LAND FORMS OF THE BARABOO DISTRICT, WISCONSIN

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ABSTRACT

The following account of the development and classification of the several different land forms of the Baraboo District, Wisconsin, is based upon the experience of the writer in taking students on field trips to that region for nearly 40 years. Most of these trips were made during April, when observation is better than in summer because there are no leaves on the trees and brush. The several land forms are classified according to their age and origin. Where the interpretations of the writer are in conflict with those of others, all views are explained and their merits compared. It is concluded that there are no proved remnants of ancient peneplains formed by ordinary erosion when the land stood much lower with respect to sea level than it now does. The upland level, known locally as Happy Hill, is accounted for by wave erosion when the ancient islands of quartzite were being submerged by the Paleozoic seas. The name, Weidman Falls, is proposed for the little known example of a stream which was let down from the overlying sandstone onto the harder quartzite beneath in relatively recent time. It is named in honor of the late Samuel Weidman, who was born a few miles to the north of this location. The enclosed depression near North Freedom is as yet not fully explained. A few new facts on the history of glaciation are included. Many errors in the old topographic maps of the area are noted, many of them discovered by the aid of air photographs.

PRECAMBRIAN LAND FORMS

Precambrian deposition and mountain building. (Fig. 1) One of back on the quartzite because it is a ground water dam. There is the major reasons why the Devils Lake Baraboo district has been visited by so many geology classes is that in it the events of the geologic past can easily be demonstrated to beginners. For instance, the ripple marks on the layers of quartzite unquestionably record deposition of sand under water. The tilted and fractured beds record uplift and mountain building. (Irving, 1877) Many facts of these ancient events remain undeciphered. It is not positively known how thick the quartzite is or whether there is more than one quartz-

