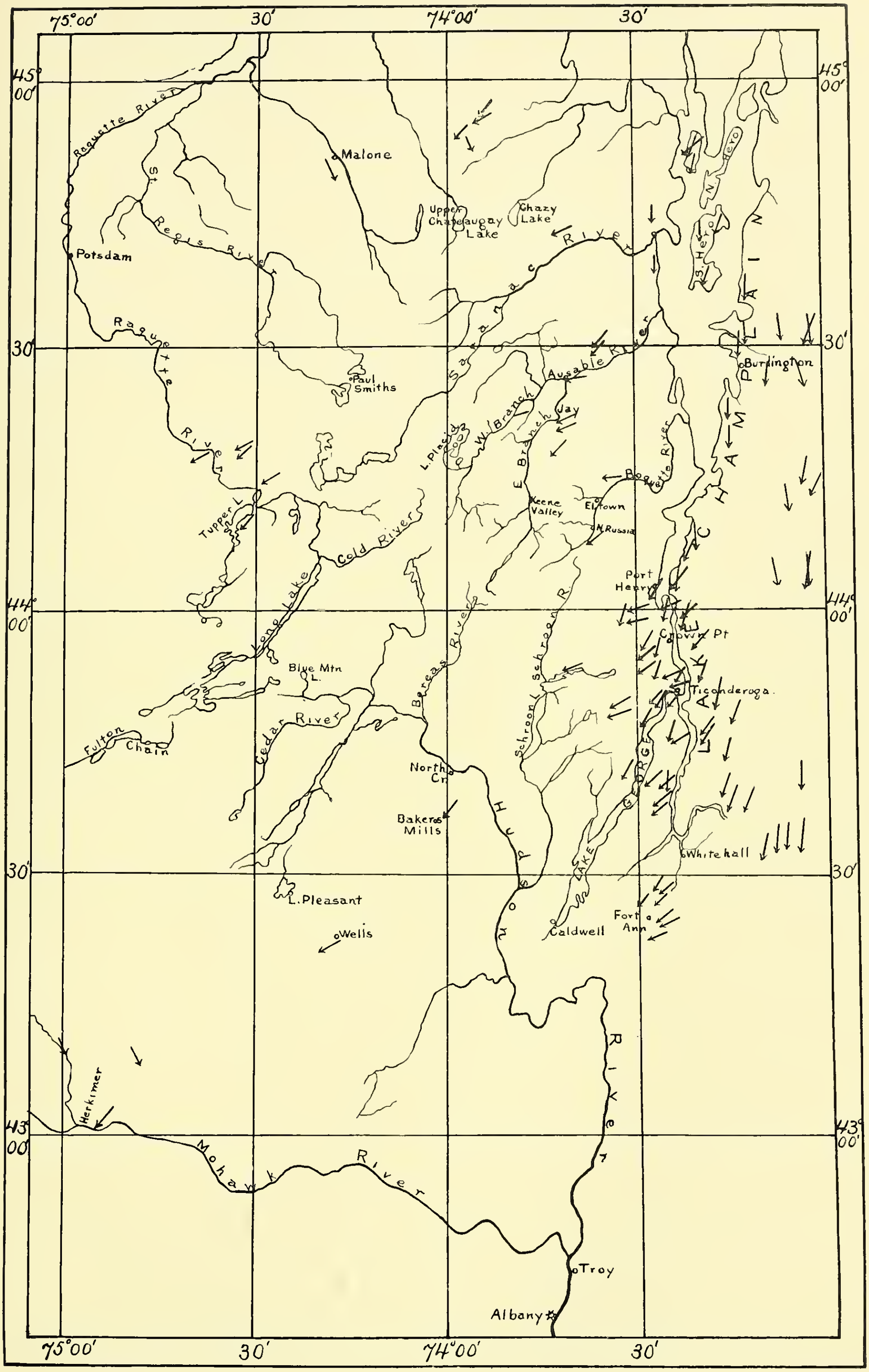
---

[1] T. C. Chambelin, "Preliminary paper on the Terminal Moraine of the Second Glacial Epoch." *Third Annual Report U. S. Geol. Surv.*, pp. 295–402.

[2] R. D. Salisbury, "Drift Phenomena of the Palisade Ridge," *Annual Report Geol. Surv. of New Jersey, 1893*, pp. 157–225.

[3] For summary of literature on Canada see Sir J. William Dawson, *The Canadian Ice Age*, Montreal, 1893.

[4] R. Bell, "Glacial Phenomena in Canada," *Bull. Geol. Soc. Amer.*, Vol. I, 1890.


75°00'
30'
74°00'
30'
45° 00'
30'
44° 00'
30'
43° 00'
Raquette River
St. Regis River
Potsdam
Raquette River
Malone
Upper Chateaugay Lake
Chazy Lake
Saranac River
N. Hero
S. Hero
Paul Smiths
Ausable River
Burlington
Lake Champlain
W. Branch
E. Branch
Jay
L. Placid
Tupper L.
Cold River
Keene Valley
El.town
N. Russia
Boquette River
Port Henry
Long Lake
Crown Pt
Blue Mtn L.
Boreas River
Schroon L.
Schroon R.
Ticonderoga.
Cedar River
Fulton Chain
North Cr.
Bakers Mills
Lake George
Whitehall
L. Pleasant
Wells
Caldwell
Fort Ann
Hudson River
Herkimer
Mohawk River
Troy
Albany

for its progress, and to become stagnant in narrow passes.[1] The St. Lawrence valley was therefore a natural channel for ice moving from Labrador, and in the same way at the junction of the St. Lawrence and Champlain valleys two broad outlets of easy progress were afforded. The Adirondack highlands, with their steep-sided, narrow passes were most unfavorable to glacier motion.

STRIÆ AND GENERAL NATURE OF ADIRONDACK ICE MOVEMENT.

Striæ in the Champlain valley are somewhat variable in direction. The prevailing direction is southwest, but cross striæ are found, and southeast directions are not uncommon. This is what might be expected on the hypothesis that the Adirondacks were filled with nearly stagnant ice. The ice stream coming down the St. Lawrence would be forced either to turn aside to the south or to push on in its own direction against a great immovable mass. The northern part of the Champlain valley would therefore be a critical point, and slight variations in the amount of ice, or in temperature, or other variable factors, might make great differences in the direction of motion.

Upon the crystalline rocks of the Adirondacks proper the direction is uniformly southwest. No striæ were observed in this region in other directions, except those which could be clearly shown to be influenced by some topographic variation of local character. There appears to be no change in direction with altitude. The approach to the high and rugged mountains is marked by a conspicuous decrease in the number of striæ, which is what would be expected if the ice were stagnant in the valleys. Chamberlin observes that ice movements as a rule are from the basins to the highlands, due to the increase in relative rate of waste with the retardation of the ice mass. In the Adirondacks this appears to have had but slight expression ; such data as are available indicate that ice which had once passed the critical point at the boundary of the region, passed on toward

---

[1] T. C. CHAMBERLIN, "Rock Scorings of the Great Ice Invasion," *Seventh Annual Report, U. S. Geol. Surv.*, 1885–86, pp. 155–248.

the southwest without very great deflection. The bottoms of the deeper valleys in the interior not only show no striæ, but very little smoothing and polishing, while preglacial fault cliffs stand out perfectly sharply, with scarcely a sign of corrasion. The summits however have been markedly smoothed; the abundant bowlders of Potsdam sandstone on even the highest peaks give unquestionable evidence that the region was entirely buried, and by ice in vigorous motion. The conclusion reached is, therefore, that the ice entered the region from the northeast, flowing on in that direction where open valleys afforded opportunity, becoming stagnant in narrow valleys, and finally at the time of its greatest advance burying the region entirely, an upper southwestward moving current passing over the stagnant valley masses below.

The accompanying table enumerates all the striæ that have been accurately recorded from the region. In the literature there are many references of an indefinite nature, speaking of striæ in general northeasterly directions. These were of necessity omitted from the table and map, but the references to them indicate that striæ are more numerous than is shown on the map. Not a single record has been found among the highest mountains. The map shows the three zones of striation: a zone along the Champlain valley where striæ are very numerous and variable in direction; a zone along the gneissic hills where they are less numerous and prevailingly northeast; and a zone among the high anorthosite peaks, where striæ are entirely lacking, though the mountain tops here are conspicuously smooth. The readings taken by Professor Kemp along Lake Champlain and Lake George are so numerous that they could not all be put upon the map, hence the contrast is even more striking than it appears. Farther north along Lake Champlain striæ appear to be as numerous as in the southern region, but accurate records have not been taken in many localities. All readings are referred to the true north; each striation is credited to its observer in the right hand column of the table. In Vermont and the Islands in Lake Champlain the striæ on the map are taken from Hitchcock.[1]

---

[1] *Geology of Vermont*, Vol. I.

TABLE OF STRIÆ IN THE ADIRONDACKS.

CLINTON COUNTY.

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
S. 35 W.	Ellenburgh	Northwest corner, near Franklin county	......	Potsdam	H. P. C.
S.	"	Ditto, and near Clinton township line	......	Gneiss	"
S. 45 W.	"	6 miles east of last	......	Potsdam	"
S. 10 E.	"	2 miles south-southeast from first	......	"	"
S. 20 W.	"	1 mile northeast from third	......	"	"
S. 35 E.	Clinton	1 mile east of Churubusco	......	"	"
S.	"	3 miles northeast of last	.....	"	"
S. 30 W.	Ausable	3 miles north of Clintonville	......	"	"
S. 40 W.	"	2 miles north of last, near Peru township line	......	"	"
S. 55 W.	Saranac	5 miles south, and 1 mile east from Dannemora village	......	"	"
S. 5 E.	Plattsburg	On Bluff Point, ¼ mile west of Hotel Champlain	......	Chazy	"
S.	"	2½ miles north of Plattsburgh, near Beekmantown line	......	"	"
N. 15 E. N. 15 W.	Dannemora	On shore of Chateaugay Lake	......	Potsdam	"

FRANKLIN COUNTY.

N. 20 E.	Malone	4 miles southwest of Malone	......	Gneiss	H. P. C.
S.	"	8 miles south of Malone (At Branch pond outlet)	......	Augite Syenite	"

ESSEX COUNTY.

N. 92 E.	Jay	Near Ausable Forks	......	Gneiss	J. F. K.
N. 52 E.	"	Lower Jay	......	Anorthosite	"
N. 52 E.	"	2 miles east of last	......	"	"
N. 12 E.	"	Southeast of Upper Jay	......	....	"
N. 28 E.	Crown Point	West of Crown Point village	200	Gneiss	"
N. 12 E.	"	West of Crown Point village	......	"	I. H. O.
N. 38 E.	"	Near Lake Champlain, 1 mile north of Burdick's Crossing	100	Calciferous	J. F. K.
N. 42 E. N. 47 E.	"	Burdick's Crossing	150	"	"
N. 12 E. N. 62 E.	"	Coot Hill	1,100	Granite Gneiss	"
N. 49 E.	"	Sugar Hill	400	Gray Gneiss	"

ESSEX COUNTY.—*Continued.*

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
N. 47 E. N. 27 E.	Crown Point	Breed's Hill	300	Calciferous	J. F. K.
N. 57 E.	"	South of Towner Pond	600	Gabbro Gn's	I. H. O.
N. 50 E.	"	South of Towner Pond	1,200	Pegmatite	"
N. 62 E. N. 32 E.	Ticonderoga	3 miles east of Street Road	200	Calciferous	J. F. K.
N. 57 E.	"	½ mile south of last	200	"	"
N. 44 E. N. 22 E.	"	½ mile south of last	*	....	"
N. 57 E.	"	2 miles north of Addison Junction	200	....	"
N. 52 E.	"	Addison Junction	150	Calciferous	"
N. 52 E. N. 27 E.	"	Ticonderoga village near outlet of Lake George	200	Syenite	"
N. 52 E.	"	½ mile south	200	Sed. Gneiss	"
N. 47 E.	"	Mt. Hope	300	Calciferous	"
N. 67 E.	"	Northeast of Delano	200	Pegmatite	"
N. 37 E.	"	Delano	100	Calciferous	"
N. 42 E.	"	1 mile west of Cook's Mountain	300	....	"
N. 47 E.	"	½ mile southwest of last	400	....	"
N. 32 E.	"	½ mile south of last	500	....	"
N. 25 E.	"	In Ticonderoga village, north of river	200	Syenite	"
N. 22 E.	"	½ mile southwest of last	200	....	"
N. 42 E.	"	North of Ticonderoga ruin	150	Potsdam	"
N. 62 E.	"	½ mile east of last	120	....	"
N. 47 E.	"	1 mile northeast of Baldwin	350	Potsdam	"
N. 30 E.	Hague	Point south of Friend's Point	340	Gneiss	"
N. 62 E.	Wilmington	West of Ausable River, 3 miles southwest of Wilmington village	1,300	....	"
N. 72 E.	Lewis	Near town of Lewis	650	....	"
N. 70 E.	Moriah	3 miles south of Moriah village	1,000	Gneiss	"
N. 65 E.	"	½ mile south of last	1,100	"	"
N. 70 E.	"	4 miles south of Moriah village	1,100	"	I. H. O.
N. 52 E.	Elizabethtown	1 mile southwest of New Russia, on the Boquet	680	....	J. F. K.
N. 70 E.	Schroon	North shore of Paradox Lake	820	Gneiss	I. H. O.

