WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY.

E. A. BIRGE, Director. **C. R. VAN HISE, Consulting Geologist.**

BULLETIN NO. V. EDUCATIONAL SERIES NO. 1.

THE GEOGRAPHY

OF THE

REGION ABOUT DEVIL'S LAKE

AND THE

DALLES OF THE WISCONSIN,

With Some Notes on Its Surface Geology.

BY

ROLLIN D. SALISBURY, A. M.,
Professor of Geographic Geology, University of Chicago,

AND

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Wisconsin Geological and Natural History Survey.

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PART I.

THE TOPOGRAPHY.

WITH SOME NOTES ON THE SURFACE GEOLOGY.

GEOGRAPHY AND SURFACE GEOLOGY OF THE DEVIL'S LAKE REGION.

CHAPTER I.

GENERAL GEOGRAPHIC FEATURES.

This report has to do with the physical geography of the area in south central Wisconsin, shown on the accompanying sketch map, Plate I. The region is of especial interest, both because of its striking scenery, and because it illustrates clearly many of the principles involved in the evolution of the geography of land surfaces.

Generally speaking, the region is an undulating plain, above which rise a few notable elevations, chief among which are the Baraboo quartzite ranges, marked by diagonal lines on Plates I and II. These elevations have often been described as two ranges. The South or main range lies three miles south of Baraboo, while the North or lesser range, which is far from continuous, lies just north of the city.

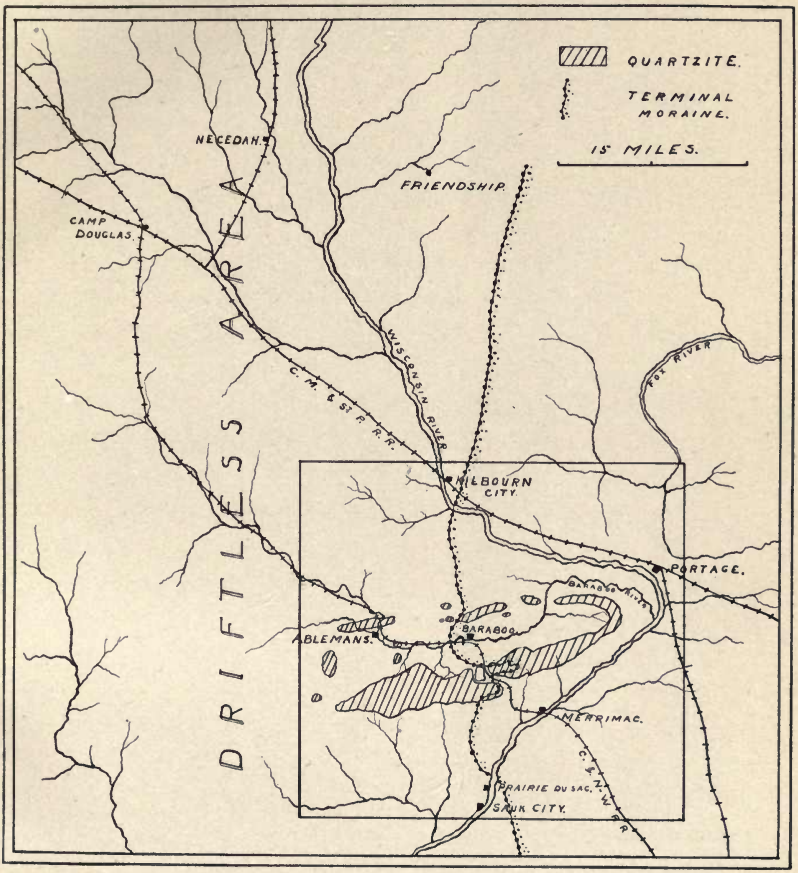
The main range has a general east-west trend, and rises with bold and sometimes precipitous slopes 500 to 800 feet above its surroundings. A deep gap three or four miles south of Baraboo (Plates II, V, p. 14, and XXXVII, p. 108) divides the main range into an eastern and a western portion, known respectively as the *East and West bluffs* or *ranges*. In the bottom of the gap lies Devil's lake (i, Plate II and Plate XXXVII), perhaps the most striking body of water of its size in the state, if not in the whole northern interior. A general notion of the topography of a small area in the immediate vicinity of the lake may be obtained from Plate XXXVII.

The highest point in the range is about four miles east of the lake, and has an elevation of more than 1,600 feet above sea level, more than 1,000 feet above Lake Michigan, and about 800 feet above the Baraboo valley at its northern base. The eastward extension of the west range (Plate XXXVII) lying south of the lake, and popularly known as the *Devil's nose,* reaches an elevation of a little more than 1,500 feet.

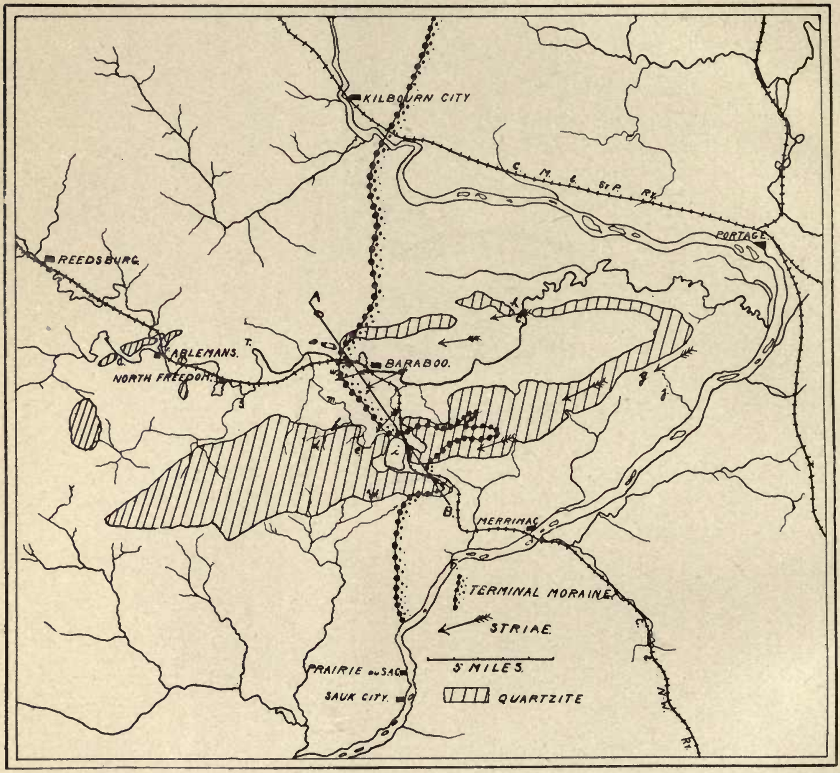
The lesser or North quartzite range (Plate II) rises 300 feet to 500 feet above its surroundings. It assumes considerable prominence at the Upper and Lower narrows of the Baraboo (b and c, Plate II, c, Plate XXXVII and Plate IV, p. 13). The North range is not only lower than the South range, but its slopes are generally less steep, and, as Plate II shows, it is also less continuous. The lesser elevation and the gentler slopes make it far less conspicuous. About three miles southwest of Portage (Plate II) the North and South ranges join, and the elevation at the point of union is about 450 feet above the Wisconsin river a few miles to the east.

The lower country above which these conspicuous ridges rise, has an average elevation of about 1,000 feet above the sea, and extends far beyond the borders of the area with which this report is concerned. The rock underlying it in the vicinity of Baraboo is chiefly sandstone, but there is much limestone farther east and south, in the area with which the Baraboo region is topographically continuous. Both the sandstone and limestone are much less resistant than the quartzite, and this difference has had much to do with the topography of the region.

The distinctness of the quartzite ridges as topographic features is indicated in Plate XXXVII by the closeness of the contour lines on their slopes. The same features are shown in Figs. 1 and 2, which represent profiles along two north-south lines passing through Baraboo and Merrimac respectively.



General map showing the location of the chief points mentioned in this report. The location of the area shown in Plate XXXVII, centering about Baraboo, is indicated.



Map of Area considered in this Report.

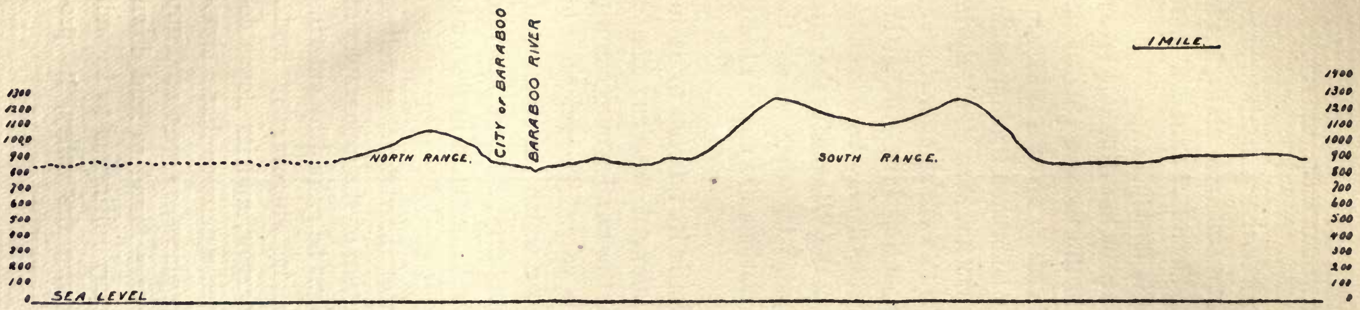


FIG. 1.—Profile along a line extending due north and south from Baraboo across the north and south ranges. The dotted continuation northward, represents the extension of the profile beyond the topographic map, Plate XXXVII.

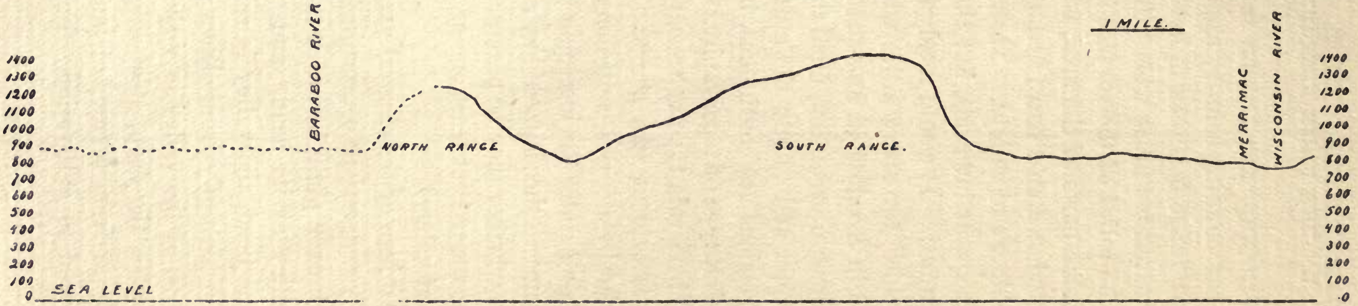


FIG. 2.—Profile north from Merrimac across the quartzite ranges. The dotted continuation northward represents the extension of the profile beyond the topographic map, Plate XXXVII.

I. THE PLAIN SURROUNDING THE QUARTZITE RIDGES.

Topography.—As seen from the top of the quartzite ridges, the surrounding country appears to be an extensive plain, but at closer range it is seen to have considerable relief although there are extensive areas where the surface is nearly flat.

The relief of the surface is of two somewhat different types. In some parts of the area, especially in the western part of the tract shown on Plate II, the surface is made up of a succession of ridges and valleys. The ridges may be broken by depressions at frequent intervals, but the valleys are nowhere similarly interrupted. It would rarely be possible to walk along a ridge or "divide" for many miles without descending into valleys; but once in a valley in any part of the area, it may be descended without interruption, until the Baraboo, the Wisconsin, the Mississippi, and finally the gulf is reached. In other words, the depressions are continuous, but the elevations are not. This is the first type of topography.

Where this type of topography prevails its relation to drainage is evident at a glance. All the larger depressions are occupied by streams continuously, while the smaller ones contain running water during some part of the year. The relations of streams to the depressions, and the wear which the streams effect, whether they be permanent or temporary, suggest that running water is at least one of the agencies concerned in the making of valleys.

An idea of the general arrangement of the valleys, as well as many suggestions concerning the evolution of the topography of the broken plain in which they lie might be gained by entering a valley at its head, and following it wherever it leads. At its head, the valley is relatively narrow, and its slopes descend promptly from either side in such a manner that a cross-section of the valley is V-shaped. In places, as west of Camp Douglas, the deep, steep-sided valleys are found to lead down and out from a tract of land so slightly rolling as to be well adapted to cultivation. Following down the valley, its progressive increase in width and depth is at once evident, and at the same time small tributary valleys come in from right and left. At no great distance from the heads of the valleys, streams are found in their bottoms.

As the valleys increase in width and depth, and as the tributaries become more numerous and wider, the topography of which the valleys are a feature, becomes more and more broken. At first the tracts between the streams are in the form of ridges, wide if parallel valleys are distant from one another, and narrow if they are near. The ridges wind with the valleys which separate them. Whatever the width of the inter-stream ridges, it is clear that they must become narrower as the valleys between them become wider, and in following down a valley a point is reached, sooner or later, where the valleys, main and tributary, are of such size and so numerous that their slopes constitute a large part of the surface. Where this is true, and where the valleys are deep, the land is of little industrial value except for timber and grazing. When, in descending a valley system, this sort of topography is reached, the roads often follow either the valleys or the ridges, however indirect and crooked they may be. Where the ridges separating the valleys in such a region have considerable length, they are sometimes spoken of as "hog backs." Still farther down the valley system, tributary valleys of the second and lower orders cross the "hog backs," cutting them into hills.

By the time this sort of topography is reached, a series of flats is found bordering the streams. These flats may occur on both sides of the stream, or on but one. The topography and the soil of these flats are such as to encourage agriculture, and the river flats or alluvial plains are among the choicest farming lands.

With increasing distance from the heads of the valleys, these river plains are expanded, and may be widened so as to occupy the greater part of the surface. The intervening elevations are there relatively few and small. Their crests, however, often rise to the same level as that of the broader inter-stream areas farther up the valleys. The relations of the valleys and the high lands separating them, is such as to suggest that there are, generally speaking, two sets of flat surfaces, the higher one representing the upland in which the valleys lie, the lower one representing the alluvial plains of the streams. The two sets of flats are at once separated and connected by slopes. At the head of a drainage system, the upland flats predominate; in the lower courses, the river plains; in an intermediate stage, the slopes are more conspicuous than either upper or lower flat.

Southwest from Devil's lake and northwest from Sauk City, in the valley of Honey creek, and again in the region southwest from Camp Douglas, the topography just described is well illustrated. In both these localities, as in all others where this type of topography prevails, the intimate relations of topography and drainage cannot fail to suggest that the streams which are today widening and deepening the valleys through which they flow, had much to do with their origin and development. This hypothesis, as applied to the region under consideration, may be tested by the study of the structure of the plain.

The second type of topography affecting the plain about the quartzite ranges is found east of a line running from Kilbourn City to a point just north of Prairie du Sac. Though in its larger features the area east of this line resembles that to the west, its minor features are essentially different. Here there are many depressions which have no outlets, and marshes, ponds, and small lakes abound. Not only this, but many of the lesser elevations stand in no definite relation to valleys. The two types of topography make it clear that they were developed in different ways.

Structure.—Examination of the country surrounding the Baraboo ridges shows that its surface is underlaid at no great depth by horizontal or nearly horizontal beds of sandstone and limestone (see Plates XVI, p. 49, XXVIII, p. 70, and Frontispiece). These beds are frequently exposed on opposite sides of a valley, and in such positions the beds of one side are found to match those on the other. This is well shown along the narrow

FIG. 1.

Ripple marks on a slab of Potsdam sandstone.

FIG. 2.

Piece of Potsdam conglomerate. The larger pebbles are about three inches in diameter.

valley of Skillett creek just above the "Pewit's nest." Here the swift stream is rapidly deepening its channel, and it is clear that a few years hence, layers of sandstone which are now continuous beneath the bed of the creek will have been cut through, and their edges will appear on opposite sides of the valley just as higher layers do now. Here the most skeptical might be convinced that the layers of rock on either side of the narrow gorge were once continuous across it, and may see, at the same time, the means by which the separation was effected. Between the slight separation, here, where the valley is narrow, and the great separation where the valleys are wide, there are all gradations. The study of progressively wider valleys, commencing with such a gorge as that referred to, leaves no room for doubt that even the wide valleys, as well as the narrow ones, were cut out of the sandstone by running water.

The same conclusion as to the origin of the valleys may be reached in another way. Either the beds of rock were formed with their present topography, or the valleys have been excavated in them since they were formed. Their mode of origin will therefore help to decide between these alternatives.

Origin of the sandstone and limestone.—The sandstone of the region, known as the *Potsdam* sandstone, consists of medium sized grains of sand, cemented together by siliceous, ferruginous, or calcareous cement. If the cement were removed, the sandstone would be reduced to sand, in all respect similar to that accumulating along the shores of seas and lakes today.

The surfaces of the separate layers of sandstone are often distinctly ripple-marked (Fig. 1, Pl. III), and the character of the markings is identical in all essential respects with the ripples which affect the surface of the sand along the shores of Devil's lake, or sandy beaches elsewhere, at the present time. These ripple marks on the surfaces of the sandstone layers must have originated while the sand was movable, and therefore before it was cemented into sandstone.

In the beds of sandstone, fossils of marine animals are found. Shells, or casts of shells of various sorts are common, as are also the tracks and burrowings of animals which had no shells. Among these latter signs of life may be mentioned the borings of worms. These borings are not now always hollow, but their fillings are often so unlike the surrounding rock, that they are still clearly marked. These worm borings, like the ripple marks, show that the sand was once loose.

The basal beds of the sandstone are often conglomeratic. The conglomeratic layers are made up of water-worn pieces of quartzite, Plate III, Fig. 2, p. 9, ranging in size from small pebbles to large bowlders. The interstices of the coarse material are filled by sand, and the whole cemented into solid rock. The conglomeratic phase of the sandstone may be seen to advantage at Parfrey's glen (*a*, Plate XXXVII, p. 108) and Dorward's glen, (*b*, same plate) on the East bluff of Devil's lake above the Cliff House, and at the Upper narrows of the Baraboo, near Ablemans. It is also visible at numerous other less accessible and less easily designated places.

From these several facts, viz.: the horizontal strata, the ripple-marks on the surfaces of the layers, the fossils, the character of the sand, and the water-worn pebbles and bowlders of the basal conglomerate, positive conclusions concerning the origin of the formation may be drawn.

The arrangement in definite layers proves that the formation is sedimentary; that is, that its materials were accumulated in water whither they had been washed from the land which then existed. The ripple-marks show that the water in which the beds of sand were deposited was shallow, for in such water only are ripple-marks made.[1] Once developed on the surface of the sand they may be preserved by burial under new deposits, just as ripple-marks on sandy shores are now being buried and preserved.

The conglomerate beds of the formation corroborate the conclusions to which the composition and structure of the sandstone point. The water-worn shapes of the pebbles and stones show

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[1] Ripple marks are often seen on the surface of wind-blown sand, but the other features of this sandstone show that this was not its mode of accumulation.

that they were accumulated in water, while their size shows that the water must have been shallow, for stones of such sizes are handled only by water of such slight depth that waves or strong currents are effective at the bottom. Furthermore, the large bowlders show that the source of supply (quartzite) must have been close at hand, and that therefore land composed of this rock must have existed not far from the places where the conglomerate is found.

The fossils likewise are the fossils of aquatic life. Not only this, but they are the fossils of animals which lived in salt water. The presence of salt water, that is, the sea, in this region when the sand of the sandstone was accumulating, makes the wide extent of the formation rational.

From the constitution and structure of the sandstone, it is therefore inferred that it accumulated in shallow sea water, and that, in the vicinity of Devil's lake, there were land masses (islands) of quartzite which furnished the pebbles and bowlders found in the conglomerate beds at the base of the formation.

This being the origin of the sandstone, it is clear that the layers which now appear on opposite sides of valleys must once have been continuous across the depressions; for the sand accumulated in shallow water is never deposited so as to leave valleys between ridges. It is deposited in beds which are continuous over considerable areas.

Within the area under consideration, limestone is much less widely distributed than sandstone. Thin beds of it alternate with layers of sandstone in the upper portion of the Potsdam formation, and more massive beds lie above the sandstone on some of the higher elevations of the plain about the quartzite ridge. This is especially true in the southern and southwestern parts of the region shown on Plate II. The limestone immediately overlying the sandstone is the *Lower Magnesian* limestone.

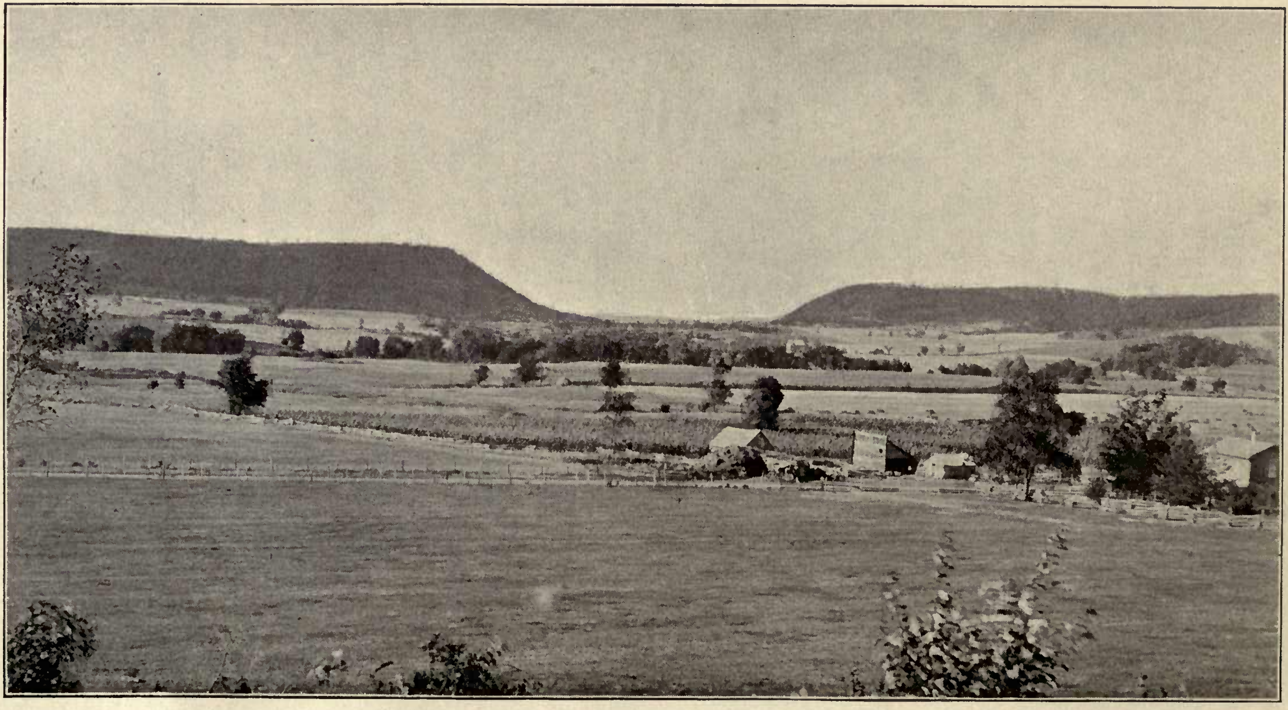
The beds of limestone, like those of the sandstone beneath, are horizontal or nearly so, and the upper formation lies conformably on the lower. The limestone does not contain water-worn pebbles, and the surfaces of its layers are rarely if ever ripple-marked; yet the arrangement of the rock in distinct layers which carry fossils of marine animals shows that the limestone, like the sandstone beneath, was laid down in the sea. The bearing of this origin of the limestone on the development of the present valleys is the same as that of the sandstone.

Origin of the topography.—The topography of the plain surrounding the quartzite ridges, especially that part lying west of Devil's lake, is then an erosion topography, developed by running water. Its chief characteristic is that every depression leads to a lower one, and that the form of the elevations, hills or ridges, is determined by the valleys. The valleys were made; the hills and ridges left. If the material carried away by the streams could be returned, the valleys would be filled to the level of the ridges which bound them. Were this done, the restored surface would be essentially flat. It is the sculpturing of such a plain, chiefly by running water, which has given rise to the present topography.

In the development of this topography the more resistant limestone has served as a capping, tending to preserve the hills and ridges. Thus many of the hills, especially in the southwest portion of the area shown in Plate II, are found to have caps of the Lower Magnesian formation. Such hills usually have flat tops and steep or even precipitous slopes down to the base of the capping limestone, while the standstone below, weathering more readily, gives the lower portions of the hills a gentler slope.

The elevations of the hills and ridges above the axes of the valleys or, in other words, the relief of the plain is, on the average, about 300 feet, only a few of the more prominent hills exceeding that figure.

The topography east of the line between Kilbourn City and Prairie du Sac is not of the unmodified erosion type, as is made evident by marshes, ponds and lakes. The departure from the erosion type is due to a mantle of glacial drift which masks the topography of the bedded rock beneath. Its nature, and the



The Lower Narrows of the Baraboo from a point on the South range.

topographic modifications which it has produced, will be more fully considered in a later part of this report (p. 85).

II. THE QUARTZITE RIDGES.

Topography.—The South or main quartzite range, about 23 miles in length and one to four miles in width, rises 500 feet to 800 feet above the surrounding sandstone plain. Its slopes are generally too steep for cultivation, and are clothed for the most part with a heavy growth of timber, the banks of forest being broken here and there by cultivated fields, or by the purple grey of the rock escarpments too steep for trees to gain a foothold. With the possible exception of the Blue mounds southwest of Madison, this quartzite range is the most obtrusive topographic feature of southern Wisconsin.

As approached from the south, one of the striking features of the range is its nearly even crest. Extending for miles in an east-west direction, its summit gives a sky-line of long and gentle curves, in which the highest points are but little above the lowest. Viewed from the north, the evenness of the crest is not less distinct, but from this side it is seen to be interrupted by a notable break or notch at Devil's lake (Plates V and XXXVII). The pass across the range makes a right-angled turn in crossing the range, and for this reason is not seen from the south.

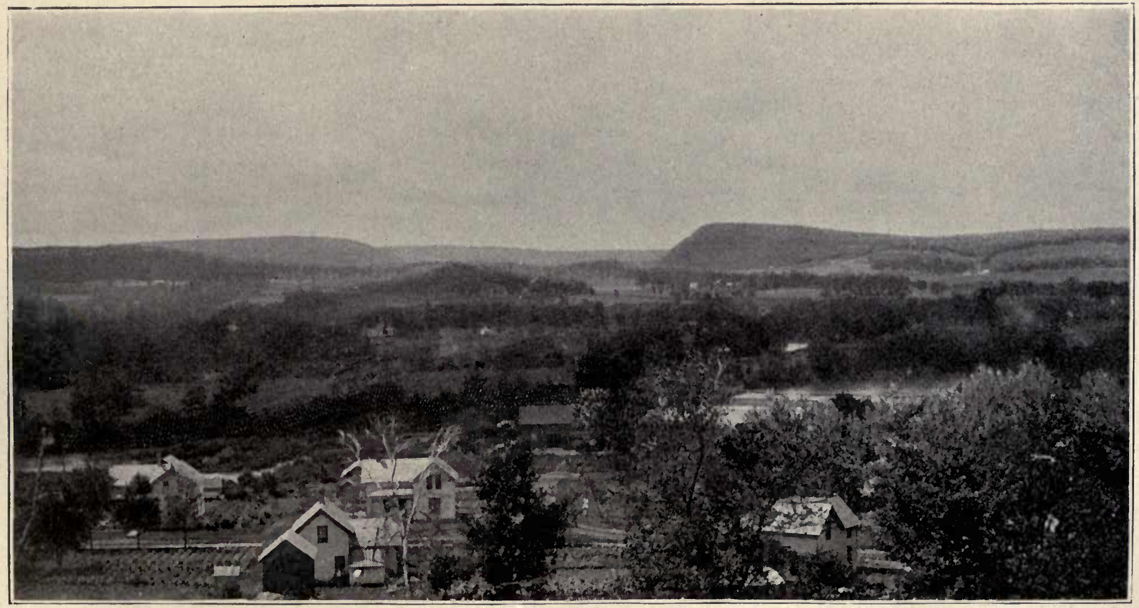
The North or lesser quartzite range lying north of Baraboo is both narrower and lower than the south range, and its crest is frequently interrupted by notches or passes, some of which are wide. Near its eastern end occurs the striking gap known as the *Lower narrows* (Plate IV) through which the Baraboo river escapes to the northward, flowing thence to the Wisconsin. At this narrows the quartzite bluffs rise abruptly 500 feet above the river. At *a* and *b*, Plate II, there are similar though smaller breaks in the range, also occupied by streams. The connection between the passes and streams is therefore close.

There are many small valleys in the sides of the quartzite ranges (especially the South range) which do not extend back to their crests, and therefore do not occasion passes across them. The narrow valleys at *a* and *b* in Plate XXXVII, known as Parfrey's and Dorward's glens, respectively, are singularly beautiful gorges, and merit mention as well from the scenic as from the geologic point of view. Wider valleys, the heads of which do not reach the crest, occur on the flanks of the main range (as at *d* and *e*, Plate II) at many points. One such valley occurs east of the north end of the lake (*x*, Plate XXXVII), another west of the south end (*y*, Plate XXXVII), another on the north face of the west bluff west of the north end of the lake and between the East and West Sauk roads, and still others at greater distances from the lake in both directions. It is manifest that if the valleys were extended headward in the direction of their axes, they would interrupt the even crest. Many of these valleys, unlike the glens mentioned above, are very wide in proportion to their length. In some of these capacious valleys there are beds of Potsdam sandstone, showing that the valleys existed before the sand of the sandstone was deposited.

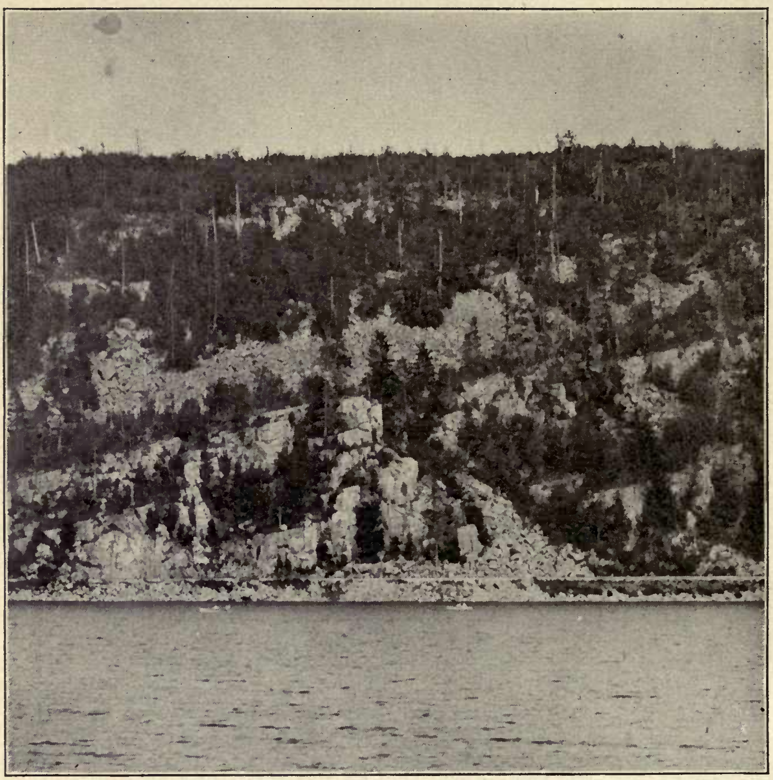
The structure and constitution of the ridges.—The quartzite of the ridges is nothing more nor less than altered sandstone. Its origin dates from that part of geological time known to geologists as the Upper Huronian period (see p. 23). The popular local belief that the quartzite is of igneous origin is without the slightest warrant. It appears to have had its basis in the notion that Devil's lake occupies an extinct volcanic crater. Were this the fact, igneous rock should be found about it.

Quartzite is sandstone in which the intergranular spaces have been filled with silica (quartz) brought in and deposited by percolating water subsequent to the accumulation of the sand. The conversion of sandstone into quartzite is but a continuation of the process which converts sand into sandstone. The Potsdam or any other sandstone formation might be converted into quartzite by the same process, and it would then be a *metamorphic* rock.

Like the sandstone, the quartzite is in layers. This is perhaps nowhere so distinctly shown on a large scale as in the bluffs at



The Notch in the South quartzite range, at Devil's Lake.



The east bluff of Devil's lake, showing the dip of quartzite (to the left), and talus above and below the level where the beds are shown.

Devil's lake, and at the east end of the Devil's nose. On the East bluff of the lake, the stratification is most distinctly seen from the middle of the lake, from which point the photograph reproduced in Plate VI was taken.

Unlike the sandstone and limestone, the beds of quartzite are not horizontal. The departure from horizontality, technically known as the *dip,* varies from point to point (Fig. 4). In the East bluff of the lake as shown in Plate VI, the dip is about 14° to the north. At the Upper and Lower narrows of the Baraboo (*b* and *c*, Plate II) the beds are essentially vertical, that is, they have a dip of about 90°. Between these extremes, many intermediate angles have been noted. Plate VII represents a view near Ablemans, in the Upper narrows, where the nearly vertical beds of quartzite are well exposed.

The position of the beds in the quartzite is not always easy of recognition. The difficulty is occasioned by the presence of numerous cleavage planes developed in the rock after its conversion into quartzite. Some of these secondary cleavage planes are so regular and so nearly parallel to one another as to be easily confused with the bedding planes. This is especially liable to make determinations of the dip difficult, since the true bedding was often obscured when the cleavage was developed.

In spite of the difficulties, the original stratification can usually be determined where there are good exposures of the rock. At some points the surfaces of the layers carry ripple marks, and where they are present, they serve as a ready means of identifying the bedding planes, even though the strata are now on edge. Layers of small pebbles are sometimes found. They were horizontal when the sands of the quartzite were accumulating, and where they are found they are sufficient to indicate the original position of the beds.

Aside from the position of the beds, there is abundant evidence of dynamic action[1] in the quartzite. Along the railway at Devil's lake, half a mile south of the Cliff House, thin

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[1] Irving: "The Baraboo Quartzite Ranges." Vol. II, Geology of Wisconsin, pp. 504–519. Van Hise: "Some Dynamic Phenomena Shown by the Baraboo Quartzite Ranges of Central Wisconsin." Jour. of Geol., Vol. I, pp. 347–355.

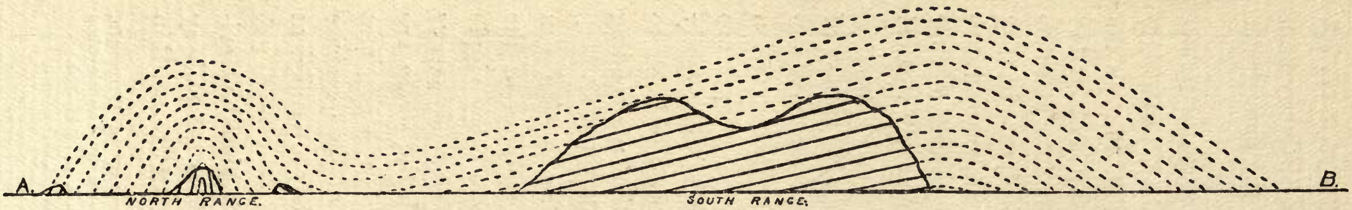


FIG. 4.—Diagram made by plotting the different dips now at hand along a section from A to B, Plate II (p. 5), and connecting them so as to show the structure indicated by the known data. The full lines, oblique or vertical, represent the beds of quartzite. The continuous line above them represents the present surface of the quartzite, while the dotted lines suggest the continuation of the beds which completed the great folds of which the present exposures appear to be remnants.