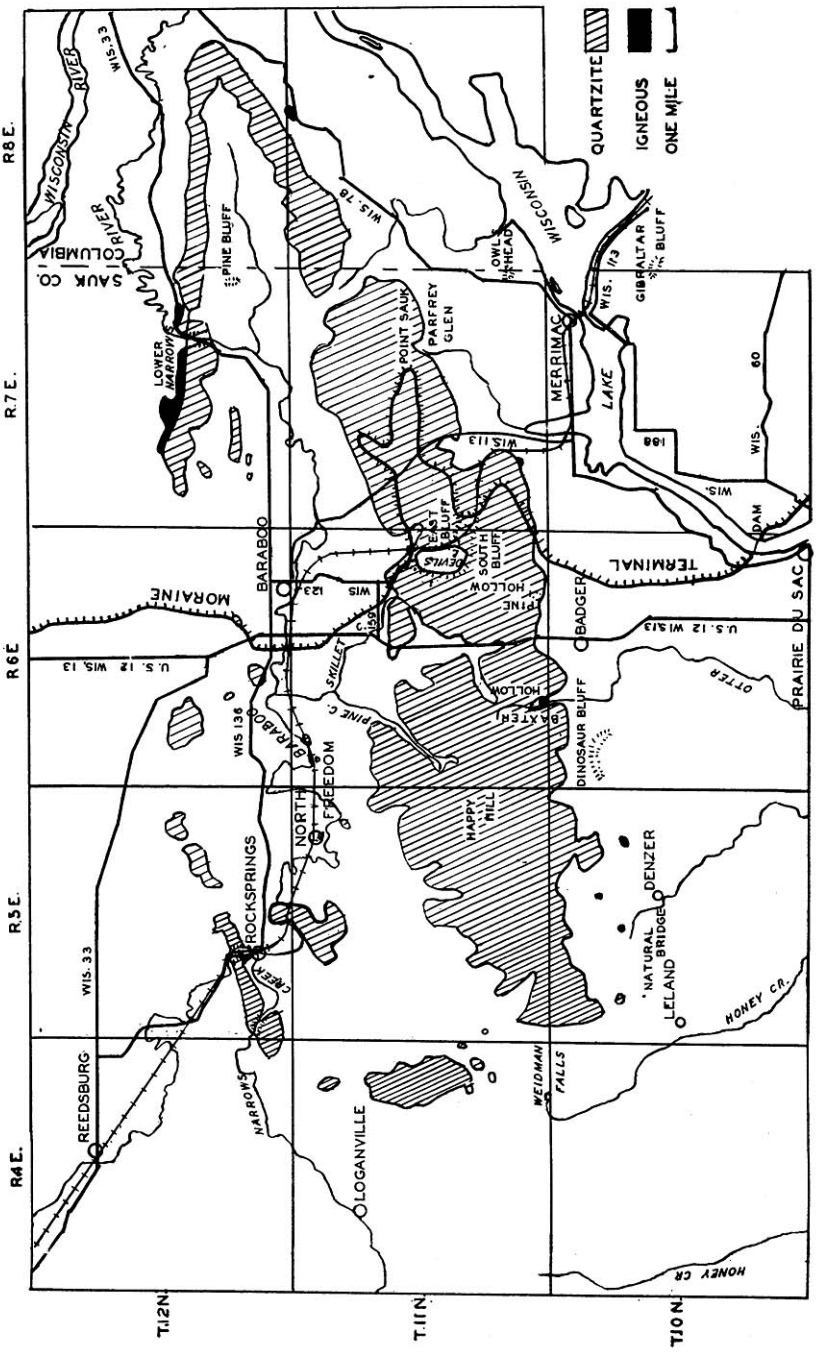

FIGURE 1. Outline map of Baraboo, showing major geological features.

ite formation. A large part of the facts discovered during the period of exploration and development of the iron ore resources has been lost to science. Mining and drilling ceased soon after the First World War (Weidman, 1904).

Precambrian land forms. There is no record of land forms older than those of the prolonged erosion of the mountains built from quartzite and associated sediments. This period of erosion led to mature, or perhaps even old, land forms, for quartzite is extremely

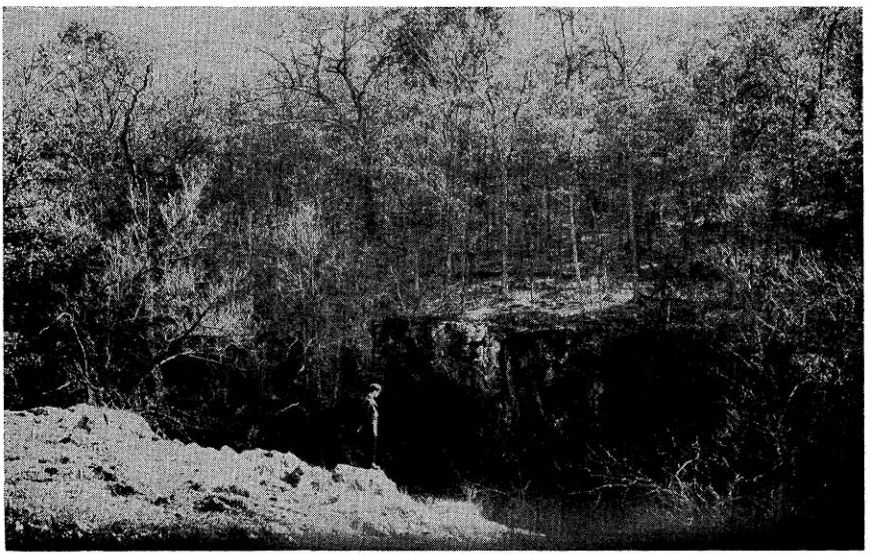

FIGURE 2. Weidman Falls from north, showing smooth surface of quartzite and narrow gorge eroded in quartzite by superimposed stream.

resistant to weathering and erosion. It is insoluble, and although brittle, is very hard to break. The landscape formed during the time that the surrounding Precambrian igneous rocks were reduced to low relief was rather gently sloping with few cliffs, although the quartzite synclinal remnant rose fully a thousand feet above the surrounding country. This ancient surface is commonly called the Precambrian peneplain but no part of it is entirely unaltered by either marine or subaerial erosion since its formation. Good examples of the Precambrian surface of the quartzite can be found throughout the district and their age is indisputable where there is more or less cover of later strata. An excellent example is the smooth upper surface of vertical quartzite layers at the gorge of Weidmans Falls (Fig. 2). This exposure is evidently part of a hogback on the quartzite because it is a ground water dam. There is

always water flowing over the falls from a spring held against one of the sides of this buried ridge. Figure 3 shows the smooth slopes of quartzite on which there are only rare exposures; similar topography occurs over large areas of quartzite, for instance in the north part of Baxter Hollow and in the area north of Pine Hollow (Fig. 4). It has been suggested (Alden, 1918, p. 170) that the depression southwest of North Freedom, which Weidman described as a kettle hole (Weidman, 1904, p. 102), is the result of solution of the deeply buried Precambrian dolomite which affected the over-