* Scratches faulted by crack N. 30 E.

HERKIMER COUNTY.

S. 30 E.	....	1 mile north of Salisbury Centre	......	* Gneiss	H. P. C.
S. 10 E.	....	2½ miles north, a little west of Middleville	......	Trenton	"
S. 30 W.	....	2 miles south and 1 mile west of Little Falls	......	Birdseye	"

* Of Grenville series.

ST. LAWRENCE COUNTY.

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
S. 45 W.	....	N. Y. C. & H. R. railroad cut, 2½ miles north of Horse Shoe station......	......	Augite Syenite	H. P. C.
S. 40 W.	....	Railroad cut 1½ miles north of Horse Shoe..........	......	Augite Syenite	"
N. 80 W.	....	Railroad cut ½ mile east of Childwold.............	......	Gneiss *	"
N. 75 W.	....	Railroad cut ½ mile south of Childwold.............	......	Augite * Syenite	"
S. 30 W.	....	East shore of Big Tupper..	......	Augite † Syenite	"

*These two readings are apparently of basal motion, influenced by the Raquette valley and the mass of Arab Mountain to the south, the ice moving west around it.

†Four different readings.

WARREN COUNTY.

N. 20 E.	Johnsburg	3 miles east of Baker's Mills	......	Gneiss	J. F. K.

WASHINGTON COUNTY.

N. 62 E.	Putnam	2 miles east of Lake George, opposite Hague.........	500	Potsdam	J. F. K.
N. 52 E.	"	½ mile east and slightly north of last............	600	"	"
N. 52 E.	"	1 mile south of last........	600	"	"
N. 67 E.	"	1 mile west of Putnam station	......	Calciferous	"
N. 47 E.	Dresden	Bluff Head...............	400	Gneiss	"
N. 37 E. N. 27 E.	"	2 miles west of last........	1,100	"	"*
N. 32 E.	"	½ mile southwest of last (on Spruce Mountain)	1,200	Gabbro	"
N. 62 E.	"	2 miles east of last (near Lake Champlain)........	200	Gneiss	"
N. 42 E.	"	East side of Spruce Mountain..................	1,400	"	"
N. 37 E.	"	½ mile east of last	1,150	"	"
N. 42 E.	"	1 mile north of Dresden Centre	500	"	"
N. 42 E.	"	½ mile north of Dresden Centre.................	450	Syenite	"
N. 52 E.	"	1 mile west of Dresden Centre....................	1,100	....	"

*Crossing striæ.

WASHINGTON COUNTY.—*Continued.*

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
N. 42 E.	Dresden	Dresden Centre...........	500	Gneiss	J. F. K.
N. 37 E.	"	½ mile south of last.......	500	"	"
N. 32 E.	"	1 mile slightly south of east of last (near Lake Champlain)..................	100	"	"
N. 32 E.	"	½ mile south of last.......	100	"	"
N. 37 E.	"	East of Long Pond........	1,000	Potsdam	"
N. 45 E.	Fort Ann	....	......	....	"
N. 40 E.	"	....	......	....	"
N. 28 E.	"	....	......	....	"
N. 55 E.	"	....	......	....	"
N. 50 E.	"	....	......	....	"
N. 60 E.	"	....	......	....	"
N. 55 E.	"	....	......	....	"

The widest valleys, and hence the most favorable for ice movement, were the Champlain and St. Lawrence valleys bounding the region. Therefore, as the ice advanced down the lower St. Lawrence, it must have split into two streams on either side of the Adirondacks; at the time of its maximum extent these two streams flowed around the obstruction, their edges meeting in the Mohawk valley near Utica; as it retreated the valley portions melted first, forming lakes in the depressions, while local glaciers were left on the highest mountains.

These results are entirely in accordance with the phenomena to be found in the Mohawk valley.[1] Later work completely bears out the early suggestion of Chamberlin, in the report already cited.[2] After discussing the moraines of the Mohawk valley he says:

> I hesitate at this stage of the inquiry to encourage any confident opinion in regard to the exact history of glacial movements in the Mohawk valley, further than the general presumption that massive currents having their ulterior channels in the Champlain valley on the one hand, and in the St. Lawrence on the other, swept around the Adirondacks and entered the

---

[1] ALBERT PERRY BRIGHAM, "Topography and Glacial Deposits of Mohawk Valley," *Bull. Geol. Soc. of America*, Vol. IX, pp. 183-210.

[2] T. C. CHAMBERLIN, *Third Annual Report*, *U. S. Geol. Surv.*, pp. 295-402.

Mohawk valley at either extremity, while a feebler current, at the height of glaciation, probably passed over the Adirondacks and gave to the whole a southerly trend.

The detailed work of Brigham has already proved the accuracy of this general statement for the Mohawk valley. The data gathered for the present paper tend to show its truth as regards the Adirondack area.

GLACIAL DEPOSITS.

The glacial deposits of the Adirondacks belong to the time of retreat and melting of the ice. Very little true morainal material is found, whereas stratified drift is abundant. The reason for this condition is evident; during the time of maximum advance of the ice the Adirondacks were so far from the border as to be within the area where movement was too vigorous for deposition; such deposits as there are belong to the time when the melting ice afforded opportunity for the deposition of its drift in bodies of water. Lake Champlain is the shrunken remnant of a large body of water[1] which occupied the depression, while ice still stood in the St. Lawrence valley. Shore deposits were laid down along the border of this lake, while mud was laid down farther out in its waters. Large deltas were formed at the mouths of the streams. With the further retreat of the ice to the north, the waters of this lake subsided, and the shore deposits and deltas were formed farther and farther out, successively overlapping on the clays of the preceding stage.[2] During a part of this period the Champlain valley was an arm of the sea, some of the sands and clays containing marine fossils.

On the great plain to the north true morainal material is found, though sparingly. The plain is overlain by a succession of sand plains at various levels. Deltas are numerous. The complete history of these successive stages has not been attempted, nor their correlation with the Champlain deposits.

---

[1] "Lake Hudson-Champlain," See WARREN UPHAM, *Bull. Geol. Soc. Amer.*, Vol. III, 1891.

[2] H. P. CUSHING, "Geology of Clinton County," *Fifteenth Ann. Rept. N. Y. State Geologist.*

Overlying these sand plains local moraines are found, which appear from the character of the drift, to have been deposited by glaciers radiating from the center of the Adirondack highlands after the melting of the main body of the ice.[1]

Local moraines are also to be found in the valleys of the central part of the region. Such moraines always overlie stratified deposits and by their position and their character indicate a period of local glaciation. The cirques on the side of many of the higher mountains afford further evidence of the same phenomenon. There is no evidence of extensive local glaciation, of the nature of an ice cap such as Professor Chamberlin describes in Greenland; the moraines are too infrequent and the region too thoroughly covered by drift brought by the advancing ice from the northeast which would have been removed by extensive glaciation. The evidence points to the presence of local valley glaciers in a few isolated localities.

The closing stages of the ice invasion were marked by the presence of lakes in the larger valleys. Evidence of them is to be seen in the frequent flat valley floors of stratified drift, and the deltas opposite the mouths of tributary valleys. A remarkably fine example of such a lake is to be seen near Elizabethtown, the town itself standing on a delta terrace.[2] There are many such lake flats, which were probably contemporaneous with the Champlain submergence, existing as lakes in the interior at the time Lake Champlain was a sea bay. Many of these lakes were held up by stagnant ice, and the draining of them took place in late Champlain time when the climate was too warm for ice to remain. Others were held up by drift, and the extinction of these took place in Recent time partly from draining and partly from filling by sediment and choking by vegetation.

Terraces are to be found along some of the larger rivers,

---

[1] H. P. CUSHING, "Report on the Potsdam and Pre-Cambrian Boundary North of the Adirondacks," *Sixteenth Ann. Rept. N. Y. State Geologist.*

[2] H. RIES, "A Pleistocene Lake Bed at Elizabethtown, Essex Co., N. Y.," *Trans. N. Y. Acad. Sc.*, 13 (1893), p. 197.

notably the Schroon and upper Hudson. The upper terrace of the Schroon suggests an origin as a "kame terrace," deposited against the side of a mass of stagnant ice. It has been so much eroded postglacially (its removed material being often blown into dunes on the lower terrace), that its complete history will need more careful study than has yet been given.

Professor Spencer claims to have traced the Iroquois beach for some miles north of the Adirondacks,[1] his interpretation being questioned by Messrs. Gilbert[2] and Taylor.[3] No thorough work has yet been done and the northern deposits are few and scattered. The problem, therefore, of the correlation of the Pleistocene stratified deposits of the three regions — the Champlain valley, the plain north and west of the Adirondacks, and the Adirondacks proper — is quite unsolved. The question of a Pleistocene subsidence, advocated by Professor Spencer is also an open one.

EROSION HISTORY OF THE ADIRONDACKS.

Certain main lines of drainage were established before the close of Cambrian time. These are tremendously modified by later adjustments, notably from faulting and glaciation, but the Cambrian drainage can be made out and is in some localities remarkably similar to the present.[4] The Cambrian topography was mature, streams being located along the soft limestone of the Grenville series, while the harder gneisses stood out as rounded ridges. As the Adirondack island sank beneath the Ordovician sea, these mature rivers were drowned and sediments deposited along their courses. At the close of Trenton time the region was wholly submerged. No evidence of this complete submergence is forthcoming from the Adirondacks themselves,

---

[1] "The Iroquois Shore North of the Adirondacks," *Bull. Geol. Soc. Amer.*, Vol. III (1891), pp. 488-92.

[2] Discussion of the above by GILBERT, *op. cit.*, pp. 492-95.

[3] F. R. TAYLOR, "Lake Adirondack," *Amer. Geol.* (1897), Vol. XIX, pp. 392-96.

[4] J. F. KEMP, "Physiography of the Eastern Adirondacks in the Cambrian and Ordovician Periods," *Bull. Geol. Soc. Amer.*, Vol. VIII, 408-12.

but the homogeneous character of the deposits surrounding them, and the entire absence of any indications of shore formations or island character, point very strongly in this direction. No sediments are found later than the Utica slate until the post-glacial submergence caused the deposition of the Champlain clays. The region was, therefore, above the sea for an immense period of time and its erosion history is a hard one to read. The close of Ordovician time was the date of uplift ; the region was affected by the same movements which caused the Green mountain uplift. But whereas the Vermont region was subjected to great folding and metamorphism, in New York the effect was less pronounced and resulted in faulting only.[1]

These faults are the most conspicuous features of the present topography. They have caused numerous drainage adjustments and have produced most marked effects upon the whole subsequent physiographic history. The faults run in general northeast-southwest directions, and were accompanied by block tilting towards the east. The drainage lines have placed themselves along the fault lines, and the tributaries on opposite sides work against an abrupt fault cliff, or a gentle tilted slope, respectively. Those with the slope for their course have a conspicuous advantage, and have extended their courses much farther back than those flowing in the opposite direction. Some of the above facts were brought out by Professor Brigham,[2] who noted on the maps that the southeastward flowing tributaries had much longer courses.

Throughout the remainder of Palæozoic time the region was a land area, and very little trace of the sequence of events has been found. The time was long enough for many erosion cycles, but such evidence as there is points toward gentle simultaneous erosion and uplift, perfect baselevel being at no time

---

[1] H. P. CUSHING, "Report on the Boundary between the Potsdam and Pre-Cambrian rocks north of the Adirondacks," *Sixteenth Ann. Rept. N. Y. State Geologist*, 1896.

[2] "Note on Trellised Drainage in the Adirondacks," *Am. Geol.*, Vol. XXI (1898), p. 219.

produced. In the north Dr. Cushing has found indications of two peneplains and two periods of uplift.[1] The upper level is marked by the somewhat uneven sky line of the hilltops; the second by the valley levels. The diversity of altitude indicates that when the earlier erosion period was terminated by uplift, the surface was uneven. The observations of the writer in the south are in complete agreement with those of Dr. Cushing in the north.

The uplift which terminated both the cycles was of a dome-shaped nature, being greatest in the Macy region. The result is that as the central region is approached the valleys grow deeper, the vertical distance between the two levels necessarily growing greater the more nearly the center of uplift is approached. The highest mountains stood out as low monadnocks above both peneplains.

The dates of these two erosion cycles are a matter of much uncertainty. The uplifts which terminated them are certainly of comparatively recent date, since, as observed by Cushing, the axis of elevation is most pronounced, and the fault scarps of the same age are remarkably fresh. Definite correlations cannot be made until the topographic maps are completed, not only for the Adirondack region itself, but for the region connecting the Adirondack with the Appalachian region. There seems a strong probability that the upper Adirondack level will prove to be the northward extension of the Cretaceous peneplain of New Jersey and Pennsylvania.[2] Brigham has suggested[3] that the plateau south of the Mohawk is to be regarded as a possible northward extension of this Cretaceous plain. This plateau, like the Kittatinny peneplain, is almost level, and is cut on soft Palæozoic rocks. As already shown, there is reason to believe that the

---

[1] "Geology of Franklin County," *Eighteenth Ann. Rept. N. Y. State Geologist*, 1898.