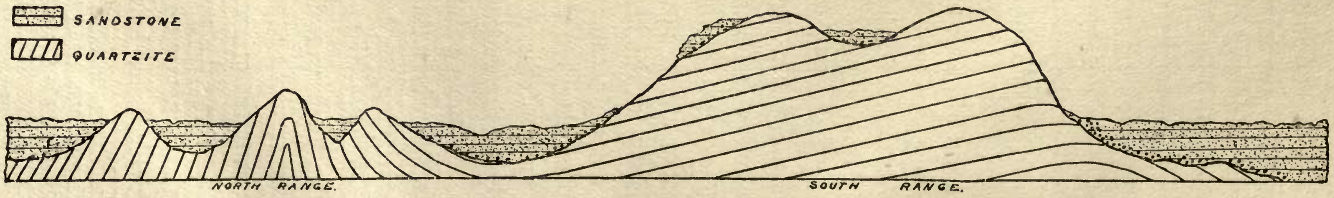
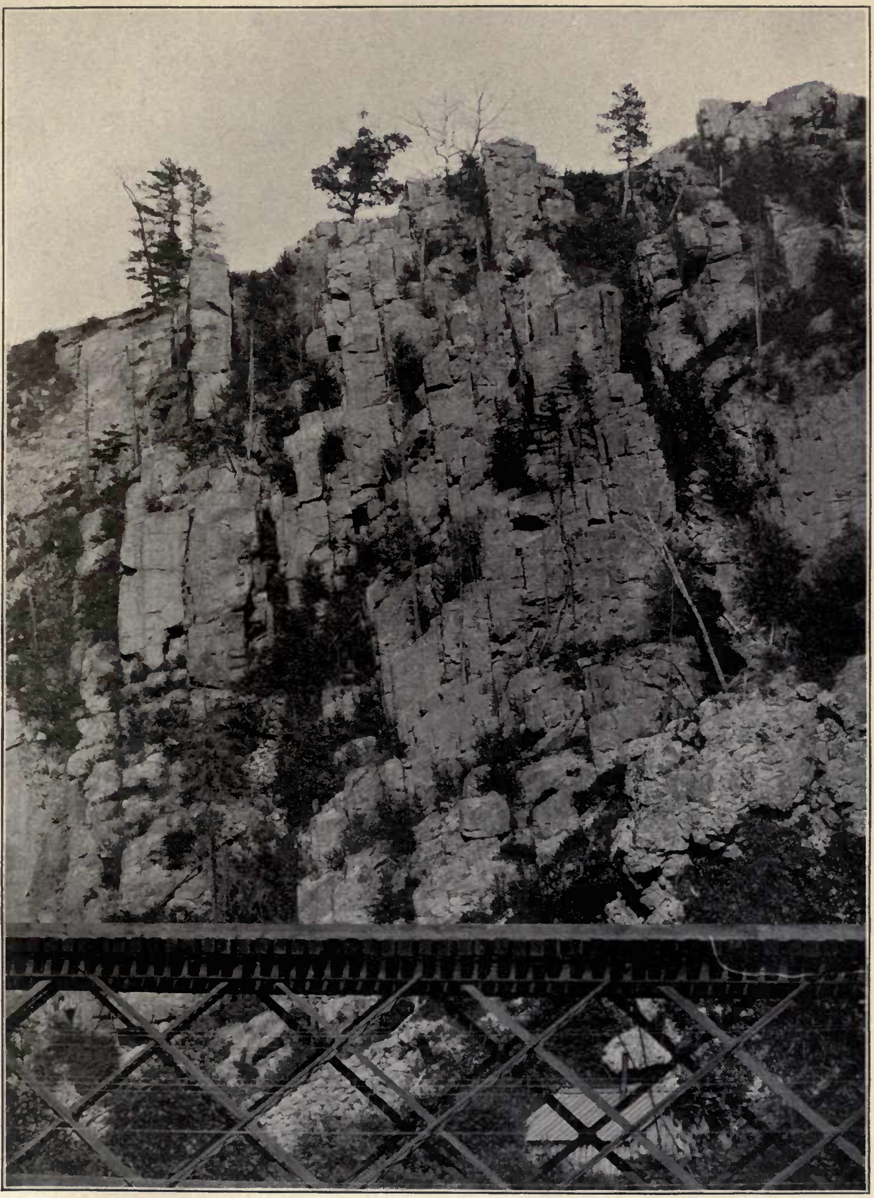


FIG. 5.—A diagrammatic section showing the relation of the sandstone to the quartzite.



The East Bluff at the Upper Narrows of the Baraboo near Ablemans, showing the vertical position of the beds of quartzite. In the lower right-hand corner, above the bridge, appears some of the breccia mentioned on p. 18.

Vertical shear zone in face of east bluff at Devil's lake.

zones of schistose rock may be seen parallel to the bedding planes. These zones of schistose rock a few inches in thickness were developed from the quartzite by the slipping of the rock on either side. This slipping presumably occurred during the adjustment of the heavy beds of quartzite to their new positions, at the time of tilting and folding, for no thick series of rock can be folded without more or less slipping of the layers on one another. The slipping (adjustment) takes place along the weaker zones. Such zones of movement are sometimes known as *shear zones,* for the rock on the one side has been sheared (slipped) over that on the other.

Near the shear zones parallel to the bedding planes, there is one distinct vertical shear zone (Plate VIII) three to four feet in width. It is exposed to a height of fully twenty-five feet. Along this zone the quartzite has been broken into angular fragments, and at places the crushing of the fragments has produced a "friction clay." Slipping along vertical zones would be no necessary part of folding, though it might accompany it. On the other hand, it might have preceded or followed the folding.

Schistose structure probably does not always denote shearing, at least not the shearing which results from folding. Extreme pressure is likely to develop schistosity in rock, the cleavage planes being at right angles to the direction of pressure. It is not always possible to say how far the schistosity of rock at any given point is the result of shear, and how far the result of pressure without shear.

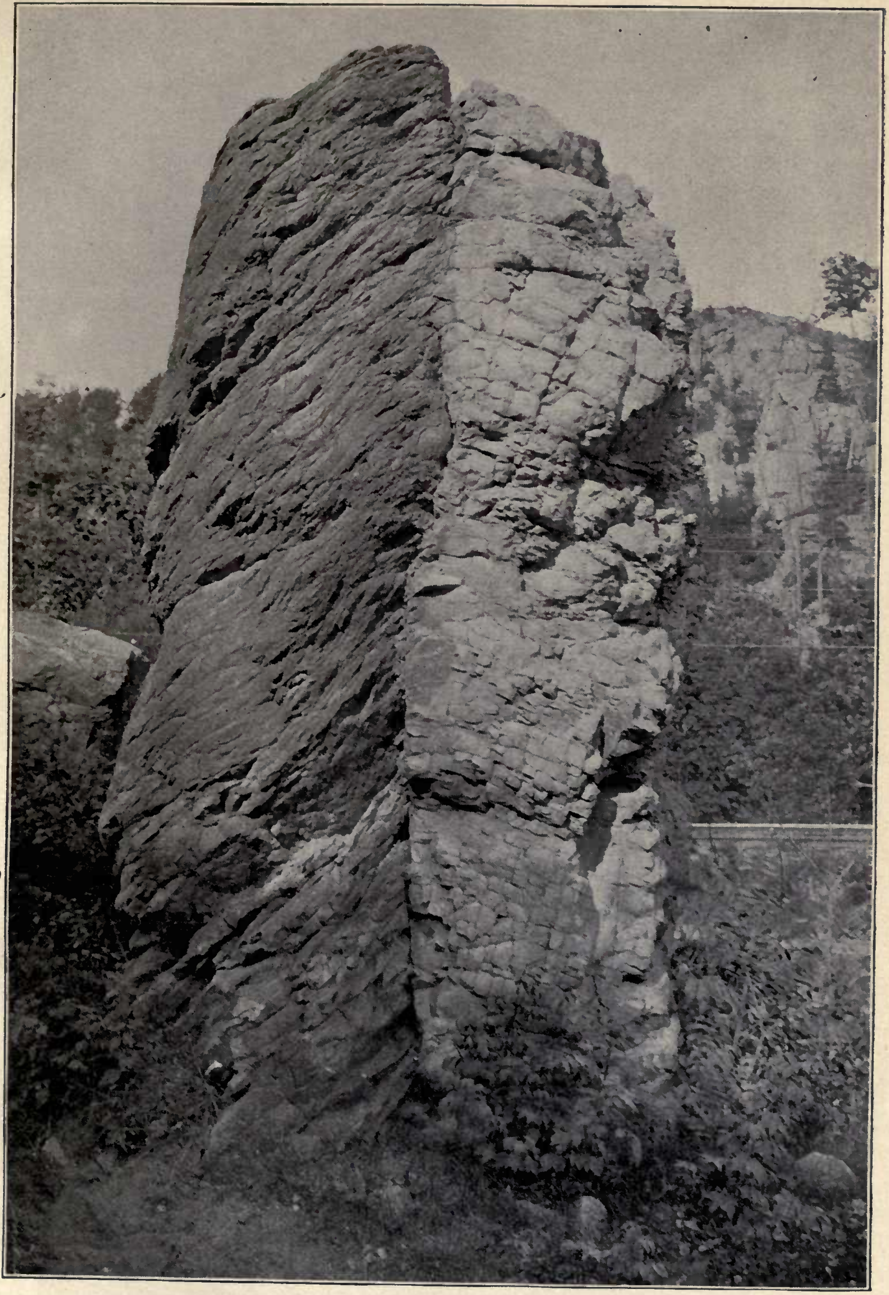
Schistose structure which does not appear to have resulted from shear, at least not from the shear involved in folding, is well seen in the isolated quartzite mound about four miles southwest of Baraboo on the West Sauk road (*f,* Plate II). These quartzite schists are to be looked on as metamorphosed quartzite, just as quartzite is metamorphosed sandstone.

At the Upper narrows of the Baraboo also (b, Plate II, p. 5), evidence of dynamic action is patent. Movement along bedding planes with attendant development of quartz schist has occurred here as at the lake (Plate IX). Besides the schistose belts, a wide zone of quartzite exposed in the bluffs at this locality has been crushed into angular fragments, and afterwards re-cemented by white quartz deposited from solution by percolating waters (Plate X). This quartzite is said to be brecciated. Within this zone there are spots where the fragments of quartzite are so well rounded as to simulate water-worn pebbles. Their forms appear to be the result of the wear of the fragments on one another during the movements which followed the crushing. Conglomerate originating in this way is *friction conglomerate* or *Reibungsbreccia.*

The crushing of the rock in this zone probably took place while the beds were being folded; but the brecciated quartzite formed by the re-cementation of the fragments has itself been fractured and broken in such a manner as to show that the formation has suffered at least one dynamic movement since the development of the breccia. That these movements were separated by a considerable interval of time is shown by the fact that the re-cementation of the fragmental products of the first movement preceded the second.

What has been said expresses the belief of geologists as to the origin of quartzite and quartz schists; but because of popular misconception on the point it may here be added that neither the changing of the sandstone into quartzite, nor the subsequent transformation of the quartzite to schist, was due primarily to heat. Heat was doubtless generated in the mechanical action involved in these changes, but it was subordinate in importance, as it was secondary in origin.

Igneous rock is associated with the quartzite at a few points. At *g* and *h*, Plate II (p. 5) there are considerable masses of porphyry, sustaining such relations to the quartzite as to indicate that they were intruded into the sedimentary beds after the deposition of the latter.



A mass of quartzite *in situ*, in the road through the Upper Narrows near Ableman's. The bedding, which is nearly vertical, is indicated by the shading, while the secondary cleavage approaches horizontality.

Brecciated quartzite near Ablemans in the Upper Narrows. The darker parts are quartzite, the lighter parts the cementing quartz.

III. RELATIONS OF THE SANDSTONE OF THE PLAIN TO THE QUARTZITE OF THE RIDGES.

The horizontal beds of Potsdam sandstone may be traced up to the bases of the quartzite ranges, where they may frequently be seen to abut against the tilted beds of quartzite. Not only this, but isolated patches of sandstone lie on the truncated edges of the dipping beds of quartzite well up on the slopes, and even on the crest of the ridge itself. In the former position they may be seen on the East bluff at Devil's lake, where horizontal beds of conglomerate and sandstone rest on the layers of quartzite which dip 14° to the north.

The stratigraphic relations of the two formations are shown in Fig. 5 which represents a diagrammatic section from A to B, Plate II. Plate XI is reproduced from a photograph taken in the Upper narrows of the Baraboo near Ablemans, and shows the relations as they appear in the field. The quartzite layers are here on edge, and on them rest the horizontal beds of sandstone and conglomerate. Similar stratigraphic relations are shown at many other places. This is the relationship of *unconformity.*

Such an unconformity as that between the sandstone and the quartzite of this region shows the following sequence of events: 1) the quartzite beds were folded and lifted above the sea in which the sand composing them was originally deposited; 2) a long period of erosion followed, during which the crests of the folds were worn off; 3) the land then sank, allowing the sea to again advance over the region; 4) while the sea was here, sand and gravel derived from the adjacent lands which remained unsubmerged, were deposited on its bottom. These sands became the Potsdam sandstone.

This sequence of events means that between the deposition of the quartzite and the sandstone, the older formation was disturbed and eroded. Either of these events would have produced an unconformity; the two make it more pronounced. That the disturbance of the older formation took place before the later sandstone was deposited is evident from the fact that the latter formation was not involved in the movements which disturbed the former.

Although the sandstone appears in patches on the quartzite ranges, it is primarily the formation of the surrounding plains, occupying the broad valley between the ranges, and the territory surrounding them. The quartzite, on the other hand, is the formation of the ridges, though it outcrops at a few points in the plain. (Compare Plates II and XXXVII.) The striking topographic contrasts between the plains and the ridges is thus seen to be closely related to the rock formations involved. It is the hard and resistant quartzite which forms the ridges, and the less resistant sandstone which forms the lowlands about them.

That quartzite underlies the sandstone of the plain is indicated by the occasional outcrops of the former rock on the plain, and from the fact that borings for deep wells have sometimes reached it where it is not exposed.

The sandstone of the plain and the quartzite of the ridges are not everywhere exposed. A deep but variable covering of loose material or *mantle rock (drift)* is found throughout the eastern part of the area, but it does not extend far west of Baraboo. This mantle rock is so thick and so irregularly disposed that it has given origin to small hills and ridges. These elevations are superimposed on the erosion topography of the underlying rock, showing that the drift came into the region after the sandstone, limestone, and quartzite had their present relations, and essentially their present topography. Further consideration will be given to the drift in a later part of this report.

The northeast wall of the Upper Narrows, north of Ableman's, showing the horizontal Potsdam sandstone and conglomerate lying unconformably on the quartzite, the beds of which are vertical.

PART II.

HISTORY OF THE TOPOGRAPHY.

CHAPTER II.

OUTLINE OF THE HISTORY OF THE ROCK FORMATIONS WHICH SHOW THEMSELVES AT THE SURFACE.

I. THE PRE-CAMBRIAN HISTORY OF THE QUARTZITE.

From loose sand to quartzite.—To understand the geography of a region it is necessary to understand the nature of the materials, the sculpture of which has made the geography.

It has already been indicated (p. 14) that the Huronian quartzite of which the most prominent elevations of this region are composed, was once loose sand. Even at the risk of repetition, the steps in its history are here recounted. The source of the sand was probably the still older rocks of the land in the northern part of Wisconsin. Brought down to the sea by rivers, or washed from the shores of the land by waves, the sand was deposited in horizontal or nearly horizontal beds at the bottom of the shallow water which then covered central and southern Wisconsin. Later, perhaps while it was still beneath the sea, the sand was converted into sandstone, the change being effected partly by compression which made the mass of sand more compact, but chiefly by the cementation of its constituent grains into a coherent mass. The water contained in the sand while consolidation was in progress, held in solution some slight amount of silica, the same material of which the grains of sand themselves are composed. Little by little this silica in solution was deposited on the surfaces of the sand grains, enlarging them, and at the same time binding them together. Thus the sand became sandstone. Continued deposition of silica between and around the grains finally filled the interstitial spaces, and when this process was completed, the sandstone had been converted into quartzite. While quartzite is a metamorphic sandstone, it is not to be understood that sandstone cannot be metamorphosed in other ways.

Uplift and deformation. Dynamic metamorphism.—After the deposition of the sands which later became the quartzite, the beds were uplifted and deformed, as their present positions and relations show (p. 16). It is not possible to say how far the process of transformation of sand into quartzite was carried while the formation was still beneath the shallow sea in which it was deposited. The sand may have been changed to sandstone, and the sandstone to quartzite, before the sea bottom was converted into land, while on the other hand, the formation may have been in any stage of change from sand to quartzite, when that event occurred. If the process of change was then incomplete, it may have been continued after the sea retired, by the percolating waters derived from the rainfall of the region.

Either when first converted into land, or at some later time, the beds of rock were folded, and suffered such other changes as attend profound dynamic movements. The conversion of the sandstone into quartzite probably preceded the deformation, since many phenomena indicate that the rock was quartzite and not sandstone when the folding took place. For example, the crushing of the quartzite (now re-cemented into brecciated quartzite) at Ablemans probably dates from the orogenic movements which folded the quartzite, and the fractured bits of rock often have corners and edges so sharp as to show that the rock was thoroughly quartzitic when the crushing took place.

The uplift and deformation of the beds was probably accomplished slowly, but the vertical and highly tilted strata show that the changes were profound (see Fig. 4).

The dynamic metamorphism which accompanied this profound deformation has already been referred to (p. 15). The folding of the beds involved the slipping of some on others, and this resulted in the development of quartz schist along the lines of severest movement. Changes effected in the texture and structure of the rock under such conditions constitute *dynamic* *metamorphism.* In general, the metamorphic changes effected by dynamic action are much more profound than those brought about in other ways, and most rocks which have been profoundly metamorphosed, were changed in this way. Dynamic action generates heat, but contrary to the popular notion, the heat involved in profound metamorphism is usually secondary, and the dynamic action fundamental.

At the same time that quartz schist was locally developed from the quartzite, crushing probably occurred in other places. This is *demorphism,* rather than metamorphism.

Erosion of the quartzite.—When the Huronian beds were raised to the estate of land, the processes of erosion immediately began to work on them. The heat and the cold, the plants and the animals, the winds, and especially the rain and the water which came from the melting of the snow, produced their appropriate effects. Under the influence of these agencies the surface of the rock was loosened by weathering, valleys were cut in it by running water, and wear and degradation went on at all points.

The antagonistic processes of uplift and degradation went on for unnumbered centuries, long enough for even the slow processes involved to effect stupendous results. Degradation was continuous after the region became land, though uplift may not have been. On the whole, elevation exceeded degradation, for some parts of the quartzite finally came to stand high above the level of the sea,—the level to which all degradation tends.

Fig. 4 (p. 16) conveys some notion of the amount of rock which was removed from the quartzite folds about Baraboo during this long period of erosion. The south range would seem to represent the stub of one side of a great anticlinal fold, a large part of which (represented by the dotted lines) was carried away, while the north range may be the core of another fold, now exposed by erosion.

Some idea of the geography of the quartzite at the close of this period of erosion may be gained by imagining the work of later times undone. The younger beds covering the quartzite of the plains have a thickness varying from zero to several hundred feet, and effectually mask the irregularities of the surface of the subjacent quartzite. Could they be removed, the topography of the quartzite would be disclosed, and found to have much greater relief than the present surface; that is, the vertical distance between the crest of the quartzite ridge, and the surface of the quartzite under the surrounding lowlands, would be greater than that between the same crest and the surface of the sandstone. But even this does not give the full measure of the relief of the quartzite at the close of the long period of erosion which followed its uplift, for allowance must be made for the amount of erosion which the crests of the quartzite ranges have suffered since that time. The present surface therefore does not give an adequate conception of the irregularity of the surface at the close of the period of erosion which followed the uplift and deformation of the quartzite. So high were the crests of the quartzite ranges above their surroundings at that time, that they may well be thought of as mountainous. From this point of view, the quartzite ranges of today are the partially buried mountains of the pre-Potsdam land of south central Wisconsin.

When the extreme hardness of the quartzite is remembered and also the extent of the erosion which affected it (Fig. 4) before the next succeeding formation was deposited, it is safe to conclude that the period of erosion was very long.

Thickness of the quartzite.—The thickness of the quartzite is not known, even approximately. The great thickness in the south range suggested by the diagram (Fig. 4) may perhaps be an exaggeration. Faulting which has not been discovered may have occurred, causing repetition of beds at the surface (Fig. 6), and so an exaggerated appearance of thickness. After all allowances have been made, it is still evident that the thickness of the quartzite is very great.

II. THE HISTORY OF THE PALEOZOIC STRATA.

The subsidence.—Following the long period of erosion, the irregular and almost mountainous area of central Wisconsin was depressed sufficiently to submerge large areas which had been land. The subsidence was probably slow, and as the sea advanced from the south, it covered first the valleys and lowlands, and later the lower hills and ridges, while the higher hills and ridges of the quartzite stood as islands in the rising sea. Still later, the highest ridges of the region were themselves probably submerged.

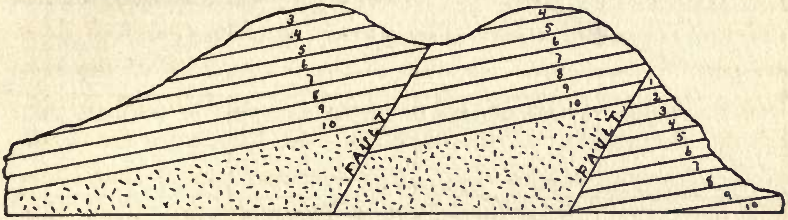


FIG. 6.—A diagrammatic cross-section, showing how, by faulting, the apparent thickness of the quartzite would be increased.

The Potsdam sandstone (and conglomerate).—So soon as the sea began to overspread the region, its bottom became the site of deposition, and the deposition continued as long as the submergence lasted. It is to the sediments deposited during the earlier part of this submergence that the name *Potsdam* is given.

The sources of the sediments are not far to seek. As the former land was depressed beneath the sea, its surface was doubtless covered with the products of rock decay, consisting of earths, sands, small bits and larger masses of quartzite. These materials, or at least the finer parts, were handled by the waves of the shallow waters, for they were at first shallow, and assorted and re-distributed. Thus the residuary products on the submerged surface, were one source of sediments.

From the shores also, so long as land areas remained, the waves derived sediments. These were composed in part of the weathered products of the rock, and in part of the undecomposed rock against which the waves beat, after the loose materials had been worn away. These sediments derived from the shore were shifted, and finally mingled with those derived from the submerged surface.

So long as any part of the older land remained above the water, its streams brought sediments to the sea. These also were shifted by the waves and shore currents, and finally deposited with the others on the eroded surface of the quartzite. Thus sediments derived in various ways, but inherently essentially similar, entered into the new formation.

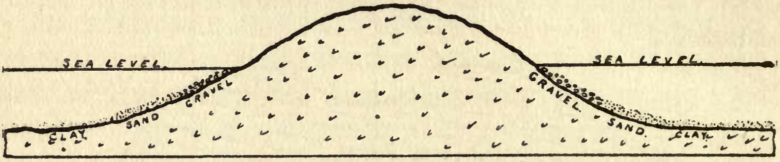


FIG. 7.—Diagram to illustrate the theoretical disposition of sediments about an island.

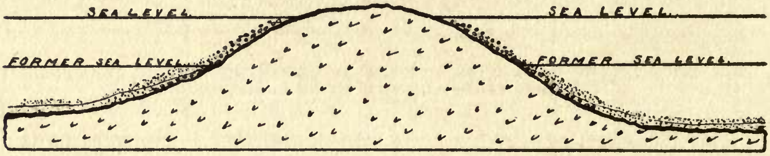


FIG. 8.—Same as Fig. 7, except that the land has been depressed.

The first material to be deposited on the surface of the quartzite as it was submerged, was the coarsest part of the sediment. Of the sediment derived by the waves from the coasts, and brought down to the sea by rivers, the coarsest would at each stage be left nearest the shore, while the finer was carried progressively farther and farther from it. Thus at each stage the sand was deposited farther from the shore than the gravel, and the mud farther than the sand, where the water was so deep that the bottom was subject to little agitation by waves. The theoretical distribution of sediments about an island as it was depressed, is illustrated by the following diagrams, Figs. 7 and 8. It will be seen that the surface of the quartzite is immediately overlain by conglomerate, but that the conglomerate near its top is younger than that near its base.

In conformity with this natural distribution of sediments, the basal beds of the Potsdam formation are often conglomeratic (Fig. 9, Plate III, p. 9, Fig. 2, and Plate XXV, p. 68). This may oftenest be seen near the quartzite ridges, for here only is the base of the formation commonly exposed. The pebbles and larger masses of the conglomerate are quartzite, like that of the subjacent beds, and demonstrate the source of at least some of the material of the younger formation. That the pebbles and bowlders are of quartzite is significant, for it shows that the older formation had been changed from sandstone to quartzite, before the deposition of the Potsdam sediments. The sand associated with the pebbles may well have come from the breaking up of the quartzite, though some of it may have been washed in from other sources by the waters in which the deposition took place.

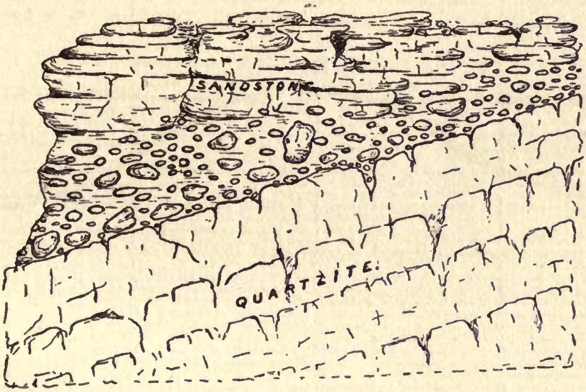


FIG. 9.—Sketch showing relation of basal Potsdam conglomerate and sandstone to the quartzite, on the East bluff at Devil's lake, behind the Cliff house.

The basal conglomerate may be seen at many places, but nowhere about Devil's lake is it so well exposed as at Parfrey's glen (*a,* Plate XXXVII, p. 108), where the rounded stones of which it is composed vary from pebbles, the size of a pea, to bowlders more than three feet in diameter. Other localities where the conglomerates may be seen to advantage are Dorward's glen (*b,* Plate XXXVII), the East bluff at Devil's lake just above the Cliff house, and at the Upper narrows of the Baraboo, above Ablemans.

While the base of the Potsdam is conglomeratic in many places, the main body of it is so generally sandstone that the formation as a whole is commonly known as the Potsdam sandstone.

The first effect of the sedimentation which followed submergence was to even up the irregular surface of the quartzite, for the depressions in the surface were the first to be submerged, and the first to be filled. As the body of sediment thickened, it buried the lower hills and the lower parts of the higher ones. The extent to which the Potsdam formation buried the main ridge may never be known. It may have buried it completely, for as already stated (p. 19) patches of sandstone are found upon the main range. These patches make it clear that some formation younger than the quartzite once covered essentially all of the higher ridge. Other evidence to be adduced later, confirms this conclusion. It has, however, not been demonstrated that the high-level patches of sandstone are Potsdam.

There is abundant evidence that the subsidence which let the Potsdam seas in over the eroded surface of the Huronian quartzite was gradual. One line of evidence is found in the cross-bedding of the sandstone (Plate XII) especially well exhibited in the Dalles of the Wisconsin. The beds of sandstone are essentially horizontal, but within the horizontal beds there are often secondary layers which depart many degrees from horizontality, the maximum being about 24°. Plates XXVII, p. 68, and XII, give a better idea of the structure here referred to than verbal description can.

The explanation of cross-bedding is to be found in the varying conditions under which sand was deposited. Cross-bedding denotes shallow water, where waves and shore currents were effective at the bottom where deposition is in progress. For a time, beds were deposited off shore at a certain angle, much as in the building of a delta (Fig. 10). Then by subsidence of the bottom, other layers with like structure were deposited over the first. By this sequence of events, the dip of the secondary layers should be toward the open water, and in this region their dip is

Steamboat rock,—an island in the Dalles of the Wisconsin.

generally to the south. At any stage of deposition the waves engendered by storms were liable to erode the surface of the deposits already made, and new layers, discordant with those below, were likely to be laid down upon them. The subordinate layers of each deposit might dip in any direction. If this process were repeated many times during the submergence, the existing complexity would be explained.

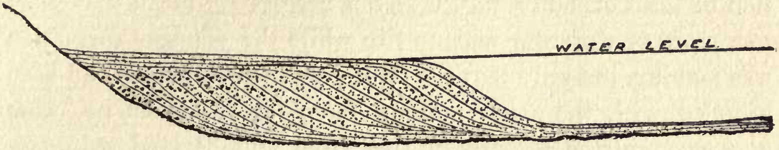


FIG. 10.—A diagrammatic cross-section of a delta.

The maximum known thickness of the Potsdam sandstone in Wisconsin is about 1,000 feet, but its thickness in this region is much less. Where not capped by some younger formation, its upper surface has suffered extensive erosion, and the present thickness therefore falls short of the original. The figures given above may not be too great for the latter.

The Lower Magnesian limestone.—The conditions of sedimentation finally changed in the area under consideration. When the sand of the sandstone was being deposited, adjacent lands were the source whence the sediments were chiefly derived. The evidence that the region was sinking while the sand was being deposited shows that the land masses which were supplying the sand, were becoming progressively smaller. Ultimately the sand ceased to be washed out to the region here described, either because the water became too deep,[1] or because the source of supply was too distant. When these relations were brought about, the conditions were favorable for the deposition of sediments which were to become limestone. These sediments consisted chiefly of the shells of marine life, together with an unknown amount of lime carbonate precipitated from the waters of the sea. The limestone contains no coarse, and but little fine material derived from the land, and the surfaces of its lay-

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[1] A few hundred feet would suffice.

ers are rarely if ever ripple-marked. The materials of which it is made must therefore have been laid down in quiet waters which were essentially free from land-derived sediments. The depth of the water in which it was deposited was not, however, great, for the fossils are not the remains of animals which lived in abysmal depths.

The deposition of limestone sediments following the deposition of the Potsdam sands, does not necessarily mean that there was more or different marine life while the younger formation was making, but only that the shells, etc., which before had been mingled with the sand, making fossiliferous sandstone, were now accumulated essentially free from land-derived sediment, and therefore made limestone.

Like the sandstone beneath, the limestone formation has a wide distribution outside the area here under discussion, showing that conditions similar to those of central Wisconsin were widely distributed at this time.

The beds of limestone are conformable on those of the sandstone, and the conformable relations of the two formations indicate that the deposition of the upper followed that of the lower, without interruption.

The thickness of the Lower Magnesian limestone varies from less than 100 to more than 200 feet, but in this region its thickness is nearer the lesser figure than the larger. The limestone is now present only in the eastern and southern parts of the area, though it originally covered the whole area.

The St. Peters sandstone.—Overlying the Lower Magnesian limestone at a few points, are seen remnants of St. Peters sandstone. The constitution of this formation shows that conditions of sedimentation had again changed, so that sand was again deposited where the conditions had been favorable to the deposition of limestone but a short time before. This formation has been recognized at but two places (*d* and *e*) within the area shown on Plate XXXVII, but the relations at these two points are such as to lead to the conclusion that the formation may once have covered the entire region. This sandstone formation is very like the sandstone below. Its materials doubtless came from the lands which then existed. The formation is relatively thin, ranging from somewhat below to somewhat above 100 feet.

The change from the deposition of limestone sediments to sand may well have resulted from the shoaling of the waters, which allowed the sand to be carried farther from shore. Rise of the land may have accompanied the shoaling of the waters, and the higher lands would have furnished more and coarser sediments to the sea.

Younger beds.—That formations younger than the St. Peters sandstone once overlaid this part of Wisconsin is almost certain, though no remnants of them now exist. Evidence which cannot be here detailed[1] indicates that sedimentation about the quartzite ridges went on not only until the irregularities of surface were evened up, but until even the highest peaks of the quartzite were buried, and that formations as high in the series as the Niagara limestone once overlay their crests. Before this condition was reached, the quartzite ridges had of course ceased to be islands, and at the same time had ceased to be a source of supply of sediments. The aggregate thickness of the Paleozoic beds in the region, as first deposited, was probably not less than 1,500 feet, and it may have been much more. This thickness would have buried the crests of the quartzite ridges under several hundred feet of sediment (see Fig. 11).

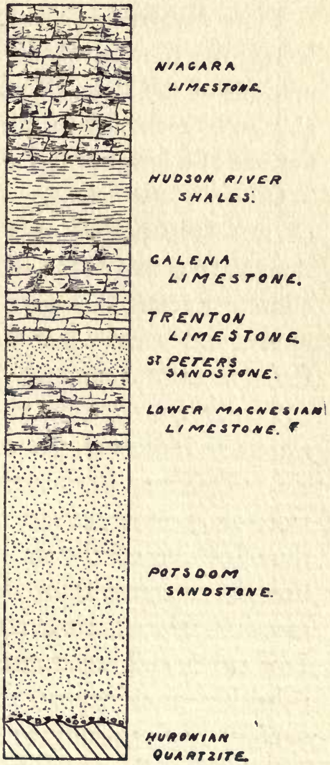

FIG. 11.—The geological formations of southern Wisconsin in the order of their occurrence. Not all of these are found about Devil's lake.

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[1] Jour. of Geol., Vol. III (pp. 655–67).

It is by no means certain that south central Wisconsin was continuously submerged while this thick series of beds was being deposited. Indeed, there is good reason to believe that there was at least one period of emergence, followed, after a considerable lapse of time, by re-submergence and renewed deposition, before the Paleozoic series of the region was complete. These movements, however, had little effect on the geography of the region.

Finally the long period of submergence, during which several changes in sedimentation had taken place, came to an end, and the area under discussion was again converted into land.

Time involved.—Though it cannot be reduced to numerical terms, the time involved in the deposition of these several formations of the Paleozoic must have been very long. It is probably to be reckoned in millions of years, rather than in denominations of a lower order.

Climatic conditions.—Little is known concerning the climate of this long period of sedimentation. Theoretical considerations have usually been thought to lead to the conclusion that the climate during this part of the earth's history was uniform, moist, and warm; but the conclusion seems not to be so well founded as to command great confidence.

The uplift.—After sedimentation had proceeded to some such extent as indicated, the sea again retired from central Wisconsin. This may have been because the sea bottom of this region rose, or because the sea bottom in other places was depressed, thus drawing off the water. The topography of this new land, like the topography of those portions of the sea bottom which are similarly situated, must have been for the most part level. Low swells and broad undulations may have existed, but no considerable prominences, and no sudden change of slope. The surface was probably so flat that it would have been regarded as a level surface had it been seen.

The height to which the uplift carried the new land surface at the outset must ever remain a matter of conjecture. Some estimate may be made of the amount of uplift which the region has suffered since the beginning of this uplift, but it is unknown how much took place at this time, and how much in later periods of geological history.

The new land surface at once became the site of new activities. All processes of land erosion at once attacked the new surface, in the effort to carry its materials back to the sea. The sculpturing of this plain, which, with some interruption, has continued to the present day, has given the region the chief elements of its present topography. But before considering the special history of erosion in this region, it may be well to consider briefly the general principles and processes of land degradation.

CHAPTER III.

GENERAL OUTLINE OF RAIN AND RIVER EROSION.

Elements of erosion.—The general process of subaerial erosion is divisible into the several sub-processes of weathering, transportation, and corrasion.[1]

Weathering is the term applied to all those processes which disintegrate and disrupt exposed surfaces of rock. It is accomplished chiefly by solution, changes in temperature, the wedge-work of ice and roots, the borings of animals, and such chemical changes as surface water and air effect. The products of weathering are transported by the direct action of gravity, by glaciers, by winds, and by running water. Of these the last is the most important.

Corrasion is accomplished chiefly by the mechanical wear of streams, aided by the hard fragments such as sand, gravel and bowlders, which they carry. The solution effected by the waters of a stream may also be regarded as a part of corrasion. Under ordinary circumstances solution by streams is relatively unimportant, but where the rock is relatively soluble, and where conditions are not favorable for abrasion, solution may be more important than mechanical wear.

So soon as sea bottom is raised to the estate of land, it is attacked by the several processes of degradation. The processes of weathering at once begin to loosen the material of the surface if it be solid; winds shift the finer particles about, and with the first shower transportation by running water begins. Weathering prepares the material for transportation and transportation leads to corrasion. Since the goal of all material transported by

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[1] There is an admirable exposition of this subject in Gilbert's "Henry Mountains."

running water is the sea, subaerial erosion means degradation of the surface.

Erosion without valleys.—In the work of degradation the valley becomes the site of greatest activity, and in the following pages especial attention is given to the development of valleys and to the phases of topography to which their development leads.