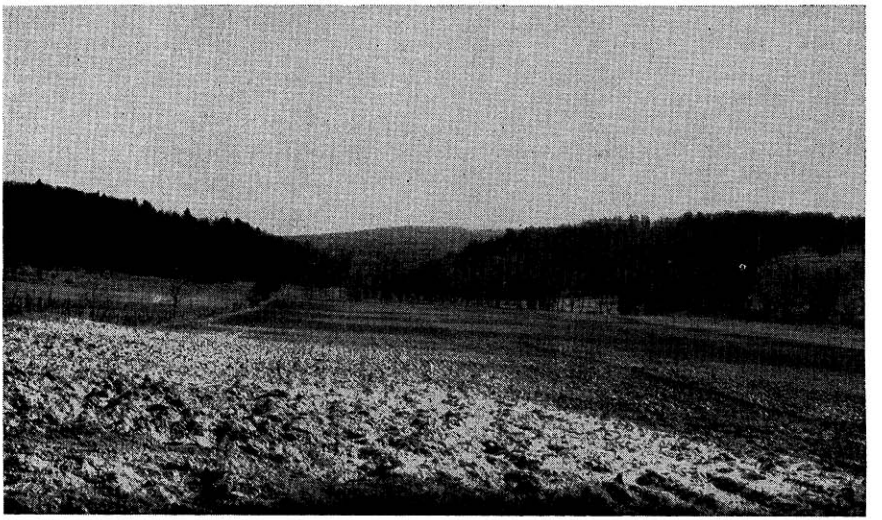

FIGURE 3. Five different land forms: upland plain, mature slopes on quartzite, valley of superimposed stream (Skillet Creek), top of delta in Glacial Lake Baraboo, and endmoraine of Cary glacier.

lying sandstone. The theory requires a very large solution cavity, for a collapse area normally becomes smaller and smaller upward. If the iron ore exploration holes gave any clue, their records are not available and many have been lost (Ekern and Thwaites, 1930).

Upland plain. The crests of the higher quartzite hills are truncated by a plain which lies, as far as incomplete measurements indicate, between 1450 and 1480 feet above sea level. West of Devils Lake this plain, which is level enough for marginal farms, is known as Happy Hill. The plain is present in all three hills which border Devils Lake: West, South, and East bluffs. Fig. 5 shows that it bevels the tilted layers of quartzite. Farther west this fact is more marked because the dip of the quartzite is greater (Fig. 6). The plain is little known in the glaciated part of the district because of

the cover of drift. In the unglaciated area, it is overlain by clay which contains much angular quartzite fragments which have been gathered into stone fences over considerable areas. A few fragments of Paleozoic chert are also present (Fig. 7). Some geologists regarded this plain (Martin, 1916, p. 68, 1932, p. 74 and Smith, 1937, pp. 128, 129) as remnants of a once continuous peneplain formed in Precambrian time and later dissected. The hypothesis had the advantage of removing the formation of the plain to a very distant time, but one may well ask just how quartzite could have ever been reduced to a level surface. It is virtually insoluble and weathers into a rubble of angular fragments which is not easily removed by either slope wash or mass movement. The idea of Precambrian peneplanation may, therefore, be rejected. It involves preservation of unaltered remnants on the tops of the bluffs alongside 1,000 foot valleys.

Hanging valley problem. At several places along the south side of the Baraboo quartzite there are mature valleys which hang above the present surface and the buried rock floor adjacent to the bluffs. Fig. 4 is a contour map showing one of these as surveyed by several students. The shape of the valleys above the break in slope is characteristic of those of Precambrian age and this conclusion is checked by the occurrence of younger sandstone remnants within the upper parts of these valleys. There may be more examples not yet discovered, because of the crude contouring of the old maps. The example given is cut by a narrow gorge known as Pine Hollow (omitted on Denzer quadrangle) which was later eroded into the floor of the older broad valley. It contains no younger sediments. Hypotheses may be advanced that: (1) the valleys had the lower parts removed by erosion of the Paleozoic sea, (2) the valleys were eroded to an ancient base level before the surrounding Precambrian rock was eroded, that is they are relics of a cycle of erosion within the Precambrian, or (3) they were eroded during a still stand during either burial or exhuming of the quartzite. The second hypothesis is not acceptable, for there are no remnants of Cambrian sandstone within the narrow gorges and there should be if they are Precambrian. The idea of wave erosion at a level corresponding to the upper part of the Eau Claire member of the Dresbach formation of Cambrian age is difficult to understand because the direction of Cambrian waves and currents as shown by sediments clearly shows that the south side of the quartzite islands was sheltered. Shale extends at least as far south as the Wisconsin-Black Earth valleys. On the other hand there is evidence of wave action on the southeast side of the quartzite by the presence of considerable conglomerate, which—near the shore—is interbedded with shale and siltstone. It is noteworthy that the slope of the quartzite