[2] W. M Davis, "The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States," *Bull. Geol. Soc. Amer.*, Vol. II, p. 560.

[3] A. P. Brigham, "Topography and Glacial Deposits of the Mohawk Valley," *Bull. Geol. Soc. Amer.*, Vol. IV, pp. 183–210.

Trenton entirely covered the Adirondacks, having since been removed except in the case of a few outliers. The pre-Cretaceous erosion period reduced the soft rocks of the Appalachian region to almost absolute baselevel; in the Adirondacks the same period sufficed to clean out nearly all the softer rocks from the valleys, and to reduce the more resistant crystallines to a condition of moderate slopes and slight relief. The tilting of the plain in the Adirondacks is such as to bring its level into close relation to those further south as well as to the less certainly Cretaceous peneplain of New England. If this correlation proves to be correct, the dome-shaped uplift of the Adirondacks marks the western and northern corner of a great post-Cretaceous uplift. The lower Adirondack level would correspond to the Tertiary level elsewhere observed.

The age of this lower level in the Adirondacks can be fixed with more certainty. The valley floor on which the drift was deposited consisted of the level described, into which the streams had just begun to incise their channels. They must have been rejuvenated in Pliocene or post-Pliocene time, since they had just begun to lower their levels before the ice invasion. If the rejuvenation of them closed the Pliocene, the cutting of the level must have been in the period immediately preceding, or in the earlier Tertiary.

When the ice invaded the region it encountered a drainage long established and well adjusted, but physiographically young in that the region had recently been uplifted and its streams rejuvenated. After its withdrawal it left the valleys completely drift-filled, and the courses of the rapidly cutting streams determined by the slope of the drift. The resulting drainage modifications are numerous.

Rivers.—The preglacial divides had been determined by two axes of uplift, a north-south and an east-west axis intersecting in the Marcy region. The postglacial divides are of drift, deposited in the old valleys, and although conforming in a general way to the old directions the streams are often in quite new channels. Often a few rods of drift is all that separates St.

Lawrence, Champlain, and Hudson drainage. The principal Adirondack rivers—Raquette, St. Regis, Saranac, Ausable, Boquet, Schroon, Boreas, and Indian—are alike in that their sources lie in chains of lakes which owe their origin to glacial agencies. The stream profiles are convex, indicating a young drainage. The lower courses consist of series of still waters, separated by falls or rapids, the whole system owing its character to the occasional wearing off of the drift. Cushing describes several falls with still waters above and below, whose existence is due to the postglacial uncovering of hard ledges of rock. Obviously any rock is harder than drift, and such a dam and fall will be found wherever any bed rock is uncovered. On the inlet to Paradox Lake is such a fall over crystalline limestone of the Grenville series, which is the softest rock of the region. Obviously these falls are temporary, and will be worn back into gorges accompanying a draining of the lakes, until a mature and concave profile is produced.

Lakes.—Lakes of various origins are present in the Adirondacks, and their study would well repay more careful investigation than has yet been given them. They are commonest along the headwaters of rivers, and are here usually due to some form of drift filling in an old valley. Many other lakes, and those notably the smallest, occupy rock basins. Cushing observes that none such have been found in Franklin county, though he admits the possibility that certain lakes may belong to this category. In the southern Adirondacks rock basins are by far the commonest type; here they are usually associated with faulting, but the smoothed nature of their bounding rocks, and the frequency of scorings, suggest the possibility that ice erosion may have been at least a partial factor.

The western gneissic area of low relief and gentle slopes is pre-eminently a land of lakes. They often occur in chains, connected by short stretches of river. The divides are low and usually of drift. These series of lakes represent broad preglacial river valleys, locally deepened and widened by the ice during its advance, and filled with water-deposited drift during its period of melting. The result of this combined erosion and deposition is that lake basins are formed in some old channels, while others are completely filled, for considerable distances, and the streams pushed into new courses.

I. H. Ogilvie.

Geological Department,
Columbia University.

THE LARAMIE PLAINS RED BEDS AND THEIR AGE.[1]

THERE is not another formation in the entire Rocky Mountain region as conspicuous or as universal as the Red Beds. Go where you will, you find the strata of this dark red formation very near the base of the mountain ranges, often forming conspicuous hogbacks, and furnishing examples of wind erosion seldom if ever equaled. No formation in the arid west is so welcome to a geologist as he enters a field for the first time; for its lithological characteristics are so marked and uniform that it forms a horizon indicator that immediately furnishes a working basis.

From the days of the pioneer geologists in the Rocky Mountains, the majority have assigned the Red Beds to the Triassic. A few have been quite guarded in their opinions, and have given the matter unusual attention; but it has been the consensus of opinion that the formation was barren of fossils, and, since it was usually found above Coal-measures and below Jurassic, that it must be Triassic.

Hayden was the first geologist to publish anything in reference to the Laramie Plains. Unfortunately his observations were of the roughest reconnaissance type. In referring to the geology of the Laramie Mountains he says:[2]

> East of the Big Laramie River, and along the western slope of the Laramie range, the entire series of unchanged rocks are visible, inclining at moderate angles, from the mountain sides. On the west side of this range the slope is more gentle, and the Carboniferous, Triassic, Jurassic, and Cretaceous beds present their upturned edges clearly to the scrutiny of the geologist.
>
> The nucleus is red syenite for the most part, while from the margins

In referring to the structure of the same region, in the same report, he says:[3]

---

[1] Published by permission of the director of the United States Geological Survey.

[2] HAYDEN, *Second Annual Report*, p. 89.

[3] *Ibid.*, p. 82.

incline, from either side, unchanged rocks belonging to the Carboniferous, Triassic, Jurassic, Cretaceous, and in some localities Tertiary.

In both of these references Hayden took it for granted that the Red Beds were Triassic.

The next important geological contribution to science in reference to the Laramie Plains Beds appears in the *Systematic Geological Report of the Fortieth Parallel Survey*, under the heading of "Triassic," pp. 249, 250, which reads as follows:

> Directly overlying the Palæozoic limestones, in conformable superposition, and not infrequently overlapping the Palæozoic, and coming directly into nonconformable contact with the Archean, appear the well-known Rocky Mountain Red Beds, which, from their position between the Coal-measures below and the well-recognized Jurassic beds above, have been generally assigned to the Triassic age. Reserving all discussion of the validity of this assignment to later pages of this chapter, it is proposed here to give simply a brief statement of their physical condition and continuity along the flanks of Colorado Range within the field of this exploration. From the lower limit of the map nearly up to the forty-first parallel, the Red Beds lie directly upon the Archean, and form, with soft, friable strata, a remarkable contrast with the adjoining crystalline rocks, the red series varying in thickness from 300 to 850 feet. It is interesting to observe that where they are in direct contact with the Archean rocks they have a dip rarely exceeding 15 degrees, and often retaining an approximation to the horizontal; while to the north, where erosion has been deep enough to reach and uncover the Palæozoic series, the dip increases to the vertical, with exceptional instances of slightly reversed position. The region of contact between the Trias and the Archean affords an interesting display of the mode of deposition of the coarse, friable gravel and sandy material of the Trias upon the hard irregularities of the crystalline series.

In the same chapter, pages 256–58, King refers to the Red Beds in the southern portion of the Laramie Plains as follows:

> South of the railroad on the western side the contact of the Trias with the Archean is rather interesting. It is seen gradually to overlap the gentle inclinations in thin beds, and to abut squarely against the steeper slopes of the Archean. In general, it dips gently away from the Archean, the Trias ridges being defined by the harder beds which have protected from erosion the softer and more shaly portions below; and wherever there are lines of erosion parallel to the contact-line with the Archean, the steeper or more escarped faces are turned toward the range.
>
> Gypsum deposits are well shown north of the Willow Creek and the

North Park road, where they occur through a thickness of at least 80 or 100 feet, and are interstratified with dark, intensely red sandstones. South of the road are some remarkably eroded forms suggestive of ruined cities.

West of Antelope Creek the Trias extends twelve miles to the south of the Wyoming and Colorado boundary, filling a bay-like depression in the Archean body. Here are exposed, along the eastern side of Laramie Valley, 1,200 feet of beds having a very slight dip to the north and west, a high, abrupt wall of nearly 1,000 feet presented toward the plains. Upon the front of this escarped precipice may be seen the interstratified marls and limestones of the Jura, overlying the heavier red gypsiferous beds of the Trias. In contact with the Archean body the sandstones are of coarse, ash-colored materials containing angular fragments and rounded pebbles, with more or less calcareous matter in the cement, followed by a hard, thin, cherty limestone which passes up into reddish-gray sandstone, and above this the usual beds of coarse red sand, with numerous red clay beds, varying shaly, which give a prevailing argillaceous character to a wide zone of sandstone. Within this red argillaceous series are thin beds of pure clay and white gypsum, the latter varying from two or three inches up to several feet, with one solid body of twenty-two feet inclosed between two series of intensely red, dark, indurated sand-rock. Above the gypsiferous zone occur heavy red sandstones, which pass through yellowish friable beds with marly intercalations into the calcareous beds of the conformable Jura.

The following section illustrates the chief features of the Triassic series, as displayed here, beginning at the summit:

1. Yellowish-red sandstone, passing down into fine, deep-red, evenly bedded, strongly coherent sandstone - - - - - - - - - 375 to 400 feet.
2. Argillaceous shales and argillaceous sands, with interstratified layers of fine pure clay, the whole prevailing red, with grayish and yellowish-red zones carrying four or five beds of gypsum, one reaching twenty-two feet in thickness; in all 150 feet.
3. Red compact sandstones, beds of varying thickness, some coarser and some finer - - - - - - - - - - - - - 250 feet.
4. Reddish-gray sandstones carrying a bed of cherty limestone four or five feet thick; the whole - - - - - - - - - - - 175 feet.
5. Coarse, friable, ash-colored sandstones of remarkably loose texture, matrix containing more or less calcareous matter, with sheets of pebbles, partly rounded and partly angular cherty masses, together with some fragments of Archean schists, both hornblendic and granitoid - - - - - - 150 to 200 feet.

There is no question but that King visited the Red Mountain area while making his survey; for there is no other place on the Laramie Plains where the Red Beds rise in nearly vertical walls upward of 500 feet. At the beginning of the chapter from which the above extracts were taken King states that he will discuss the validity of the term "Triassic" as applied to the Red Beds at the close of the chapter, but I have failed to find his reference.

A portion of the Red Beds of the Laramie Plains occupies a belt of varying width along the western base of the Laramie Mountains. North of Laramie for a distance of forty miles the width varies from three to four miles, and the surface is gently rolling to within a short distance of the range, where there are now and then low hogbacks that have been cut with transverse gulches. South from Laramie the width gradually increases, and at Red Buttes is about six miles, and the eastern portion is marked with a great many eroded buttes which rise from 15 to 50 feet above the surface. Almost due south from Red Buttes there is a long, narrow spur of Archean rocks known as Boulder ridge, projecting into the valley country, causing the Red Beds to narrow down to about three miles. North and east of the Archean exposure there is a tongue-like mass of Red Beds extending into a depression in the Archean to the south of Tie Siding, and, if the width of the formation east and west is estimated from this place, it will be over twelve miles. Southward from Boulder Ridge the Red Beds widen rapidly toward the Colorado line, and near that place have an east and west expansion of about eighteen miles. In Colorado they form a narrow, V-shaped mass that occupies the angle at the intersection of the Laramie and Medicine Bow Mountains; but are nearly covered with Jurassic and Dakota formations.

Generally speaking, the topography of the Red Beds on the Laramie Plains is quite level or gently rolling. Occasionally the hogbacks are found near the ranges, and in three localities the surface is characterized by numerous buttes that have been worn into grotesque figures by wind erosion. These localities are Red Buttes, at the termination of Boulder Ridge and Sand Creek. In the latter place the wind-sculptured rocks are scattered along the valley for a distance of six miles, and present some of the most remarkable examples of wind erosion known in the state. The general forms are irregular domes of cross-bedded red sandstone, which rise from 20 to 75 feet above the valley. These are occasionally consolidated into a wall with vertical sides, and this capped with grotesque figures altogether too complicated to admit of description here. The west winds cut notches, gaps, and in some places channels, to a depth of 20 or more feet. There are isolated, irregular towers that rise from 50 to 75 feet, and in some instances these have been nearly undermined by the greater erosion at their base, and in a few places they are found already tumbled to the ground. On Sand Creek, and on the Colorado-Wyoming line, Chimney Rock, with its curious rugged exterior, rises to a height of 350 feet above the stream that flows at its base.

The geological section that follows extends from the Archean mass east of Sand Creek, westward to and including Red Mountain, and has been constructed as follows: Nos. 1 to 44 inclusive, were measured on the eastern side of the formation. To the westward the gypsum and aragonite beds were found in the Payne ranch; but the thickness of the formation between the gypsum and No. 44 was not taken, nor were the Red Beds measured above the gypsum in this locality. Red Mountain has been faulted up so as to expose all of the Red Beds from below the gypsum beds upwards, and on account of the accessibility of this section the measurements from No. 44 upwards were taken at this point. The two sections have not been accurately put together, since it was impossible with limited time to locate the upper portion of the first part of the section at Red Mountain.