If a new land surface were to come into existence, composed of materials which were perfectly homogeneous, with slopes of absolute uniformity in all directions, and if the rain, the winds and all other surface agencies acted uniformly over the entire area, valleys would not be developed. That portion of the rainfall which was not evaporated and did not sink beneath the surface, would flow off the land in a sheet. The wear which it would effect would be equal in all directions from the center. If the angle of the slope were constant from center to shore, or if it increased shoreward, the wear effected by this sheet of water would be greatest at the shore, because here the sheet of flowing water would be deepest and swiftest, and therefore most effective in corrasion.

The beginning of a valley.—But land masses as we know them do not have equal and uniform slopes to the sea in all directions, nor is the material over any considerable area perfectly homogeneous. Departure from these conditions, even in the smallest degree, would lead to very different results.

That the surface of newly emerged land masses would, as a rule, not be rough, is evident from the fact that the bottom of the sea is usually rather smooth. Much of it indeed is so nearly plane that if the water were withdrawn, the eye would scarcely detect any departure from planeness. The topography of a land mass newly exposed either by its own elevation or by the withdrawal of the sea, would ordinarily be similar to that which would exist in the vicinity of Necedah and east of Camp Douglas, if the few lone hills were removed, and the very shallow valleys filled. Though such a surface would seem to be moderately uniform as to its slopes, and homogeneous as to its material, neither the uniformity nor the homogeneity are perfect, and the rain water would not run off in sheets, and the wear would not be equal at all points.

Let it be supposed that an area of shallow sea bottom is raised above the sea, and that the elevation proceeds until the land has an altitude of several hundred feet. So soon as it appears above the sea, the rain falling upon it begins to modify its surface. Some of the water evaporates at once, and has little effect on the surface; some of it sinks beneath the surface and finds its way underground to the sea; and some of it runs off over the surface and performs the work characteristic of streams. So far as concerns modifications of the surface, the run-off is the most important part.

The run-off of the surface would tend to gather in the depressons of the surface, however slight they may be. This tendency is shown on almost every hillside during and after a considerable shower. The water concentrated in the depressions is in excess of that flowing over other parts of the surface, and therefore flows faster. Flowing faster, it erodes the surface over which it flows more rapidly, and as a result the initial depressions are deepened, and *washes* or *gullies* are started.

Should the run-off not find irregularities of slope, it would, at the outset, fail of concentration; but should it find the material more easily eroded along certain lines than along others, the lines of easier wear would become the sites of greater erosion. This would lead to the development of gullies, that is, to irregularities of slope. Either inequality of slope or material may therefore determine the location of a gully, and one of these conditions is indispensable.

Once started, each wash or gully becomes the cause of its own growth, for the gully developed by the water of one shower, determines greater concentration of water during the next. Greater concentration means faster flow, faster flow means more rapid wear, and this means corresponding enlargement of the depression through which the flow takes place. The enlargement effected by successive showers affects a gully in all dimen-

FIG. 1.

A very young valley.

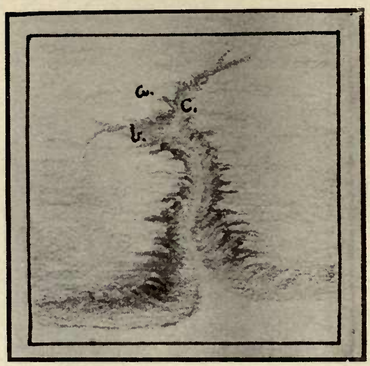


FIG. 2.

A valley in a later stage of development.

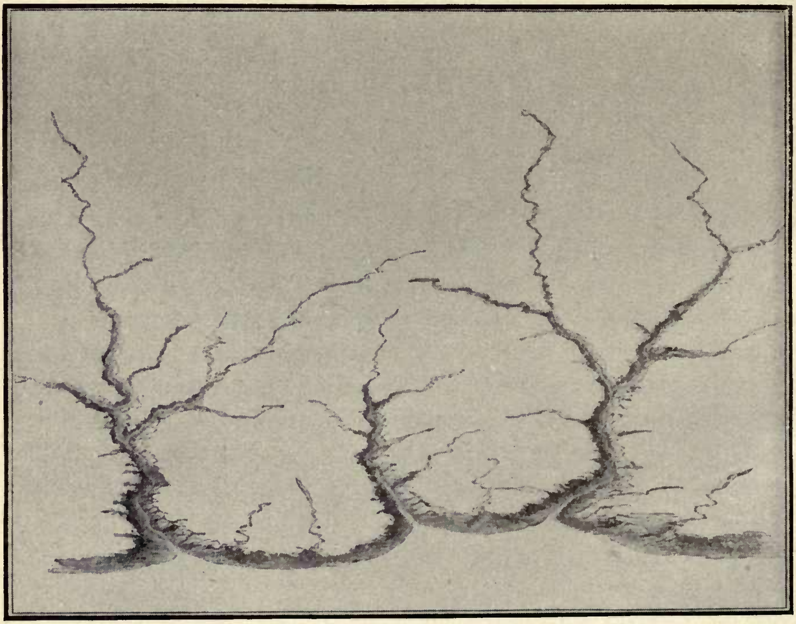


FIG. 3.

Young valleys.

sions. The water coming in at its head carries the head back into the land (head erosion), thus lengthening the gully; the water coming in at its sides wears back the lateral slopes, thus widening it; and the water flowing along its bottom deepens it. Thus gullies grow to be ravines, and farther enlargement by the same processes converts ravines into valleys. A river valley therefore is often but a gully grown big.

The course of a valley.—In the lengthening of a gully or valley headward, the growth will be in the direction of greatest wear. Thus in Plate XIII, Fig. 1, if the water coming in at the head of the gully effects most wear in the direction *a*, the head of the gully will advance in that direction; if there be most wear in the direction *b* or *c*, the head will advance toward one of these points. The direction of greatest wear will be determined either by the slope of the surface, or by the nature of the surface material. The slope may lead to the concentration of the entering waters along one line, and the surface material may be less resistant in one direction than in another. If these factors favor the same direction of head-growth, the lengthening will be more rapid than if but one is favorable. If there be more rapid growth along two lines, as *b* and *c*, Plate XIII, Fig. 1, than between them, two gullies may develop (Plate XIII, Fig. 2). The frequent and tortuous windings common to ravines and valleys are therefore to be explained by the inequalities of slope or material which affected the surface while the valley was developing.

Tributary valleys.—Following out this simple conception of valley growth, we have to inquire how a valley system (a main valley and its tributaries) is developed. The conditions which determine the location and development of gullies in a new land surface, determine the location and development of tributary gullies. In flowing over the lateral slopes of a gully or ravine, the water finds either slope or surface material failing of uniformity. Both conditions lead to the concentration of the water along certain lines, and concentration of flow on the slope of an erosion depression, be it valley or gully, leads to the development of a tributary depression. In its growth, the tributary repeats, in all essential respects, the history of its main. It is lengthened headward by water coming in at its upper end, is widened by side wash, and deepened by the downward cutting of the water which flows along its axis. The factors controlling its development are the same as those which controlled the valley to which it is tributary.

There is one peculiarity of the courses of tributaries which deserves mention. Tributaries, as a rule, join their mains with an acute angle up stream. In general, new land surfaces, such as are now under consideration, slope toward the sea. If a tributary gully were to start back from its main at right angles, more water would come in on the side away from the shore, on account of the seaward slope of the land. This would be true of the head of the gully as well as of other portions, and the effect would be to turn the head more and more toward parallelism with the main valley. Local irregularities of surface may, and frequently do, interfere with these normal relations, so that the general course of a tributary is occasionally at right angles to its main. Still more rarely does the general course of a tributary make an acute angle with its main on the down stream side. Local irregularities of surface determine the windings of a tributary, so that their courses for longer or shorter distances may be in violation of the general rule (c, Fig. 43, p. 139); but on the whole, the valleys of a system whose history has not been interrupted in a region where the surface material is not notably heterogeneous, follow the course indicated above. This is shown by nearly every drainage system on the Atlantic Coastal plain which represents more nearly than any other portion of our continent, the conditions here under consideration. Fig. 12 represents the drainage system of the Mullica river in southern New Jersey and is a type of the Coastal plain river system.

How a valley gets a stream.—Valleys may become somewhat deep and long and wide without possessing permanent streams, though from their inception they have *temporary* streams, the water for which is furnished by showers or melting snow. Yet sooner or later, valleys come to have permanent streams. How are they acquired? Does the valley find the stream or the stream the valley? For the answer to these questions, a brief digression will be helpful.

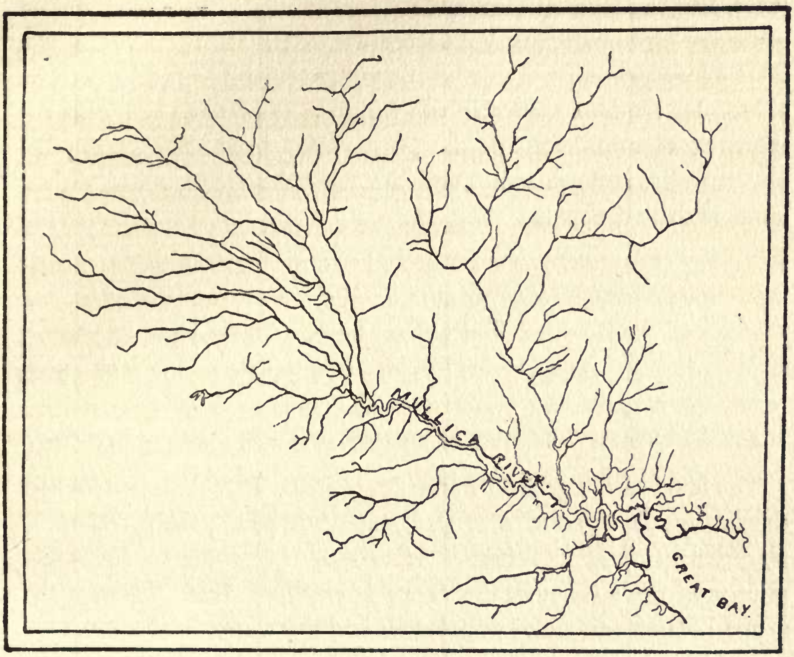


FIG. 12.—A typical river system of the Coastal plain type.

In cultivated regions, wells are of frequent occurrence. In a flat region of uniform structure, the depth at which well water may be obtained is essentially constant at all points. If holes (wells 1 and 2, Fig. 13) be excavated below this level, water seeps into them, and in a series of wells the water stands at a nearly common level. This means that the sub-structure is full of water up to that level. These relations are illustrated by Fig. 13. The diagram represents a vertical section through a flat region from the surface (*s s*) down below the bottom of wells. The water stands at the same level in the two cells (1 and 2), and the plane through them, at the surface of the water, is the *ground water level.* If in such a surface a valley were to be cut until its bottom was below the ground water level, the water would seep into it, as it does into the wells; and if the amount were sufficient, a permanent stream would be established. This is illustrated in Fig. 13. The line A A represents the ground water level, and the level at which the water stands in the wells, under ordinary circumstances. The bottom of the valley is below the level of the ground water, and the water seeps into it from either side. Its tendency is to fill the valley to the level A A. But instead of accumulating in the open valley as it does in the enclosed wells, it flows away, and the ground water level on either hand is drawn down.

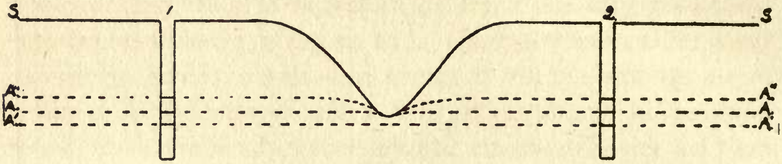


FIG. 13.—Diagram illustrating the relations of ground water to streams.

The level of the ground water fluctuates. It is depressed when the season is dry (A′ A′), and raised when precipitation is abundant (A″ A″). When it is raised, the water in the wells rises, and the stream in the valley is swollen. When it falls, the ground water surface is depressed, and the water in the wells becomes lower. If the water surface sinks below the bottom of the wells, the wells "go dry;" if below the bottom of the valley, the valley becomes for the time being, a "dry run." When a well is below the lowest ground-water level its supply of water never fails, and when the valley is sufficiently below the same level, its stream does not cease to flow, even in periods of drought. On account of the free evaporation in the open valley, the valley depression must be somewhat below the level necessary for a well, in order that the flow may be constant.

It will be seen that *intermittent* streams, that is, streams which flow in wet seasons and fail in dry, are intermediate between streams which flow after showers only, and those which flow without interruption. In the figure the stream would become dry if the ground water level sank to A′ A′.

It is to be noted that a permanent stream does not normally precede its valley, but that the valley, developed through gully-hood and ravine-hood to valley-hood by means of the temporary streams supplied by the run-off of occasional showers, *finds a stream,* just as diggers of wells find water. The case is not altered if the stream be fed by springs, for the valley finds the spring, as truly as the well-digger finds a "vein" of water.

Limits of a valley.—So soon as a valley acquires a permanent stream, its development goes on without the interruption to which it was subject while the stream was intermittent. The permanent stream, like the temporary one which preceded it, tends to deepen and widen its valley, and, under certain conditions, to lengthen it as well. The means by which these enlargements are affected are the same as before. There are limits, however, in length, depth, and width, beyond which a valley may not go. No stream can cut below the level of the water into which it flows, and it can cut to that level only at its outlet. Up stream from that point, a gentle gradient will be established over which the water will flow without cutting. In this condition the stream is *at grade.* Its channel has reached *baselevel,* that is, the level to which the stream can wear its bed. This grade is, however, not necessarily permanent, for what was baselevel for a small stream in an early stage of its development, is not necessarily baselevel for the larger stream which succeeds it at a later time.

Weathering, wash, and lateral corrasion of the stream continue to widen the valley after it has reached baselevel. The bluffs of valleys are thus forced to recede, and the valley is widened at the expense of the upland. Two valleys widening on opposite sides of a divide, narrow the divide between them, and may ultimately wear it out. When this is accomplished, the two valleys become one. The limit to which a valley may widen on either side is therefore its neighboring valley, and since, after two valleys have become one by the elimination of the ridge between them, there are still valleys on either hand, the final result of the widening of all valleys must be to reduce all the area which they drain to baselevel. As this process goes forward, the upper flat into which the valleys were cut is being restricted in area, while the lower flats developed by the streams in the valley bottoms are being enlarged. Thus the lower flats grow at the expense of the higher.

There are also limits in length which a valley may not exceed. The head of any valley may recede until some other valley is reached. The recession may not stop even there, for if, on opposite sides of a divide, erosion is unequal, as between 1A and 1B, Fig. 14, the divide will be moved toward the side of less rapid erosion, and it will cease to recede only when erosion on the two sides becomes equal (4A *and* 4B). In homogeneous material this will be when the slopes on the two sides are equal.

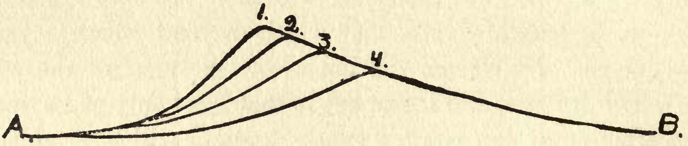


FIG. 14.—Diagram showing the shifting of a divide. The slopes 1A and 1B are unequal. The steeper slope is worn more rapidly and the divide is shifted from 1 to 4, where the two slopes become equal and the migration of the divide ceases.

It should be noted that the lengthening of a valley headward is not normally the work of the permanent stream, for the permanent stream begins some distance below the head of the valley. At the head, therefore, erosion goes on as at the beginning, even after a permanent stream is acquired.

Under certain circumstances, the valley may be lengthened at its debouchure. If the detritus carried by it is deposited at its mouth, or if the sea bottom beyond that point rise, the land may be extended seaward, and over this extension the stream will find its way. Thus at their lower, as well as at their upper ends, both the stream and its valley may be lengthened.

A cycle of erosion.—If, along the borders of a new-born land mass, a series of valleys were developed, essentially parallel to one another, they would constitute depressions separated by elevations, representing the original surface not yet notably affect-

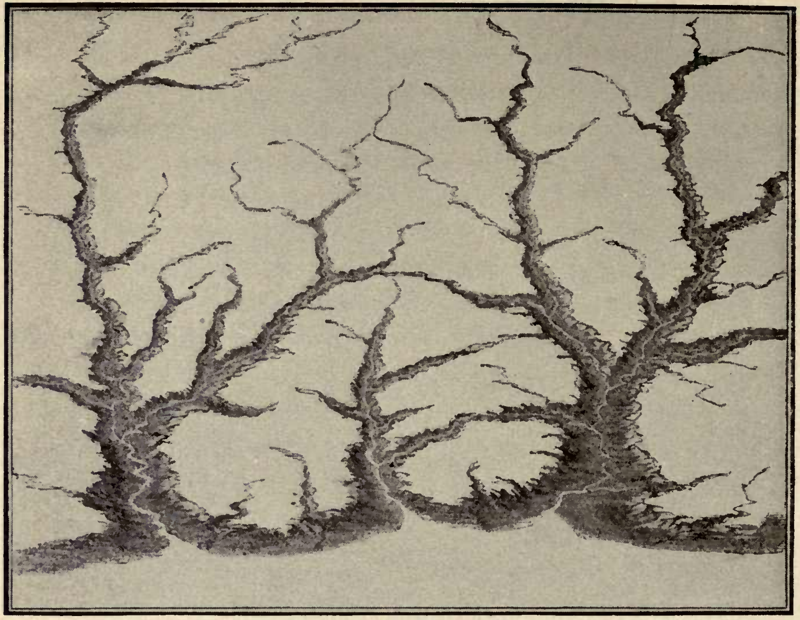


FIG. 1.
The same valleys as shown in Plate XIII, Fig. 3, in a later stage of development.

FIG. 2.
Same valleys as shown in Fig. 1, in a still later stage of development.

ed by erosion (see Plate XIV, Fig. 1). These inter-valley areas might at first be wide or narrow, but in process of time they would necessarily become narrow, for, once, a valley is started, all the water which enters it from either side helps to wear back its slopes, and the wearing back of the slopes means the widening of the valleys on the one hand and the narrowing of the inter-valley ridges on the other. Not only would the water running over the slopes of a valley wear back its walls, but many other processes conspire to the same end. The wetting and drying, the freezing and the thawing, the roots of plants and the borings of animals, all tend to loosen the material on the slopes or walls of the valleys, and gravity helps the loosened material to descend. Once in the valley bottom, the running water is likely to carry it off, landing it finally in the sea. Thus the growth of the valley is not the result of running water alone, though this is the most important single factor in the process.

Even if valleys developed no tributaries, they would, in the course of time, widen to such an extent as to nearly obliterate the intervening ridges. The surface, however, would not easily be reduced to perfect flatness. For a long time at least there would remain something of slope from the central axis of the former inter-stream ridge, toward the streams on either hand; but if the process of erosion went on for a sufficiently long period of time, the inter-stream ridge would be brought very low, and the result would be an essentially flat surface between the streams, much below the level of the old one.

The first valleys which started on the land surface (see Plate XIII, Fig. 3) would be almost sure to develop numerous tributaries. Into tributary valleys water would flow from their sides and from their heads, and as a result they would widen and deepen and lengthen just as their mains had done before them. By lengthening headward they would work back from their mains some part, or even all of the way across the divides separating the main valleys. By this process, the tributaries cut the divides between the main streams into shorter cross-ridges. With the development of tributary valleys there would be many lines of drainage instead of two, working at the area between two main streams. The result would be that the surface would be brought low much more rapidly, for it is clear that many valleys within the area between the main streams, widening at the same time, would diminish the aggregate area of the upland much more rapidly than two alone could do.

The same thing is made clear in another way. It will be seen (Plate XIV, Figs. 1 and 2) that the tributaries would presently dissect an area of uniform surface, tending to cut it into a series of short ridges or hills. In this way the amount of sloping surface is greatly increased, and as a result, every shower would have much more effect in washing loose materials down to lower levels, whence the streams could carry them to the sea.

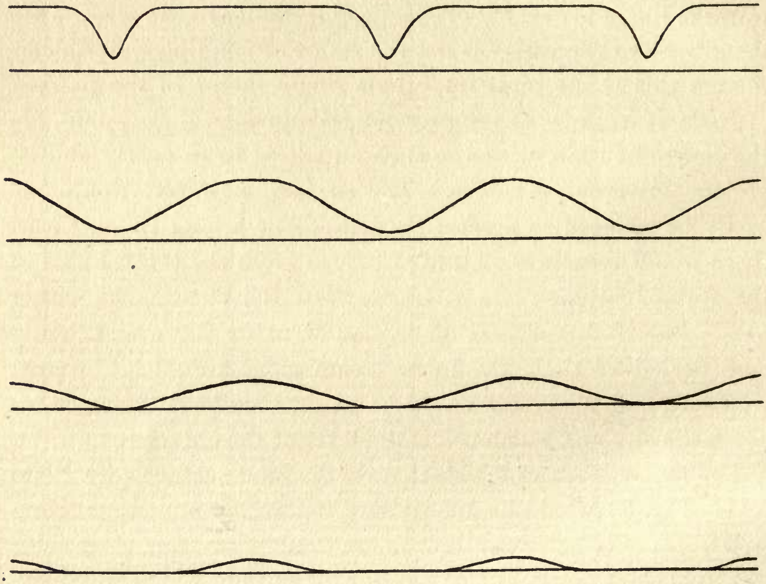


FIG. 15.—Cross-sections showing various stages of erosion in one cycle.

The successive stages in the process of lowering a surface are suggested by Fig. 15, which represents a series of cross-sections of a land mass in process of degradation. The uppermost section represents a level surface crossed by young valleys. The next lower represents the same surface at a later stage, when the

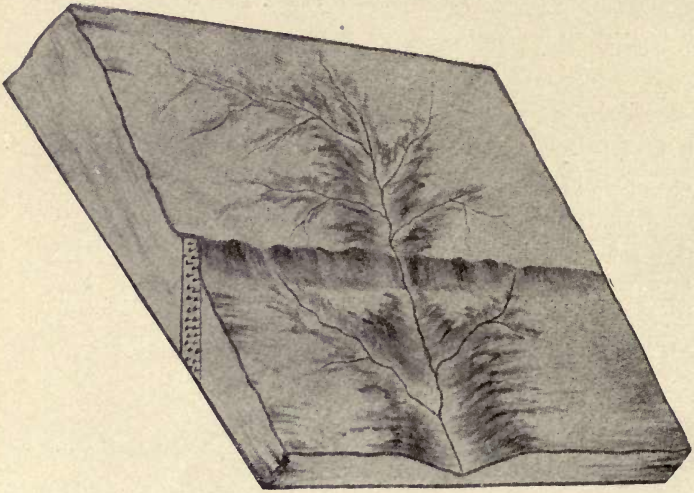


Diagram illustrating how a hard inclined layer of rock becomes a ridge in the process of degradation.

valleys have grown larger, while the third and succeeding sections represent still later stages in the process of degradation. Plate XIII, Fig. 3, and Plate XIV, Figs. 1 and 2, represent in another way the successive stages of stream work in the general process of degradation.

In this manner a series of rivers, operating for a sufficiently long period of time, might reduce even a high land mass to a low level, scarcely above the sea. The new level would be developed soonest near the sea, and the areas farthest from it would be the last—other things being equal—to be brought low. The time necessary for the development of such a surface is known as a *cycle of erosion,* and the resulting surface is a *base-level plain,* that is, a plain as near sea level as river erosion can bring it. At a stage shortly preceding the base-level stage the surface would be a *peneplain.* A peneplain, therefore, is a surface which has been brought toward, but not to base-level. Land surfaces are often spoken of as young or old in their erosion history according to the stage of advancement which has been made toward baseleveling. Thus the Colorado canyon, deep and impressive as it is, is, in terms of erosion, a young valley, for the river has done but a small part of the work which must be done in order to bring its basin to baselevel.

Effects of unequal hardness.—The process of erosion thus sketched would ultimately bring the surface of the land down to base-level, and in case the material of the land were homogeneous, the last points to be reduced would be those most remote from the axes of the streams doing the work of leveling. But if the material of the land were of unequal hardness, those parts which were hardest would resist the action of erosion most effectively. The areas of softer rock would be brought low, and the outcrops of hard rock (Plate XV) would constitute ridges during the later stages of an erosion cycle. If there were bodies of hard rock, such as the Baraboo quartzite, surrounded by sandstone, such as the Potsdam, the sandstone on either hand would be worn down much more readily than the quartzite, and in the course of degradation the latter would come to stand out prominently. The region in the vicinity of Devil's lake is in that stage of erosion in which the quartzite ridges are conspicuous (Plate XXXVII). The less resistant sandstone has been removed from about them, and erosion has not advanced so far since the isolation of the quartzite ridges as to greatly lower their crests. The harder strata are at a level where surface water can still work effectively, even though slowly, upon them, and in spite of their great resistance they will ultimately be brought down to the common level. It will be seen that, from the point of view of subaerial erosion, a base-level plain is the only land surface which is in a condition of approximate stability.

Falls and rapids.—If in lowering its channel a stream crosses one layer of rock much harder than the next underlying, the deepening will go on more rapidly on the less resistant bed. Where the stream crosses from the harder to the less hard, the gradient is likely to become steep, and a rapids is formed. These conditions are suggested in Fig. 16 which represents the successive profiles (*a b, a c, d e, f e, g e,* and *h e*) of a stream crossing from a harder to a softer formation. Below the point *a* the stream is flowing over rock which is easily eroded, while above that point its course is over a harder formation. Just below *a* (profile *a b*) the gradient has become so steep that there are *rapids.* Under these conditions, erosion is rapid just beyond the crossing of the hard layer, and the gradient becomes higher and higher. When the steep slope of the rapids approaches verticality, the rapids become a *fall* (profile *a c*).

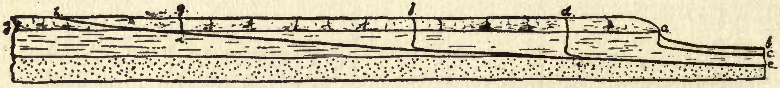


FIG. 16.—Diagram to illustrate the development of a rapid and fall. The upper layer is harder than the strata below. The successive profiles of the stream below the hard layer are represented by the lines *a b, a c, d e, f e, g e,* and *h e.*

As the water falls over the precipitous face and strikes upon the softer rock below, part of it rebounds against the base of

Skillett Falls, in the Potsdam formation, three miles southwest of Baraboo. The several small falls are occasioned by slight inequalities in the hardness of the layers.

the vertical face (Fig. 16). The result of wear at this point is the undermining of the hard layer above, and sooner or later, portions of it will fall. This will occasion the recession of the fall (profile *d e* and *f e*). As the fall recedes, it grows less and less high. When the recession has reached the point *i,* or, in other words, when the gradient of the stream below the fall crosses the junction of the beds of unequal hardness, as it ultimately must, effective undermining ceases, and the end of the fall is at hand.

When the effective undercutting ceases because the softer bed is no longer accessible, the point of maximum wear is transferred to the top of the hard bed just where the water begins to fall (*g,* Fig. 16). The wear here is no greater than before, though it is greater relatively. The relatively greater wear at this point destroys the verticality of the face, converting it into a steep slope. When this happens, the fall is a thing of the past, and rapids succeed. With continued flow the bed of the rapids becomes less and less steep, until it is finally reduced to the normal gradient of the stream (*h e*), when the rapids disappear.

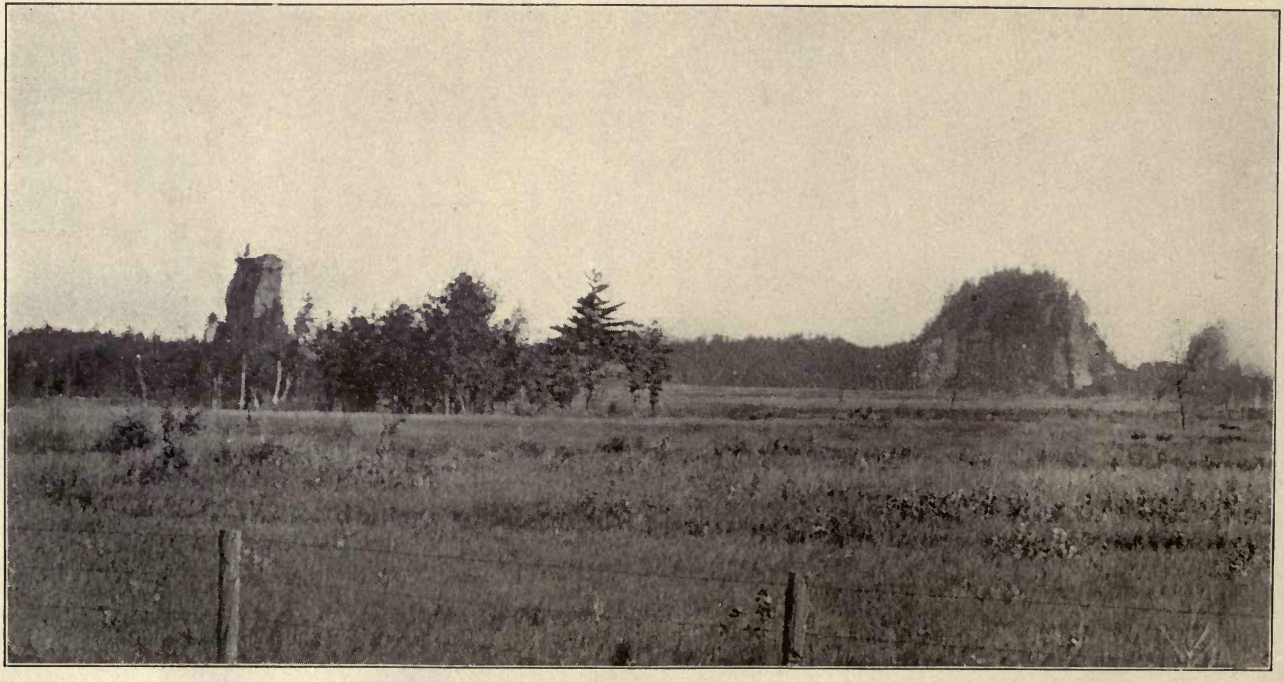
When thin layers of rock in a stream's course vary in hardness, softer beds alternating with harder ones, a series of falls such as shown in Plate XVI, may result. As they work up stream, these falls will be obliterated one by one. Thus it is seen that falls and rapids are not permanent features of the landscape. They belong to the younger period of a valley's history, rather than to the older. They are marks of topographic youth.

Narrows.—Where a stream crosses a hard layer or ridge of rock lying between softer ones, the valley will not widen so rapidly in the hard rock as above and below. If the hard beds be vertical, so that their outcrop is not shifted as the degradation of the surface proceeds, a notable constriction of the valley results. Such a constriction is a *narrows.* The Upper and Lower narrows of the Baraboo (Plate IV, p. 13) are good examples of the effect of hard rock on the widening of a valley.

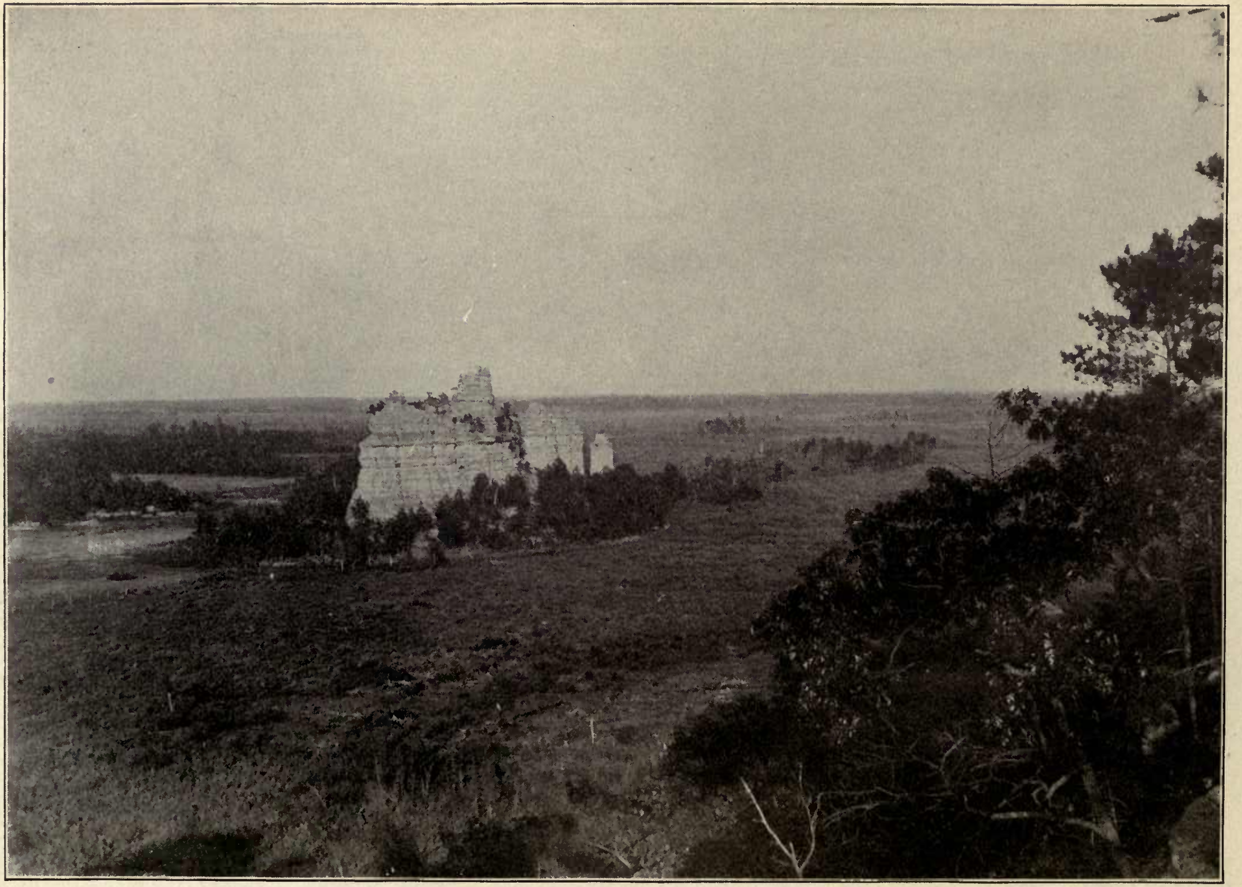
Erosion of folded strata.—The processes of river erosion would not be essentially different in case the land mass upon which erosion operated were made of tilted and folded strata. The folds would, at the outset, determine the position of the drainage lines, for the main streams would flow in the troughs (synclines) between the folds (anticlines). Once developed, the streams would lower their beds, widen their valleys, and lengthen their courses, and in the long process of time they would bring the area drained nearly to sea-level, just as in the preceding case. It was under such conditions that the general processes of subaerial erosion operated in south central Wisconsin, after the uplift of the quartzite and before the deposition of the Potsdam sandstone. It was then that the principal features of the topography of the quartzite were developed.

In regions of folded strata, certain beds are likely to be more resistant than others. Where harder beds alternate with softer, the former finally come to stand out as ridges, while the outcrops of the latter mark the sites of the valleys. Such alternations of beds of unequal resistance give rise to various peculiarities of drainage, particularly in the courses of tributaries. These peculiarities find no illustration in this region and are not here discussed.

Base-level plains and peneplains.—It is important to notice that a plane surface (base-level) developed by streams could only be developed at elevations but slightly above the sea, that is, at levels at which running water ceases to be an effective agent of erosion; for so long as a stream is actively deepening its valley, its tendency is to roughen the area which it drains, not to make it smooth. The Colorado river, flowing through high land, makes a deep gorge. All the streams of the western plateaus have deep valleys, and the manifest result of their action is to roughen the surface; but given time enough, and the streams will have cut their beds to low gradients. Then, though deepening of the valleys will cease, widening will not, and inch by inch and shower by shower the elevated lands be-



A group of mounds on the plain southwest from Camp Douglas. The base-level surface is well shown, and above it rise the remnants of the higher plain from which the lower was reduced.



Castle Rock near Camp Douglas. In this view the relation of the erosion remnant to the extensive base-leveled surface is well shown.

tween the valleys will be reduced in area, and ultimately the whole will be brought down nearly to the level of the stream beds. This is illustrated by Fig. 15.

It is important to notice further that if the original surface on which erosion began is level, there is no stage intermediate between the beginning and the end of an erosion cycle, when the surface is again level, or nearly so, though in the stage of a cycle next preceding the last—the peneplain stage (fourth profile, Fig. 15)—the surface approaches flatness. 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 seaward.