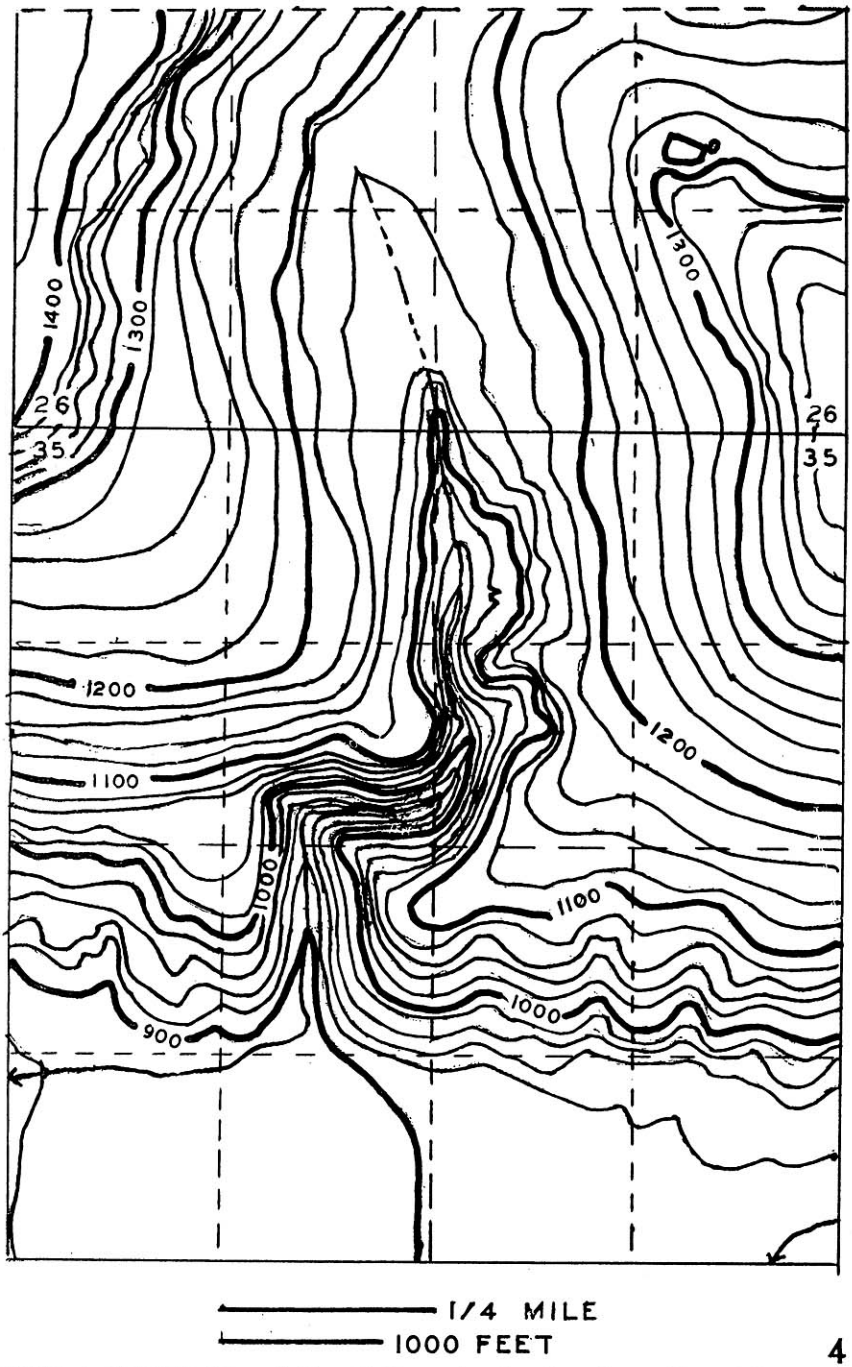

FIGURE 4. Contour map of Pine Hollow, showing hanging valley with incised gorge.

is steeper below the level of these hanging valleys than it is above. The north side of the quartzite is so covered with Paleozoic sediments that it has not been investigated for similar hanging valleys. If due to wave erosion of the lower parts, they should be more abundant on the north side than on the south.