While at work during the last of November in the vicinity of Red Mountain, I discovered a fauna in the midst of the Red Beds, and to make its position clear I append the following section:

GEOLOGICAL SECTION.

	Feet.	Inches.
Archean granite, badly decomposed, base of Red Beds - -	10	0
1. Conglomerate, shading into coarse sandstone of a reddish-brown color - - - - - - - - - - - - - -	1	6
2. Fine grained reddish conglomerate and sandstone - - - -	17	0
3. Soft sandstone, shading from gray to red - - - - - -	25	4
4. Whitish sandstone, with a few thin bands of red - - - -	2	6

	Feet.	Inches.
5. Thin-bedded reddish and whitish sandstone	1	6
6. Reddish argillaceous sandstone	12	10
7. Whitish sandstone and conglomerate	2	9
8. Soft, maroon-colored to whitish argillaceous sandstone	1	5
9. Coarse light-gray sandstone	0	9
10. Alternating bands of grayish to maroon-colored sandstone	15	3
11. Mottled sandstone, red with greenish-white blotches	3	9
12. Red shaly sandstone	1	5
13. Drab calcareous sandstone	1	2
14. Maroon-colored to light colored soft sandstone	2	4
15. Reddish sandstone, with light-colored small circular patches	0	7
16. Coarse-grained sandstone, very soft, mostly light-colored with reddish streaks	20	2
17. Coarse-grained sandstone, with a few bands of greenish-gray conglomerate	19	3
18. Dark-red sandstone, blotched with greenish gray	3	3
19. Fine-grained conglomerate, grayish, with cross-bedded red strata	2	9
20. Reddish conglomerate, cross-bedded with many angular fragments	26	4
21. Red sandstone and fine-grained conglomerate with whitish bands, only partially exposed	27	1
22. Dark gray to brown sandstone	1	6
23. Maroon-colored to whitish, soft, thin-bedded sandstone	37	11
24. Red shaly sandstone	3	8
25. Red and whitish cross-bedded sandstone	13	5
26. Red sandstone, with pebbles at base	4	0
27. Fine-grained cross-bedded conglomerate	3	10
28. Red to gray sandstone, evenly bedded, with large fragments of plant(?) remains. These are found to lie conformable to the bedding plains, and are from two to four inches in diameter and often several feet in length	21	5
29. Red sandstone, rather hard	9	0
30. Red coarse-grained cross-bedded sandstone, with flint nodules and grayish-green patches	11	0
31. Red sandstone	9	7
32. Red to brownish sandstone, with a few lighter-colored streaks	19	8
33. Red sandstone, with drab particles near the top	4	2
34. Coarse-grained cross-bedded red sandstone	6	2
35. Dark red sandstone, with light-colored streak	12	4
36. Red to gray cross-bedded sandstone	2	3
37. Fine-grained light sandstone	2	7
38. Coarse red sandstone and conglomerate	10	5
39. Dark red sandstone, rather hard, and in strata varying from 8 to 22 inches in thickness	15	8
40. Shelly drab limestone	2	2

		Feet.	Inches.
41.	Brick-red sandstone, massive and thick bedded at base; changing to exceedingly cross-bedded structure above. This band weathers into the most peculiar wind-carved figures, which are so common along Sand Creek, where there are several hundred of them. The usual form is a dome, but there are columns, spires, arches, and figures altogether too numerous to refer to here. In reality this band weathers with a peculiar topography which can be easily traced	51	7
42.	Whitish and red shaly sandstone, light bands alternating with the red	61	8
43.	Red shaly sandstone, capped with 2 feet of hard red sandstone	34	7
44.	Red sandstone, mottled with grayish-green blotches. The surface talus covered, and detailed measurements could not be made	151	8
	There is an interval at this point in the section that has not been measured; but the thickness is of slight importance and will not amount to 50 feet.		
45.	Red sandstone	15	0
46.	Greenish to gray soft sandstone	20	0
47.	Grayish to reddish sandstone, containing the following genera of fossils: Allorisma, Pleurophorus, Bellerophon, Myallina, Aviculopecten, Dentalium(?), Pleurotomaria(?), several small gasteropods, and some remains of vertebrates	1 to 4	0
48.	Gypsum bed, excellent quality	50	0
49.	Red clay and gypsum strata alternating, and one of the clay bands containing innumerable aragonites (pseudomorphs after hanksite)	20	0
50.	Red sandstone and shale	100	
51.	Gray wavy-bedded quartzite	3 to 5	0
52.	Red sandstone and shales. Light red and shaly at base; heavy bedded and dark maroon-colored near the top, with no change in general coloration	675	0
	Total	1,578	2

Measurements from 45 to 52, inclusive, are subject to revision.

The genera referred to in No. 47 are so characteristic that it is not necessary to discuss their geological position; they belong to the Palæozoic, and resemble to a marked degree the fossils of the Kansas and Nebraska Permian. This places all of the strata below the fossiliferous band in the Palæozoic. There remains a formation of about eight hundred feet in thickness, with the gypsum beds at its base in a questionable position, and some may wish to retain these beds in the Triassic.

All of the pioneer geologists who studied the Laramie Plains commented on the Red Beds resting on the Archean south of the Union Pacific railroad, and also upon the conformable contact of the Red Beds and the limestones further northward. From my recent investigation I have found that the limestones shade almost imperceptibly into the red sandstones, and that the strata of the lower portion of the Red Beds are identical with the strata of limestones to the northward, the difference in the lithological characteristics being due to the varied physical conditions during sedimentation. Here is a very peculiar instance where rocks of the same age, and, in fact, identical strata, have been differentiated on purely lithological grounds. Just what proportion of the Red Beds will be equivalent to the limestones has not been determined; but probably not less than five hundred feet of the strata near the Colorado line will correspond to limestones and light-colored sandstones some fifteen or twenty miles to the northward, and possibly a greater thickness.

From the data in hand it will be observed that physical conditions favoring the deposition of Red Beds had been in existence for a long time prior to the forming of the fossiliferous band containing the Palæozoic fossils. Above the fossiliferous horizon the formation is made up of the same, or similar, red sandstones and shales; but it is more uniform in color and persistent in its lithological characteristics, and to the northward these strata do not merge into limestones. On the other hand, the Red Beds are conformable throughout, and there is no line of demarkation discovered thus far that would act as a basis of subdivision. There are a few beds of gypsum and limestone, but these are not persistent enough to be utilized as boundary lines. For the above reasons I am in favor of placing the Red Beds in the Palæozoic.

From a palæontological standpoint, likewise, it seems advisable to refer the Red Beds to the Palæozoic. The fauna referred to is purely Palæozoic, and without the slightest evidence of Mesozoic types. It would be unreasonable to expect that a Mesozoic fauna could have developed from the one referred to in No. 47 in the little time required to have accumulated eight hundred feet of gypsum and sandstone. I realize that this is based purely upon theory; but nevertheless it seems advisable at this time to offer this suggestion. If adopted, it will deprive the eastern Rocky Mountain region of the term "Triassic," and make the basal member of the Mesozoic the Jurassic. Further west, especially along the flanks of the Wasatch Mountains, there are undoubted Triassic beds.

A second question to settle will be the position of these Red Beds in the Palæozoic. Already the limestones along the Laramie Mountains have been referred to the Upper Carboniferous by several geologists; but upon very slight palæontological evidence. None of the early investigators were able to find many fossiliferous bands. In recent years I have found quite a fauna in the limestones, and this resembles the Kansas and Nebraska fauna of the Permian. The fossiliferous bands are near the top of the formation, and there may be typical Coal-measure fossils below; but such have not been discovered, and I am inclined to believe that the limestones of the Laramie Mountains correspond very nearly with the Permian of the Missouri Valley. The Red Beds merge into the limestones or rest conformably upon them, and here we have conditions very similar to those that have been recently discussed from southern Kansas and to the southward. From our present knowledge, it seems advisable to refer the Red Beds of the Laramie Plains to the Permian. This classification has been suggested to me before. Only a few years ago Dr. Williston, while making me a visit, remarked: "Why do you not place the Red Beds in the Permian?" I stated "that we had never been able to discover any fossil remains to guide us in identifying them as Permian." At the time he advanced the idea that the Red Beds in Wyoming were very much like the Red Beds of Kansas.

Further evidence concerning the fossils may be looked for, and I believe that many more localities will be found where fossils have been preserved that will materially aid in the future work. The finding of vertebrate remains is also of importance.

The bones found are so fragmentary as to be beyond identification; but further search will, beyond question, yield better results. The invertebrates have been placed in the hands of Dr. Girty, of the United States Geological Survey, for study, and as soon as he has finished his work there will be a joint paper published that will consider the limestones as well as the Red Beds of the Laramie Plains and their geological position.

WILBUR C. KNIGHT.

UNIVERSITY OF WYOMING,
March 18, 1902.

THE COMPOSITION, ORIGIN, AND RELATIONSHIPS OF THE CORNIFEROUS FAUNA IN THE APPALACHIAN PROVINCE OF NORTH AMERICA.

THE Devonian was pre-eminently a period of provincial development of marine faunas. In the Appalachian Province of North America, lying to the west of the ancient Appalachian land and to the east of the Wisconsin-Ozark land, there were introduced successively, with little or no foreshadowing, the Helderbergian, Oriskany, Corniferous, Hamilton, and Upper Devonian faunas. Each of these faunas possesses characteristics peculiar to itself which could not have been derived from the next preceding fauna, but which must have been in process of evolution during a long period of time in some other region of the earth. It is perhaps not too much to assume that each of these faunas had its ultimate origin from the earlier, more cosmopolitan fauna of Silurian time, and that their evolutions were in progress contemporaneously, each in its own more or less isolated province. Their succession, therefore, in the Appalachian Province may be entirely accidental rather than genetic.

The amount of faunal change initiated with the introduction of these various faunas differs greatly in degree. In the case of the Hamilton fauna, there are a large number of species which are common also to the preceding Corniferous fauna; in fact, the great majority of the members of the Hamilton fauna are a residuum or an evolution product from the Corniferous fauna. The number of strange forms[1] introduced is small, but they are of such a nature as to show the presence at this time of a means of communication between the Appalachian province and a southern hemisphere province, probably in South America. The presence of these forms, with the internal changes which

---

[1] The chief of these exotic Hamilton species are *Tropidoleptus carinatus* Con., *Vitulina pustulosa* H., and *Chonetes coronatus* Con.

were in progress, serves to give a character to the Hamilton fauna which is unmistakable.

The faunal change at the opening of the Upper Devonian was far more profound than that which initiated the Hamilton, and it has been shown by Williams,[1] that the foreign element in these faunas, initiated in the Cuboides fauna of the Tully limestone in New York, had its origin in the Middle Devonian faunas of the Eurasian province, and that it found its way into the Appalachian province by way of the Mackenzie Valley of Northwestern Canada, southeastwardly through Manitoba and Iowa.

The life changes introduced with the Corniferous fauna were perhaps even more profound than the changes which took place with the introduction of the Eurasian faunas at the opening of Upper Devonian time. The Corniferous fauna is a large and varied one, and is one of the most widespread of the Devonian faunas of the Appalachian province. Strata containing the fauna are present in New York, where the formation is known as the Onondaga limestone. In Ohio the fauna occurs in the Columbus limestone, and in southern Indiana and Kentucky in the Jeffersonville limestone. The fauna occurs also in southern Illinois near Grand Tower, and reaches as far to the north as northern Michigan. It occurs also in Ontario, to the north of Lake Erie. The fauna has its best development in the central portion of the province, especially in central Ohio and in the neighborhood of the falls of the Ohio River.

The most comprehensive list of invertebrate species occurring in the fauna in the central portion of the province is that which has been published by Whitfield[2] for the region about Columbus, O. It does not, perhaps, contain the names of all members of the fauna as it occurs throughout the entire province, but it is a representative list, and will serve the purpose of making comparison between this fauna and the preceding Oriskany fauna. For a revised list of the vertebrate genera of the fauna I am indebted to Dr. C. R. Eastman, of the Museum of Comparative Zoölogy at Cambridge. The list of

---

[1] *Bull. Geol. Soc. Am.*, Vol. I, p. 481.

[2] *Geol. Surv. Ohio*, Vol. VII, pp. 434–40.

Oriskany species used for comparison with the Corniferous fauna is the one prepared by Schuchert.[1] In this Oriskany list, however, the forms occurring only at Cayuga, Ontario, have been eliminated, for reasons that will appear later, as they cannot be considered as being members of the pure Oriskany fauna. In both the lists some changes in nomenclature have been made, in accordance with recent usage. Only the genera are recorded, the number following each generic name indicating the number of species.

COMPARATIVE LISTS OF THE CORNIFEROUS AND ORISKANY FAUNAS.

CORNIFEROUS.		ORISKANY.	
PORIFERA.			
Receptaculites	1		
HYDROZOA.			
Stromatopora	5		
Cannopora	2		
ANTHOZOA.		ANTHOZOA.	
Favosites	7	Favosites	2
Michelinia	2		
Emmonsia	1		
Trychopora	1		
Aulopora	3		
Syringopora	3		
Eridophyllum	3		
Stylastrea	1		
Zaphrentis	5		
Cyathophyllum	2		
Hadriophyllum	1		
Heliophyllum	2		
Aulocophyllum	1		
Cystiphyllum	2		
ECHINODERMATA.		ECHINODERMATA.	
Megistocrinus	1	Homocrinus	1
Dolatocrinus	2	Mariacrinus	4
Nucleocrinus	1	Edriocrinus	1
Codaster	1	Anomalocystites	1
Ancyrocrinus	1		

---

[1] *Ann. Rept. N. Y. State Geol.*, for 1888, pp. 52–54.