No definite degree of slope can be fixed upon as marking a base-level. The angle of slope which would practically stop erosion in a region of slight rainfall would be great enough to allow of erosion if the precipitation were greater. All that can be said, therefore, is that the angle of slope must be low. The Mississippi has a fall of less than a foot per mile for some hundreds of miles above the gulf. A small stream in a similar situation would have ceased to lower its channel before so low a gradient was reached.

The nearest approach to a base-leveled region within the area here under consideration is in the vicinity of Camp Douglas and Necedah (see Plate I, p. 4). This is indeed one of the best examples of a base-leveled plain known. Here the broad plain, extending in some directions as far as the eye can reach, is as low as it could be reduced by the streams which developed it. The erosion cycle which produced the plain was, however, not completed, for above the plain rise a few conspicuous hills (Plates XVII and XVIII, and Fig. 17), and to the west of it lie the highlands marking the level from which the low plain was reduced.

Where a region has been clearly base-leveled, isolated masses or ridges of resistant rock may still stand out conspicuously above it. The quartzite hill at Necedah is an example. Such hills are known as *monadnocks*. This name was taken from

Mount Monadnock which owes its origin to the removal of the surrounding less resistant beds. The name has now become generic. Many of the isolated hills on the peneplain east of Camp Douglas are perhaps due to superior resistance, though the rock of which they are composed belongs to the same formation as that which has been removed.

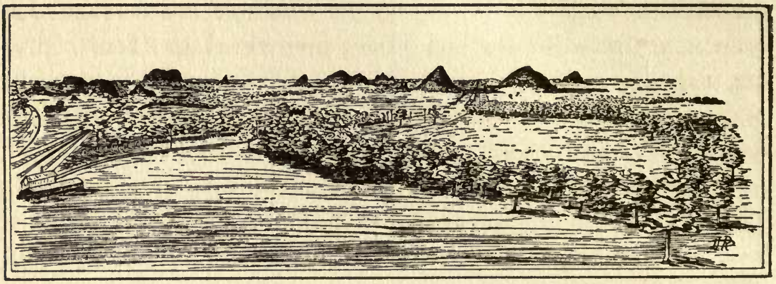


FIG. 17.—Sketch, looking northwest from Camp Douglas.

CHARACTERISTICS OF VALLEYS AT VARIOUS STAGES OF DEVELOPMENT.

In the early stages of its development a depression made by erosion has steep lateral slopes, the exact character of which is determined by many considerations. Its normal cross-section is usually described as V-shaped (Fig. 18). In the early stages of its development, especially if in unconsolidated material, the slopes are normally convex inward. If cut in solid rock, the cross section may be the same, though many variations are likely to appear, due especially to the structure of the rock and to inequalities of hardness. If a stream be swift enough to carry

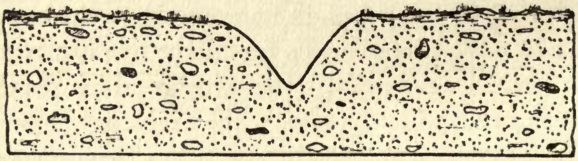


FIG. 18.—Diagrammatic cross-section of a young valley.

off not only all the detritus descending from its slopes, but to abrade its bed effectively besides, a steep-sided gorge develops. If it becomes deep, it is a canyon. For the development of a canyon, the material of the walls must be such as is capable of standing at a high angle. A canyon always indicates that the down-cutting of a stream keeps well ahead of the widening.

Of young valleys in loose material (drift) there are many examples in the eastern portion of the area here described. Shallow canyons or gorges in rock are also found. The gorge of Skillett creek at and above the Pewit's nest about three miles southwest from Baraboo, the gorge of Dell creek two miles south of Kilbourn City, and the Dalles of the Wisconsin at Kilbourn City may serve as illustrations of this type of valley.

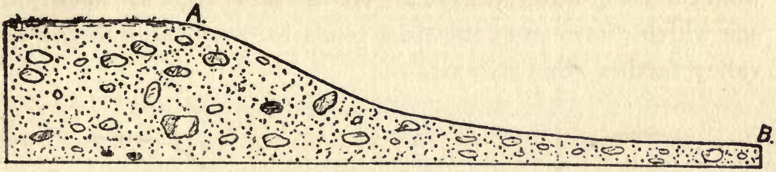


Fig. 19.—Diagrammatic profile of a young valley.

The profile of a valley at the stage of its development corresponding to the above section is represented diagrammatically by the curve A B in Fig. 19. The sketch (Pl. XIX, Fig. 1) represents a bird's-eye view of a valley in the same stage of development.

Fig. 20.—Diagrammatic cross-section of a valley at a stage corresponding with that shown in Plate XIX, Fig. 2.

At a stage of development later than that represented by the V-shaped cross-section, the corresponding section is U-shaped, as shown in Fig. 20. The same form is sketched in Plate XIX, Fig. 2. This represents a stage of development where detritus descending the slopes is not all carried away by the stream, and where the valley is being widened faster than it is deepened. Its slopes are therefore becoming gentler. The profile of the valley at this stage would be much the same as that in the preceding, except that the gradient in the lower portion would be lower.

Still later the cross section of the valley assumes the shape shown in Fig. 21, and in perspective the form sketched in Plate XX, Fig. 1. This transformation is effected partly by erosion, and partly by deposition in the valley. When a stream has cut its valley as low as conditions allow, it becomes sluggish. A sluggish stream is easily turned from side to side, and, directed against its banks, it may undercut them, causing them to recede at the point of undercutting. In its meanderings, it undercuts at various points at various times, and the aggregate result is the widening of the valley. By this process alone the stream would develop a flat at grade. At the same time all the drainage which comes in at the sides tends to carry the walls of the valley farther from its axis.

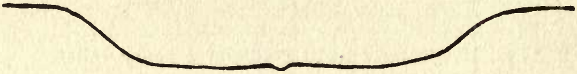


Fig. 21.—Diagrammatic cross-section of a valley at a stage later than that shown in Fig. 20.

A sluggish stream is also generally a depositing stream. Its deposits tend to aggrade (build up) the flat which its meanderings develop. When a valley bottom is built up, it becomes wider at the same time, for the valley is, as a rule, wider at any given level than at any lower one. Thus the U-shaped valley is finally converted into a valley with a flat bottom, the flat being due in large part to erosion, and in smaller part to deposition. Under exceptional circumstances the relative importance of these two factors may be reversed.

It will be seen that the cross-section of a valley affords a clue to its age. A valley without a flat is young, and increasing age is indicated by increasing width. Valleys illustrating all stages of development are to be found in the Devil's lake region. The valley of Honey creek southwest of Devil's lake may be taken

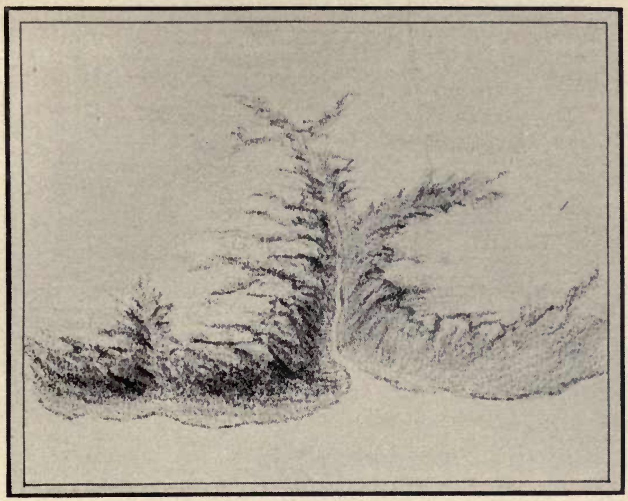


FIG. 1.

Sketch of a valley at the stage of development corresponding to the cross section shown in Fig. 18.

FIG. 2.

Sketch of a valley at the stage of development corresponding to the cross section shown in Fig. 20.

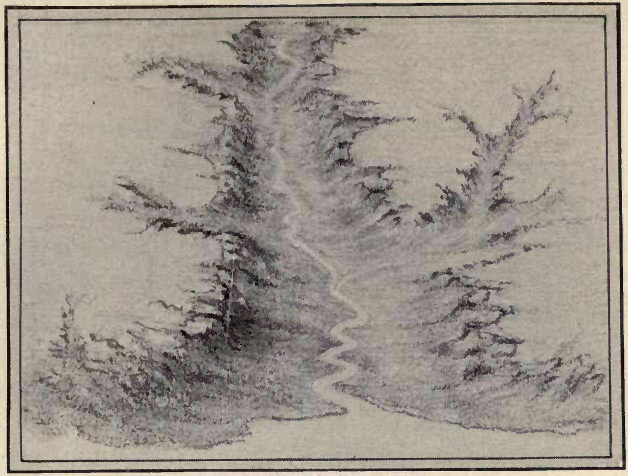


FIG. 1.

Sketch of a part of a valley at the stage of development corresponding to the cross section shown in Fig 21.

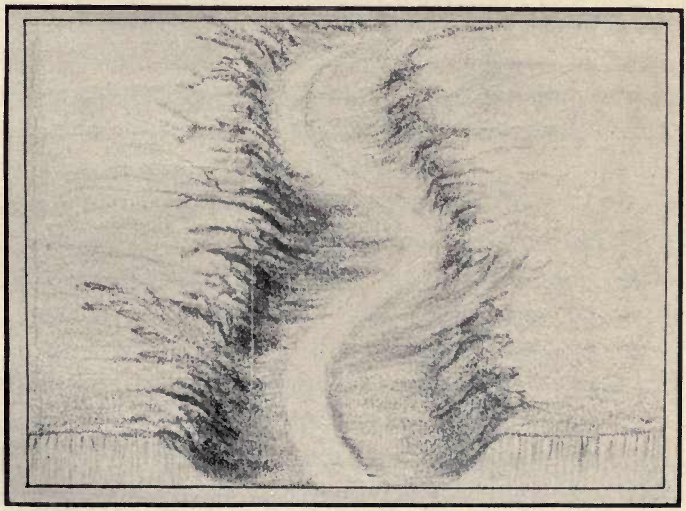


FIG. 2.

Sketch of a section of the Baraboo valley.

as an illustration of a valley at an intermediate stage of development, while examples of old valleys are found in the flat country about Camp Douglas and Necedah.

Transportation and Deposition.

Sediment is carried by streams in two ways: (1) by being rolled along the bottom, and (2) by being held in suspension. Dissolved mineral matter (which is not sediment) is also carried in the water. By means of that rolled along the bottom and carried in suspension, especially the former, the stream as already stated abrades its bed.

The transporting power of a stream of given size varies with its velocity. Increase in the declivity or the volume of a stream increases its velocity and therefore its transportive power. The transportation effected by a stream is influenced 1) by its transporting power, and 2) by the size and amount of material available for carriage. Fine material is carried with a less expenditure of energy than an equal amount of coarse. With the same expenditure of energy therefore a stream can carry a greater amount of the former than of the latter.

Since the transportation effected by a stream is dependent on its gradient, its size, and the size and amount of material available, it follows that when these conditions change so as to decrease the carrying power of the river, deposition will follow, if the stream was previously fully loaded. In other words, a stream will deposit when it becomes overloaded.

Overloading may come about in the following ways: (1) By decrease in gradient, checking velocity and therefore carrying power; (2) by decrease in amount of water, which may result from evaporation, absorption, etc.; (3) by change in the shape of the channel, so that the friction of flow is increased, and therefore the force available for transportation lessened; (4) by lateral drainage bringing in more sediment than the main stream can carry; (5) by change in the character of the material to which the stream has access; for if it becomes finer, the coarse material previously carried will be dropped, and the fine taken; and (6) by the checking of velocity when a stream flows into a body of standing water.

Topographic forms resulting from stream deposition.—The topographic forms resulting from stream deposition are various. At the bottoms of steep slopes, temporary streams build *alluvial cones* or *fans*. Along its flood-plain portion, a stream deposits more or less sediment on its flats. The part played by deposition in building a river flat has already been alluded to. A depositing stream often wanders about in an apparently aimless way across its flood plain. At the bends in its course, cutting is often taking place on the outside of a curve while deposition is going on in the inside. The valley of the Baraboo illustrates this process of cutting and building. Fig. 2, Plate XX, is based upon the features of the valley within the city of Baraboo.

Besides depositing on its flood-plain, a stream often deposits in its channel. Any obstruction of a channel which checks the current of a loaded stream occasions deposition. In this way "bars" are formed. Once started, the bar increases in size, for it becomes an obstacle to flow, and so the cause of its own growth. It may be built up nearly to the surface of the stream, and in low water, it may become an island by the depression of the surface water. In some parts of its course, as about Merrimac, the Wisconsin river is marked by such islands at low water, and by a much larger number of bars.

At their debouchures, streams give up their loads of sediment. Under favorable conditions deltas are built, but delta-building has not entered into the physical history of this region to any notable extent.

Rejuvenation of Streams.

After the development of a base-level plain, its surface would suffer little change (except that effected by underground water) so long as it maintained its position. But if, after its development, a base-level plain were elevated, the old surface in a new position would be subject to a new series of changes identical in kind with those which had gone before. The elevation would give the established streams greater fall, and they would reassume the characteristics of youth. The greater fall would accelerate their velocities; the increased velocities would entail increased erosion; increased erosion would result in the deepening of the valleys, and the deepening of the valleys would lead to the roughening of the surface. But in the course of time, the *rejuvenated* streams would have cut their valleys as low as the new altitude of the land permitted, that is, to a new base-level. The process of deepening would then stop, and the limit of vertical relief which the streams were capable of developing, would be attained. But the valleys would not stop widening when they stopped deepening, and as they widened, the intervening divides would become narrower, and ultimately lower. In the course of time they would be destroyed, giving rise to a new level surface much below the old one, but developed in the same position which the old one occupied when it originated; that is, a position but little above sea level.

If at some intermediate stage in the development of a second base-level plain, say at a time when the streams, rejuvenated by uplift, had brought half the elevated surface down to a new base-level, another uplift were to occur, the half completed cycle would be brought to an end, and a new one begun. The streams would again be quickened, and as a result they would promptly cut new and deeper channels in the bottoms of the great valleys which had already been developed. The topography which would result is suggested by the following diagram (Fig. 22)

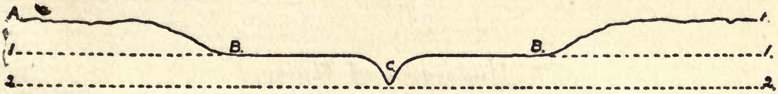


Fig. 22.—Diagram (cross-section), illustrating the topographic effect of rejuvenation by uplift.

which illustrates the cross-section which would be found after the following sequence of events: (1) The development of a base-level, A A; (2) uplift, rejuvenation of the streams, and a new cycle of erosion half completed, the new base-level being at B B; (3) a second uplift, bringing the second (incomplete) cycle of erosion to a close, and by rejuvenating the streams, inaugurating the third cycle. As represented in the diagram, the third cycle has not progressed far, being represented only by the narrow valley C. The base-level is now 2–2, and the valley represented in the diagram has not yet reached it.

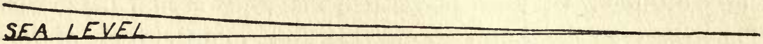


FIG. 23.—Normal profile of a valley bottom in a non-mountainous region.

The rejuvenation of a stream shows itself in another way. The normal profile of a valley bottom in a non-mountainous region is a gentle curve, concave upward with gradient increasing from debouchure to source. Such a profile is shown in Fig. 23. Fig. 24, on the other hand, is the profile of a rejuvenated stream. The valley once had a profile similar to that shown in Fig. 23. Below B its former continuation is marked by the dotted line B C. Since rejuvenation the stream has deepened the lower part of its valley, and established there a profile in harmony with the new conditions. The upper end of the new curve has not yet reached byond B.

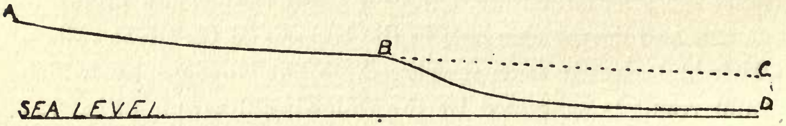


FIG. 24.—Profile of a stream rejuvenated by uplift.

Underground Water.

In what has preceded, reference has been made only to the results accomplished by the water which runs off over the surface. The water which sinks beneath it is, however, of no small importance in reducing a land surface. The enormous amount of mineral matter in solution in spring water bears witness to the efficiency of the ground water in dissolving rock, for since the water did not contain the mineral matter when it entered the soil, it must have acquired it below the surface. By this means alone, areas of more soluble rock are lowered below those of less solubility. Furthermore, the water is still active as a solvent agent after a surface has been reduced to so low a gradient that the run-off ceases to erode mechanically.

CHAPTER IV.

EROSION AND THE DEVELOPMENT OF STRIKING SCENIC FEATURES.

The uplift following the period of Paleozoic deposition in south central Wisconsin, inaugurated a period of erosion which, with some interruptions, has continued to the present day. The processes of weathering began as soon as the surface was exposed to the weather, and corrasion by running water began with the first shower which fell upon it. The sediment worn from the land was carried back to the sea, there to be used in the building of still younger formations.

The rate of erosion of a land surface depends in large measure upon its height. As a rule, it is eroded rapidly if high, and but slowly if low.

It is not known whether the lands of central Wisconsin rose to slight or to great heights at the close of the period of Paleozoic sedimentation. It is therefore not known whether the erosion was at the outset rapid or slow. If the land of southern Wisconsin remained low for a time after the uplift which brought the Paleozoic sedimentation to a close, weathering would have exceeded transportation and corrasion. A large proportion of the rainfall would have sunk beneath the surface, and found its way to the sea by subterranean routes. Loosening of material by alternate wetting and drying, expansion and contraction, freezing and thawing, and by solution, might have gone on steadily, but so long as the land was low, there would have been little run-off, and that little would have flowed over a surface of gentle slopes, and transportation would have been at a minimum. On the whole, the degradation of the land under these conditions could not have advanced rapidly.

If, on the other hand, the land was raised promptly to a considerable height, erosion would have been vigorous at the outset. The surface waters would soon have developed valleys which the streams would have widened, deepened and lengthened. Both transportation and corrasion would have been active, and whatever material was prepared for transportation by weathering, and brought into the valleys by side-wash, would have been hurried on its way to the sea, and degradation would have proceeded rapidly.

Establishment of drainage.—Valleys were developed in this new land surface according to the principles already set forth. Between the valleys there were divides, which became higher as the valleys became deeper, and narrower as the valleys widened. Ultimately the ridges were lowered, and many of them finally eliminated in the manner already outlined. The distance below the original surface and that at which the first series of new flats were developed is conjectural, but it would have depended on the height of the land. So far as can now be inferred, the new base-plain toward which the streams cut may have been 400 or 500 feet below the crests of the quartzite ridges. It was at this level that the oldest base-plain of which this immediate region shows evidence, was developed.

Had the quartzite ranges not been completely buried by the Paleozoic sediments, they would have appeared as ridges on the new land surface, and would have had a marked influence on the development of the drainage of the newly emerged surface. But as the ranges were probably completely buried, the drainage lines were established regardless of the position of the hard, but buried ridges. When in the process of degradation the quartzite surfaces were reached, the streams encountered a formation far more resistant than the surrounding sandstone and limestone. As the less resistant strata were worn away, the old quartzite ridges, long buried, again became prominent topographic features. In this condition they were "resurrected mountains."

If, when erosion on the uplifted surface of Paleozoic rocks began, a valley had been located directly over the buried quartzite ridge, and along its course, it would have been deepened normally until its bottom reached the crest of the hard formation. Then, instead of sinking its valley vertically downward into the quartzite, the stream would have shifted its channel down the slope of the range along the junction of the softer and harder rock (Fig. 25). Such changes occasioned by the nature and position of the rock concerned, are known as *adjustments.*

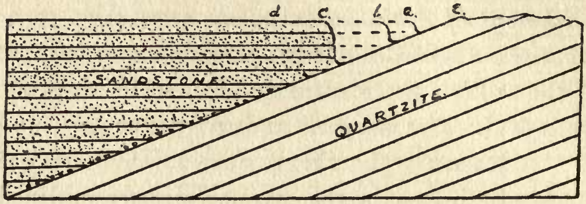


FIG. 25.—Diagram illustrating the hypothetical case of a stream working down the slope of the quartzite range. The successive sections of the valley are suggested by the lines ae, be, ce and de.

Streams which crossed the quartzite ridges on the overlying strata might have held their courses even after their valleys were lowered to the level of the quartzite. Such streams would have developed narrows at the crossing of the quartzite. In so far as there were passes in the quartzite range before the deposition of the Paleozoic beds, they were filled during the long period of sedimentation, to be again cleared out during the subsequent period of erosion. The gap in the South range now occupied by the lake was a narrows in a valley which existed, though perhaps not to its present depth, before the Potsdam sandstone was deposited. It was filled when the sediments of that formation were laid down, to be again opened, and perhaps deepened, in the period of erosion which followed the deposition of the Paleozoic series

During the earliest period of erosion of which there is positive evidence, after the uplift of the Paleozoic beds, the softer formations about the quartzite were worn down to a level 400 or 500 feet below the crests of the South quartzite range. At this lower level, an approximate plain, a peneplain, was developed, the level of which is shown by numerous hills, the summits of which now reach an elevation of from 1,000 to 1,100 feet above the sea. At the time of its development, this peneplain was but little above sea level, for this is the only elevation at which running water can develop such a plain. Above the general level of this plain rose the quartzite ranges as elongate monadnocks,[1] the highest parts of which were fully 500 feet above the plain. A few other points in the vicinity failed to be reduced to the level of the peneplain. The 1,320 foot hill (*d*, Plate XXXVII, p. 108), one and one-half miles southeast of the Lower narrows, and Gibraltar Rock (*e*, same Plate), two miles southeast of Merrimac, rose as prominences above it. It is possible that these crests are remnants of a base-level plain older than that referred to above. If while the quartzite remained much as now, the valleys in the sandstone below 1,000 or 1,100 feet were filled, the result would correspond in a general way to the surface which existed in this region when the first distinctly recognizable cycle of erosion was brought to a close. Above the undulating plain developed in the sandstone and limestone, the main quartzite ridge would have risen as a conspicuous ridge 400 to 500 feet.

This cycle had not been completed, that is, the work of base-leveling had not been altogether accomplished, when the peneplain was elevated, and the cycle, though still incomplete, brought to a close. By the uplift, the streams were rejuvenated, and sunk their valleys into the elevated peneplain. Thus a new cycle of erosion was begun, and the uplifted peneplain was dissected by the quickened streams which sank their valleys promptly into the slightly resistant sandstone. At their new base-level, they ultimately developed new flats. This cycle of erosion appears to have advanced no farther than to the development of wide flats along the principal streams, such as the Wisconsin and the Baraboo, and narrow ones along the subordinate water courses, when it was interrupted. Along the main streams the new flats were at a level which is now from 800 to

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[1] **See page 51.**

900 feet above the sea, and 700 to 800 feet below the South quartzite range. It was at this time that the plains about Camp Douglas and Necedah, already referred to, were developed. During this second incomplete cycle, the quartzite ranges, resisting erosion, came to stand up still more prominently than during the first.

The interruption of this cycle was caused by the advent of the glacial period which disturbed the normal course of erosion. This period was accompanied and followed by slight changes of level which also had their influence on the streams. The consideration of the effects of glaciation and of subsequent river erosion are postponed, but it may be stated that within the area which was glaciated the post-glacial streams have been largely occupied in removing the drift deposited by the ice from the preglacial valleys, or in cutting new valleys in the drift. The streams outside the area of glaciation were less seriously disturbed.

At levels other than those indicated, partial base-levels are suggested, and although less well marked in this region, they might, in the study of a broader area, bring out a much more complicated erosion history. As already suggested, one cycle may have preceded that the remnants of which now stand 1,000–1,100 feet above sea level, and another may have intervened between this and that marked by the 800 to 900 foot level.

From the foregoing it is clear that the topography of the region is, on the whole, an erosion topography, save for certain details in its eastern portion. The valleys differ in form and in size, with their age, and with the nature of the material in which they are cut; while the hills and ridges differ with varying relations to the streams, and with the nature of the material of which they are composed.

Striking Scenic Features.

In a region so devoid of striking scenery as the central portion of the Mississippi basin, topographic features which would be

Cleopatra's Needle. West Bluff of Devil's Lake.

Turk's Head. West Bluff of Devil's Lake.

Devil's Doorway, East of Devil's Lake.

passed without special notice in regions of greater relief, become the objects of interest. But in south central Wisconsin there are various features which would attract attention in any region where the scenery is not mountainous.

On the bluffs at Devil's lake there are many minor features which are sure to attract the attention of visitors. Such are "Cleopatra's Needle" (Plate XXI), "Turk's Head" (Plate XXII), and the "Devil's Doorway" (Plate XXIII).

These particular forms have resulted from the peculiar weathering of the quartzite. The rock is affected by several systems of vertical or nearly vertical joint planes (cracks), which divide the whole formation into a series of vertical columns. There are also horizontal and oblique planes of cleavage dividing the columns, so that the great quartzite pile may be said to be made up of a series of blocks, which are generally in contact with one another. The isolated pillars and columns which have received special names have been left as they now stand by the falling away of the blocks which once surrounded them. They themselves must soon follow. The great talus slopes at the base of the bluffs, such as those on the west side of the lake and on the East bluff near its southeast corner, Plate XXIV, are silent witnesses of the extent to which this process has already gone. The blocks of rock of which they are composed have been loosened by freezing water, by the roots of trees, and by expansion and contraction due to changing temperature, and have fallen from their former positions to those they now occupy. Their descent, effected by gravity directly, is, it will be noted, the first step in their journey to the sea, the final resting place of all products of land degradation.

The Baraboo bluffs.—Nowhere in southern Wisconsin, or indeed in a large area adjacent to it, are there elevations which so nearly approach mountains as the ranges of quartzite in the vicinity of Baraboo and Devil's lake. So much has already been said of their history that there is need for little further description. Plate IV gives some idea of the appearance of the ranges. The history of the ranges, already outlined, involves the following stages: (1) The deposition of the sands in Huronian time; (2) the change of the sand to sandstone and the sandstone to quartzite; (3) the uplift and deformation of the beds; (4) igneous intrusions, faulting, crushing, and shoaring, with the development of schists accompanying the deformation; (5) a prolonged period of erosion during which the folds of quartzite were largely worn away, though considerable ridges, the Huronian mountains of early Cambrian times, still remained high above their surroundings; (6) the submergence of the region, finally involving even the crests of the ridges of quartzite; (7) a protracted period of deposition during which the Potsdam sandstone and several later Paleozoic formations were laid down about, and finally over, the quartzite, burying the mountainous ridges; (8) the elevation of the Paleozoic sea-bottom, converting it into land; (9) a long period of erosion, during which the upper Paleozoic beds were removed, and the quartzite re-discovered. Being much harder than the Paleozoic rocks, the quartzite ridges again came to stand out as prominent ridges, as the surrounding beds of relatively slight resistance were worn away. They are "resurrected" mountains, though not with the full height which they had in pre-Cambrian time, for they are still partially buried by younger beds.

The narrows in the quartzite.—There are four narrows or passes in the quartzite ridges, all of which are rather striking features. One of them is in the South range, one in the North range near its eastern end, while the others are in an isolated area of quartzite at Ablemans which is really a continuation of the North range. Two of these narrows are occupied by the Baraboo river, one by Narrows creek, and the fourth by Devil's lake.

From Ablemans to a point several miles east of Baraboo, the Baraboo river flows through a capacious valley. Where it crosses the North range, six miles or more north of east of Baraboo, the broad valley is abruptly constricted to a narrow pass with precipitous sides, about 500 feet high (c, Plate XXXVII). This constriction is the Lower narrows, conspicuous from many

Talus slope on the east bluff of Devil's lake.

points on the South range, and from the plains to the north. Beyond the quartzite, the valley again opens out into a broad flat.

Seen from a distance, the narrows has the appearance of an abrupt notch in the high ridge (Plate IV, p. 13). Seen at closer range, the gap is still more impressive. It is in striking contrast with the other narrows in that there are no talus accumulations at the bases of the steep slopes, and in that the slopes are relatively smooth and altogether free from the curious details of sculpture seen in the other gaps where the slopes are equally steep.

The Upper narrows of the Baraboo at Ablemans (b, Plate II), is in some ways similar to the Lower, though less conspicuous because less deep. Its slopes are more rugged, and piles of talus lie at their bases as at Devil's lake. This narrows also differs from the Lower in that the quartzite on one side is covered with Potsdam conglomerate, which overlies the truncated edges of the vertical layers of quartzite with unconformable contact. So clear an example of unconformity is not often seen. Potsdam sandstone is also seen to rest against the quartzite on either side of the narrows (Fig. 26), thus emphasizing the unconformity. The beauty and interest of this narrows is enhanced by the quartzite breccia (p. 18) which appears on its walls.

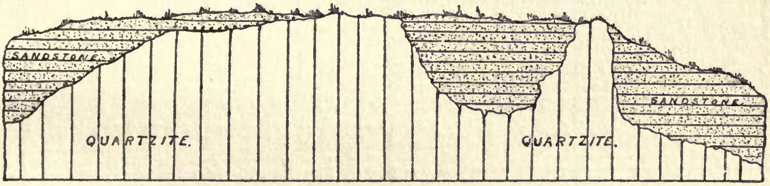

FIG. 26.—A generalized diagrammatic cross-section at the Upper narrows, to show the relation of the sandstone to the quartzite.

One and one-half miles west of Ablemans (*a,* Plate II) is the third pass in the north quartzite ridge. This pass is narrower than the others, and is occupied by Narrows creek. Its walls are nearly vertical and possess the same rugged beauty as those at Ablemans. As at the Upper narrows, the beds of quartzite here are essentially vertical. They are indeed the continuation of the beds exposed at that place.

The fourth narrows is across the South range (i, Plate II). It is not now occupied by a stream, though like the others it was cut by a stream, which was afterwards shut out from it. Because of its depth, 600 feet, and the ruggedness of its slopes, and because of its occupancy by the lake, this pass is the center of interest for the whole region. So much has already been said concerning it in other portions of this report that further description is here omitted. The manner in which the pass was robbed of its stream will be discussed later (p. 138).

The history of these several narrows, up to the time of the glacial period may now be summarized. Since remnants of Potsdam sandstone are found in some of them, it is clear that they existed in pre-Cambrian time,[1] and there is no reason to doubt that they are the work of the streams of those ancient days, working as streams now work. Following the pre-Cambrian period of erosion during which the notches were cut, came the submergence of the region, and the gaps were filled with sand and gravel, and finally the ridges themselves were buried. Uplift and a second period of erosion followed, during which the quartzite ranges were again exposed by the removal of the beds which overlay them, and the narrows cleaned out and deepened, and again occupied by streams This condition of things lasted up to the time when the ice invaded the region.

Glens.—No enumeration of the special scenic features of this region would be complete without mention of Parfrey's and Dorward's glens (*a* and *b*, Plate XXXVII, and Plate XXV). Attention has already been directed to them as illustrations of young valleys, and as places where the Potsdam conglomerate is well shown, but they are attractive from the scenic point of view. Their frequent mention in earlier parts of this report makes further reference to them at this point unnecessary.

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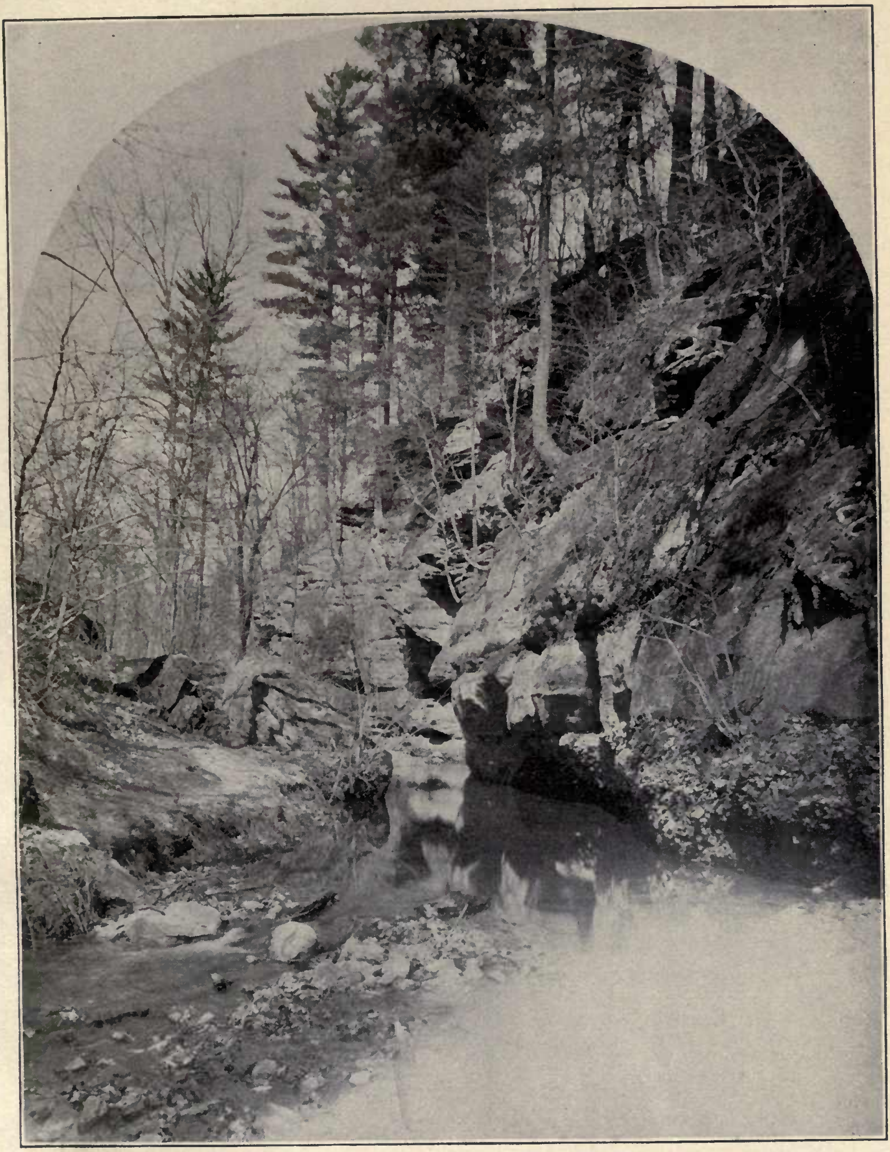
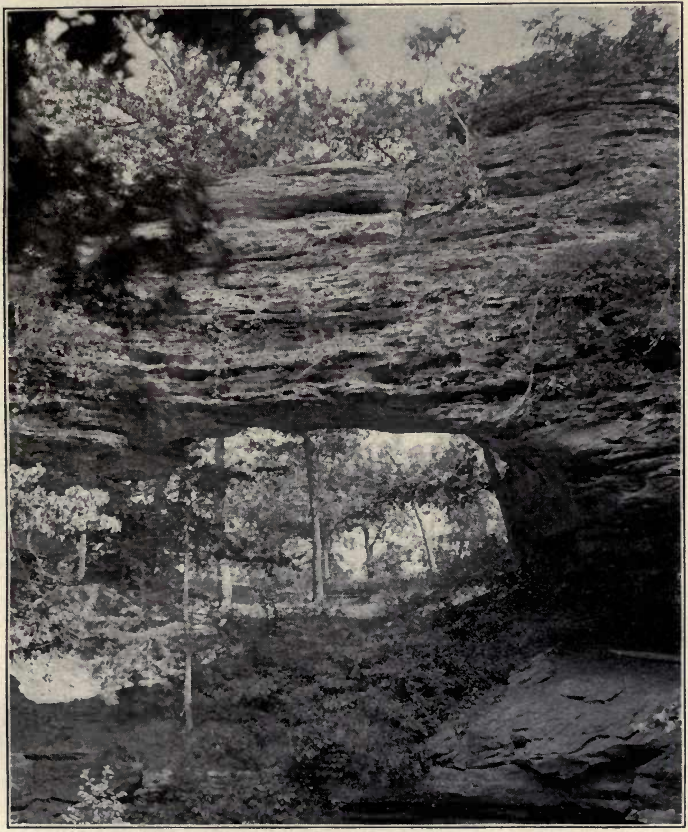
[1] It is not here asserted that these notches were as deep as now, in pre-Cambrian time. It is, however, certain that the quartzite was deeply eroded, previous to the deposition of the Potsdam sandstone.



In Dorward's Glen. The basal conglomerate of the Potsdam formation is shown at the lower right-hand corner, and is overlain by sandstone. (Photograph furnished by Mr. Wilfred Dorward).



Natural bridge near Denzer.

Navy Yard. Dalles of the Wisconsin.

Pine Hollow (k, Plate II) is another attractive gorge on the south flank of the greater quartzite range. The rock at this point is especially well exposed. This gorge is beyond the drift-covered portion of the range, and therefore dates from the pre-glacial time.

The Pewit's nest, about three miles southwest of Baraboo (m, Plate II), is another point of interest. Above the "nest," Skillett creek flows through a narrow and picturestque gorge in the Potsdam sandstone. The origin of this gorge is explained elsewhere (p. 53).

Natural Bridge.—About two miles north and a little west of the village of Denzer (Sec. 17, T. 10 N., R. 5 E.), is a small natural bridge, which has resulted from the unequal weathering of the sandstone (see Plate XXVI). The "bridge" is curious, rather than beautiful or impressive.

The Dalles of the Wisconsin.—The *dalles* is the term applied to a narrow canyon-like stretch of the Wisconsin valley seven miles in length, near Kilbourn City (see frontispiece). The depth of the gorge is from 50 to 100 feet. The part above the bridge at Kilbourn City is the "Upper dalles;" that below, the "Lower dalles." Within this stretch of the valley are perhaps the most picturesque features of the region.

The sides of the gorge are nearly vertical much of the way, and at many points are so steep on both sides that landing would be impossible. Between these sandstone walls flows the deep and swift Wisconsin river.

Such a rock gorge is in itself a thing of beauty, but in the dalles there are many minor features which enhance the charm of the whole.

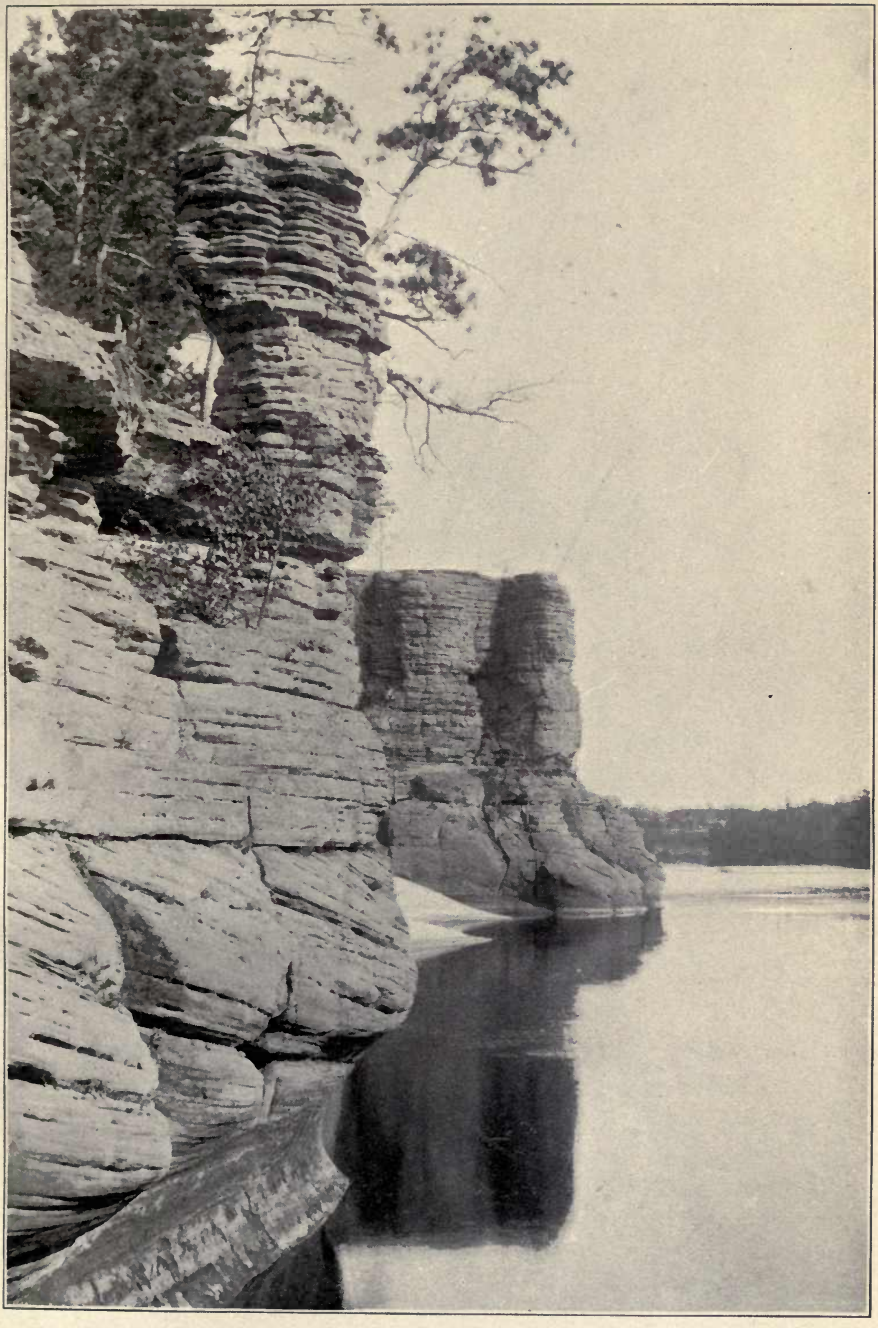
One of the features which deserves especial mention is the peculiar crenate form of the walls at the banks of the river. This is perhaps best seen in that part of the dalles known as the "Navy Yard." Plate XXVII. The sandstone is affected by a series of vertical cracks or joints. From weathering, the rock along these joints becomes softened, and the running water wears the softened rock at the joint planes more readily than other parts of its bank, and so develops a reëntrant at these points. Rain water descending to the river finds and follows the joint planes, and thus widens the cracks. As a result of stream and rain and weathering, deep reëntrant angles are produced. The projections between are rounded off so that the banks of the stream have assumed the crenate form shown in Plate XXVIII, and Frontispiece.

When this process of weathering at the joints is carried sufficiently far, columns of rock become isolated, and stand out on the river bluffs as "chimneys" (Plate XXVIII). At a still later stage of development, decay of the rock along the joint planes may leave a large mass of rock completely isolated. "Steamboat rock" (Plate XII, p. 30) and "Sugar bowl" (Plate XXIX) are examples of islands thus formed.

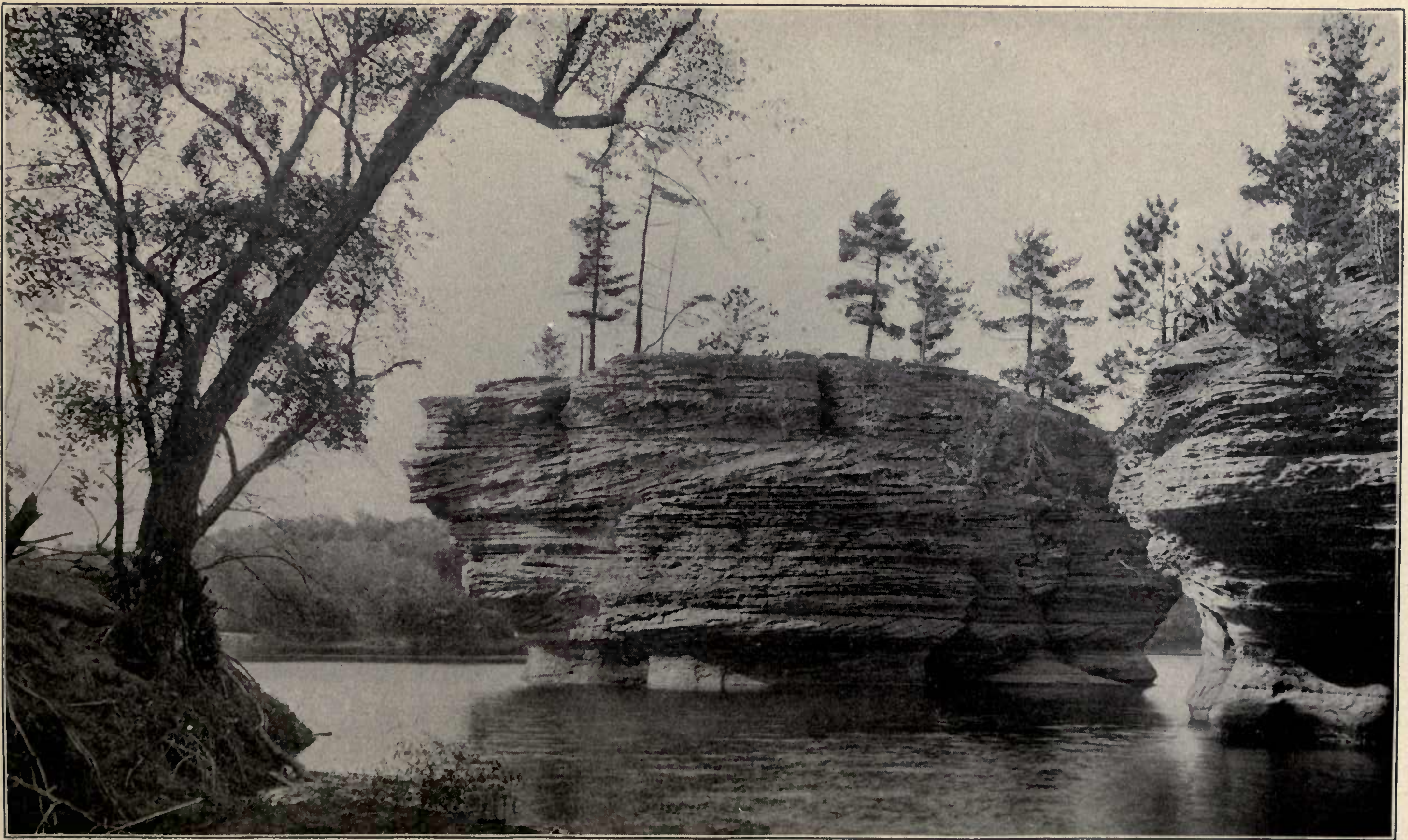
The walls of sandstone weather in a peculiar manner at some points in the Lower dalles, as shown on Plate XXX. The little ridges stand out because they are harder and resist weathering better than the other parts. This is due in part at least to the presence of iron in the more resistant portions, cementing them more firmly. In the process of segregation, cementing materials are often distributed unequally.

The effect of differences in hardness on erosion is also shown on a larger scale and in other ways. Perhaps the most striking illustration is *Stand rock* (Plate XXXI, p. 72), but most of the innumerable and picturesque irregularities on the rock walls are to be accounted for by such differences.

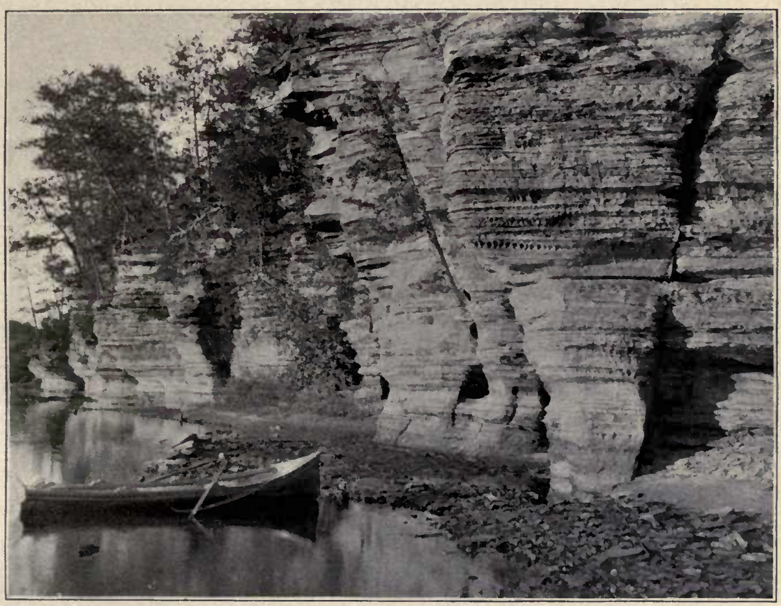
Minor valleys tributary to the Wisconsin, such as *Witch's gulch* and *Cold Water canyon* deserve mention, both because of their beauty, and because they illustrate a type of erosion at an early stage of valley development. In character they are comparable to the larger gorge to which they are tributary. In the downward cutting, which far exceeds the side wear in these tributary canyons, the water has excavated large bowl or jug-like forms. In Witch's gulch such forms are now being excavated. They are developed just below falls, where the water carrying debris, eddies, and the jugs or pot-holes are the result



Chimney Rock. Dalles of the Wisconsin. Cross-bedding well shown in foreground near bottom.



An Island in the Lower Dalles.



View in lower Dalles showing peculiar honeycomb weathering.

of the wear effected by the eddies. The "Devil's jug" and many similar hollows are thus explained.

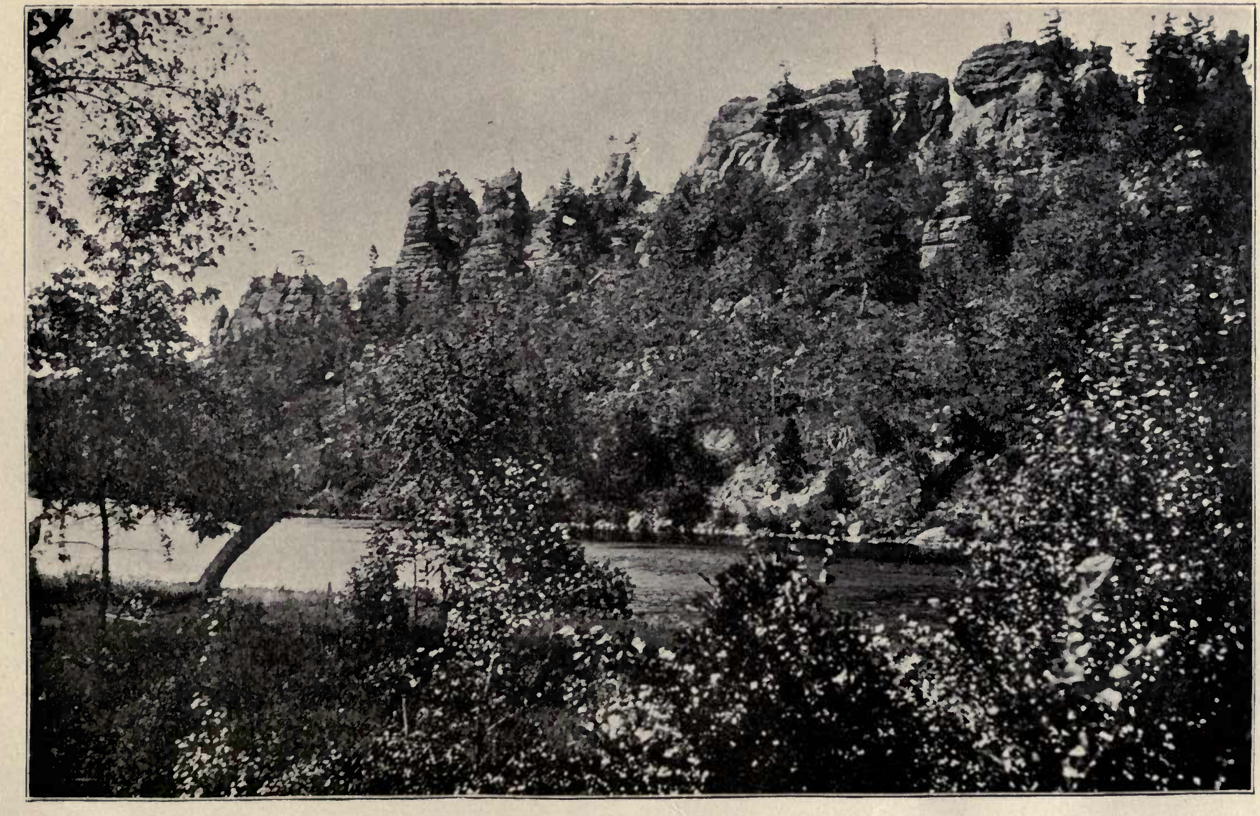
The mounds and castle rocks.—In the vicinity of Camp Douglas and over a large area to the east, are still other striking topographic forms, which owe their origin to different conditions, though they were fashioned by the same forces. Here there are many "tower" or "castle" rocks, which rise to heights varying from 75 to 190 feet above the surrounding plain. They are remnants of beds which were once continuous over the low lands above which the hills now rise. In Plates XVII and XVIII (p. 51) the general character of these hills is shown. The rock of which they are composed is Potsdam sandstone, the same formation which underlies most of the area about Baraboo. The effect of the vertical joints and of horizontal layers of unequal hardness is well shown. Rains, winds, frosts, and roots are still working to compass the destruction of these picturesque hills, and the talus of sand bordering the "castle" is a reminder of the fate which awaits them. These hills are the more conspicuous and the more instructive since the plain out of which they rise is so flat. It is indeed one of the best examples of a base-level plain to be found on the continent.

The crests of these hills reach an elevation of between 1,000 and 1,100 feet. They appear to correspond with the level of the first peneplain recognized in the Devil's lake region. It was in the second cycle of erosion, when their surroundings were brought down to the new base-level, that these hills were left. West of Camp Douglas, there are still higher elevations, which seem to match Gibraltar rock (see p. 63).

The Friendship "mounds" north of Kilbourn City, the castellated hills a few miles northwest of the same place, and Petenwell peak on the banks of the Wisconsin (Plate XXXII), are further examples of the same class of hills. All are of Potsdam sandstone.

In addition to the "castle" rocks and base-level plain about Camp Douglas, other features should be mentioned. No other portion of the area touched upon in this report affords such fine examples of the different types of erosion topography. In the base-level plain are found "old-age" valleys, broad and shallow, with the stream meandering in a wide flood-plain. Traveling up such a valley, the topography becomes younger and younger, and the various stages mentioned on p. 46, and suggested in Plate XIX, Figs. 1 and 2, and Plate XX (p. 54), Fig. 1, are here illustrated.

Stand Rock. Upper end of the Upper Dalles.



Petenwell Peak.

CHAPTER V.

THE GLACIAL PERIOD.

The eastern part of the area with which this report deals, is covered with a mantle of drift which, as already pointed out, has greatly modified the details of its topography. To the consideration of the drift and its history attention is now turned.

The drift.—The drift consists of a body of clay, sand, gravel and bowlders, spread out as a cover of unequal thickness over the rock formations beneath. These various classes of material may be confusedly commingled, or they may be more or less distinctly separated from one another. When commingled, all may be in approximately equal proportions, or any one may predominate over any or all the others to any extent.

It was long since recognized that the materials of the drift did not originate where they now lie, and that, in consequence, they sustain no genetic relationship to the strata on which they rest. Long before the drift received any special attention from geologists, it was well known that it had been transported from some other locality to that where it now occurs. The early conception was that it had been drifted into its present position from some outside source by water. It was this conception of its origin which gave it the name of *drift.* It is now known that the drift was deposited by glacier ice and the waters which arose from its melting, but the old name is still retained.

Clearly to understand the origin of the drift, and the method by which it attained its present distribution, it may be well to consider some elementary facts and principles concerning climate and its effects, even at the risk of repeating what is already familiar.

Snow fields and ice sheets.—The temperature and the snowfall of a region may stand in such a relation to each other that the summer's heat may barely suffice to melt the winter's snow. If under these circumstances the annual temperature were to be reduced, or the fall of snow increased, the summer's heat would fail to melt all the winter's snow, and some portion of it would endure through the summer, and through successive summers, constituting a perennial snow-field. Were this process once inaugurated, the depth of the snow would increase from year to year. The area of the snow-field would be extended at the same time, since the snow-field would so far reduce the surrounding temperature as to increase the proportion of the annual precipitation which fell as snow. In the course of time, and under favorable conditions, the area of the snow-field would attain great dimensions, and the depth of the snow would become very great.

As in the case of existing snow fields the lower part of the snow mass would eventually be converted into ice. Several factors would conspire to this end. 1. The pressure of the overlying snow would tend to compress the lower portion, and snow rendered sufficiently compact by compression would be regarded as ice. 2. Water arising from the melting of the surface snow by the sun's heat, would percolate through the superficial layers of snow, and, freezing below, take the form of ice. 3. On standing, even without pressure or partial melting, snow appears to undergo changes of crystallization which render it more compact. In these and perhaps other ways, a snow-field becomes an ice-field, the snow being restricted to its surface.

Eventually the increase in the depth of the snow and ice in a snow-field will give rise to new phenomena. Let a snow and ice field be assumed in which the depth of snow and ice is greatest at the center, with diminution toward its edges. The field of snow, if resting on a level base, would have some such cross-section as that represented in the diagram, Fig. 27.

When the thickness of the ice has become considerable, it is evident that the pressure upon its lower and marginal parts will be great. We are wont to think of ice as a brittle solid. If in its place there were some plastic substance which would yield to pressure, the weight of the ice would cause the marginal parts to extend themselves in all directions by a sort of flowing motion.

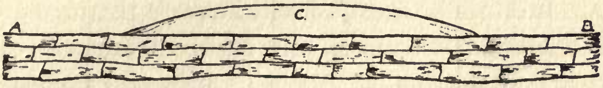


FIG. 27.—Diagrammatic cross-section of a field of ice and snow (c) resting on a level base A–B.

Under great pressure, many substances which otherwise appear to be solid, exhibit the characteristics of plastic bodies. Among the substances exhibiting this property, ice is perhaps best known. Brittle and resistant as it seems, it may yet be molded into almost any desirable form if subjected to sufficient pressure, steadily applied through long intervals of time. The changes of form thus produced in ice are brought about without visible fracture. Concerning the exact nature of the movement, physicists are not agreed; but the result appears to be essentially such as would be brought about if the ice were capable of flowing, with extreme slowness, under great pressure continuously applied.

In the assumed ice-field, there are the conditions for great pressure and for its continuous application. If the ice be capable of moving as a plastic body, the weight of the ice would induce gradual movement outward from the center of the field, so that the area surrounding the region where the snow accumulated would gradually be encroached upon by the spreading of the ice. Observation shows that this is what takes place in every snow-field of sufficient depth. Motion thus brought about is glacier motion, and ice thus moving is glacier ice.

Once in motion, two factors would determine the limit to which the ice would extend itself: 1) the rate at which it advances; and 2) the rate at which the advancing edge is wasted. The rate of advance would depend upon several conditions, one of which, in all cases, would be the pressure of the ice which started and which perpetuates the motion. If the pressure be increased the ice will advance more rapidly, and if it advance more rapidly, it will advance farther before it is melted. Other things remaining constant, therefore, increase of pressure will cause the ice-sheet to extend itself farther from the center of motion. Increase of snowfall will increase the pressure of the snow and ice field by increasing its mass. If, therefore, the precipitation over a given snow-field be increased for a period of years, the ice-sheet's marginal motion will be accelerated, and its area enlarged. A decrease of precipitation, taken in connection with unchanged wastage would decrease the pressure of the ice and retard its movement. If, while the rate of advance diminished, the rate of wastage remained constant, the edge of the ice would recede, and the snow and ice field be contracted.

The rate at which the edge of the advancing ice is wasted depends largely on the climate. If, while the rate of advance remains constant, the climate becomes warmer, melting will be more rapid, and the ratio between melting and advance will be increased. The edge of the ice will therefore recede. The same result will follow, if, while temperature remains constant, the atmosphere becomes drier, since this will increase wastage by evaporation. Were the climate to become warmer and drier at the same time, the rate of recession of the ice would be greater than if but one of these changes occurred.

If, on the other hand, the temperature over and about the ice-field be lowered, melting will be diminished, and if the rate of movement be constant, the edge of the ice will advance farther than under the earlier conditions of temperature, since it has more time to advance before it is melted. An increase in the humidity of the atmosphere, while the temperature remains constant, will produce the same result, since increased humidity of the atmosphere diminishes evaporation. A decrease of temperature, decreasing the melting, and an increase of humidity, decreasing the evaporation, would cause the ice to advance farther than either change alone, since both changes decrease the wastage. If, at the same time that conditions so change as to increase the rate of movement of the ice, climatic conditions so change as to reduce the rate of waste, the advance of the ice before it is melted will be greater than where only one set of conditions is altered. If, instead of favoring advance, the two series of conditions conspire to cause the ice to recede, the recession will likewise be greater than when but one set of conditions is favorable thereto.

Greenland affords an example of the conditions here described. A large part of the half million or more square miles which this body of land is estimated to contain, is covered by a vast sheet of snow and ice, thousands of feet in thickness. In this field of snow and ice, there is continuous though slow movement. The ice creeps slowly toward the borders of the island, advancing until it reaches a position where the climate is such as to waste (melt and evaporate) it as rapidly as it advances.

The edge of the ice does not remain fixed in position. There is reason to believe that it alternately advances and retreats as the ratio between movement and waste increases or decreases. These oscillations in position are doubtless connected with climatic changes. When the ice edge retreats, it may be because the waste is increased, or because the snowfall is decreased, or both. In any case, when the ice edge recedes from the coast, it tends to recede until its edge reaches a position where the melting is less rapid than in its former position, and where the advance is counterbalanced by the waste. This represents a condition of equilibrium so far as the edge of the ice is concerned, and here the edge of the ice would remain so long as the conditions were unchanged.

When for a period of years the rate of melting of the ice is diminished, or the snowfall increased, or both, the ice edge advances to a new line where melting is more rapid than at its former edge. The edge of the ice would tend to reach a position where waste and advance balance. Here its advance would cease, and here its edge would remain so long as climatic conditions were unchanged.

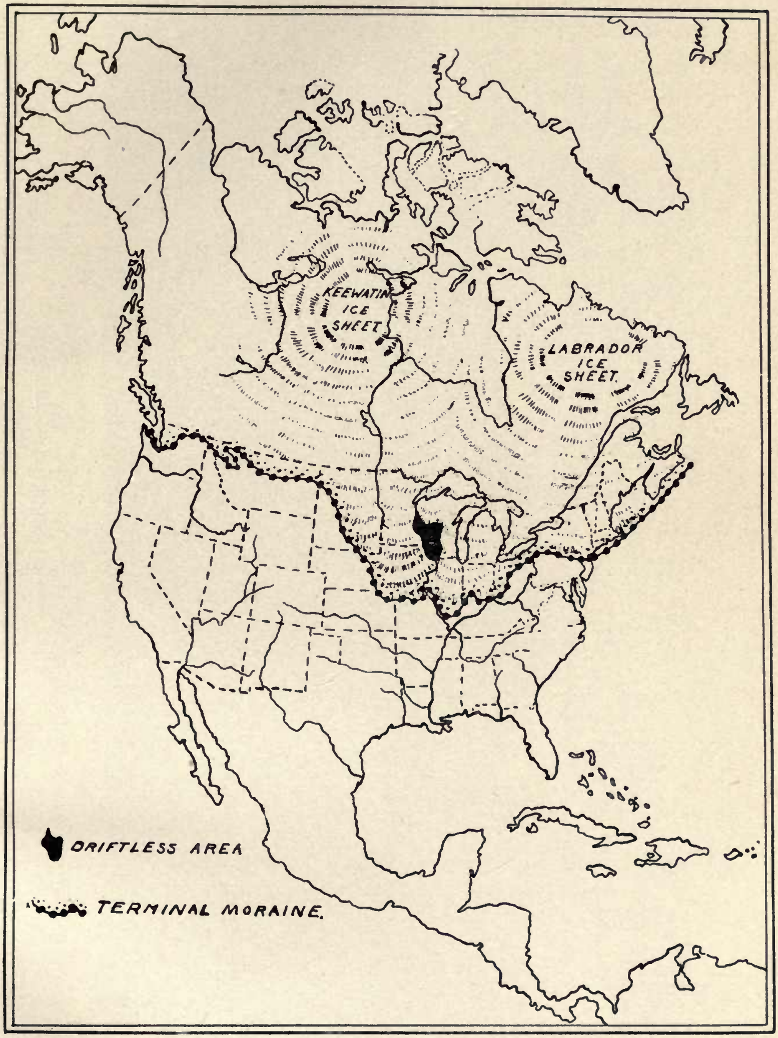
If the conditions determining melting and flowage be continually changing, the ice edge will not find a position of equilibrium, but will advance when the conditions are favorable for advance, and retreat when the conditions are reversed.

Not only the edge of the ice in Greenland, but the ends of existing mountain glaciers as well, are subject to fluctuation, and are delicate indices of variations in the climate of the regions where they occur.

The North American ice sheet.—In an area north of the eastern part of the United States and in another west of Hudson Bay it is believed that ice sheets similar to that which now covers Greenland began to accumulate at the beginning of the glacial period. From these areas as centers, the ice spread in all directions, partly as the result of accumulation, and partly as the result of movement induced by the weight of the ice itself.

The ice sheets spreading from these centers came together south of Hudson's bay, and invaded the territory of the United States as a single sheet, which, at the time of its greatest development, covered a large part of our country (Plate XXXIII), its area being known by the extent of the drift which it left behind when it was melted. In the east, it buried the whole of New England, most of New York, and the northern parts of New Jersey and Pennsylvania. Farther west, the southern margin of the ice crossed the Ohio river in the vicinity of Cincinnati, and pushed out over the uplands a few miles south of the river. In Indiana, except at the extreme east, its margin fell considerably short of the Ohio; in Illinois it reached well toward that river, attaining here its most southerly latitude. West of the Mississippi, the line which marks the limit of its advance curves to the northward, and follows, in a general way, the course of the Missouri river. The total area of the North American ice sheet, at the time of its maximum development, has been estimated to have been about 4,000,000 square miles, or about ten times the estimated area of the present ice-field of Greenland.

Within the general area covered by the ice, there is an area of several thousand square miles, mainly in southwestern Wisconsin, where there is no drift. The ice, for some reason, failed



The North American Ice Sheet, at the time of maximum development.

View from the north of the Owl's Head, a hill two miles north of east of Merrimac, which has been shaped by the ice. The side to the left is the stone side.

to cover this *driftless area* though it overwhelmed the territory on all sides.

Plate II shows the limit of ice advance in the area here described. The region may have been affected by the ice of more than one glacial epoch, but the chief results now observable were effected during the last, and the others need not be considered.

The Work of Glacier Ice.

As the edge of an ice sheet, or as the end of a glacier, retreats, the land which it has previously covered is laid bare, and the effects which the passage of the ice produced may be seen. In some cases one may actually go back a short distance beneath the ice now in motion, and see its mode of work and the results it is effecting. The beds of living glaciers, and the beds which glaciers have recently abandoned, are found to present identical features. Because of their greater accessibility, the latter offer the better facilities for determining the effects of glaciation.

The conspicuous phenomena of abandoned glacier beds fall into two classes, 1) those which pertain to the bed rock over which the ice moved, and 2) those which pertain to the drift left by the ice.

Erosive work of the ice.—Effect on topography.—The leading features of the rock bed over which glacier ice has moved, are easily recognized. Its surface is generally smoothed and polished, and frequently marked by lines (striæ) or grooves, parallel to one another. An examination of the bottom of an active glacier discloses the method by which the polishing and scoring are accomplished.

The lower surface of the ice is thickly set with a quantity of clay, sand, and stony material of various grades of coarseness. These earthy and stony materials in the base of the ice are the tools with which it works. Thus armed, the glacier ice moves slowly forward, resting down upon the surfaces over which it passes with the whole weight of its mass, and the grinding action between the stony layer at the base of the ice and the rock bed over which it moves, is effective. If the material in the bottom of the ice be fine, like clay, the rock bed is polished. If coarser materials, harder than the bed-rock, be mingled with the fine, the rock bed of the glacier will be scratched as well as polished. If there are bowlders in the bottom of the ice they may cut grooves or gorges in the underlying rock. The grooves may subsequently be polished by the passage over and through them of ice carrying clay or other fine, earthy matter.

All these phases of rock wear may be seen about the termini of receding glaciers, on territory which they have but recently abandoned. There can thus be no possible doubt as to the origin of the polishing, planing and scoring.

There are other peculiarities, less easily defined, which characterize the surface of glacier beds. The wear effected is not confined to the mere marking of the surface over which it passes. If prominences of rock exist in its path, as is often the case, they oppose the movement of the ice, and receive a corresponding measure of abrasion from it. If they be sufficiently resistant they may force the ice to yield by passing over or around them; but if they be weak, they are likely to be destroyed.

As the ice of the North American ice sheet advanced, seemingly more rigid when it encountered yielding bodies, and more yielding when it encountered resistant ones, it denuded the surface of its loose and movable materials, and carried them forward. This accumulation of earthy and stony debris in the bottom of the ice, gave it a rough and grinding lower surface, which enabled it to abrade the land over which it passed much more effectively than ice alone could have done. Every hill and every mound which the ice encountered contested its advance. Every sufficiently resistant elevation compelled the ice to pass around or over it; but even in these cases the ice left its marks upon the surface to which it yielded. The powerful pressure of pure ice, which is relatively soft, upon firm hills of rock, which are relatively hard, would effect little. The hills would wear the ice, but the effect of the ice on the hills would be slight. But where the ice is supplied with earthy and stony material derived from the rock itself, the case is different. Under these conditions, the ice, yielding only under great pressure and as little as may be, rubs its rock-shod base over every opposing surface, and with greatest severity where it meets with greatest resistance. Its action may be compared to that of a huge "flexible-rasp" fitting down snugly over hills and valleys alike, and working under enormous pressure.

The abrasion effected by a moving body of ice under such conditions would be great. Every inch of ice advance would be likely to be attended by loss to the surface of any obstacle over or around which it is compelled to move. The sharp summits of the hills, and all the angular rugosities of their surfaces would be filed off, and the hills smoothed down to such forms as will offer progressively less and less resistance. If the process of abrasion be continued long enough, the forms, even of the large hills, may be greatly altered, and their dimensions greatly reduced. Among the results of ice wear, therefore, will be a lowering of the hills, and a smoothing and softening of their contours, while their surfaces will bear the marks of the tools which fashioned them, and will be polished, striated or grooved, according to the nature of the material which the ice pressed down upon them during its passage. Figs. 28 and 29 show the topographic effects which ice is likely to produce by erosion. Plate XXXIV is a hill two miles northeast of Merrimac, which shows how perfectly the wear actually performed corresponds to that which might be inferred.

FIG. 28.—A hill before the ice passes over it.

A rock hill was sometimes left without covering of drift after having been severely worn by the ice. Such a hill is known as a *roche moutonnée.* An example of this type of hill occurs three miles north of east of Baraboo at the point marked *z* on Plate

XXXVII, (p. 108). This hill, composed of quartzite, is less symmetrical than those shown in Figs. 28 and 29. Its whole surface, not its stoss side only, has been smoothed and polished by the ice. This hill is the most accessible, the most easily designated, and, on the whole, the best example of a *roche moutonnée* in the region, though many other hills show something of the same form.

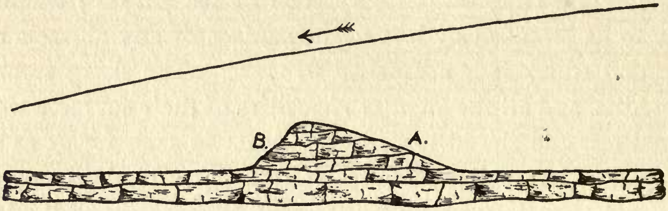


Fig. 29.—The same hill after it has been eroded by the ice. *A* the stoss side. *B* the lee side.

It was not the hills alone which the moving ice affected. Where it encountered valleys in its course they likewise suffered modification. Where the course of a valley was parallel to the direction of the ice movement, the ice moved through it. The depth of moving ice is one of the determinants of its velocity, and because of the greater depth of ice in valleys, its motion here was more rapid than on the uplands above, and its abrading action more powerful. Under these conditions the valleys were deepened and widened.