BRYOZOA.

Strictopora	1
Lichenalia	1

BRACHIOPODA.

Orbiculoidea	1
Crania	2
Rhipidomella	2
Schizophoria	1
Orthothetes	2
Stropheodonta	6
Strophonella	1
Leptaena	1
Pholidostrophia	1
Chonetes	5
Productella	1
Spirifer	12
Reticularia	1
Cyrtina	1
Meristella	2
Nucleospira	1
Atrypa	1
Camarotoechia	4
Rhynchonella	1
Pentamerella	1
Eunella	1

PELECYPODA.

Aviculopecten	2
Pterinea	1
Mytilarca	2
Conocardium	1
Goniophora	1
Paracyclus	2
Modiomorpha	2
Sanguinolites	1

GASTEROPODA.

Platyceras	7
Platyostoma	1
Euomphalus	1
Turbo	2
Isonema	3

BRACHIOPODA.

Orbiculoidea	1
Pholidops	2
Rhipidomella	2
Dalmanella	1
Anoplia	1
Stropheodonta	4
Strophonella	1
Leptaena	1
Hipparionyx	1
Chonostrophia	1
Metaplasia	1
Spirifer	6
Reticularia	1
Cyrtina	1
Meristella	4
Rhynchospira	1
Anoplotheca	3
Camarotoechia	2
Rhynchonella	6
Eatonia	4
Rensselaeria	4
Megalanteris	1
Beachia	1

PELECYPODA.

Avicula	3
Megambonia	2

GASTEROPODA.

Platyceras	10
Strophostylus	4
Cyrtolites ?	1

Gasteropoda.—*Continued.*			
Xenophora	1		
Naticopsis	3		
Loxonema	4		
Orthonema	1		
Macrocheilus	1		
Pleurotomaria	4		
Murchisonia	3		
Dentalium	1		
Bellerophon	3		
Pteropoda.		Pteropoda.	
Conularia	1	Conularia	1
Tentaculites	1	Tentaculites	1
Cephalopoda.		Cephalopoda.	
Orthoceras	3	Orthoceras	1
Trematoceras	1		
Gomphoceras	4		
Cyrtoceras	3		
Gyroceras	5		
Trilobita.		Trilobita.	
Dalmanites	3	Homalonatus	2
Phacops	1		
Proetus	1		
Vertebrata.			
Acanthaspis.			
Acantholepis.			
Asterosteus.			
Cladodus.			
Coccosteus.			
Cyrtacanthus.			
Dinichthys.			
Dipterus.			
Machaeracanthus.			
Macropetalichthys.			
Onychodus.			
Palaeomylus.			
Ptyctodus.			
Rhynchodus.			

The conspicuous elements in the Corniferous fauna, when compared with the Oriskany, are the great abundance of corals and the large number of fishes. There is also a very much larger representation of mollusks in the Corniferous fauna; and even among the brachiopoda, where the two faunas have a greater similarity than elsewhere, they are conspicuously different, especially by reason of the absence from the later fauna of genera which were conspicuous in the earlier one. Corals were practically absent from the Oriskany fauna, but in the Corniferous they are everywhere present, usually in abundance, and in some portions of the province they must have grown in great coral reefs. The cephalopods are among the rarest of fossils in the Oriskany fauna, but in the Corniferous there are many of them, often of large size, among which are present straight, curved, and closely coiled forms. Both in its coral element and in its cephalopod element, as well as in the remaining mollusks, there is a strong suggestion in the Corniferous of a recurrence, with profound modifications to be sure, of the more ancient Niagaran fauna, which had occupied the same province at an earlier period. It is altogether probable that the Corniferous fauna was in large part truly an evolution product from the Niagaran, after that fauna had withdrawn from the interior and had become isolated in some province upon the border of the continent after the close of Silurian time.

In its geographic distribution the Corniferous fauna is practically limited to the Appalachian basin in all directions except to the north. The fauna is not known to occur to the east or south of the Appalachian land, which formed the barrier to the interior basin in those directions. Neither does it extend beyond the Wisconsin-Ozark barrier, which was the western boundary of the basin. To the north, however, the fauna occurs beyond the interior province, in the Hudson's Bay basin, which then, as now, was probably connected with the Arctic basin. In a "provisional list of fossils collected between the Long Portage of the Missinaibi branch of the Moose River and Moose Factory," Whiteaves[1] has recorded a list of thirty-three species. Among these are some thirteen corals belonging to genera and species which occur commonly in the Corniferous fauna of the Appala-

---

[1] *Geol. Surv. Canada*, "Rept. of Prog. 1877-8," p. 50.

chian province, and the associated species are such as to leave no doubt in regard to the entire fauna being a representative of the Corniferous fauna of the interior basin. In another place, from the same general region, Whiteaves[1] has recorded a fauna of ten species with the following remark:

> The fossils described or mentioned above show clearly that the rocks from which they were collected are of Devonian age, also that they belong to the horizon of the Corniferous limestone.

Of these ten species, six are corals, and one, *Macropetalichthys sullivanti*, is one of the most characteristic of the fishes found in the fauna in Ohio.

The Devonian faunas of the Arctic region are practically unknown, but two genera of the Corniferous fishes of the Appalachian province, *Acanthaspis* and *Onychodus*, are known to occur in the Devonian strata of Spitzbergen.[2] Nine of the total thirteen genera are also known from the middle Devonian of the Eifel region of Germany, and three from Bohemia. Many of the invertebrate members of the Corniferous fauna also have representatives in the middle Devonian faunas of central Europe.

From the geographic distribution of the Corniferous fauna, it may be suggested that the province in which it originated was situated somewhere in the Arctic regions, and that representatives of it migrated southward both into North America and into Europe. It has been suggested elsewhere[3] that the typical Niagaran fauna, as it exists in the Appalachian province, came into the region from the north through the junction of the Hudson's Bay basin with the interior basin, and, when it withdrew from the interior, it doubtless followed the same route by which it had entered. During the period of disturbance or readjustment between Silurian and Devonian time it is not improbable that the restricted Niagaran fauna became isolated in the Arctic region, and that from the elements of this fauna, during a long period of time, the Corniferous fauna evolved. This hypothesis,

---

[1] *Geol. Surv. Canada*, "Rept. of Prog., 1875–76," pp. 316–20.

[2] Private communication from Dr. C. R. Eastman.

[3] JOUR. GEOL., Vol. VII, p. 692.

however, does not account for the remarkable vertebrate element in the Corniferous fauna, as there was nothing in the Niagaran fauna which could have given origin to it. It is possible that the fishes of the Corniferous fauna originated from some fresh water fish fauna which was forced to adapt itself to marine conditions with the encroachment of the Corniferous sea upon the land. During the Corniferous epoch, in the Appalachian province, communication was again established over the same route by which the Niagaran faunas had found their way into the interior basin.

The relationship of the Corniferous to the Oriskany fauna at Cayuga, Ontario, also bears upon the point of entrance of the Corniferous fauna into the Appalachian basin. This locality is approximately the most northwestern extension of the typical Oriskany fauna, and is where it approaches most closely to the hypothetical point of entrance of the younger fauna. Here the two faunas become intimately commingled, a large number of the typical corals, besides other Corniferous types, being associated with such characteristic Oriskany species as *Spirifer arenosus*, *Hipparionyx proximus*, *Anoplotheca flabellites*, etc., as if it were here that the Corniferous fauna first came in contact with the Oriskany. It is because of this relationship that the species found in the Oriskany fauna only at Cayuga, and not further east, have been eliminated from the preceding list of Oriskany species given for comparison with the Corniferous fauna, it being assumed that they were not members of the true Oriskany fauna, but were representatives of the immigrating Corniferous fauna.

In the Devonian faunas of the Eureka District of Nevada,[1] many representatives of the Corniferous fauna of the Appalachian province have been recognized. Among these are several of the characteristic corals, although but few of the fish remains have been detected. In the Kanab Cañon of northern Arizona,[2] however, which is situated in the same Great Basin province, a strongly marked horizon of Devonian fishes has been

[1] WALCOTT, *Monog. U. S. Geol. Surv.*, Vol. VIII.

[2] *Monog. U. S. Geol. Surv.*, Vol. VIII, p. 7.

recorded. That the Great Basin province had communication with the original province in which the Corniferous fauna had its development, is quite certain, although there was probably no direct communication between the Great Basin and the Appalachian provinces, notwithstanding the identity of many species in the two regions.

There are also present in the Devonian faunas of the Great Basin province many species which are identical with Hamilton species in the Appalachian province, but they do not occur at any definite horizon in the Devonian of the region, but are distributed from the bottom to the top. Among these species, however, in no case has there been recorded any of the typically southern hemisphere forms which are so characteristic of the Appalachian Hamilton fauna, all of the Hamilton species in the Great Basin Devonian being such as doubtless had their origin from members of the Corniferous fauna, and it is probable that the Great Basin province never had communication with the Southern Hemisphere province which sent its immigrants into the Appalachian province during Hamilton time.

In the Devonian faunas of the Iowan or Northwestern province there is an element so strongly suggestive of the Corniferous that Dr. Barris[1] at one time went so far as to refer some of the Devonian beds of eastern Iowa to the Corniferous. That there is a Corniferous element in these faunas, exhibiting itself especially among the corals, cannot be denied ; but associated with this element, either directly or in accompanying strata, there is another element so entirely foreign to the Corniferous that the reference of any of the Iowan Devonian strata to the Corniferous cannot be entertained. The Eurasian origin of the characteristic element of the Iowan Devonian faunas and of the upper Devonian faunas of the Appalachian province has been established, and the pathway of communication from the Eurasian to the Appalachian province was through the Mackenzie basin of the northwest, which doubtless communicated with the Arctic province where originated the Corniferous fauna. It is

---

[1] *Proc. Davenport Acad. Nat. Sci.*, Vol. II, p. 261.

not strange, then, that some elements of the Corniferous fauna became mingled with this Eurasian fauna as it migrated toward the Appalachian province. This will account for the presence of a considerable number of species which are common to both the Appalachian Hamilton and the Iowan faunas. In all cases these species are forms such as *Cyrtina hamiltonensis*, *Pholidostrophia iowensis*, *Stropheodonta demissa*, etc., which either were present in the Corniferous fauna, or had their nearest allies in that fauna. In the case of the genus *Schizophoria* we have an example of a form which was well represented in the Cornifersus fauna by the species *S. propinqua*, but which became almost extinct in the Appalachian Hamilton fauna, to be reintroduced into the Appalachian province with the opening of Upper Devonian time by such species as *S. tulliensis* and *S. striatula*.

In the Great Basin province the two Devonian faunas having a definite stratigraphic sequence are first, the fauna with Corniferous affinities in the lower strata of the section, and, second, the Eurasian fauna allied to that of the Iowan and the upper Devonian faunas of the Appalachian provinces. Both of these faunas doubtless entered the region by the same route from a nearly north direction.

The value of any hypothesis proposed for the explanation of natural phenomena must rest upon the number and variety of observed facts for which it offers an explanation. The hypothesis that the Corniferous fauna had its origin in an Arctic province seems to afford an explanation for many facts relative to the geographic distribution and the faunal relationships of some of our Devonian faunas in America, and may thus stand as a working hypothesis which future observations will either strengthen or overthrow.

STUART WELLER.

THE UNIVERSITY OF CHICAGO.

EDITORIAL.

WITH this number of the JOURNAL there appears the first section of a series of articles of more than ordinary moment to petrographers. The initial article by Mr. Cross is the first installment of a historical review of the various systems of classification of igneous rocks developed in the nineteenth century. This essay is the result of a conscientious and critical study of petrographical classifications in their historical aspects, and presents an admirable synopsis of this complicated subject. Quite by itself it will certainly be found of great service to students of petrography in furnishing them with a perspective view of the growth of our present unsatisfactory system. The second part will appear in the next number of the JOURNAL.

Aside from its inherent interest, a special value lies in its introductory relations to a still more important essay on "A Classification and Nomenclature of Igneous Rocks," which will occupy the whole of the sixth number of the JOURNAL. The system proposed in this article is the outcome of some years of collaboration by Messrs. Cross, Iddings, Pirsson, and Washington, and represents the united judgment of these experienced petrographers. The system is radically different from those in present use, and the nomenclature is new. The self-abnegation shown by these four petrographers in merging their individual views and preferences in a common effort to produce a working system in advance of the present unsatisfactory one is a pleasant token of the healthful relations of petrographic workers.

T. C. C.

Reviews.

Genesis of Ore Deposits. Published by the American Institute of Mining Engineers, New York, 1901. 8vo., 806 pages, illustrated. Price, $6.00.

The compilation and republication of the papers recently presented to the Institute, and bearing on the genesis of ore deposits, has resulted in a notable volume. Beginning with the famous treatise presented by Professor Franz Pošepnỳ at the Chicago meeting of 1893, and including the discussions at that and the succeeding meetings at Virginia Beach, Bridgeport, and in Florida, the volume is continued by an important group of papers read at the Washington meeting in 1900, with the succeeding discussions. It is concluded by a bibliography of additional papers on the same subject, read before the Institute, of 188 titles. The showing is a most remarkable one, and the volume includes a statement of almost every advance in knowledge of the principles of ore genesis made in America within the last ten years; not that in every case it is the fullest statement of the authors' views made here, but practically every advance made within that period in the study of American ore deposits, aside from regional work, is represented by an author's statement. The most notable exception is the comprehensive and valuable paper by Mr. Penrose on the "Superficial Alteration of Ore Deposits," contributed to this JOURNAL in 1894.[1] In all, twenty-two contributors are listed in the table of contents of the volume. There are eleven general papers and twenty-one criticisms or discussions. The full list of authors is as follows: R. W. Raymond, Franz Pošepnỳ, W. P. Blake, Arthur Winslow, T. A. Rickard, Horace Winchell, John A. Church, S. F. Emmons, G. F. Becker, F. M. F. Cazin, Joseph LeConte, C. R. Van Hise, Walter Harvey Weed, Waldemar Lindgren, R. Beck, L. de Launay, Arthur L. Collins, H. Foster Bain, Charles R. Keyes, Frank D. Adams, J. H. L. Vogt, and J. F. Kemp.

Although the whole volume has been edited, much of it translated, and most of it obtained by the personal solicitation of the secretary of

---

[1] JOUR. GEOL., Vol. II, pp. 288–317.

the Institute, Mr. R. W. Raymond, it is characteristic of his modesty that his name appears in the volume only among those of the contributors. Nevertheless, in preparing the volume, Mr. Raymond has performed a service which his fellow-workers will more and more appreciate as the work comes to assume its rightful place; that of the standard statement of modern views on ore deposits.

Covering, as it does, practically a decade of discussion, and being made up, as it is, of the statements of so many workers, it is in a peculiar degree a summary of present belief with just enough of discarded theory to give a proper perspective. The period from 1893 to 1901 has been particularly fruitful in the study of ore deposits, and, as is so often true, much of the discussion which has led to the clearing up of certain phases at least of the problem of the genesis of ores, came from the clear and unequivocal statement of an extremist; one, furthermore, whose ideas were radically opposed to those most generally current at the time. Up to 1893 American scientific opinion was strongly committed to the doctrine of lateral secretion; not, however, exactly in the sense proposed by Sandberger in his famous treatise[1] defining that doctrine. A characteristic expression of the broader American view is that of Emmons in his report on the Leadville district.[2] According to this view, ore deposits in general represent concentrations made by underground waters, the material being derived from the leaching of the country rock, not necessarily of the immediate vicinity. The waters were believed to be meteoric in origin, and more or less closely connected with the ordinary surface circulation.

In 1893 Professor Pošepnỳ, with charming spirit, and fortifying his argument with many illustrations drawn from notes accumulated during a long and intimate study of ore deposits, combated this view most vigorously. Beginning with a clear and accurate analysis of the subterranean water circulation, he discriminated sharply a vadose or shallow circulation from a deep circulation, basing the distinction mainly upon the chemical constitution and effects of the two waters; a difference already clearly recognized and made use of in America by both Le Conte and Chamberlain, but not generally recognized as fully as it deserved. As characteristic of the difference between the waters of the two circulations, and most significant for purposes of the discussion, it was pointed out that the water of the vadose circulation in

[1] *Untersuchungen uber Erzgange*, Weisbaden, 1885.

[2] *Monograph XII*, *U. S. Geol. Surv.*, Washington, 1886.

only the rarest instances deposits sulphides, while these salts are the characteristic deposit of waters of deep circulation. Since the bulk of the ore deposits, neglecting certain clearly recognized but minor classes over which there is no dispute, are made up of sulphides or their alterative products, it was held that the ores must have been made by the deeper circulation, and that the waters making the deposits must have been "ascending." In the earlier portion of the paper there are statements making clear the relations between the two circulations, and showing that one is but the counterpart of the other (pp. 27–28); there are later numerous statements which throw the matter into confusion (pp. 39, 56, etc.) While there is not such a clear statement as would be desirable, we are led to infer that the waters of the deep circulation are in some mysterious way cut off from and different from those of the shallow circulation, and that they are connected with a certain deep region, or barysphere, "the peculiar home of the heavy metals." The existence of this region is inferred from the usual calculations based upon the difference in density between the earth as a whole and the rocks of the surface of the earth. The very existence of a barysphere, in the sense of a central region of the earth heavier by reason of a greater abundance of the heavy materials, is to be questioned,[1] however, on many grounds.

In the discussion of Pošepný's paper, which followed its presentation, some of his criteria were discredited, and Rickard struck the keynote when he stated that neither ascending nor descending was the proper term to apply to the ore-depositing waters, but that circulating was the true descriptive term. This was characterized by Pošepný as "a step backward." The most trenchant and significant criticism, however, was that of Professor LeConte, who showed the great improbability, if not actual impossibility, of any surface waters penetrating to the depth of the assumed barysphere, and who then pertinently inquired, If the waters which deposited the ores were not meteoric in origin, where did they come from? Were they constituent waters originally occluded in the primal magma? This is on its face highly improbable, particularly in view of the fact, so clearly recognized by Pošepný, that any ore deposit necessarily indicates the passage of a considerable body of water through the space now occupied by the ore.

At the close of the discussion, then, we are left with the conclusion that ore deposits, in general, are formed by the circulation of under-

---

[1] See particularly Arrhenius, as cited by VOGT, *op. cit.*, p. 638.

ground waters, the material being gathered from the rocks through which the waters pass, and that the sulphide ores are formed principally by the returning or ascending portion of the circulation. This conception, amplified and defended with many arguments and examples, is the keynote of the paper by Van Hise, which forms the natural beginning of the second part of the volume. Since Professor Van Hise's views have already been presented in this JOURNAL,[1] no review of them need be made here.

The criticism of Van Hise's views has been principally along two lines : (1) Is the conception presented by him of a universal underground circulation moving in obedience to gravitative stress a true one ? and (2) is such a circulation competent to account for ore bodies such as actually occur without calling in the very frequent and active agency of eruptive forces ? It appears to the reviewer that, to a considerable extent, the criticism is based upon an erroneous understanding of the hypothesis, and to a minor extent upon a misconception of facts. A universal underground water circulation does not necessarily mean universally saturated rocks. The great difference in permeability of rocks precludes their having an equal water content. If a larger emphasis be placed upon the influence of impervious strata, the supposed difficulties largely disappear. Professor Kemp cites a number of deep workings which are dry (696–701), and states a belief that the amount of water which penetrates to depths is probably comparatively small. Such citations, however, are only significant when the full details of each case are fully understood. For example, the Congress mine in Arizona has been cited, by another, as an instance of a very deep mine which is notoriously dry. The illustration loses its force, however, when it is remembered (1) that the region is one in which the water level is everywhere far below the *present* surface, and (2) that the Congress vein is a very shallow dipping one. "Very deep," as measured along the vein, is, accordingly, not "very deep" as measured vertically. Again the Vindicator, Hull City, and neighboring mines at Cripple Creek go down a thousand feet or more in perfectly dry ground, but they start only a short distance laterally, but at a considerable altitude above Wilson Creek. Furthermore, anyone visiting the workings will at once see the clearest evidence of the former action of underground waters ; in this case evidently oxidizing surface waters.

---

[1] JOUR. GEOL., Vol. VIII, pp. 730–70, 1900.

Perhaps a still clearer example is that of certain mine workings in the Newhouse tunnel at Idaho Springs, Colo. This tunnel is driven north from South Clear Creek a distance of more than two miles under Seaton Mountain and toward Central City. It attains a maximum vertical depth of 1,710 feet, or approximately 2,200 feet, as measured along the dip of the veins. The slopes of the Gem workings in this tunnel are so dusty that there is difficulty in obtaining men who will work in them permanently, yet the month that the tunnel cut through this vein the men had to wear a full outfit of rubber boots, slickers, and rubber hats, and the tunnel drift still yields a notable flow of water. When the Addudle vein was cut, approximately a year ago, there was another small flood, and to this day the vein is raining into the tunnel steadily. In this instance, despite the steady downpour, the old surface workings are as full of water as ever. That the waters encountered in the tunnel belong to the ordinary underground circulation and come from the surface is proven by their oxidizing character. In general, along the tunnel the main flow of water comes from the veins, but nevertheless there seems to be a minor but steady seepage through the country rock. A rough measure of this seepage is given by certain work in the Franklin mine. The first of February, this year, the sixth level yielded a flow of approximately 7,000 gallons per day. Since then the drifts have been extended 250 feet, adding approximately 5,000 square feet of surface for seepage, and not intersecting any important cross veins or fractures, and yet the flow has slightly more than doubled. Since there has been no corresponding increase in the amount of water elsewhere, it seems clear that the larger flow is due to the greater surface. The fifth level of this mine, by the way, since pumping began on the sixth, is dry, but on the first level there is a drift not connected with the lower workings, full of water. Clearly in this case the different portions of the vein matter vary greatly as regards permeability. Cross-cut tunnels generally yield little water except as they intersect fractures; but I know of none which does not have a water box along the bottom and a steady stream of water flowing through it; that is, while the flow is practically confined to the fractures, the rock, measured in bulk, none the less contains water in quantity. The evidence, then, points to a widespread underground circulation, though there are admittedly dry or impervious beds, and admittedly measurable flows are nearly always confined to visible cavities.

It is furthermore pertinent to inquire, with Le Conte, if it be held that the waters from which the ores were deposited do not originally come from the surface, and if the "ascending currents" are not fed by equivalent "descending currents," what is the nature of this water, and whence its source? It is admitted by practically all students of the problem that the deposits in question are the work of waters of some sort.

The question whether the waters derive their motive force from gravitative stress is one which must be answered in each case with an eye to the facts of the particular case. Admittedly the friction between the moving fluid and the walls of the conduit decreases the pressure, and, supposedly at least, the friction might become so great as to wholly stop the flow. In the case of water moving through supercapillary tubes this cannot on the average be true, so long as the distance measured is vertical, and the tubes are approximately regular, since the pressure increases *pari passu* with the friction. The flow is further increased presumably by decreasing viscosity resulting from heat. It may be stated at once that probably, as it seems to the reviewer, the major flow concerned in the formation of ore deposits is that through supercapillary tubes. In the matter of flow through capillary tubes, there is some doubt, since the laws of such flow under high pressure seem not well understood; but if Poisenille's law be applicable, the result must be the same, since the flow is proportional to the pressure itself, which increases directly with the depth. Wherever the underground waters are in motion it is difficult to conceive of their not flowing in obedience to gravitative forces; except in very especial and particular instances where the little understood gaseous pressure may become operative.

In regard to the second question, whether ores are not more directly dependent upon the phenomena of vulcanism than would be inferred from a general reading of Van Hise's paper, it is but fair to state that he evidently recognizes these forces as important, though he devoted more space to less generally recognized phases of the problem. It has been tacitly assumed by all parties to the discussion that heated waters under pressure have been the main agents in collecting the material which makes up the ore bodies. The underground waters may become heated by (1) contact with volcanic rocks recently injected into the outer crust of the earth, (2) by contact with rocks heated by dynamic action, (3) by penetrating to a sufficient depth to absorb heat from the interior of the earth, and (4) by chemical activity between the water and the material in the rocks. The waters may come under pressure (1) by increasing gravitative stress due to increased head as they gain in depth, (2) by expansion in confined space as a result of heat, and (3) by gaseous pressure, itself perhaps the result of chemical activity. With all these sources of heat and pressure available, the important point is to discover which ones have probably been operative to the largest extent. To the reviewer it seems clear that, as pointed out by Vogt and Kemp, the intrusion into the outer crust of the earth of molten rock from below has probably been the largest single factor in heating the underground waters. The distribution of the mineral districts in connection with the distribution of these eruptives and of hot springs affords a powerful argument for this conclusion. The close association of ore deposits, eruptive rocks, and hot springs has been so often pointed out as to need no further citation. The exceptions, such as the lead and zinc deposits of the Mississippi valley, have uniformly been found on careful study to differ in genesis from the more common type of sulphide ore deposits exemplified in the usual occurrence of the precious metals in the Rocky Mountain region.

A body of molten rock, forced up into the cooler mass above, must produce a profound disturbance of the ordinary underground circulation. Its quickening and vivifying influence is bound to be stupendous, and the marks of the intrusion are apt to be permanent. The underground waters of such a district will be warm for centuries after the magma itself has consolidated and become fixed in form and place. An instructive instance, and one believed not to be exceptional, is that of Idaho Springs, in Colorado. There are here hot springs which presumably are the last surviving mark of volcanic activity in the district. The youngest rocks present are certain andesitic dikes, whose age is approximately fixed by andesitic débris found in Tertiary beds near the mouth of Clear Creek Cañon, at Golden. Since the intrusion of these dikes the whole country has been profoundly sculptured, and the interval must certainly have been a very long one, yet the underground waters, as shown by the hot springs, still penetrate to some portion of the uncooled rock. The ore bodies of the district are closely related to these andesites; indeed, the veins usually occur along the contact of the andesite and the Archean country rock, and in places are merely mineralized portions of the andesite itself. So far as is known there are no considerable ore bodies in the surrounding Archean not connected in some way with the andesite. Furthermore, no considerable mining district in Boulder, Gilpin, or Clear Creek counties occurs except where these andesites are present, even though the same Archean country rock is everywhere present, and in all probability was subjected to the action of ordinary underground waters for many times as long before the intrusion as after. Under these conditions the connection of the ore bodies with the disturbance of the underground circulation by the intrusion of the eruptive rock can hardly be doubted. The possibility of their being formed by normal underground circulation counts for little as against the fact that, in the long time from Archean to Tertiary, they were not formed, and in the relatively short time since, under the new conditions, they were.