Where the courses of the valleys were transverse to the direction of ice movement, the case was different. The ice was too viscous to span the valleys, and therefore filled them. In this case it is evident that the greater depth of the ice in the valley will not accelerate its motion, since the ice in the valley-trough and that above it are in a measure opposed. If left to itself, the ice in the valley would tend to flow in the direction of the axis of the valley. But in the case under consideration, the ice which lies above the valley depression is in motion at right angles to the axis of the valley. Under these circumstances three cases might arise:

(1) If the movement of the ice sheet over the valley were able to push the valley ice up the farther slope, and out on the opposite highland, this work would retard the movement of the upper ice, since the resistance to movement would be great. In this case, the thickness of the ice is not directly and simply a determinant of its velocity. Under these conditions the bottom of the valley would not suffer great erosion, since ice did not move along it; but that slope of the valley against which the ice movement was projected would suffer great wear (Fig. 30). The valley would therefore be widened, and the slope suffering greatest wear would be reduced to a lower angle. Shallow valleys, and those possessing gentle slopes, favor this phase of ice movement and valley wear.

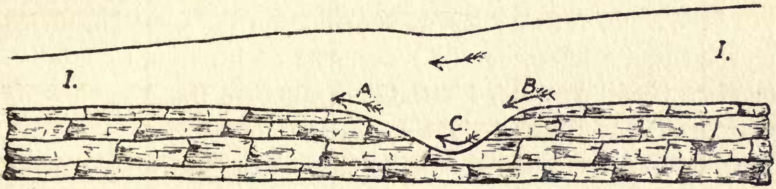


FIG. 30.—Diagram showing effect on valley of ice moving transversely across it.

(2) The ice in the valley might become stationary, in which case it might serve as a bridge for the upper ice to cross on (Fig. 31). In this case also the total thickness of ice will not be a determinant of its velocity, for it is the thickness of the moving ice only, which influences the velocity. In this case the valley would not suffer much wear, so long as this condition of things continued. Valleys which have great depth relative to the thickness of the ice, and valleys whose slopes are steep, favor this phase of movement.

(3) In valleys whose courses are transverse to the direction of ice movement, transverse currents of ice may exist, following the direction of the valleys. If the thickness of the ice be much greater than the depth of the valley, if the valley be capacious, and if one end of it be open and much lower than the other, the ice filling it may move along its axis, while the upper ice con-

tinues in its original course at right angles to the valley. In this case the valley would be deepened and widened, but this effect would be due to the movement along its course, rather than to that transverse to it.

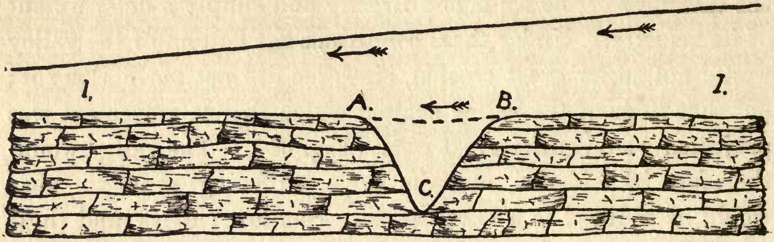


FIG. 31—Diagram to illustrate case where ice fills a valley (C) and the upper ice then moves on over the filling.

If the course of a valley were oblique to the direction of ice movement, its effect on the movement of ice would be intermediate between that of valleys parallel to the direction of movement, and those at right angles to it.

It follows from the foregoing that the corrasive effects of ice upon the surface over which it passed, were locally dependent on pre-existent topography, and its relation to the direction of ice movement. In general, the effort was to cut down prominences, thus tending to level the surface. But when it encountered valleys parallel to its movement they were deepened, thus locally increasing relief. Whether the reduction of the hills exceeded the deepening of the valleys, or whether the reverse was true, so far as corrasion alone is concerned, is uncertain. But whatever the effect of the erosive effect of ice action upon the total amount of relief, the effect upon the contours was to make them more gentle. Not only were the sharp hills rounded off, but even the valleys which were deepened were widened as well, and in the process their slopes became more gentle. A river-erosion topography, modified by the wearing (not the depositing) action of the ice, would be notably different from the original, by reason of its gentler slopes and softer contours (Figs. 28 and 29).

Deposition by the ice. Effect on topography.—On melting, glacier ice leaves its bed covered with the debris which it gathered during its movement. Had this debris been equally distributed on and in and beneath the ice during its movement, and had the conditions of deposition been everywhere the same, the drift would constitute a mantle of uniform thickness over the underlying rock. Such a mantle of drift would not greatly alter the topography; it would simply raise the surface by an amount equal to the thickness of the drift, leaving elevations and depressions of the same magnitude as before, and sustaining the same relations to one another. But the drift carried by the ice, in whatever position, was not equally distributed during transportation, and the conditions under which it was deposited were not uniform, so that it produced more or less notable changes in the topography of the surface on which it was deposited.

The unequal distribution of the drift is readily understood. The larger part of the drift transported by the ice was carried in its basal portion; but since the surface over which the ice passed was variable, it yielded a variable amount of debris to the ice. Where it was hilly, the friction between it and the ice was greater than where it was plain, and the ice carried away more load. From areas where the surface was overspread by a great depth of loose material favorably disposed for removal, more debris was taken than from areas where material in a condition to be readily transported was meager. Because of the topographic diversity and lithological heterogeneity of the surface of the country over which it passed, some portions of the ice carried much more drift than others, and when the ice finally melted, greater depths of drift were left in some places than in others. Not all of the material transported by the ice was carried forward until the ice melted. Some of it was probably carried but a short distance from its original position before it lodged. Drift was thus accumulating at some points beneath the ice during its onward motion. At such points the surface was being built up; at other points, abrasion was taking place, and the surface was being cut down. The drift mantle of any region does not, therefore, represent simply the material which was on and in and beneath the ice of that place at the time of its melting, but it represents, in addition, all that lodged beneath the ice during its movement.

The constant tendency was for the ice to carry a considerable part of its load forward toward its thinned edge, and there to leave it. It follows that if the edge of the ice remained constant in position for any considerable period of time, large quantities of drift would have accumulated under its marginal portion, giving rise to a belt of relatively thick drift. Other things being equal, the longer the time during which the position of the edge was stationary, the greater the accumulation of drift. Certain ridge-like belts where the drift is thicker than on either hand, are confidently believed to mark the position where the edge of the ice-sheet stood for considerable periods of time.

Because of the unequal amounts of material carried by different parts of the ice, and because of the unequal and inconstant conditions of deposition under the body of the ice and its edge, the mantle of drift has a very variable thickness; and a mantle of drift of variable thickness cannot fail to modify the topography of the region it covers. The extent of the modification will depend on the extent of the variation. This amounts in the aggregate, to hundreds of feet. The continental ice sheet, therefore, modified the topography of the region it covered, not only by the wear it effected, but also by the deposits it made.

In some places it chanced that the greater thicknesses of drift were left in the positions formerly marked by valleys. Locally the body of drift was so great that valleys were completely filled, and therefore completely obliterated as surface features. Less frequently, drift not only filled the valleys but rose even higher over their former positions than on either side. In other places the greater depths of drift, instead of being deposited in the valleys, were left on pre-glacial elevations, building them up to still greater heights. In short, the mantle of drift of unequal thickness was laid down upon the rock surface in such a manner that the thicker parts sometimes rest on hills and ridges, sometimes on slopes, sometimes on plains, and sometimes in valleys.

Fig. 32.—Diagrammatic section showing relation of drift to underlying rock, where the drift is thick relative to the relief of the rock. *a* and *b* represent the location of post-glacial valleys.

These relations are suggested by Figs. 32 and 33. From them it will be seen that in regions where the thickness of the drift is great, relative to the relief of the underlying rock, the topography may be completely changed. Not only may some of the valleys be obliterated by being filled, but some of the hills may be obliterated by having the lower land between them built up to their level. In regions where the thickness of the drift is slight, relative to the relief of the rock beneath, the hills cannot be buried, and the valleys cannot be completely filled, so that the relative positions of the principal topographic features will remain much the same after the deposition of the drift, as before (Fig. 33).

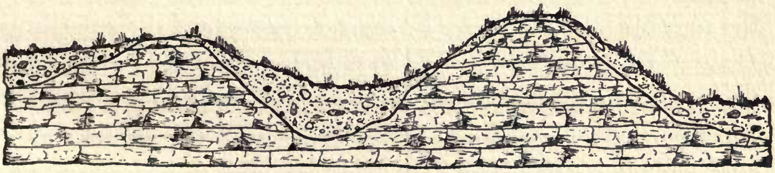


Fig. 33.—Diagrammatic section showing relation of drift to underlying rock where the drift is thin relative to the relief of the underlying rock.

In case the pre-glacial valleys were filled and the hills buried, the new valleys which the surface waters will in time cut in the drift surface will have but little correspondence in position with those which existed before the ice incursion. A new system of valleys, and therefore a new system of ridges and hills, will be developed, in some measure independent of the old. These relations are illustrated by Fig. 32.

Inequalities in the thickness of drift lead to a still further modification of the surface. It frequently happened that in a plane or nearly plane region a slight thickness of drift was deposited at one point, while all about it much greater thicknesses were left. The area of thin drift would then constitute a depression, surrounded by a higher surface built up by the thicker deposits. Such depressions would at first have no outlets, and are therefore unlike the depressions shaped by rain and river erosion. The presence of depressions without outlets is one of the marks of a drift-covered (glaciated) country. In these depressions water may collect, forming lakes or ponds, or in some cases only marshes and bogs.

DIRECTION OF ICE MOVEMENT.

The direction in which glacier ice moved may be determined in various ways, even after the ice has disappeared. The shapes of the rock hills over which the ice passed (p. 81), the direction from which the materials of the drift came, and the course of the margin of the drift, all show that the ice of south central Wisconsin was moving in a general southwest direction. In the rock hills, this is shown by the greater wear of their northeast ("stoss") sides (Plate XXXIV, p. 82). From the course of the drift margin, the general direction of movement may be inferred when it is remembered that the tendency of glacier ice on a plane surface is to move at right angles to its margin.

For the exact determination of the direction of ice movement, recourse must be had to the striæ on the bed-rock. Were the striated rock surface perfectly plane, and were the striæ even lines, they would only tell that the ice was moving in one of two directions. But the rock surface is not usually perfectly plane, nor the striæ even lines, and between the two directions which lines alone might suggest, it is usually possible to decide. The minor prominences and depressions in the rock surface were shaped according to the same principles that govern the shaping of hills (Fig. 29) and valleys (Fig. 30); that is, the stoss sides of the minor prominences, and the distal sides of small depressions suffered the more wear. With a good compass, the direction of the striæ may be measured to within a fraction of a degree, and thus the direction of ice movement in a particular place be definitely determined. The striæ which have been determined about Baraboo are shown on Plate II, p. 5.

Effect of topography on movement.—The effect of glaciation on topography has been sketched, but the topography in turn exerted an important influence on the direction of ice movement. The extreme degree of topographic influence is seen in mountain regions like the Alps, where most of the glaciers are confined strictly to the valleys.

As an ice sheet invades a region, it advances first and farthest along the lines of least resistance. In a rough country with great relief, tongues or lobes of ice would push forward in the valleys, while the hills or other prominences would tend to hold back or divide the onward moving mass. The edge of an ice sheet in such a region would be irregular. The marginal lobes of ice occupying the valleys would be separated by re-entrant angles marking the sites of hills and ridges.

If the ice crossed a plane surface above which rose a notable ridge or hill, the first effect of the hill would be to indent the ice. The ice would move forward on either side, and if its thickness became sufficiently great, the parts moving forward on either side would again unite beyond it. A hill thus surrounded by ice is a *nunatak.* Later, as the advancing mass of ice became thicker, it might completely cover the hill; but the thickness of ice passing over the hill would be less than that passing on either side by an amount equal to the height of the hill. It follows that as ice encounters an isolated elevation, three stages in its contest with the obstruction may be recognized: 1) the stage when the ridge or hill acts as a wedge, dividing the moving ice into lobes, Fig. 34; 2) the nunatak stage, when the ice has pushed forward and reunited beyond the hill, Fig. 35; 3) the stage when the ice has become sufficiently deep to cover the hill.

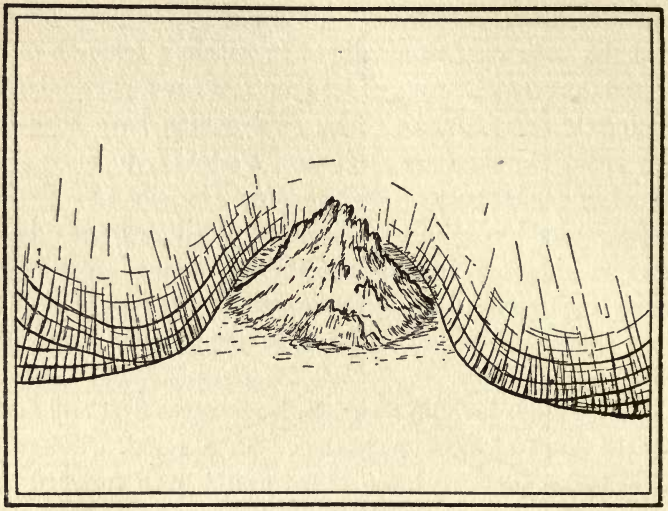


FIG. 34.—Diagrammatic representation of the effect of a hill on the edge of the ice.

After the ice has disappeared, the influence of the obstruction might be found in the disposition of the drift. If recession began during the first stage, that is, when the ice edge was separated into lobes, the margin of the drift should be lobate, and would loop back around the ridge from its advanced position on either side. If recession began during the second stage, that is, when the lobes had become confluent and completely surrounded the hill, a *driftless area* would appear in the midst of drift. If recession began during the third stage, that is, after the ice had moved on over the obstruction, the evidence of the sequence might be obliterated; but if the ice moved but a short distance beyond the hill, the thinner ice over the hill would have advanced less far than the thicker ice on either side (Fig. 35), and the margin of the drift would show a re-entrant pointing back toward the hill, though not reaching it. All these conditions are illustrated in the Devil's lake region.

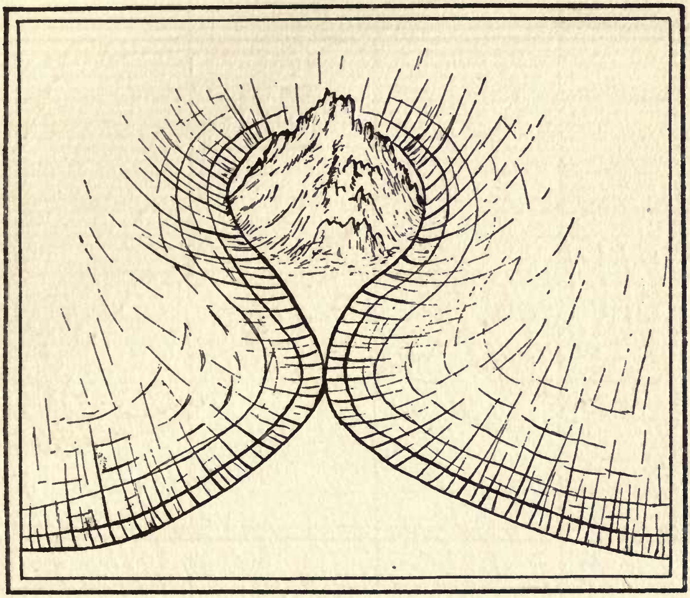


FIG. 35.—Same as Fig. 34, when the ice has advanced farther.

Limit of the Ice.

The region under description is partly covered with drift, and partly free from it. The limit of the ice, at the time of its maximum expansion is well defined at many points, and the nature and position of the drift limit are so unique as to merit attention (see Plates II, p. 5, and XXXVII, p. 108). They illustrate many of the principles already discussed.

The ice which covered the region was the western margin of the Green Bay lobe (Fig. 36) of the last continental ice sheet. Its limit in this region is marked by a ridge-like accumulation of drift, the *terminal moraine,* which here has a general north-south direction. The region may have been affected by the ice of more than one epoch, but since the ice of the last epoch advanced as far to the west in this region as that of any earlier epoch, the moraine is on the border between the

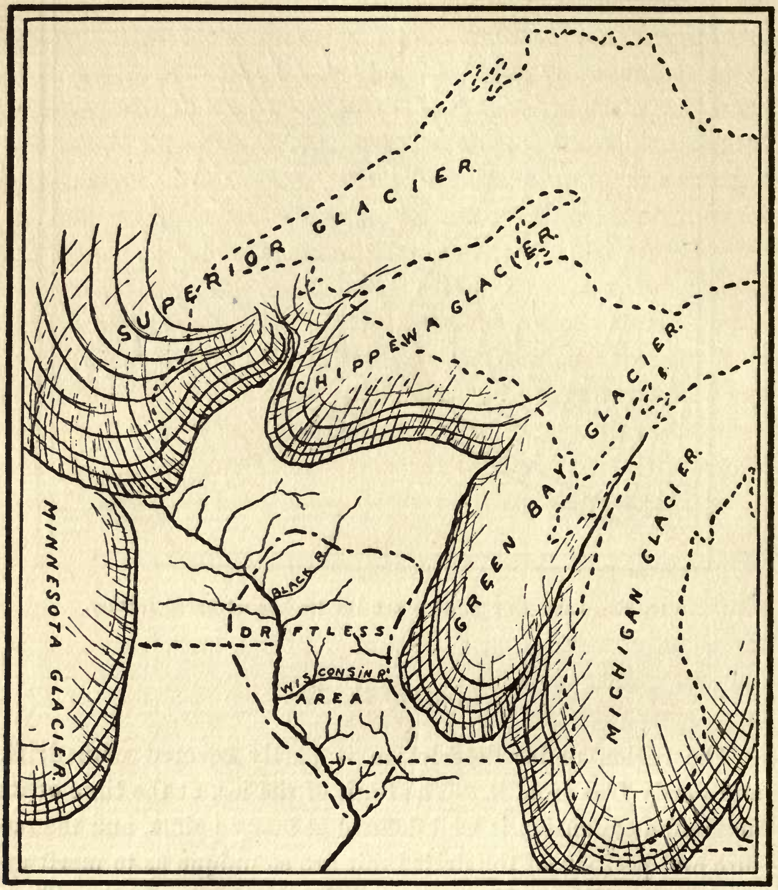


FIG. 36.—Map showing relations of lobes of ice during the Wisconsin ice epoch, to the driftless area.

glaciated country to the east, and the driftless area to the west (Plates I and II). That part of the moraine which lies west of the Wisconsin river follows a somewhat sinuous course from Kilbourn City to a point a short distance north of Prairie du

Sac. The departures from this general course are especially significant of the behavior of glacier ice.

In the great depression between the quartzite ranges, the moraine bends westward, showing that the ice advanced farther on the lowlands than on the ridges. As the moraine of this low area approaches the south range, it curves to the east. At the point southwest of Baraboo where the easterly curve begins to show itself, the moraine lies at the north base of the quartzite range; but as it is traced eastward, it is found to lie higher and higher on the slope of the range, until it reaches the crest nearly seven miles from the point where the eastward course was assumed. At this point it crosses the range, and, once across the crest, it turns promptly to the westward on the lower land to the south. Here the ice advanced up the valley between the East bluff (east of the lake) and the Devil's nose (Plate XXXVII), again illustrating the fact that lowlands favor ice advance. The valley between the Devil's nose and the East bluff is a narrow one, and the ice advanced through it nearly to the present site of the lake. Meanwhile the restraining influence of the "nose" was making itself felt, and the margin of the ice curved back from the bottom of the bluff near Kirkland, to the top of the bluff at the end of the nose. Here the edge of the ice crossed the point of the nose, and after rounding it, turned abruptly to the west. Thence its edge lay along the south slope of the ridge, descending from the crest of the ridge at the nose, to the base of the ridge two miles farther west. Here the ice reached its limit on the lowland, and its edge, as marked by the moraine, turned southward, reaching the Wisconsin river about a mile and a half above Prairie du Sac.

The course of the terminal moraine across the ridges is such as the margin of the ice would normally have when it advanced into a region of great relief. The great loop in the moraine with its eastern extremity at *k*, Plate XXXVII, is explained by the presence of the quartzite ridge which retarded the advancing ice while it moved forward on either side. The minor loop around the Devil's nose is explained in the same way. Both the main loop, and the smaller one on the nose, illustrate the point made on p. 89.

The narrow and curious loop at *m*, is of a slightly different origin, though in principle the same. It is in the lee of a high point in the quartzite ridge. The ice surmounted this point, and descended its western slope; but the thickness of the ice passing over the summit was so slight that it advanced but a short distance down the slope before its force was exhausted, while the thicker ice on either side advanced farther before it was melted.

Glacial Deposits.

Before especial reference is made to the drift of this particular region, it will be well to consider the character of drift deposits in general. When the ice of the continental glacier began its motion, it carried none of the stony and earthy debris which constitute the drift. These materials were derived from the surface over which the ice moved.

From the method by which it was gathered, it is evident that the drift of any locality may contain fragments of rock of every variety which occurs along the route followed by the ice which reached that locality. Where the ice had moved far, and where there were frequent changes in the character of the rock constituting its bed, the variety of materials in the drift is great. The heterogeneity of the drift arising from the diverse nature of the rocks which contributed to it is *lithological heterogeneity*—a term which implies the commingling of materials derived from different rock formations. Thus it is common to find pieces of sandstone, limestone, quartzite, granite, gneiss, schist, etc., intimately commingled in the drift, wherever the ice which produced it passed over formations of these several sorts of rock. Lithological heterogeneity is one of the notable characteristics of glacial formations.

Another characteristic of the drift is its *physical heterogeneity*. As first gathered from the bed of moving ice, some of the

Cut in drift, showing its physical heterogeneity materials of the drift were fine and some coarse. The tendency of the ice in all cases was to reduce its load to a still finer condition. Some of the softer materials, such as soft shale, were crushed or ground to powder, forming what is known in common parlance as clay. Clayey (fine) material is likewise produced by the grinding action of ice-carried bowlders upon the rock-bed, and upon one another. Other sorts of rock, such as soft sandstone, were reduced to the physical condition of sand, instead of clay, and from sand to bowlders all grades of coarseness and fineness are represented in the glacial drift.

Since the ice does not assort the material which it carries, as water does, the clay, sand, gravel and bowlders will not, by the action of the ice, be separated from one another. They are therefore not stratified. As left by the ice, these physically heterogeneous materials are confusedly commingled. The finer parts constitute a matrix in which the coarser are embedded.

Physical heterogeneity (Plate XXXV), therefore, is another characteristic of glacial drift. It is not to be understood that the proportions of these various physical elements, clay, sand, gravel, and bowlders, are constant. Locally any one of them may predominate over any or all the others to any extent.

Since lithological and physical heterogeneity are characteristics of glacial drift, they together afford a criterion which is often of service in distinguishing glacial drift from other surface formations. It follows that this double heterogeneity constitutes a feature which can be utilized in determining the former extension of existing glaciers, as well as the former existence of glaciers where glaciers do not now exist.

Another characteristic of glacial drift, and one which clearly distinguishes it from all other formations with which it might be confounded, is easily understood from its method of formation. If the ice in its motion holds down rock debris upon the rock surface over which it passes with such pressure as to polish and striate the bed-rock, the material carried will itself suffer wear comparable to that which it inflicts. Thus the stones, large and small, of glacial drift, will be smoothed and striated.

This sort of wear on the transported blocks of rock, is effected both by the bed-rock reacting on the bowlders transported over it, and by bowlders acting on one another in and under the ice. The wear of bowlders by bowlders is effected wherever adjacent ones are carried along at different rates. Since the rate of motion of the ice is different in different parts of the glacier, the mutual abrasion of transported materials is a process constantly in operation. A large proportion of the transported stone and blocks of rock may thus eventually become striated.

From the nature of the wear to which the stones are subjected when carried in the base of the ice, it is easy to understand that their shapes must be different from those of water-worn materials. The latter are rolled over and over, and thus lose all their angles and assume a more or less rounded form. The former, held more or less firmly in the ice, and pressed against the underlying rock or rock debris as they are carried slowly forward, have their faces planed and striated. The planation and striation of a stone need not be confined to its under surface. On either side or above it other stones, moving at different rates, are made to abrade it, so that its top and sides may be planed and scored. If the ice-carried stones shift their positions, as they may under various circumstances, new faces will be worn. The new face thus planed off may meet those developed at an earlier time at sharp angles, altogether unlike anything which water-wear is capable of producing. The stone thus acted upon shows a surface bounded by planes and more or less beveled, instead of a rounded surface such as water wear produces. We find, then, in the shape of the bowlders and smaller stones of the drift, and in the markings upon their surfaces, additional criteria for the identification of glacier drift (Plate XXXVI).

The characteristics of glacial drift, so far as concerns its constitution, may then be enumerated as, 1) its lithological, and 2) physical heterogeneity; 3) the shapes, and 4) the markings of the stones of the drift. In structure, the drift which is strictly glacial, is unstratified.

In the broadest sense of the term, all deposits made by glacier

Glaciated stones, showing both form and striae. (Matz.)

ice are *moraines.* Those made beneath the ice and back from its edge constitute the *ground moraine,* and are distinguished from the considerable marginal accumulations which, under certain conditions, are accumulated at or near the margin. These marginal accumulations are *terminal moraines.* Associated with the moraines which are the deposits of the ice directly, there are considerable bodies of stratified gravel and sand, the structure of which shows that they were laid down by water. This is to be especially noted, since lack of stratification is popularly supposed to be the especial mark of the formations to which the ice gave rise.

These deposits of stratified drift lie partly beyond the terminal moraine, and partly within it. They often sustain very complicated relations both to the ground and terminal moraines.

The drift as a whole is therefore partly stratified and partly unstratified. Structurally the two types are thoroughly distinct, but their relations are often most complex, both horizontally and vertically. A fuller consideration of these relations will be found on a later page.

The Ground Moraine.

The ground moraine constitutes the great body of the glacial drift. *Bowlder clay,* a term descriptive of its constitution in some places, and *till,* are other terms often applied to the ground moraine. The ground moraine consists of all the drift which lodged beneath the ice during its advance, all that was deposited back from its edge while its margin was farthest south, and most of that which was deposited while the ice was retreating. From this mode of origin it is readily seen that the ground moraine should be essentially as widespread as the ice itself. Locally, however, it failed of deposition. Since it constitutes the larger part of the drift, the characteristics already enumerated (p. 95) as belonging to drift in general are the characteristics of the till. Wherever obstacles to the progress of the ice lay in its path, there was a chance that these obstacles, rising somewhat into the lower part of the ice, would constitute barriers against which debris in the lower part of the ice would lodge. It might happen also that the ice, under a given set of conditions favoring erosion, would gather a greater load of rock-debris than could be transported under the changed conditions into which its advance brought it. In this case, some part of the load would be dropped and over-ridden. Especially near the margin of the ice where its thickness was slight and diminishing, the ice must have found itself unable to carry forward the loads of debris which it had gathered farther back where its action was more vigorous. It will be readily seen that if not earlier deposited, all material gathered by the under surface of the ice would ultimately find itself at the edge of the glacier, for given time enough, ablation will waste all that part of the ice occupying the space between the original position of the debris, and the margin of the ice. Under the thinned margin of the ice, therefore, considerable accumulations of drift must have been taking place while the ice was advancing. While the edge of the ice sheet was advancing into territory before uninvaded, the material accumulated beneath its edge at one time, found itself much farther from the margin at another and later time. Under the more forcible ice action back from the margin, the earlier accumulations, made under the thin edge, were partially or wholly removed by the thicker ice of a later time, and carried down to or toward the new and more advanced margin. Here they were deposited, to be in turn disturbed and transported still farther by the farther advance of the ice.

Since in its final retreat the margin of the ice must have stood at all points once covered by it, these submarginal accumulations of drift must have been made over the whole country once covered by the ice. The deposits of drift made beneath the marginal part of the ice during its retreat, would either cover the deposits made under the body of the ice at an earlier time, or be left alongside them. The constitution of the two phases of till, that deposited during the advance of the ice, and that deposited during its retreat, is essentially the same, and there is nothing in their relative positions to sharply differentiate them. They are classed together as *subglacial till.*

Subglacial till was under the pressure of the overlying ice. In keeping with these conditions of accumulation, the till often possesses a firmness suggestive of great compression. Where its constitution is clayey it is often remarkably tough. Where this is the case, the quality here referred to has given rise to the suggestive name "hard pan." Where the constitution of the till is sandy, rather than clayey, this firmness and toughness are less developed, or may be altogether wanting, since sand cannot be compressed into coherent masses like clay.

Constitution.—The till is composed of the more or less comminuted materials derived from the land across which the ice passed. The soil and all the loose materials which covered the rock entered into its composition. Where the ice was thick and its action vigorous, it not only carried away the loose material which it found in its path, but, armed with this material, it abraded the underlying rock, wearing down its surface and detaching large and small blocks of rock from it. It follows that the constitution of the till at any point is dependent upon the nature of the soil and rock from which it was derived.

If sandstone be the formation which has contributed most largely to the till, the matrix of the till will be sandy. Where limestone instead of sandstone made the leading contribution to it, the till has a more earthy or clayey matrix. Any sort of rock which may be very generally reduced to a fine state of division under the mechanical action of the ice, will give rise to clayey till.

The nature and the number of the bowlders in the till, no less than the finer parts, depend on the character of the rock overridden. A hard and resistant rock, such as quartzite, will give rise to more bowlders in proportion to the total amount of material furnished to the ice, than will softer rock. Shale or soft sandstone, possessing relatively slight resistance, will be much more completely crushed. They will, therefore, yield proportionately fewer bowlders than harder formations, and more of the finer constituents of till.

The bowlders taken up by the ice as it advanced over one sort of rock and another, possessed different degrees of resistance. The softer ones were worn to smaller dimensions or crushed with relative ease and speed. Bowlders of soft rock are, therefore, not commonly found in any abundance at great distances from their sources. The harder ones yielded less readily to abrasion, and were carried much farther before being destroyed, though even such must have suffered constant reduction in size during their subglacial journey. In general it is true that bowlders in the till, near their parent formations, are larger and less worn than those which have been transported great distances.

The ice which covered this region had come a great distance and had passed over rock formations of many kinds. The till therefore contains elements derived from various formations; that is, it is lithologically heterogeneous. This heterogeneity cannot fail to attract the attention of one examining any of the many exposures of drift about Baraboo at road gradings, or in the cuts along the railway. Among the stones in the drift at these exposures are limestone, sandstone, quartzite, diabase, gabbro, gneiss, granite, schist, and porphyry, together with pieces of flint and chert.

Such an array may be found at any of the exposures within the immediate vicinity of Devil's lake. To the north, and a few miles to the south of the Baraboo ranges, the quartzite from these bluffs, and the porphyry from the point marked *h* in Plate II, (p. 5) are wanting, though other varieties of porphyry are present. The ice moved in a general west-southwest direction in this region, and the quartzite in the drift, so far as derived from the local formation, is therefore restricted to a narrow belt.

The physical heterogeneity may be seen at all exposures, and is illustrated in Plate XXXV (p. 95). The larger stones of the drift are usually of some hard variety of rock. Near the Baraboo ranges, the local quartzite often predominates among the bowlders, and since such bowlders have not been carried far, they are often little worn. Away from the ranges, the bowlders are generally of some crystalline rock, such as granite and diabase. Bowlders of these sorts of rock are from a much more distant source, and are usually well worn.

In general the till of any locality is made up largely of material derived from the formations close at hand. This fact seems to afford sufficient warrant for the conclusion that a considerable amount of deposition must have gone on beneath the ice during its movement, even back from its margin. To take a concrete illustration, it would seem that the drift of southeastern Wisconsin should have had a larger contribution than it has of material derived from Canadian territory, if material once taken up by the ice was all or chiefly carried down to its thinned edge before deposition. The fact that so little of the drift came from these distant sources would seem to prove that a large part of the material moved by the ice, is moved a relatively short distance only. The ice must be conceived of as continually depositing parts of its load, and parts which it has carried but a short distance, as it takes up new material from the territory newly invaded.

In keeping with the character of till in general, that about Devil's lake was derived largely from the sandstone, limestone and quartzite of the immediate vicinity, while a much smaller part of it came from more distant sources. This is especially noticeable in the fine material, which is made up mostly of the comminuted products of the local rock.

Topography.—The topography of the ground moraine is in general the topography already described (p. 85) in considering the modification of preglacial topography effected by ice deposition. As left by the ice, its surface was undulating. The undulations did not take the form of hills and ridges with intervening valleys, but of swells and depressions standing in no orderly relationship to one another. Undrained depressions are found in the ground moraine, but they are, as a rule, broader and shallower than the "kettles" common to terminal moraines.

It is in the broad, shallow depressions of the ground moraine that many of the lakes and more of the marshes of southeastern Wisconsin are located.

The rolling, undulating topography characteristic of ground moraines is well shown about the City of Baraboo and between that point and the lake, and at many less easily designated points about Merrimac.

In thickness the ground moraine reaches at least 160 feet, though its average is much less—too little to obliterate the greater topographic features of the rock beneath. It is, however, responsible for many of the details of the surface.

Terminal Moraines.

The marginal portion of the ice sheet was more heavily loaded—certainly more heavily loaded relative to its thickness—than any other. Toward its margin the thinned ice was constantly losing its transportive power, and at its edge this power was altogether gone. Since the ice was continually bringing drift down to this position and leaving it there, the rate of drift accumulation must have been greater, on the average, beneath the edge of the ice than elsewhere.

Whenever, at any stage in its history, the edge of the ice remained essentially constant in position for a long period of time, the corresponding submarginal accumulation of drift was great, and when the ice melted, the former site of the stationary edge would be marked by a broad ridge or belt of drift, thicker than that on either side. Such thickened belts of drift are *terminal moraines.* It will be seen that a terminal moraine does not necessarily mark the terminus of the ice at the time of its greatest advance, but rather its terminus at any time when its edge was stationary or nearly so.

From the conditions of their development it will be seen that these submarginal moraines may be made up of materials identical with those which constitute the ground moraine, and such is often the case. But water arising from the melting of the ice, played a much more important role at its margin than farther back beneath it. One result of its greater activity may be seen in the greater coarseness which generally characterizes the material of the terminal moraine as compared with that of the adjacent ground moraine. This is partly because the water carried away such of the finer constituents as it was able to transport, leaving the coarser behind. Further evidence of the great activity of water near the margin of the ice is to be seen in the relatively large amount of assorted and stratified sand and gravel associated with the terminal moraine.

Such materials as were carried on the ice were dropped at its edge when the ice which bore them melted from beneath. If the surface of the ice carried many bowlders, many would be dropped along the line of its edge wherever it remained stationary for any considerable period of time. A terminal moraine therefore embraces 1) the thick belt of drift accumulated beneath the edge of the ice while it was stationary, or nearly so; and 2) such debris as was carried on the surface of the ice and dumped at its margin. In general the latter is relatively unimportant.

At various stages in its final retreat, the ice made more or less protracted halts. These halting places are marked by marginal moraines of greater or less size, depending on the duration of the stop, and the amount of load carried.

A terminal moraine is not the sharp and continuous ridge we are wont to think it. It is a belt of thick drift, rather than a ridge, though it is often somewhat ridge-like. In width, it varies from a fraction of a mile to several miles. In the region under consideration it is rarely more than fifty feet high, and rarely less than a half mile wide, and a ridge of this height and width is not a conspicuous topographic feature in a region where the relief is so great as that of the Devil's lake region.

Topography of terminal moraines.—The most distinctive feature of a terminal moraine is not its ridge-like character, but its peculiar topography. In general, it is marked by depressions without outlets, associated with hillocks and short ridges comparable in dimensions to the depressions. Both elevations and depressions are, as a rule, more abrupt than in the ground moraine. In the depressions there are many marshes, bogs, ponds and small lakes. The shapes and the abundance of round and roundish hills have locally given rise to such names as "The Knobs," "Short Hills," etc. Elsewhere the moraine has been named the "Kettle Range" from the number of kettle-like depressions in its surface. It is to be kept in mind that it is the association of the "knobs" and "kettles," rather than either feature alone, which is the distinctive mark of terminal moraine topography.

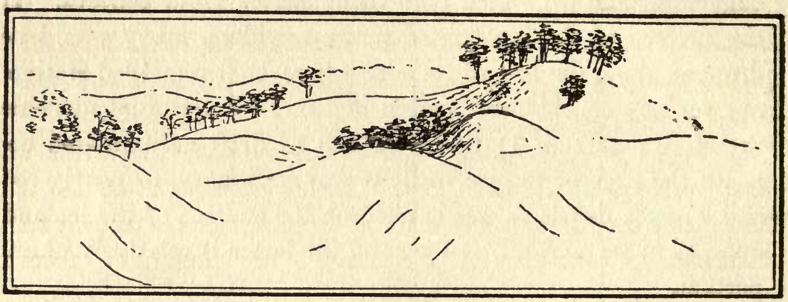


FIG. 37.—Sketch of terminal moraine topography, on the quartzite ridge east of Devil's lake. (Matz.)