It is equally clear, however, from a study of the ore bodies, that the process of their formation occupied a long period, as measured by ordinary standards. The ores are associated with the most altered portions of the eruptives. They occupy often fissures in the latter which could only have been formed after the rock had consolidated and cooled sufficiently to be amenable to the ordinary stresses existing in the rocks of the surface of the earth. The halogen elements are conspicuously absent, and there is no known reason for inferring that pneumatolitic action was prominent when the ore bodies were formed. It may be added that the veins are typical "fissure veins" carrying sulphide ores; the very class of deposits principally under discussion.

Among the many phases of ore bodies, aside from the problem of their primary genesis, which are discussed in the volume under review, there are none more important than the secondary enrichment of the sulphides, and the metasomatic processes in fissure veins. The first is discussed in separate papers of Emmons and Weed and in portions of papers by Van Hise, Rickard, and de Launay. The second is treated in considerable detail by Lindgren.

Starting from a disposition to question Pošepný's dictum that sulphides were not formed by the waters of the vadose circulation, Emmons, Weed, and Van Hise have independently worked out the process by which the sulphide ore bodies at and near the water level become enriched by material carried down from the oxidized ores above. The process depends principally upon the relative affinity of the various metals concerned for oxygen and sulphur, by which, for example, iron sulphide comes to act as a precipitant for zinc and lead when the latter are present as a sulphate. The process is well founded on known principles, and the phenomena accounted for are among the most common and heretofore most puzzling encountered in mining. The solving of this difficulty is likely to be of the highest practical utility.

Mr. Lindgren's paper on metasomatic processes gives sharp definition to many heretofore hazy phenomena and will be of considerable utility both in the development of theory and practice.

In general, the volume is notable in that for the first time the results of recent investigations in physical chemistry are applied to the solution of the problems of ore genesis. The results attained are most promising, and open up enticing vistas of what may be expected from further investigations along these lines. For example, the question may be asked whether, in seeking an explanation of the chemical problems involved, we have not relied too exclusively upon the influences of heat and pressure. If we keep in mind the very large place in the field of research which the diminutive ion now holds, and the close relations obtaining between ions and electric forces, one may well question whether here is not a fruitful field for investigation. The startling results already obtained in physiological investigations by studying the operation and effects of the electro-motive force hint at perhaps equally important results awaiting the investigator in other fields.

H. FOSTER BAIN.

IDAHO SPRINGS, COLO.

SUMMARIES OF THE LITERATURE OF STRUCTURAL MATERIALS. I.

EDWIN C. ECKEL.

UNDER this heading the writer purposes to summarize at intervals the literature relating to the economic geology of building stone, road materials, cements, lime, gypsum, clays, etc. Except when the word "comment" expressly appears, the matter presented will be simply a summary of the statements and opinions appearing in the paper under discussion. The writer will endeavor to indicate briefly the scope of each paper, following this by a résumé of the *original* matter contained in it.

BABCOCK, E. J. *Clays of Economic Value* (*in North Dakota*). First Report North Dakota Geol. Surv. Pp. 27–55, 3 plates, 1901.

The clays of North Dakota are derived from the Pleistocene, the Laramie, and the Fort Pierre division of the Cretaceous. The Pleistocene clays include the yellow and blue brick clays of the Red River valley; the stoneware clays and fire clays of Dickinson and the clays of Minot and Plenty Mine are probably Laramie; while the shales about Park River and the Pembria Mountains are in the Fort Pierre. Analyses of European and New Jersey clays are quoted, with notes on the qualities requisite for the various clay products. Detailed descriptions of North Dakota clays, with analyses and tests, are then given.

Clays suitable for the manufacture of common brick are widely distributed, and plants are in operation at Fargo, Minot, Bismarck, Burlington, Grand Forks, Drayton, and many other places.

Near Minot, at Bismarck, in Mercer county, and at the Lehigh mine, clays occur which are adapted to use in the manufacture of pipe, tile, and terra cotta. None of these are at present used.

Fire clays and stoneware clays are found at only one locality in the state, near Dickinson, Stark county. These clays are in the Laramie, and outcrop in quantity on the bluffs near the town. A large fire-brick plant is now in operation at this point, the product being of very high grade.

BLATCHLEY, W. S. *Oolite and Oolitic Stone for Portland Cement Manufacture.* Twenty-fifth Ann. Rept. Indiana Dept. Geol. and Natural Resources. Pp. 322–330, Pl. 13, 1901.

Pure limestones occur in Crawford, Harrison, Washington, Lawrence, Monroe, and Owen counties, Indiana. Analyses show that the lime carbonate usually exceeds 95 per cent., with rarely more than 1 per cent. magnesium carbonate. Clays and shales of suitable quality are, in many places, near the limestones. Several companies have been organized to utilize these limestones and clays in the manufacture of Portland cement.

BUCKLEY, E. R. *The Clays and Clay Industries of Wisconsin.* Bulletin 7, Part I, Wisconsin Geol. and Nat. Hist. Surv. 8vo, pp. 304, Pl. 55, 1901.

Chapters on the origin, composition, classification, and properties of clays precede detailed descriptions of the clay deposits and industries of Wisconsin.

Buckley discusses previous classifications and offers a scheme based primarily on origin and secondarily on position :

I. Residual, derived from
  a. Granitic or gneissoid rocks.
  b. Basic igneous rocks.
  c. Limestone or dolomite.
  d. Slate or shale.
  e. Sandstone.
II. Transported, by
  a. Gravity assisted by water.
    Deposits near the heads and along the slopes of ravines.
  b. Ice.
    Deposits resulting mainly from the melting of the ice of the Glacial Epoch.
  c. Water.
    1. Marine.
    2. Lacustrine.
    3. Alluvial.
  d. Wind.
    Loess.

The residual clays of Wisconsin are not of much economic importance except in the driftless area, where clays resulting from the decomposition of limestone are extensively worked for brick manufacture. Glacial clays are important in the northern part of Wisconsin, and include some of the best and some of the poorest clays of the state. In the clays of marine origin are included the shales of the Cincinnati and Potsdam periods. The Cincinnati series has a thickness of 165 to 240 feet, and consists of interbedded limestone and shale. The shale varies greatly in composition and in hardness. Near the base of the Potsdam in the central part of the state occur interbedded layers of very soft plastic blue to brownish clay and coarse sandstone.

The lacustrine clays are perhaps the most extensive in the state. They are partly of interglacial, partly of immediately postglacial age; and in some places the clays and interbedded tills have a depth of one hundred feet or more. This thickness is not composed entirely of water-sorted material, but includes a considerable thickness of bowlder clay with pebbles of igneous rock and limestone.

River deposits of varying age are common, and furnish much clay for brick manufacture. In composition these clays vary with the rocks of the drainage basin in which they were formed, the clays of the west central part of the state being the least calcareous.

In Dunn and St. Croix counties extensive deposits of pure white kaolin occur, probably derived from the igneous rocks to the northeast and deposited by water prior to the first glacial epoch. These clays are of the highest grade, but are now shipped exclusively for use in the manufacture of paper.

Wind-borne clays are of doubtful occurrence, and in the few cases where æolian transportation seems probable, the resulting deposits are of no economic importance.

KÜMMEL, H. B. *Report on the Portland Cement Industry* (in New Jersey). Ann. Rep. N. J. State Geologist for 1900. Pp. 9–101, Figs. 1–33, Pls. 1–2, 1901.

The first chapter of this report is a discussion of the composition and materials of Portland cement in general; the second is devoted to the geologic relations of the Cambro-Ordovician rocks of Warren and Sussex counties; and the third contains detailed descriptions of the areas of Trenton limestone ("cement rock"), with notes on other limestones and the white marl deposits of New Jersey.

Overlying the relatively thin Hardiston (Lower Cambrian) quartzite of the Kittatinny valley is the great magnesian limestone series which has been described as the Kittatinny limestone by Weller and Kümmel, and as the Wallkill limestone by Wolff and Brooks. The Kittatinny limestone is usually blue, though often varying to gray drab, or even black. It is fine, even-grained, often minutely-crystalline. It usually contains 15 to 20 per cent. of magnesium carbonate, and is therefore not available for use in the manufacture of Portland cement.

Resting on the eroded surface of the Kittatinny limestone, and often commencing with a basal limestone conglomerate, is the dark blue, fossiliferous Lower Trenton limestone. Unlike the Kittatinny, it is never magnesian, but many of its beds are shaly. These shaly beds, carrying 65 to 75 per cent. lime carbonate (the remainder being silica and alumina), are the "cement rocks" which form the basis of the great Portland cement industry of New Jersey and Pennsylvania. The lime carbonate needed to carry them up to the proper composition is obtained from other beds (of purer limestone) occurring in the Trenton.

Detailed descriptions, with maps and analyses, of the exposures of Trenton limestone are given in the final chapter of the report. Certain limestones of higher horizons are also discussed in this connection, as are the deposits of white shell marls.

LEE, H. A. *Mineral Resources of Colorado — Larimer County Gypsum.* Stone, Vol. XXI, pp. 35–37, 1900.

Larimer county is the largest gypsum producer in Colorado. The gypsum deposits are associated with rocks of Jura-Cretaceous age, and occur in a basin between rocky ridges. The main quarry is operating on a knoll showing a face of gypsum 250 feet long, and 28 feet high in the middle, thinning to 7 feet at the edges. The gypsum is quite compact and gray in color. The amount of stripping does not exceed 18 inches. The material is blasted out, auger holes being bored to receive the charge of explosive.

The mill of the Consolidated Plaster Co. has a capacity of 40 tons per day of ten hours. It is built on a side hill and the gypsum is received from wagons at the top of the mill, fed through coarse and fine crushers, and then over screens to buhrstone mills. From these it is carried to five-ton kettles, two and a half hours being consumed in charging, "boiling," and discharging. No details are given concerning the retarders used.

McCALLIE, S. W. *Preliminary Report on the Roads and Road-Building Material of Georgia.* Bulletin 8, Georgia Geol. Surv., 8vo, pp. 264, Pls. 1–27, Figs. 1–28, geologic map, 1901.

The chapters of this bulletin fall naturally into three groups, treating respectively the subjects of road construction in general; the topography and geology of Georgia in relation to road construction and road building materials; and the methods of road making in the various counties of the state. The first of these groups includes chapters on the history of road construction; the value of good roads; the theory of road making, as regards locations, grades, and surfaces; the maintenance and repair of roads; the considerations governing the selection of road materials; and the tools and machines used in highway construction. These chapters furnish an excellent summary of the general subject of road making.

In the second group fall chapters on the topography of Georgia in its relation to the highways, and on the road-building materials of Georgia. A colored map shows the areas covered by the crystalline, the Palæozoic, and the Cretaceous and Tertiary rocks; and the location of the trap-dykes which occur in the crystalline area.

The Palæozoic area is divided topographically, following Hayes, into the plateau, sharp ridge and valley region. The plateaus have a level surface, but terminate in steep escarpments. Owing to the steepness of these escarpments, it is difficult to carry a road by easy grades from the valleys to a plateau, but when the elevated areas are reached the cost of construction is slight. The plateaus also affect road work by acting as barriers to free communication between their bordering valleys. The second type of surface consists of a number of sharp, parallel ridges, trending northeast and southwest, and due to the weathering of the upturned edges of hard sandstone (which, in the plateau region, lies almost horizontal). The smaller ridges are frequently intersected by streams along whose valleys cross country roads of easy grade can be constructed, while the main roads are located in the valleys, which offer no serious obstacle to construction. The valley region consists of low, wide, comparatively level valleys, in which highway construction is simple.

The crystalline area is divided into two regions — the mountainous and the plateau. The former consists of rugged peaks separated by narrow valleys, in which flow rapid streams; and road construction and maintenance is difficult and expensive. In the plateau region highway construction is easy, as light grades can be obtained, and the cost of grading is slight owing to the deep decomposition of the underlying rocks.

The Tertiary area is a plain, sloping gently southward, and traversed by large streams. Swamps and depressions along stream valleys offer the only serious obstacles to road construction which, except in these places, is very inexpensive.

The road materials occurring in the Palæozoic area are limestones, cherts, shales, and sandstones. The limestones of the area are abundant and well suited for road-metal. They are all of the Silurian age, and occur in three different formations; the Knox dolomite, the Chickamauga limestone and the Bangor limestone. Of these the first is the most important, owing to its thickness and areal extent. It is easily quarried and crushed and furnished excellent road metal. Some beds of the Chickamauga formation supply good material, as does the Bangor limestone. The areal extent of this last formation is, however, too small to make it of importance.

The Palæozic cherts are widely distributed and extensively used. They occur in both the Knox dolomite and the Fort Payne chert. The material is well suited to roads of light traffic, but inferior to limestone where the traffic is heavy. It binds well but becomes dusty in dry weather. The chert is often located favorably for working and transportation.

The shales and sandstones of the Palæozoic are locally used, but are not satisfacrory material.

In the crystalline area the rocks available for road work are granite, gneiss, diotite, trap schist, quartzite, and marble. Of these the last three are unsatisfactory as road metals. The granites, and the less well-laminated gneisses and diorites, furnish fair macadam. The trap dikes which are widely distributed in the crystalline area› furnish excellent material. These diabases are dark gray to black, fine grained, and very tough. At present this material is little used, but will probably become important.

The Tertiary area supplies limestone, buhrstone, and gravel. The limestones consist of shell fragments, with some sand, in a calcareous matrix. They have been used extensively in southern Georgia, and are very satisfactory, cementing readily into a compact, hard surface, comparatively free from dust. Buhrstone is of little use. The gravels cemented by ferruginous clays make durable and very satisfactory roads, and are largely used.

NEVIUS, J. N. *Roofing Slate Quarries of Washington County, New York.* Nineteenth Rept. N. Y. State Geologist. Pp. 135–150, Pls. 26–37, 1901.

Gives detailed descriptions of the slate quarries and quarry methods and a discussion of the general features and condition of the industry. The working quarries are located along an approximately north and south line which extends from the Hampton variegated quarries on the north, through the North Bend, Middle Granville, Granville red and the Slateville red and green quarries, and the purple and green quarries of Salem, Shushan and Cambridge. The East Whitehall (Hatch Hill) quarries are west of the northern end of this belt.

The red and green slates are cut to size at the mills. The mottled slates, being unsalable in the natural condition, are "marbleized," an enamel being applied to give imitations of marbles, etc. The refuse from the slate mills is ground and used as a pigment.

PECK, F. B. *Preliminary Notes on the Occurrence of Serpentine and Talc at Easton, Pa.* Annals N. Y. Acad. Sci., Vol. XIII, pp. 419–430, Pl. 16, Figs. 4, 5, 1901,

Chestnut Hill is a pre-Cambrian outlier near Easton, composed of a dense hornblende gneiss with interstratified beds of carbonates. These beds, five to thirty feet thick, consist of pink calcite, gray dolomite, or a mixture of the two. Along a series of thrust faults great shearing has occurred. Hornblende (usually tremolite), phlogopite, and occasionally pyroxene, occur so abundantly in these beds as locally to replace all or most of the carbonates. The calcite dolomite beds shear to a slaty, foliated talcose mass consisting of a mixture of talc, tremolite, serpentine, or without shearing, become changed to beds of nearly pure white tremolite. The phlogopite, which is developed locally in large quantities, alters quite uniformly to serpentine and constitutes the chief source of that material in the eastern quarries. One particularly attractive phase of the material quarried consists of numerous rose-colored dolomite crystals scattered through a mass of serpentine.

RIES, HEINRICH. *The Origin of Kaolin.* Trans. Amer. Ceramic Soc., Vol. II, 1900.

The author defines the kaolins as "those clays which are residual in their nature, and which burn to a sufficiently white color to be used in the manufacture of white earthenware." Thus restricted, two different modes of origin of kaolins are discussed. In most cases kaolin has been derived from the decomposition of a highly feldspathic rock, through the action of surface agencies. Von Buch, Daubree, and Collins have, however, pointed out that acid vapors (particularly that of hydrofluoric acid) coming up from below, may decompose feldspar and yield kaolin. Deep deposits, especially if containing unaltered sulphide minerals, may have been formed in this way, and the kaolins of Cornwall, England, and Zittlitz, Bohemia, have been undoubtedly so formed. All the commercially valuable deposits of the United States, however, are of the other type, being due to ordinary weathering.

RIES, HEINRICH. *Clays and Shales of Michigan.* Geol. Surv. of Mich., Vol. VIII, Pt. I, 8vo, pp. 67, Pl. I–IV, Figs. 1–6, 1900.

That part of the work relating specifically to Michigan is preceded by chapters on the origin, properties, uses, and methods of testing clays and shales. Following these are discussions of the shales and clays of Michigan.

The important shale horizons of the state are four: the Coal-measure shales, the Michigan series, the Coldwater shales, and the St. Clair shales. The Coal-measure shales are usually interbedded with the coal seams; though known to the miners as fire-clay, they are not very refractory. At Grand Ledge they are utilized for the manufacture of tile and sewer-pipe, and at Saginaw for paving brick. The shales of the Michigan series form a belt ten to twenty miles in width surrounding the Carboniferous area in the Lower Peninsula. They are best shown at Grand Rapids, where they form a bed six to ten feet thick overlying the gypsum. They are suited for common brick manufacture, for which they are at present used. The Coldwater shales are extensive and important, being used in all the Portland cement plants of the state. For this use they have been quarried extensively at Bronson, Union City, and Coldwater. According to laboratory tests, these shales show the properties desirable in the manufacture of vitrified wares. The St. Clair shales outcrop southeast of East Jordan. They weather to a tenacious clay and burn to a good red color. At Alpena a clay shale of the Traverse (Hamilton) series is used in the manufacture of Portland cement, and tests prove it to be suitable for the manufacture of high-grade brick.

The clays of the state are all Pleistocene, and represent three types: morainic or drift clays, lake clays, and river silts. The morainic clays are invariably calcareous, while the lake clays are very frequently so. The river silts are less likely to be calcareous, but are usually gritty. Morainic clays are used in the manufacture of pottery and brick at Ionia, Lansing, and Kalamazoo. The extensive brick clay deposits near Detroit are lacustrine in origin, while at Rockland a lake clay furnishes slip. At Sebewaing, Badoxe, Croswell, and Minden City river clays are used in the manufacture of brick.

RIES, HEINRICH, AND SMITH, EUGENE. *Preliminary Report on the Clays of Alabama.* Bulletin 6, Alabama Geol. Surv., 8vo, pp. 220, 1900.

This bulletin is divided into three sections. The first and third — entitled respectively "General Discussion of Clays" and "Preliminary Report on the Physical and Chemical Properties of the Clays of Alabama" — are by Ries; the second, entitled "Geological Relations of the Clays of Alabama," is by Smith.

The first section discusses the origin, mineralogy, chemical, and physical properties, methods of testing, mining, and preparation of clays.

In the second section the clays of the various geologic formations of Alabama are described. Under the head of "Archæan and Algonkian" the residual kaolins are discussed. A belt of mica schists with frequent pegmatite veins extends from Cleburne and Randolph counties through Clay and Coosa into Chilton county. In numerous cases the decay of the granite veins has given rise to kaolin deposits. All these deposits are distant from railroads, and are consequently undeveloped.

In the area underlain by the Cambrian and Silurian rocks the clay deposits are the residual clays left from the decomposition of the limestones of these formations, or concentrations of these residual clays by redeposition in ponds and other depressions, or accumulations in depressions of kaolins derived from the pegmatites above mentioned. The residual clays usually contain much silica and iron, and are largely used in the manufacture of brick. Occasionally, in the re-deposited clays, sorting has occurred during redeposition, and beds of very pure clay occur in consequence.

Thick deposits of pure white clay, suitable for stoneware and pottery, are found in the area underlain by the sub-Carboniferous in De Kalb and Calhoun counties. These are extensively mined, most of the product being shipped to Chattanooga, Tenn.

In the Carboniferous the clays underlying the coal seams have been utilized in the manufacture of pottery and firebrick at several points. Other Carboniferous shales are adapted for use in manufacturing vitrified and pressed brick and terra-cotta.

The lowermost division of the Cretaceous — the Tuscaloosa formation — carries important clay deposits. The strata composing the Tuscaloosa are prevalently yellowish and grayish sands, but subordinated to these are pink and purple sands, thinly laminated dark gray clays with leaf impressions, and great lenses of massive clays varying in quality from pure white-burning clays to dark purple and mottled clays high in iron. The Tuscaloosa occupies a belt of country extending from the northwestern corner of Alabama, where it is thirty or forty miles wide, around the border of the Palæozoic area to the Georgia state line at Columbus, where it is only a few miles in width. East of the Alabama river the proportion of clay to the rest of the strata is less than west of that river, and the clays themselves are more sandy. The purest clays are found in Fayette, Marion, Franklin, and Colbert counties. The clays above described have been long used for stoneware and pottery.

Fire clays are abundant in the lower Claiborne division of the Tertiary, in Choctaw, Clarke, and Conecuh counties. The Tertiary and post-Tertiary clays have not, however, been investigated in much detail.

Over the greater part of the coastal plain, in the river "second bottoms," yellow loams occur which are used for the manufacture of common brick. Lenses of pure plastic clays are also found in many places interstratified with Pleistocene sands.

In the third section Ries discusses the qualities requisite in clays designed for different uses, and gives detailed records of the tests and analyses of seventy-two Alabama clays.

Slosson, E. E., and Moudy, R. B. *The Laramie Cement Plaster.* Tenth Ann. Rept. Wyoming College Agri. & Mech, 1900.

The Laramie cement plaster is made from gypsum obtained a short distance south of Laramie, Wyo. The Triassic beds of the region contain much gypsum, one particular stratum of considerable thickness occurring near the base of the Trias, about two hundred feet above the Permian sandstone. The disintegrated gypsum from the outcropping edges of these beds has been washed down and redeposited in depressions in the plains. These gypsite deposits contain a considerable percentage of impurities, chiefly silica and lime carbonate. The Laramie gypsite bed has an average depth of about nine feet. The upper seven feet is pure gypsite, underlain by a "red layer" five inches thick, below which is a foot or more of gypsite resting on gravel and clay.

The Laramie cement plaster is made by the kettle process, the temperature being carried to 380–390° F. An analysis of it showed:

Ultimate.		Probable Combinations.	
SiO_2	5.50	$CaSO_4$	73.73
Al_2O_3	0.59	$CaCO_3$	7.86
CaO	37.11	CaO	2.35
MgO	1.45	$MgCO_3$	3.04
SO_3	43.37	SiO_2	5.50
CO_2	5.05	Al_2O_3	0.59
H_2O	6.93	H_2O	6.93

The dehydration is evidently not carried far enough. Experiments show that the common cactus (Opuntia platycarpia) and malva (Malvastrum coccineum), when dried and ground, form cheap and satisfactory retarders. Tests for tensile strength show that all retarders decreased the strength of the plaster.

Recent Publications

—Astronomical and Astrophysical Society of America. Third Meeting, Washington, 1901. [Reprinted from Science N. S., Vol. XV, N. 372, pp. 255–264. February 14; and No. 373, pp. 284–299, February 21, 1902.]

—Andrews, E. C. Report on the Kiandra Lead. New South Wales. Department of Mines and Agriculture. Mineral Resources No. 10. [William Applegate Gullick, Government Printer, Sydney, 1901.]

—Derby, Orville A. On the Mode of Occurrence of Topaz near Ouro Preto, Brazil. [From Amer. Jour. Sci., Vol. XI, January, 1901.]

On the Manganese Ore Deposits of the Queluz (Lafayette) District, Minas, Geraes, Brazil. [From Amer. Jour. Sci., Vol. XII, July, 1901.]

—Geological Survey Department, Summary Report of the. For the Calendar Year, 1901. [Printed by S. E. Dawson, Ottawa, 1902. Price 25 cents.]

—Hobbs, William Herbert. The Old Tungsten Mine at Trumbull, Conn. [Extract from the Twenty-second Annual Report of the United States Survey, 1900–1, Part II — Ore Deposits. Washington, 1902.]

Still Rivers of Western Connecticut. [Bull. of the Geol. Soc. of Amer. Vol. XIII, pp. 17–26, Pls. 1, 2. Rochester.]

Former Extent of the Newark System. [Bull. Geol. Soc. Amer., Vol. XIII, pp. 139–148, Rochester.]

—Hinton, C. H. The Recognition of the Fourth Dimension. [Philosophical Soc. of Washington. Bull., Vol. XIV, pp. 179–204, April, 1902.]

—Instituto Geológico de México, Boletín del. Num. 15. Las Rhyolitas de Mexico. Secunda Parte. [Offigina Tip. de la Secretaria de Fomento calle de San Andrés número 15, Mexico.]

—New York Academy of Sciences, Annals of the. Vol. XIV, Part II. [The New Era Printing Co., Lancaster, Pa.]

—Newell, Frederick Haynes. Irrigation in the United States. [Thomas Y. Crowell & Co., New York.]

—Stevenson, John J. Notes upon the Mauch Chunk of Pennsylvania. [From the American Geologist, April, 1902.]

—Upplysningar till Geologisk Öfversiktskarta öfver Sveriges Berggrund. upprättad och Utgifven af Sveriges Geologiska undersökning år, 1901. (Mit einem Résumé in Deutscher Sprache.) Ser. Ba. No. 6.

—Wolcott, Edson Ray. On the Sensitiveness of the Coherer. [Bull. of the Univ. of Wisconsin, No. 51. Science series, Vol. III, No. 1, pp. 1–20, Madison, Wis.]