The manner in which the topography of terminal moraines was developed is worthy of note. In the first place, the various parts of the ice margin carried unequal amounts of debris. This alone would have caused the moraine of any region to have been of unequal height and width at different points. In the second place, the margin of the ice, while maintaining the same *general* position during the making of a moraine, was yet subject to many minor oscillations. It doubtless receded to some slight extent because of increased melting during the summer, to advance again during the winter. In its recession, the ice margin probably did not remain exactly parallel to its former position. If some parts receded more than others, the details of the line of its margin may have been much changed during a temporary retreat. When the ice again advanced, its margin may have again changed its form in some slight measure, so as to be parallel neither with its former advanced position, nor with its position after its temporary retreat. With each successive oscillation of the edge, the details of the margin may have altered, and at each stage the marginal deposits corresponded with the edge. There might even be considerable changes in the edge of the ice without any general recession or advance, as existing glaciers show.

It was probably true of the margin of the American ice sheet, as of existing glaciers, that there were periods of years when the edge of the ice receded, followed by like periods when it remained stationary or nearly so, and these in turn followed by periods of advance. During any advance, the deposits made during the period of recession would be overridden and disturbed or destroyed.

If the ice were to retreat and advance repeatedly during a considerable period of time, always within narrow limits, and if during this oscillation the details of its margin were frequently changing, the result would be a complex or "tangle" of minor morainic ridges of variable heights and widths. Between and among the minor ridges there would be depressions of various sizes and shapes. Thus, it is conceived, many of the peculiar hillocks and hollows which characterize terminal moraines may have arisen.

Some of the depressions probably arose in another way. When the edge of the ice retreated, considerable detached masses of ice might be left beyond the main body. This might be buried by gravel and sand washed out from the moraine. On melting, the former sites of such blocks of ice would be marked by "kettles." In the marginal accumulations of drift as first deposited, considerable quantities of ice were doubtless left. When this melted, the drift settled and the unequal settling may have given rise to some of the topographic irregularities of the drift.

The terminal moraine about Devil's lake.—On the lower lands, the terminal moraine of the Devil's lake region has the features characteristic of terminal moraines in general. It is a belt of thick drift varying in width from half a mile or less to three-quarters of a mile or more. Its surface is marked by numerous hills and short ridges, with intervening depressions or "kettles." Some of the depressions among the hills contain water, making ponds or marshes, though the rather loose texture of the drift of this region is not favorable to the retention of water. The moraine belt, as a whole, is higher than the land on either side. It is therefore somewhat ridge-like, and the small, short hills and ridges which mark its surface, are but constituent parts of the larger, broader ridge.

Approached from the west, that is from the driftless side, the moraine on the lower lands is a somewhat prominent topographic feature, often appearing as a ridge thirty, forty or even fifty feet in height. Approached from the opposite direction, that is, from the ground moraine, it is notably less prominent, and its inner limit wherever located, is more or less arbitrary.

A deep, fresh railway cut in the moraine southeast of Devil's lake illustrates its complexity of structure, a complexity which is probably no greater than that at many other points where exposures are not seen. The section is represented in Fig. 38.

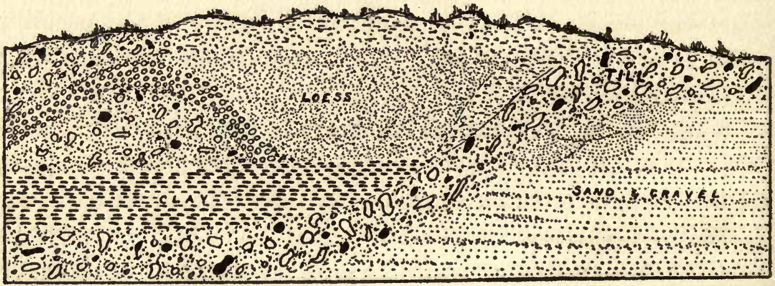


FIG. 38.—Cut through the terminal moraine just east of Kirkland, partially diagrammatic.

The stratified sand to the right retains even the ripple-marks which were developed when it was deposited. To the left, at the same level, there is a body of *till* (unstratified drift), over which is a bed of stoneless and apparently structureless clay. In a depression just above the clay with till both to the right and left, is a body of loam which possesses the characteristics of normal loess. It also contains calcareous concretions, though no shells have been found. This occurrence of loess is the more noteworthy, since loess is rarely found in association with drift of the last glacial epoch.[1]

The moraine on the main quartzite range.—In tracing the moraine over the greater quartzite range, it is found to possess a unique feature in the form of a narrow but sharply defined ridge of drift, formed at the extreme margin of the ice at the time of its maximum advance. For fully eleven miles, with but one decided break, and two short stretches where its development is not strong, this unique marginal ridge separates the drift-covered country on the one hand, from the driftless area on the other. In its course the ridge lies now on slopes, and now on summits, but in both situations preserves its identity. Where it rests on a plain, or nearly plain surface, its width at base varies from six to fifteen rods, and its average height is from twenty to thirty feet. Its crest is narrow, often no more than a single rod. Where it lies on a slope, it is asymmetrical in cross section (see Fig. 39), the shorter slope having a vertical range of ten to thirty-five feet, and its longer a range of forty to one hundred feet. This asymmetrical form persists throughout all that portion of the ridge which lies on an inclined surface, the slope of which does not correspond with the direction of the moraine. Where it lies on a flat surface, or an inclined

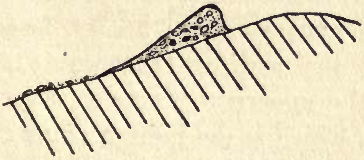


FIG. 39.—Diagrammatic cross-section of the marginal ridge as it occurs on the south slope of the Devil's Nose. The slope below, though glaciated, is nearly free from drift.

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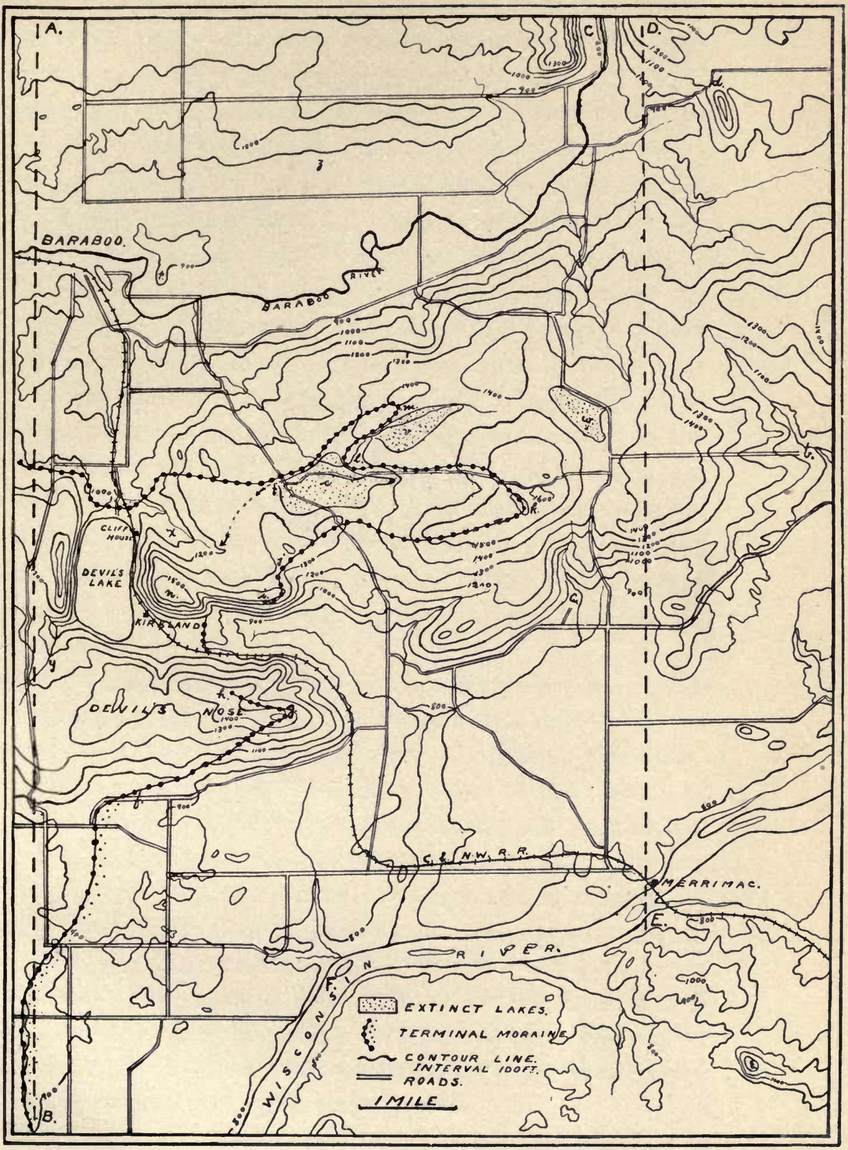
[1] An account of loess in connection with the drift of the last glacial epoch is given in the *Journal of Geology*, Vol. IV, pp. 929–987. For a general account of loess, see Sixth Annual Report of U. S. Geological Survey.

surface the slope of which corresponds in direction with the course of the ridge itself, its cross section is more nearly symmetrical (see Fig. 40). In all essential characteristics this marginal ridge corresponds with the *End-Moräne* of the Germans.

FIG. 40.—Diagrammatic cross-section of the marginal ridge as it appears when its base is not a sloping surface.

For the sake of bringing out some of its especially significant features, the ridge may be traced in detail, commencing on the south side of the west range. Where the moraine leaves the lowlands south of the Devil's nose, and begins the ascent of the prominence, the marginal ridge first appears at about the 940-foot contour (*f*, Plate XXXVII). Though at first its development is not strong, few rods have been passed before its crest is fifteen to twenty feet above the driftless area immediately to the north (see Fig. 39) and from forty to one hundred feet above its base to the south, down the slope. In general the ridge becomes more distinct with increasing elevation, and except for two or three narrow post-glacial erosion breaks, is continuous to the very summit at the end of the nose (*g*). The ridge in fact constitutes the uppermost forty or forty-five feet of the crest of the nose, which is the highest point of the west range within the area shown on the map. Throughout the whole of this course the marginal ridge lies on the south slope of the nose, and has the asymmetrical cross section shown in Fig. 39. Above (north of) the ridge at most points not a bowlder of drift occurs. So sharply is its outer (north) margin defined, that at many points it is possible to locate it within the space of less than a yard.

At the crest of the nost (*g*) the marginal ridge, without a break, swings northward, and in less than a quarter of a mile turns again to the west. Bearing to the north it presently reaches (at *h*) the edge of the precipitous bluff, bordering the



Topographic map (contour interval 100 feet) of a small area about Devil's lake, taken from the Baraboo sheet of the United States Geological Survey. Each contour line connects points of the same elevation, and the figures upon them give the heights above sea level. Where contour lines lie close together, they indicate steep slopes.

great valley at the south end of the lake. Between the two arms of the loop thus formed, the surface of the nose is so nearly level that it could have offered no notable opposition to the progress of the ice, and yet it failed to be covered by it.

In the great valley between the nose and the east bluff, the marginal ridge does not appear. In the bottom of the valley the moraine takes on its normal form, and the slopes of the quartzite ridges on either hand are much too steep to allow any body of drift, or loose material of any sort, to lodge on them.

Ascending the east bluff a little east of the point where the drift ridge drops off the west bluff, the ridge is again found (at *i*) in characteristic development. For some distance it is located at the edge of the precipitous south face of the bluff. Farther on it bears to the north, and soon crosses a col (*j*) in the ridge, building it up many feet above the level of the bed-rock. From this point eastward for about three miles the marginal ridge is clearly defined, the slopes about equal on either side, and the crest as nearly even as the topography of the underlying surface permits. The topographic relations in this part of the course are shown in Fig. 40.

At *k,* this marginal ridge attains its maximum elevation, 1,620 feet. At this great elevation, the ridge turns sharply to the northwest at an angle of more than 90°. Following this direction for little more than half a mile, it turns to the west. At some points in this vicinity the ridge assumes the normal morainic habit, but this is true for short distances only. Farther west, at *l,* it turns abruptly to the northeast and is sharply defined. It here loops about a narrow area less than sixty rods wide, and over half a mile in length, the sharpest loop in its whole course. The driftless tract enclosed by the arms of this loop is lower than the drift ridge on either hand. The ice on either side would need to have advanced no more than thirty rods to have covered the whole of it.

From the minor loop just mentioned, the marginal ridge is continued westward, being well developed for about a mile and a half. At this point the moraine swings south to the north end of Devil's lake, loses the unique marginal ridge which has characterized its outer edge across the quartzite range for so many miles, and assumes the topography normal to terminal moraines. At no other point in the United States, so far as known to the writers, is there so sharply marked a marginal ridge associated with the terminal moraine, for so long a distance.

From Plate II (p. 4) it will be seen that the moraine as a whole makes a great loop to the eastward in crossing the quartzite range. From the detailed description just given of the course of the marginal ridge, it will be seen that it has three distinct loops; one on the Devil's nose (west of *g*, Plate XXXVII, p. 108); one on the main ridge (west of *k*) and a minor one on the north side of the last (southwest of *m*). The first and third are but minor irregularities on the sides of the great loop, the head of which is at *k*.

The significant fact in connection with these irregularities in the margin of the moraine is that each loop stands in a definite relation to a prominence. The meaning of this relation is at once patent. The great quartzite range was a barrier to the advance of the ice. Acting as a wedge, it caused a re-entrant in the advancing margin of the glacier. The extent and position of the re-entrant is shown by the course of the moraine in Plate II. Thus the great loop in the moraine, the head of which is at *k,* Plate XXXVII, was caused by the quartzite range itself.

The minor loops on the sides of the major are to be explained on the same principle. Northeast of the minor loop on the north side of the larger one (*m*) there are two considerable hills, reaching an elevation of nearly 1,500 feet. Though the ice advancing from the east-northeast overrode them, they must have acted like a wedge, to divide it into lobes. The ice which reached their summits had spent its energy in so doing, and was unable to move forward down the slope ahead, and the thicker bodies of ice which passed on either side of them, failed to unite in their lee (compare Figs. 34 and 35). The application of the same principle to the loop on the Devil's nose is evident.

Constitution of the marginal ridge.—The material in the marginal ridge, as seen where erosion has exposed it, is till, abnormal, if at all, only in the large percentage of widely transported bowlders which it contains. This is especially true of the surface, where in some places 90 per cent. of the large bowlders are of very distant origin, and that in spite of the fact that the ice which deposited them had just risen up over a steep slope of quartzite, which could easily have yielded abundant bowlders. In other places the proportion of foreign bowlders is small, no more than one in ten. In general, however, bowlders of distant origin predominate over those derived close at hand.

The slope of the upper surface of the ice at the margin.—The marginal ridge on the south slope of Devil's nose leads to an inference of especial interest. Its course lies along the south slope of the nose, from its summit on the east to its base on the west. Throughout this course the ridge marks with exactness the position of the edge of the ice at the time of its maximum advance, and its crest must therefore represent the slope of the upper surface of the ice at its margin.

The western end of the ridge (*f*, Plate XXXVII) has an altitude of 940 feet, and its eastern end (*g*) is just above the 1,500-foot contour. The distance from the one point to the other is one and three-fourths miles, and the difference in elevation, 560 feet. These figures show that the slope of the ice along the south face of this bluff was about 320 feet per mile. This, so far as known, is the first determination of the slope of the edge of the continental ice sheet *at its extreme margin.* It is to be especially noted that these figures are for the extreme edge of the ice only. The angle of slope back from the edge was doubtless much less.

Stratified Drift.

While it is true that glacier ice does not distinctly stratify the deposits which it makes, it is still true that a very large part of the drift for which the ice of the glacial period was directly or indirectly responsible is stratified. That this should be so is not strange when it is remembered that most of the ice was ultimately converted into running water, just as the glaciers of today are. The relatively small portion which disappeared by evaporation was probably more than counterbalanced, at least near the margin of the ice, by the rain which fell upon it. It cannot be considered an exaggeration, therefore, to say that the total amount of water which operated on the drift, first and last, was hardly less than the total amount of the ice itself. The drift deposited by the marginal part of the ice was affected during its deposition, not only by the water which arose from the melting of the ice which did the depositing, but by much water which arose from the melting of the ice far back from the margin. The general mobility of the water, as contrasted with ice, allowed it to concentrate its activities along those lines which favored its motion, so that different portions of the drift were not affected equally by the water of the melting ice.

All in all it will be seen that the water must have been a very important factor in the deposition of the drift, especially near the margin of the ice. But the ice sheet had a marginal belt throughout its whole history, and water must have been active and effective along this belt, not only during the decadence of the ice sheet, but during its growth as well. It is further to be noted that any region of drift stood good chance of being operated upon by the water after the ice had departed from it, so that in regions over which topography directed drainage after the withdrawal of the ice, the water had the last chance at the drift, and modified it in such a way and to such an extent as circumstances permitted.

Its origin.—There are various ways in which stratified drift may arise in connection with glacier deposits. It may come into existence by the operation of water alone; or by the co-operation of ice and water. Where water alone was immediately responsible for the deposition of stratified drift, the water concerned may have owed its origin to the melting ice, or it may have existed independently of the ice in the form of lakes. When the source of the water was the melting ice, the water may have been running, when it was actively concerned in the deposition of stratified drift; or it may have been standing (glacial lakes and ponds), when it was passively concerned. When ice co-operated with water in the development of stratified drift the ice was generally a passive partner.

Glacial drainage.—The body of an ice sheet during any glacial period is probably melting more or less at some horizons all the time, and at all horizons some of the time. Most of the water which is produced at the surface during the summer sinks beneath it. Some of it may congeal before it sinks far, but much of it reaches the bottom of the ice without refreezing. It is probable that melting is much more nearly continuous in the body of a moving ice sheet than at its surface, and that some of the water thus produced sinks to the bottom of the ice without refreezing. At the base of the ice, so long as it is in movement, there is doubtless more or less melting, due both to friction and to the heat received by conduction from the earth below. Thus in the ice and under the ice there must have been more or less water in motion throughout essentially all the history of an ice sheet.

If it be safe to base conclusions on the phenomena of existing glaciers, it may be assumed that the waters beneath the ice, and to a less extent the waters in the ice, organized themselves to a greater or less degree into streams. For longer or shorter distances these streams flowed in the ice or beneath it. Ultimately they escaped from its edge. The subglacial streams doubtless flowed, in part, in the valleys which affected the land surface beneath the ice, but they were probably not all in such positions.

The courses of well-defined subglacial streams were tunnels. The bases of the tunnels were of rock or drift, while the sides and tops were of ice. It will be seen, therefore, that their courses need not have corresponded with the courses of the valleys beneath the ice. They may sometimes have followed lines more or less independent of topography, much as water may be forced over elevations in closed tubes. It is not to be inferred, however, that the subglacial streams were altogether independent of the sub-ice topography. The tunnels in which the water ran probably had too many leaks to allow the water to be forced up over great elevations. This, at least, must have been the case where the ice was thin or affected by crevasses. Under such circumstances the topography of the land surface must have been the controlling element in determining the course of the subglacial drainage.

When the streams issued from beneath the ice the conditions of flow were more or less radically changed, and from their point of issue they followed the usual laws governing river flow. If the streams entered static water as they issued from the ice, and this was true where the ice edge reached the sea or a lake, the static water modified the results which the flowing waters would otherwise have produced.

Stages in the history of an ice sheet.—The history of an ice sheet which no longer exists involves at least two distinct stages. These are 1) the period of growth, and 2) the period of decadence. If the latter does not begin as soon as the former is complete, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice sheet is believed to have been marked by temporary, but by more or less extensive intervals of decadence, while during the general period of decadence, it is probable that the ice was subject to temporary, but to more or less extensive intervals of recrudescence. For the sake of simplicity, the effects of these oscillations of the edge of the ice will be neglected at the outset, and the work of the water accompanying the two or three principal stages of an ice sheet's history will be outlined as if interruptions in the advance and in the retreat, respectively, had not occurred.

As they now exist, the deposits of stratified drift made at the edge of the ice or beyond it during the period of its maximum extension present the simplest, and at the same time most sharply defined phenomena, and are therefore considered first.

Deposits Made by Extraglacial Waters During the Maximum Extension of the Ice.

The deposits made by the water at the time of the maximum extension of the ice and during its final retreat, were never disturbed by subsequent glacier action. So far as not destroyed by subsequent erosion, they still retain the form and structure which they had at the outset. Such drift deposits, because they lie at the surface, and because they are more or less distinct topographically as well as structurally, are better known than the stratified drift of other stages of an ice sheet's history. Of stratified drift made during the maximum extension of the ice, and during its final retreat, there are several types.

A. At the edge of ice, on land.—If the subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice. With this relief, there was diminution of velocity. With the diminution of velocity, deposition of load would be likely to take place. Since these changes would be likely to occur at the immediate edge of the ice, one class of stratified drift deposits would be made in this position, in immediate contact with the edge of the ice, and their form would be influenced by it. At the stationary margin of an ice sheet, therefore, at the time of its maximum advance, ice and water must have co-operated to bring into existence considerable quantities of stratified drift.

The edge of the ice was probably ragged, as the ends of glaciers are today, and as the waters issued from beneath it, they must frequently have left considerable quantities of such debris as they were carrying, against its irregular margin, and in its re-entrant angles and marginal crevasses. When the ice against which this debris was first lodged melted, the marginal accumulations of gravel and sand often assumed the form of *kames*. A typical kame is a hill, hillock, or less commonly a short ridge of stratified drift; but several or many are often associated, giving rise to groups and areas of kames. Kames are often associated with terminal moraines, a relation which emphasizes the fact of their marginal origin.

So far as the superficial streams which flowed to the edge of the ice carried debris, this was subject to deposition as the streams descended from the ice. Such drift would tend to increase the body of marginal stratified drift from subglacial sources.

Marginal accumulations of stratified drift, made by the co-operation of running water and ice, must have had their most extensive development, other things being equal, where the margin of the ice was longest in one position, and where the streams were heavily loaded. The deposits made by water at the edge of the ice differ from those of the next class—made beyond the edge of the ice—in that they were influenced in their disposition and present topography, by the presence of ice.

In the Devil's lake region isolated and well-defined kames are not of common occurrence. There are, however, at many points hills which have something of a kame-like character. There is such a hill a mile southeast of the Court house at Baraboo, at the point marked *p*, Plate XXXVII. In this hill there are good exposures which show its structure. There are many hillocks of a general kame-like habit associated with the terminal moraine south of the main quartzite range, and north of the Wisconsin river. Many of them occur somewhat within the terminal moraine a few miles northwest of Merrimac.

B. Beyond the edge of the ice, on land.—As the waters escaping from the ice flowed farther, deposits of stratified drift were made quite beyond the edge of the ice. The forms assumed by such deposits are various, and depended on various conditions. Where the waters issuing from the edge of the ice found themselves concentrated in valleys, and where they possessed sufficient load, and not too great velocity, they aggraded the valleys through which they flowed, developing fluvial plains of gravel and sand, which often extended far beyond the ice. Such fluvial plains of gravel and sand constitute the *valley trains* which extend beyond the unstratified glacial drift in many of the valleys of the United States. They are found especially in the valleys leading out from the stouter terminal moraines of late glacial age. From these moraines, the more extensive valley trains take their origin, thus emphasizing the fact that they are deposits made by water beyond a stationary ice margin. Valley trains have all the characteristics of alluvial plains built by rapid waters carrying heavy loads of detritus. Now and then their surfaces present slight variations from planeness, but they are minor. Like all plains of similar origin they decline gradually, and with diminishing gradient, down stream. They are of coarser material near their sources, and of finer material farther away. Valley trains constitute a distinct topographic as well as genetic type.

A perfect example of a valley train does not occur within the region here discussed. There is such a train starting at the moraine where it crosses the Wisconsin river above Prairie du Sac, and extending down that valley to the Mississippi, but at its head this valley train is wide and has the appearance of an overwash plain, rather than a valley train. Farther from the moraine, however, it narrows, and assumes the normal characteristics of a valley train. It is the gravel and sand of this formation which underlies Sauk Prairie, and its topographic continuation to the westward.

Where the subglacial streams did not follow subglacial valleys, they did not always find valleys when they issued from the ice. Under such circumstances, each heavily loaded stream coming out from beneath the ice must have tended to develop a plain of stratified material near its point of issue—a sort of alluvial fan. Where several such streams came out from beneath the ice near one another, their several plains, or fans, were likely to become continuous by lateral growth. Such border plains of stratified drift differ from valley trains particularly 1) in being much less elongate in the direction of drainage; 2)in being much more extended parallel to the margin of the ice; and 3) in not being confined to valleys. Such plains stood an especially good chance of development where the edge of the ice remained constant for a considerable period of time, for it was under such conditions that the issuing waters had opportunity to do much work. Thus arose the type of stratified drift variously known as *overwash plains, outwash plains, morainic plains,* and *morainic aprons.* These plains sometimes skirt the moraine for many miles at a stretch.

Overwash plains may sometimes depart from planeness by taking on some measure of undulation, of the sag and swell (kame) type, especially near their moraine edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of overwash plains, it is to be noted, occupy the general position in which kames are likely to be formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains and overwash plains, therefore, at their upper ends and edges respectively, may take on some of the features of kames. Indeed, either may head in a kame area.

Good examples of overwash or outwash plains may be seen at various points in the vicinity of Baraboo. The plain west of the moraine just south of the main quartzite ridge has been referred to under valley trains. In Sauk Prairie, however, its characteristics are those of an outwash plain, rather than those of a valley train.

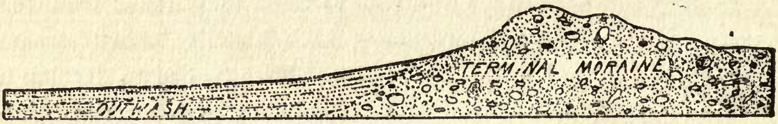


FIG. 41.—The morainic or outwash plain bordering the terminal moraine. The figure is diagrammatic, but represents, in cross section, the normal relation as seen south of the quartzite range at the east edge of Sauk Prairie, north of the Baraboo river and at some points between the South range and the Baraboo.

A good example of an outwash plain occurs southwest of Baraboo, flanking the moraine on the west (Fig. 41). Seen from the west, the moraine just north of the south quartzite range stands up as a conspicuous ridge twenty to forty feet above the morainic plain which abuts against it. Traced northward, the edge of the outwash plain, as it abuts against the moraine, becomes higher, and in Section 4, Township 11 N., Range 6 E., the moraine edge of the plain reaches the crest of the moraine (Fig. 42). From this point north to the Baraboo river the moraine scarcely rises above the edge of the outwash beyond.

FIG. 42.—The outwash plain is built up to the crest of the moraine. The figure is diagrammatic, but this relation is seen at the point marked *W*, Plate II.

North of the Baraboo river the moraine is again distinct and the overwash plain to the west well developed much of the way from the Baraboo to Kilbourn City. A portion of it is known as Webster's Prairie.

Locally, the outwash plains of this region have been much dissected by erosion since their deposition, and are now affected by many small valleys. In composition these plains are nearly everywhere gravel and sand, the coarser material being nearer the moraine. The loose material is in places covered by a layer of loam several feet deep, which greatly improves the character of the soil. This is especially true of Sauk Prairie, one of the richest agricultural tracts in the state.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt, or clay, instead of sand or gravel.

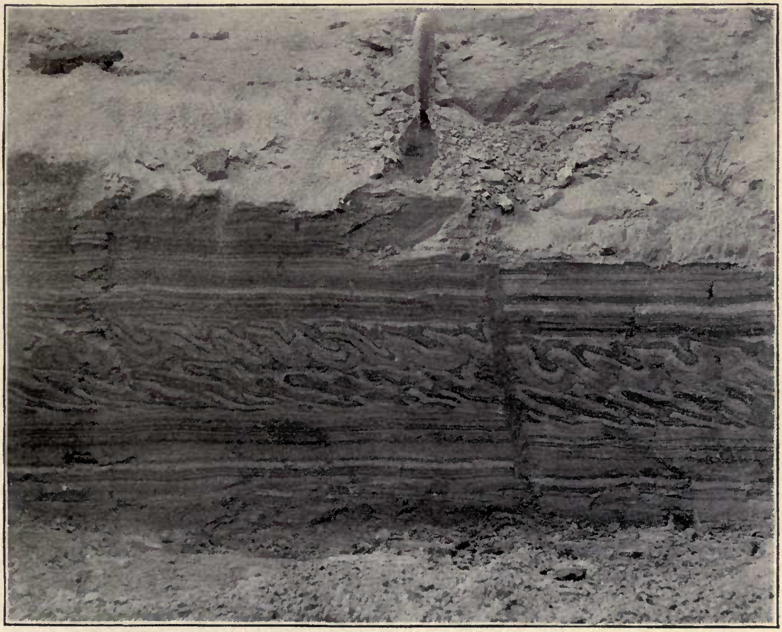
At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, were unable to develop considerable plains of stratified drift, but produced small patches instead. Such patches have received no special designation.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activity helped to supply the water with the necessary materials.

C. Deposits at and beyond the edge of the ice in standing water.—The waters which issued from the edge of the ice sometimes met a different fate. The ice in its advance often moved up river valleys. When at the time of its maximum extension, it filled the lower part of a valley, leaving the upper part free, drainage through the valley stood good chance of being blocked. Where this happened a marginal valley lake was formed. Such a lake was formed in the valley of the Baraboo when the edge of the ice lay where the moraine now is (Plate II). The waters which were held back by the ice dam, reinforced by the drainage from the ice itself, soon developed a lake above the point of obstruction. This extinct lake may be named *Baraboo lake.* In this lake deposits of laminated clay were made. They are now exposed in the brick yards west of Baraboo, and in occasional gullies and road cuts in the flat bordering the river.

At the point marked *s* (Plate XXXVII, p. 108) there was, in glacial times, a small lake having an origin somewhat different from that of Baraboo lake (see p. 133). The former site of the lake is now marked by a notable flat. Excavations in the flat show that it is made up of stratified clay, silt, sand and gravel, to the depth of many feet,—locally more than sixty. These lacustrine deposits are well exposed in the road cuts near the northwest corner of the flat, and in washes at some other points. Plate XXXVIII shows some of the silt and clay, the laminæ of which are much distorted.

Deltas must have been formed where well-defined streams entered the lakes, and *subaqueous overwash plains* where deltas became continuous by lateral growth. The accumulation of stratified drift along the ice-ward shores of such lakes must have been rapid, because of the abundant supply of detritus. These materials were probably shifted about more or less by waves and shore currents, and some of them may have been widely distributed. Out from the borders of such lakes, fine silts and clays must have been in process of deposition, at the same time that the coarse materials were being laid down nearer shore.



Distorted laminae of silt and clay.

Good examples of deltas and subaqueous overwash plains do not appear to exist in the region, although conditions for their development seem to have been present. Thus in the lake which occupied the valley of the Baraboo, conditions would seem to have been ideal for the development of such features; that is, the overwash plains previously described should, theoretically, have been subaqueous overwash plains; but if this be their character, their distinctive marks have been destroyed by subsequent erosion.

During the maximum extension of an ice sheet, therefore, there was chance for the development, at its edge or beyond it, of the following types of stratified drift: (1) kames and kame belts, at the edge of the ice; (2) fluvial plains or valley trains, in virtual contact with the ice at their heads; (3) border plains or overwash plains, in virtual contact with the ice at their upper edges; (4) ill-defined patches of stratified drift, coarse or fine near the ice; (5) subaqueous overwash plains and deltas, formed either in the sea or lakes at or near the edge of the ice; (6) lacustrine and marine deposits of other sorts, the materials for which were furnished by the waters arising from the ice. So far as this region is concerned, all the deposits made in standing water were made in lakes.

Deposits Made by Extraglacial Waters During the Retreat of the Ice.

During the retreat of any ice sheet, disregarding oscillations of its edge, its margin withdrew step by step from the position of extreme advance to its center. When the process of dissolution was complete, each portion of the territory once covered by the ice, had at some stage in the dissolution, found itself in a marginal position. At all stages in its retreat the waters issuing from the edge of the ice were working in the manner already outlined in the preceding paragraphs. Two points of difference only need be especially noted. In the first place the deposits made by waters issuing from the retreating ice were laid down on territory which the ice had occupied, and their subjacent stratum was often glacial drift. So far as this was the case, the stratified drift was super-morainic, not extra-morainic. In the second place the edge of the ice in retreat did not give rise to such sharply marked formations as the edge of the ice which was stationary. The processes which had given rise to valley trains, overwash plains, kames, etc., while the ice edge was stationary, were still in operation, but the line or zone of their activity (the edge of the ice) was continually retreating, so that the foregoing types, more or less dependent on a stationary edge, were rarely well developed. As the ice withdrew, therefore, it allowed to be spread over the surface it had earlier occupied, many incipient valley trains, overwash plains, and kames, and a multitude of ill-defined patches of stratified drift, thick and thin, coarse and fine. Wherever the ice halted in its retreat, these various types stood chance of better development.

Such deposits did not cover all the surface discovered by the ice in its retreat, since the issuing waters, thanks to their great mobility, concentrated their activities along those lines which favored their motion. Nevertheless the aggregate area of the deposits made by water outside the ice as it retreated, was great.

It is to be noted that it was not streams alone which were operative as the ice retreated. As its edge withdrew, lakes and ponds were continually being drained, as their outlets, hitherto choked by the ice, were opened, while others were coming into existence as the depressions in the surface just freed from ice, filled with water. Lacustrine deposits at the edge of the ice during its retreat were in all essential respects identical with those made in similar situations during its maximum extension.

Disregarding oscillations of the ice edge at these stages, the deposits made by extraglacial waters during the maximum extension of an ice sheet, and during its retreat, were always left at the surface, so far as the work of that ice sheet was concerned. The stratified drift laid down by extraglacial waters in these stages of the last ice sheet which affected any region of our continent still remain at the surface in much the condition in which they were deposited, except for the erosion they have since suffered. It is because of their position at the surface that the deposits referable to these stages of the last ice sheet of any given region have received most attention and are therefore most familiar.

Deposits Made by Extraglacial Waters During the Advance of the Ice.

During the advance of an ice sheet, if its edge forged steadily forward, the waters issuing from it, and flowing beyond, were effecting similar results. They were starting valley trains, overwash plains, kames, and small ill-defined patches of stratified drift which the ice did not allow them to complete before pushing over them, thus moving forward the zone of activity of extraglacial waters. Unlike the deposits made by the waters of the retreating ice, those made by the waters of the advancing stage were laid down on territory which had not been glaciated, or at least not by the ice sheet concerned in their deposition. If the ice halted in its advance, there was at such time and place opportunity for the better development of extraglacial stratified drift.

Lakes as well as streams were concerned in the making of stratified beds of drift, during the advance of the ice. Marginal lakes were obliterated by having their basins filled with the advancing ice, which displaced the water. But new ones were formed, on the whole, as rapidly as their predecessors became extinct, so that lacustrine deposits were making at intervals along the margin of the advancing ice.

Deposits made in advance of a growing ice sheet, by waters issuing from it, were subsequently overridden by the ice, to the limit of its advance, and in the process, suffered destruction, modification, or burial, in whole or in part, so that now they rarely appear at the surface.

Deposits Made by Subglacial Streams.

Before their issuance from beneath the ice, subglacial waters were not idle. Their activity was sometimes erosive, and at such times stratified deposits were not made. But where the sub-glacial streams found themselves overloaded, as seems frequently to have been the case, they made deposits along their lines of flow. Where such waters were not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand, or gravel; but where depositing streams were confined to definite channels, their deposits were correspondingly concentrated.

When subglacial streams were confined to definite channels, the same may have been constant in position, or may have shifted more or less from side to side. Where the latter happened there was a tendency to the development of a belt or strip of stratified drift having a width equal to the extent of the lateral migrations of the under-ice stream. Where the channel of the subglacial stream remained fixed in position, the deposition was more concentrated, and the bed was built up. If the stream held its course for a long period of time, the measure of building may have been considerable. In so far as these channel deposits were made near the edge of the ice, during the time of its maximum extension or retreat, they were likely to remain undisturbed during its melting. The aggraded channels then came to stand out as ridges. These ridges of gravel and sand are known as *osars* or *eskers.* It is not to be inferred that eskers never originated in other ways, but it seems clear that this is one method, and probably the principal one, by which they came into existence. Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. The essential conditions, therefore, for their formations, so far as they are the product of subglacial drainage, are 1) the confining of the subglacial streams to definite channels; and 2) a sufficient supply of detritus. One esker only has been found in the region under consideration. It is located at the point marked *j,* Plate II, seven and one-half miles northeast of Merrimac and one and one-half miles south of Alloa (*g*, Plate II). The esker is fully a quarter of a mile long, about thirty feet high, and four rods wide at its base.

Subglacial deposits of stratified drift were sometimes made on unstratified drift (till) already deposited by the ice before the location of the stream, and sometimes on the rock surfaces on which no covering of glacier drift had been spread.

It is to be kept in mind that subglacial drainage was operative during the advance of an ice sheet, during its maximum extension, and during its retreat, and that during all these stages it was effecting its appropriate results. It will be readily seen, however, that all deposits made by subglacial waters, were subject to modification or destruction or burial, through the agency of the ice, and that those made during the advance of the ice were less likely to escape than those made during its maximum extension or retreat.

RELATIONS OF STRATIFIED TO UNSTRATIFIED DRIFT.

When it is remembered that extraglacial and subglacial waters were active at all stages of an ice sheet's history, giving rise, or tending to give rise to all the phases of stratified drift enumerated above; when it is remembered that the ice of several epochs affected much of the drift-covered country; and when it is remembered further that the edge of the ice both during advance and retreat was subject to oscillation, and that each advance was likely to bury the stratified drift last deposited, beneath unstratified, it will be seen that the stratified drift and the unstratified had abundant opportunity to be associated in all relationships and in all degrees of intimacy, and that the relations of the one class of drift to the other may come to be very complex.

As a result of edge oscillation, it is evident that stratified drift may alternate with unstratified many times in a formation of drift deposited during a single ice epoch, and that two beds of till, separated by a bed of stratified drift, do not necessarily represent two distinct glacial epochs. The extent of individual beds of stratified drift, either beneath the till or inter-bedded with it, may not be great, though their aggregate area and their aggregate volume is very considerable. It is to be borne in mind that the ice, in many places, doubtless destroyed all the stratified drift deposited in advance on the territory which it occupied later, and that in others it may have left only patches of once extensive sheets. This may help to explain why it so frequently happens that a section of drift at one point shows many layers of stratified drift, while another section close by, of equal depth, and in similar relationships, shows no stratified material whatsoever.

Such deposits as were made by superglacial streams during the advance of the ice must likewise have been delivered on the land surface, but would have been subsequently destroyed or buried, becoming in the latter case, submorainic. This would be likely to be the fate of all such superglacial gravels as reached the edge of the ice up to the time of its maximum advance.

Streams descending from the surface of the ice into crevasses also must have carried down sand and gravel where such materials existed on the ice. These deposits may have been made on the rock which underlies the drift, or they may have been made on stratified or unstratified drift already deposited. In either case they were liable to be covered by till, thus reaching an inter-till or sub-till position.

Englacial streams probably do little depositing, but it is altogether conceivable that they might accumulate such trivial pockets of sand and gravel as are found not infrequently in the midst of till. The inter-till position would be the result of subsequent burial after the stratified material reached a resting place.

Complexity of relations.—From the foregoing it becomes clear that there are diverse ways by which stratified drift, arising in connection with an ice sheet, may come to be interbedded with till, when due recognition is made of all the halts and oscillations to which the edge of a continental glacier may have been subject during both its advance and retreat.

CLASSIFICATION OF STRATIFIED DRIFT ON THE BASIS OF POSITION.

In general the conditions and relations which theoretically should prevail are those which are actually found.

On the basis of position stratified drift deposits may be classified as follows:

1. *Extraglacial deposits,* made by the waters of any glacial epoch if they flowed and deposited beyond the farthest limit of the ice.

2. *Supermorainic deposits* made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extraglacial streams or lakes of a much later time. Locally too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits were for the most part extraglacial (including marginal), so far as the ice sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still superglacial.

3. *The submorainic* (*basal*) *deposits* were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice sheet may have left rock surfaces free from till covering, on which the marginal waters of the ice may have made deposits of stratified drift. These may have been subsequently covered by till during a readvance of the ice in the same epoch or in a succeeding one.

Still again, the till left by one ice sheet may have been exposed to erosion to such an extent as to have been completely worn away before the next ice advance, so that stratified deposits connected with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. *Intermorainic stratified drift* may have originated at the outset in all the ways in which supermorainic drift may originate. It may have become intermorainic by being buried in any one of the various ways in which the stratified drift may become submorainic.

CHANGES IN DRAINAGE EFFECTED BY THE ICE.

While the Ice Was on.

As the continental ice sheet invaded a region, the valleys were filled and drainage was thereby seriously disturbed. Different streams were affected in different ways. Where the entire basin of a stream was covered by ice, the streams of that basin were, for the time being, obliterated. Where the valley of a stream was partially filled with ice, the valley depression was only partially obliterated, and the remaining portion became the scene of various activities. Where the ice covered the lower course of a stream but not the upper, the ice blocked the drainage, giving rise to a lake. Where the ice covered the upper course of a stream, but not its lower, the lower portion was flooded, and though the river held its position, it assumed a new phase of activity. Streams issuing from the ice usually carry great quantities of gravel and sand, and make deposits along their lower courses. Long continued glacial drainage usually results in a large measure of aggradation. This was true of the streams of the glacial period.

Where a stream flowed parallel or approximately parallel to the edge of the advancing ice it was sometimes shifted in the direction in which the ice was moving, keeping parallel to the front of the ice. All of these classes of changes took place in this region.

Wisconsin lake.—Reference has already been made to certain lakes which existed in the region when the ice was there. The largest of these lakes was that which resulted from the blocking of the Wisconsin river. The ice crossed its present course at Kilbourn City, and its edge lay to the west of the river from that point to Prairie du Sac (see Plate I, p. 4). The waters from the area now draining into the Wisconsin must either have found an avenue of escape beneath the ice, or have accumulated in a lake west of the edge of the ice. There is reason to believe that the latter was what happened, and that a great lake covered much of the low land west of the Wisconsin river above and below Kilbourn City. The extensive gravel beds on the north flank of the quartzite bluff at Necedah, and the water-worn pebbles of local origin on the slope of Petenwell peak (Plate XXXII), as well as the gravels at other points, are presumably the work of that lake. The waters in this lake, as in that in the Baraboo valley, probably rose until the lowest point in the rim of the basin was reached, and there they had their outlet. The position of this outlet has not been definitely determined, but it has been thought to be over the divide of the Black river.[1] It is possible, so far as now known, that this lake was connected with that of the Baraboo valley. Until topographic maps of this region are made, the connections will not be easily determined.

Even after the ice had retreated past the Wisconsin, opening up the present line of drainage, the lakes did not disappear at once, for the ice had left considerable deposits of drift in the Wisconsin valley. Thus at F, Plates II (p. 5) and XXXVII (p. 108), and perhaps at other points, the Wisconsin has made cuts of considerable depth in the drift. Were these cuts filled, as they must have been when the ice melted, the drainage would be ponded, the waters standing at the level of the dam. This

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[1] Chamberlin: Geology of Wisconsin, Vol. 1.

drift obstruction at F would therefore have prolonged the history of the lake which had come into existence when the ice blocked the drainage of the Wisconsin. As the drift of the valley was removed the level of the lake sank and finally disappeared.

Baraboo lake.—Another lake which existed in this region when the ice was here, occupied the valley of the Baraboo and its tributaries when the ice blocked the valley at Baraboo. This lake occupied not only the valley of the Baraboo, but extended up the lower course of every tributary, presumably rising until it found the lowest point in the rim of the drainage basin. The location of this point, and therefore the height of the lake when at its maximum, are not certainly known, though meager data on this point have been collected. At a point three miles southeast of Ablemans on the surface of a sandstone slope, water-worn gravel occurs, the pebbles of which were derived from the local rock. On the slope below the gravel, the surface is covered with loam which has a suggestion of stratification, while above it, the soil and subsoil appear to be the product of local rock decomposition. This water-worn gravel of local origin on a steep slope facing the valley, probably represents the work of the waves of this lake, perhaps when it stood at its maximum height. This gravel is about 125 feet (aneroid measurement) above the Baraboo river to the north.

Further evidence of a shore line has been found at the point marked T, Plate II. At this place water-worn gravel of the local rock occurs in much the same relationship as that already mentioned, and at the same elevation above the Baraboo river. At a point two and one-half miles southwest of Ablemans there is local water-worn gravel, with which is mingled glacial material (pieces of porphyry and diabase) which could have reached this point only by being carried thither by floating ice from the glacier. The level of this mixed local and glacial material is (according to aneroid measurement) approximately the same as that of the other localities.

When the ice melted, an outlet was opened *via* the Lower narrows, and the water of the lake drained off to the Wisconsin by this route. Had the ice left no drift, the lake would have been promptly drained when the ice melted; but the lake did not entirely disappear immediately after the ice retreated, for the drift which the ice left obstructed drainage to the east. The moraine, however, was not so high as the outlet of the lake while the ice was on, so that, as the ice retreated, the water flowed over the moraine to the east, and drew down the level of the lake to the level of the lowest point in the moraine. The postglacial cut through the moraine is about ninety feet deep.

Besides being obstructed where crossed by the terminal moraine, the valley of the Baraboo was clogged to a less extent by drift deposits between the moraine and the Lower narrows. At one or two places near the City of Baraboo, such obstructions, now removed, appear to have existed. Just above the Lower narrows (*c*, Plate XXXVII) there is positive evidence that the valley was choked with drift. Here in subsequent time, the river has cut through the drift-filling of the preglacial valley, developing a passage about twenty rods wide and thirty-five feet deep. If this passage were filled with drift, reproducing the surface left by the ice, the broad valley above it would be flooded, producing a shallow lake.

The retreat of the ice therefore left two well defined drift dams in the valley, one low one just above the Lower narrows, and a higher one, the moraine dam, just west of Baraboo. Disregarding the influence of the ice, and considering the Baraboo valley only, these two dams would have given rise to two lakes, the upper one behind the higher dam being deeper and broader, and covering a much larger area; the lower one behind the lower dam, being both small and shallow.

Up to the time that the ice retreated past the Lower narrows, the waters of the upper and lower lakes were united, held up to a common level by the ice which blocked this pass. After the ice retreated past the Lower narrows, the level of the Baraboo lake did not sink promptly, for not until the ice had retreated past the site of the Wisconsin was the present drainage established. Meantime the waters of the Baraboo lake joined those of Wisconsin lake (p. 129) through the Lower narrows. If the lakes had been before connected at some point farther west, this connection through the narrows would not have changed the level of either. If they were not before connected, and if the Wisconsin lake was lower than the Baraboo, this connection would have drawn down the level of the latter.

Since the drainage from the Baraboo went to the Wisconsin, the Baraboo lake was not at first lowered below the level of the highest obstruction in the valley of the Wisconsin even after the ice had retreated beyond that stream. As the drift obstructions of the Wisconsin valley were lowered, the levels of all the lakes above were correspondingly brought down. When the level of the waters in these lakes was brought down to the level of the moraine dam above Baraboo, the one Baraboo lake of earlier times became two. The level of the upper of these two lakes was determined by the moraine above Baraboo, that of the lower by the highest obstruction below the moraine in either the Baraboo or Wisconsin valley. The drift obstructions in the Baraboo valley were probably removed about as fast as those in the Wisconsin, and since the obstructions were of drift, and the streams strong, the removal of the dams was probably rapid. Both the upper and lower Baraboo lakes, as well as the Wisconsin, had probably been reduced to small proportions, if not been completely drained, before the glacial period was at an end.

Devil's lake in glacial times.—While the ice edge was stationary in its position of maximum advance, its position on the north side of the main quartzite range was just north of Devil's lake (Plate XXXVII, p. 108). The high ridge of drift a few rods north of the shore is a well defined moraine, and is here more clearly marked than farther east or west, because it stands between lower lands on either side, instead of being banked against the quartzite ridge. North of the lake it rises about 75 feet above the water. When the ice edge lay in this position on the north side of the range, its front between the East bluff and the Devil's nose lay a half mile or so from the south end of the lake. In this position also there is a well defined moraine.

While the ice was at its maximum stand, it rose above these moraine ridges at either end of the lake. Between the ice at these two points there was then a notable basin, comparable to that of the present lake except that the barriers to the north and southeast were higher than now. The melting of the ice supplied abundant water, and the lake rose above its present level. The height which it attained is not known, but it is known to have risen at least 90 feet above its present level. This is indicated by the presence of a few drift bowlders on the West bluff of the lake at this height. They represent the work of a berg or bergs which at some stage floated out into the lake with bowlders attached. Bowlders dropped by bergs might be dropped at any level lower than the highest stand of the lake.

Other lakes.—Another glacial lake on the East quartzite bluff has already (p. 120) been referred to. Like the Devil's lake in glacial time, its basin was an enclosure between the ice on the one hand, and the quartzite ridge on the other. The location of this lake is shown on Plate XXXVII (*s*). Here the edge of the ice, as shown by the position of the moraine, was affected by a re-entrant curve, the two ends of which rested against the quartzite ridge. Between the ice on the one hand and the quartzite ridge on the other, a small lake was formed. Its position is marked by a notable flat.

With the exception of the north side, and a narrow opening at the northwest corner, the flat is surrounded by high lands. When the ice occupied the region, its edge held the position shown by the line marking the limit of its advance, and constituted an ice barrier to the north.[1] The area of the flat was, therefore, almost shut in, the only outlet being a narrow one at *t*, Plate XXXVII. If the filling of stratified drift which underlies the flat were removed, the bottom of the area would be much lower than at present, and much lower than the outlet at *t*. It is therefore evident that when the ice had taken its position

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[1] The moraine line on the map represents the crest of the marginal ridge rather than its outer limit, which is slightly nearer the lake margin. Stratified drift of the nature of overwash also intervenes at points between the moraine and the lake border.

along the north side of the flat, an enclosed basin must have existed, properly situated for receiving and holding water. Since this lake had but a short life and became extinct before the ice retreated, its history is here given.

At first the lake had no outlet and the water rose to the level of the lowest point (*t*) in the rim of the basin, and thence overflowed to the west. Meanwhile the sediments borne in by the glacial drainage were being deposited in the lake in the form of a subaqueous overwash plain, the coarser parts being left near the shore, while the finer were carried further out. Continued drainage from the ice continued to bring sediment into the lake, and the subaqueous overwash plain extended its delta-like front farther and farther into the lake, until its basin was completely filled. With the filling of the basin the lake became extinct. The later drainage from the ice followed the line of the outlet, the level of which corresponds with the level of the filled lake basin. This little extinct lake is of interest as an example of a glacial lake which became extinct by having its basin filled during glacial times, by sediments washed out from the ice.

Near the northwest corner of this flat, an exposure in the sediments of the old lake bed shows the curiously contorted layers of sand, silt, and clay represented in Plate XXXVIII (p. 120). The layers shown in the figure are but a few feet below the level of the flat which marks the site of the lake. It will be seen that the contorted layers are between two series of horizontal ones. The material throughout the section is made up of fine-grained sands and clays, well assorted. That these particular layers should have been so much disturbed, while those below and above remained horizontal, is strange enough. The grounding of an iceberg on the surface before the overlying layers were deposited, the action of lake ice, or the effect of expansion and contraction due to freezing and thawing, may have been responsible for the singular phenomenon. Contorted laminæ are rather characteristic of the deposits of stratified drift.

After the Ice Had Disappeared.

As has already been indicated (p. 101), the irregular deposition of glacial drift gave rise to many depressions without outlets in which surface waters collected after the ice had disappeared, forming ponds or lakes. So abundant are lakes and ponds and marshes in recently glaciated regions and so rare elsewhere, that they constitute one of the more easily recognized characteristics of a glaciated region.

After the ice had melted, the mantle of drift which it left was sometimes so disposed as to completely obliterate preglacial valleys. More commonly it filled preglacial valleys at certain points only. In still other cases a valley was not filled completely at any point, though partially at many. In this last case, the partial fillings at various points constituted dams above which drainage was ponded, making lakes. If the dams were not high enough to throw the drainage out of the valley, the lakes would have their outlets over them. The drift dam being unconsolidated would be quickly cut down by the out-flowing water, and the lake level lowered. When the dam was removed or cut to its base, the lake disappeared and drainage followed its preglacial course.

In case the valley was completely filled, or completely filled at points, the case was very different. The drainage on the drift surface was established with reference to the topography which obtained when the ice departed, and not with reference to the preglacial valleys. Wherever the preglacial valleys were completely filled, the postglacial drainage followed lines which were altogether independent of them. When preglacial valleys were filled by the drift in spots only, the postglacial streams followed them where they were not filled, only to leave them where the blocking occurred. In the former case the present drainage is through valleys which are preglacial in some places, and postglacial in others.

Thus the drainage changes effected by the drift after the ice was gone, concerned both lakes and rivers. In this region there are several illustrations of these changes.

Lakes.—The lake basins of drift-covered regions are of various types. Some of them are altogether in drift, some partly in drift and partly in rock, and some wholly in rock. Basins in the drift were likely to be developed whenever heavy deposits surrounded thin ones. They are especially common in the depressions of terminal moraines.

Another class of lake basins occurs in valleys, the basins being partly rock and partly drift. If a thick deposit of drift be made at one point in a valley, while above there is little or none, the thick deposit will form a dam, above which waters may accumulate, forming a pond or lake. Again, a ridge of drift may be deposited in the form of a curve with its ends against a rock-ridge, thus giving rise to a basin.

In the course of time, the lakes and ponds in the depressions made or occasioned by the drift will be destroyed by drainage. Remembering how valleys develop (p. 46) it is readily understood that the heads of the valleys will sooner or later find the lakes, and drain them if their bottoms be not too low.

Drainage is hostile to lakes in another way. Every stream which flows into a lake brings in more or less sediment. In the standing water this sediment is deposited, thus tending to fill the lake basin. Both by filling their basins and by lowering their outlets, rivers tend to the destruction of lakes, and given time enough, they will accomplish this result. In view of this double hostility of streams, it is not too much to say that "rivers are the mortal enemies of lakes."

The destruction of lakes by streams is commonly a gradual process, and so it comes about that the abundance and the condition of the undrained areas in a drift-covered region is in some sense an index of the length of time, reckoned in terms of erosion, which has elapsed since the drift was deposited.

In this region there were few lakes which lasted long after the ice disappeared. The basins of the Baraboo and Wisconsin lakes (p. 129) were partly of ice, and so soon as the ice disappeared, the basins were so nearly destroyed, and the drift dams that remained so easily eroded, that the lakes had but a brief history,—a history that was glacial, rather than postglacial.

The history of the little lake on the East quartzite bluff (p. 133) as already pointed out, came to an end while the ice was still present.

The beds of at least two other extinct ponds or small lakes above the level of the Baraboo are known. These are at *v* and *w,* Plate XXXVII. They owed their origin to depressions in the drift, but the outflowing waters have lowered their outlets sufficiently to bring them to the condition of marshes. Both were small in area and neither was deep.

Existing lakes.—Relatively few lakes now remain in this immediate region, though they are common in most of the country covered by the ice sheet which overspread this region. Devil's lake only is well known. The lake which stood in this position while the ice was on, has already been referred to (p. 132). After the ice had melted away, the drift which it had deposited still left an enclosure suitable for holding water. The history of this basin calls for special mention.

At the north end of the lake, and again in the capacious valley leading east from its south end, there are massive terminal moraines. Followed southward, this valley though blocked by the moraine a half mile below the lake, leads off towards the Wisconsin river, and is probably the course of a large preglacial stream. Beyond the moraine, this valley is occupied by a small tributary to the Wisconsin which heads at the moraine. To the north of the lake, the head of a tributary of the Baraboo comes within eighty rods of the lake, but again the terminal moraine intervenes. From data derived from wells it is known that the drift both at the north and south ends of the lake extends many feet below the level of its water, and at the north end, the base of the drift is known to be at least fifty feet below the level of the bottom of the lake. The draining of Devil's lake to the Baraboo river is therefore prevented only by the drift dam at its northern end. It is nearly certain also, that, were the moraine dam at the south end of the lake removed, all the water would flow out to the Wisconsin, though the data for the demonstration of this conclusion are not to be had, as already stated p. 132).

There can be no doubt that the gorge between the East and West bluffs was originally the work of a pre-Cambrian stream, though the depth of the pre-Cambrian valley may not have been so great as that of the present. Later, the valley, so far as then excavated, was filled with the Cambrian (Potsdam) sandstone, and re-excavated in post-Cambrian and preglacial time. Devil's lake then occupies an unfilled portion of an old river valley, isolated by great morainic dams from its surface continuations on either hand. Between the dams, water has accumulated and formed the lake.

Changes in Streams.

In almost every region covered by the ice, the streams which established themselves after its departure follow more or less anomalous courses. This region is no exception. Illustrations of changes which the deposition of the drift effected have already been given in one connection or another in this report.

Skillett creek.—An illustration of the sort of change which drift effects is furnished by Skillett creek, a small stream tributary to the Baraboo, southwest of the city of that name. For some distance from its head (*a* to *b*, Fig. 43) its course is through a capacious preglacial valley. The lower part of this valley was filled with the water-laid drift of the overwash plain. On reaching the overwash plain the creek therefore shifted its course so as to follow the border of that plain, and along this route, irrespective of material, it has cut a new channel to the Baraboo. The postglacial portion of the valley (*b* to *c*) is everywhere narrow, and especially so where cut in sandstone.

The course and relations of this stream suggest the following explanation: Before the ice came into the region, Skillett creek probably flowed in a general northeasterly direction to the Baraboo, through a valley comparable in size to the preglacial part of the present valley. As the ice advanced, the lower part of this valley was occupied by it, and the creek was compelled to seek a new course. The only course open to it was to the north, just west of the advancing ice, and, shifting westward as fast as the ice advanced, it abandoned altogether its former lower course. Drainage from the ice then carried out and deposited beyond the same, great quantities of gravel and sand, making the overwash plain. This forced the stream still farther west, until it finally reached its present position across a sandstone ridge or plain, much higher than its former course. Into this sandstone it has since cut a notable gorge, a good illustration of a postglacial valley. The series of changes shown by this creek is illustrative of the changes undergone by streams in similar situations and relations all along the margin of the ice.

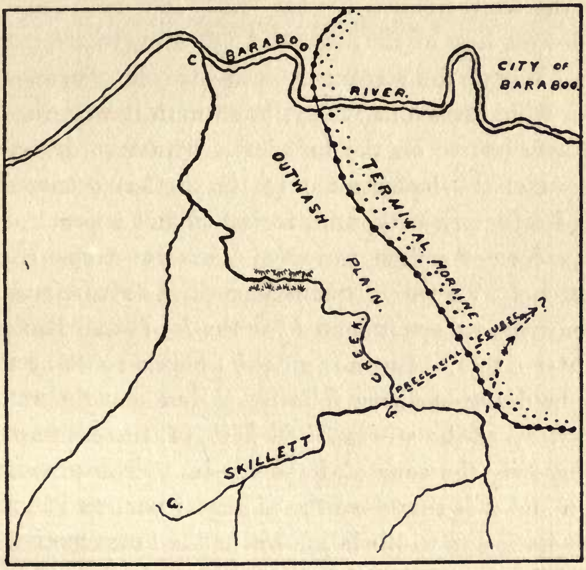

FIG. 43.—Skillett Creek, illustrating the points mentioned in the text.

The picturesque glens (Parfrey's and Dorward's) on the south face of the East bluff are the work of post-glacial streams. The preglacial valleys of this slope were obliterated by being filled during the glacial epoch.

The Wisconsin.—The preglacial course of the Wisconsin river is not known in detail, but it was certainly different from the course which the stream now follows. On Plate I (p. 4) the relations of the present stream to the moraine (and former ice-front) may be seen.[1] As the ice approached it from the east, the preglacial valley within the area here under consideration was affected first by the overwash from the moraine, and later by the ice itself, from the latitude of Kilbourn City to Prairie du Sac.

It has already been stated that the ice probably dammed the river, and that a lake was formed above Kilbourn City, reaching east to the ice and west over the lowland tributary to the river, the water rising till it found an outlet, perhaps down to the Black river valley.

When the ice retreated, the old valley had been partly filled, and the lowest line of drainage did not everywhere correspond with it. Where the stream follows its old course, it flows through a wide capacious valley, but where it was displaced, it found a new course on the broad flat which bordered its preglacial course. Displacement of the stream occurred in the vicinity of Kilbourn City, and, forced to find a new line of flow west of its former course, the stream has cut a new channel in the sandstone. To this displacement of the river, and its subsequent cutting, we are indebted for the far-famed Dalles of the Wisconsin (p. 69). But not all the present route of the river through the dalles has been followed throughout the entire postglacial history of the stream. In Fig. 44, the depression A, B, C, was formerly the course of the stream. The present course between D and E is therefore the youngest portion of the valley, and from its lesser width is known as the "narrows." During high water in the spring, the river still sends part of its waters southward by the older and longer route.

The preglacial course of the Wisconsin south of the dalles has never been determined with certainty, but rational conjectures as to its position have been made.

The great gap in the main quartzite range, a part of which is occupied by Devil's lake, was a narrows in a preglacial valley. The only streams in the region sufficiently large to be thought of

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[1] The preglacial course was probably east of the present in the vicinity of Kilbourn City.

as competent to produce such a gorge are the Baraboo and the Wisconsin. If the Baraboo was the stream which flowed through this gorge in preglacial time, the comparable narrows in the north quartzite range—the Lower narrows of the Baraboo—is to be accounted for. The stream which occupied one of these gorges probably occupied the other, for they are in every way comparable except in that one has been modified by glacial action, while the other has not.

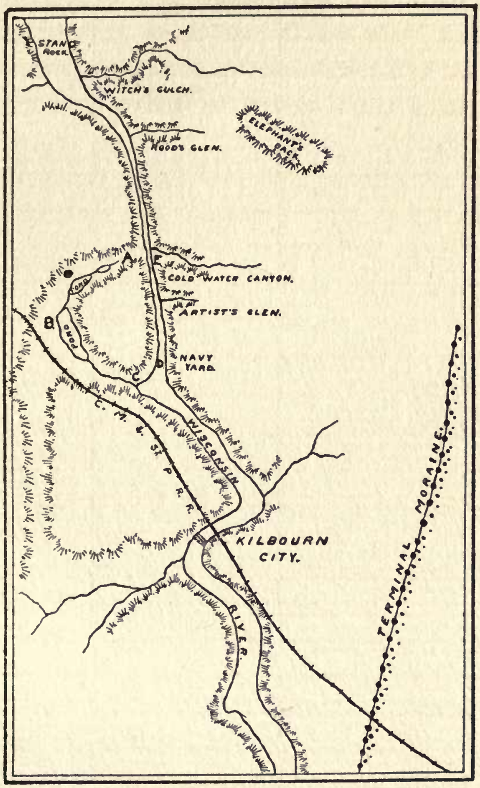

FIG. 44.—The Wisconsin valley near Kilbourn City.

The Baraboo river flows through a gorge—the Upper narrows—in the north quartzite range at Ablemans, nine miles west of Baraboo. This gorge is much narrower than either the Lower narrows or the Devil's lake gorge, suggesting the work of a lesser stream. It seems on the whole probable, as suggested by Irving,[1] that in preglacial time the Wisconsin river flowed south through what is now the Lower narrows of the Baraboo, thence through the Devil's lake gorge to its present valley to the south. If this be true, the Baraboo must at that time have joined this larger stream at some point east of the city of the same name.

The Driftless Area.

Reference has already been made to the fact that the western part of the area here described is driftless, and the line marking the limit of ice advance has been defined. Beyond this line, gravel and sand, carried beyond the ice by water, extends some distance to the west. But a large area in the southwestern part of the state is essentially free from drift, though it is crossed by two belts of valley drift (valley trains) along the Wisconsin and Mississippi rivers.

The "driftless area" includes, besides the southwestern portion of Wisconsin, the adjoining corners of Minnesota, Iowa and Illinois. In the earlier epochs of the glacial period this area was completely surrounded by the ice, but in the last or *Wisconsin epoch* it was not surrounded, since the lobes did not come together south of it as in earlier times. (Compare Plate XXXIII, p. 78 and Fig. 36.)

Various suggestions have been made in the attempt to explain the driftless area. The following is perhaps the most satisfactory:[1]

The highlands of the northern part of the state, together with the adjacent highlands of the upper peninsula of Michigan, are bordered on the north by the capacious valley of Lake Superior leading off to the west, while to the east lies the valley of Lake Michigan leading to the south. These lake valleys were presumably not so broad and deep in preglacial times as now, though perhaps even then considerable valleys.

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[1] Irving. Geology of Wisconsin, Vol. II.

[1] Chamberlin and Irving. Geology of Wisconsin, Vols. I and II.

When the ice sheet, moving in a general southward direction from the Canadian territory, reached these valleys, they led off two great tongues or lobes of ice, the one to the south through the Lake Michigan depression, the other to the south of west through the Lake Superior trough. (Fig. 36.) The highland between the lake valleys conspired with the valleys to the same end. It acted as a wedge, diverting the ice to either side. It offered such resistance to the ice, that the thin and relatively feeble sheet which succeeded in surmounting it, did not advance far to the south before it was exhausted. On the other hand, the ice following the valleys of Lakes Superior and Michigan respectively, failed to come together south of the highland until the latitude of northern Iowa and Illinois was reached. The driftless area therefore lies south of the highlands, beyond the limit of the ice which surmounted it, and between the Superior and Michigan glacial lobes above their point of union. The great depressions, together with the intervening highland, are therefore believed to be responsible for the absence of glaciation in the driftless area.

Contrast Between Glaciated and Unglaciated Areas.

The glaciated and unglaciated areas differ notably in 1) topography, 2) drainage, and 3) mantle rock.

1. *Topography.*—The driftless area has long been exposed to the processes of degradation. It has been cut into valleys and ridges by streams, and the ridges have been dissected into hills. The characteristic features of a topography fashioned by running water are such as to mark it clearly from surfaces fashioned by other agencies. Rivers end at the sea (or in lakes). Generally speaking, every point at the bottom of a river valley is higher than any other point in the bottom of the same valley nearer the sea, and lower than any other point correspondingly situated farther from the sea. This follows from the fact that rivers make their own valleys for the most part, and a river's course is necessarily downward. In a region of erosion topography therefore, tributary valleys lead down to their mains, secondary tributaries lead down to the first, and

so on; or, to state the same thing in reverse order, in every region where the surface configuration has been determined by rain and river erosion, every gully and every ravine descends to a valley. The smaller valleys descend to larger and lower ones, which in turn lead to those still larger and lower. The lowest valley of a system ends at the sea, so that the valley which joins the sea is the last member of the series of erosion channels of which the ravines and gullies are the first. It will thus be seen that all depressions in the surface, worn by rivers, lead to lower ones. The surface of a region sculptured by rivers is therefore marked by valleys, with intervening ridges and hills, the slopes of which descend to them. All topographic features are here determined by the water courses.

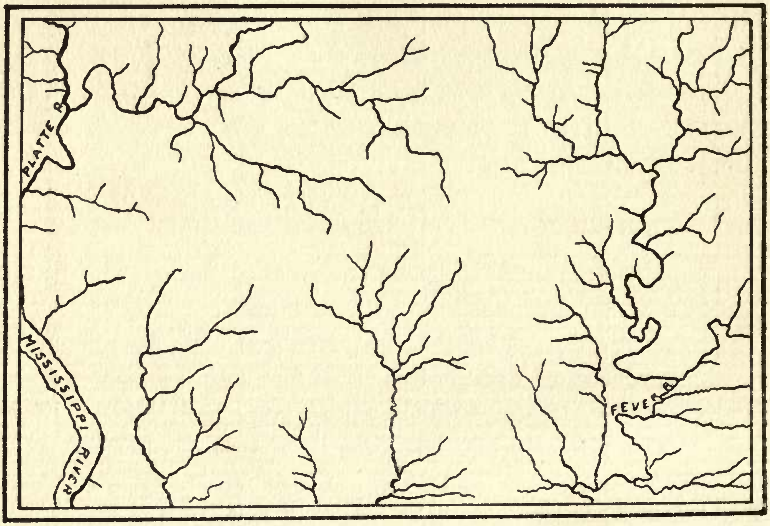

FIG. 45.—Drainage in the driftless area. The absence of ponds and marshes is to be noted.

The relief features of the glaciated area, on the other hand, lack the systematic arrangement of those of the unglaciated territory, and stream valleys are not the controlling elements in the topography.

2. *Drainage.*—The surface of the driftless area is well drained. Ponds and lakes are essentially absent, except where

streams have been obstructed by human agency. The drainage of the drift-covered area, on the other hand, is usually imperfect. Marshes, ponds and lakes are of common occurrence. These types are shown by the accompanying maps, Figs. 45 and 46, the one from the driftless area, the other from the drift-covered.

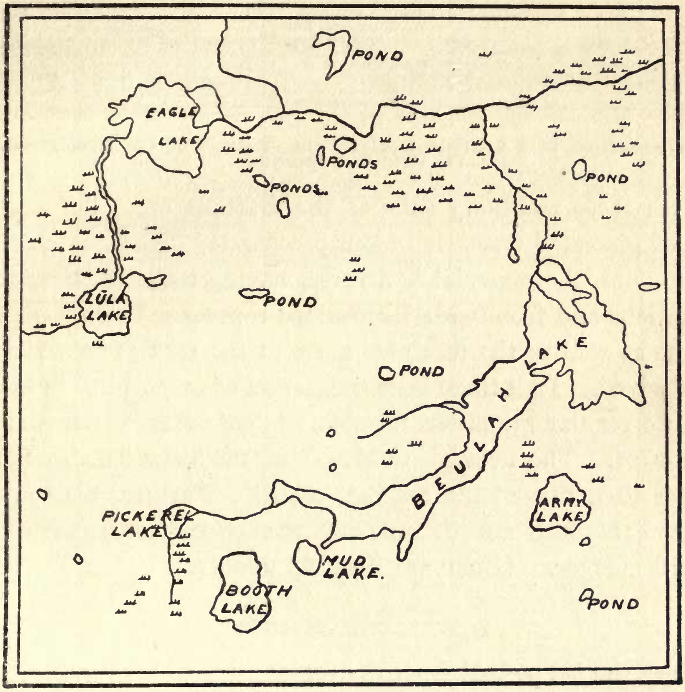

FIG. 46.—Drainage in a glaciated region. Walworth and Waukesha counties, Wisconsin, showing abundance of marshes and lakes.

3. *Mantle rock.*—The unglaciated surface is overspread to an average depth of several feet by a mantle of soil and earth which has resulted from the decomposition of the underlying rock. This earthy material sometimes contains fragments and even large masses of rock like that beneath. These fragments and masses escaped disintegration because of their greater resistance while the surrounding rock was destroyed. This mantle rock grades from fine material at the surface down through coarser, until the solid rock is reached, the upper surface of the rock being often ill-defined (Fig. 47). The thickness of the

mantle is approximately constant in like topographic situations where the underlying rock is uniform.

The residual soils are made up chiefly of the insoluble parts of the rock from which they are derived, the soluble parts having been removed in the process of disintegration.

Fig. 47.—Section in a driftless area, showing relation of the mantle rock to the solid rock beneath.

With these residuary soils of the driftless area, the mantle rock of glaciated tracts is in sharp contrast. Here, as already pointed out, the material is diverse, having come from various formations and from widely separated sources. It contains the soluble as well as the insoluble parts of the rock from which it was derived. In it there is no suggestion of uniformity in thickness, no regular gradation from fine to coarse from the surface downward. The average thickness of the drift is also much greater than that of the residual earths. Further, the contact between the drift and the underlying rock surface is usually a definite surface. (Compare Figs. 32 and 47.)

POSTGLACIAL CHANGES.

Since the ice melted from the region, the changes in its geography have been slight. Small lakes and ponds have been drained, the streams whose valleys had been partly filled, have been re-excavating them, and erosion has been going on at all points in the slow way in which it normally proceeds. The most striking example of postglacial erosion is the dalles of the Wisconsin, and even this is but a small gorge for so large a stream. The slight amount of erosion which has been accomplished since the drift was deposited, indicates that the last retreat of the ice, measured in terms of geology and geography, was very recent. It has been estimated at 7,000 to 10,000 years, though too great confidence is not to be placed in this, or any other numerical estimate of post-glacial time.

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