Summary. In summary, the Precambrian erosion forms of the quartzite where unaltered by glaciation or by later erosion are smooth and rounded with only a few small outcrop crags and cliffs. The surface as seen today is strewn with angular fragments of the bed rock imbedded in clay. This clay did not originate from decay of the quartzite as apparently was once supposed. (Alden, 1918, p. 59; Geib and others, 1925, p. 11). Even the contact with the summit plain is more or less rounded. Most hills which do not rise to this level have rounded summits.

Paleozoic

Burial of the quartzite. Submergence after erosion of the Precambrian mountains led to deposition of nearly horizontal strata of sandstone and dolomite of Paleozoic age. That these strata buried the remnants of the ancient mountains completely is indicated by the following facts: (1) 25 miles to the south is Blue Mound capped with a remnant of Silurian strata with a top elevation of 1716 feet whereas the highest known quartzite is only about 1480 feet; (2) there are Paleozoic chert fragments on the highest unglaciated part of the Baraboo quartzite and much of the clay soil (Baraboo silt loam, Geib and others, 1925) of the unglaciated area is apparently residual from dolomite not from quartzite; (3) the drainage arrangement shows little effect of the quartzite topography on major stream courses; and (4) several small exposures of Paleozoic conglomerate have been found at the margin of the summit plain. From this evidence it follows that many stream valleys are the result of superposition of the drainage from the emerged Paleozoic strata. There has been much discussion on discrimination of such valleys from those formed in Precambrian time and filled with sediments. A good example of such a valley occurs at the old sandstone quarry just northeast of Rock Springs (Ableman). The sandstone at that locality was once extensively used for abutments, retaining walls, and paving blocks because it is harder than the normal Cambrian sandstone. There must have been ground water alteration in such situations, for there is also a strong suggestion of the removal of cementing quartz from parts of the buried quartzite including boulders of quartzite in the conglomerate.

Superimposed stream valleys. The best key to discrimination of the valleys of superimposed streams is their youthful appearance

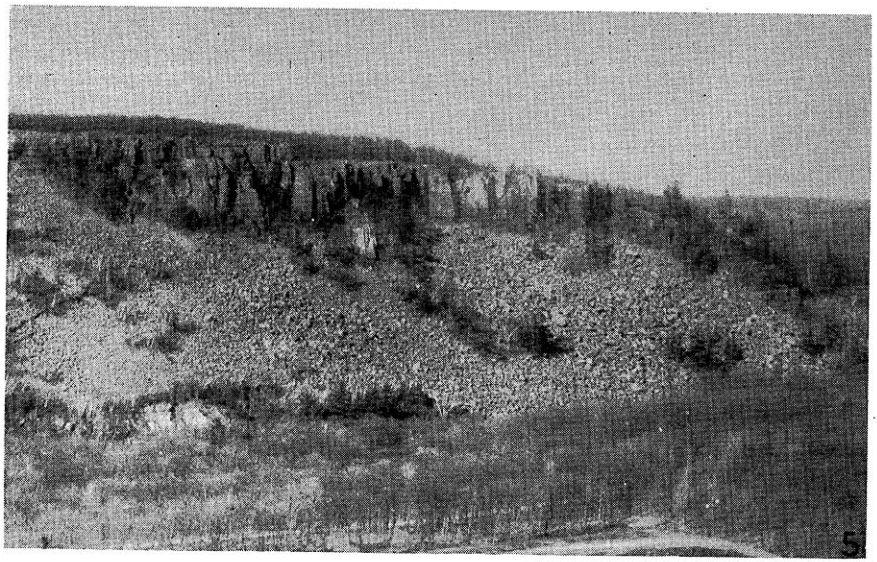

FIGURE 5. East Bluff, Devils Lake, from South Bluff showing bevel of strata by upland plain.

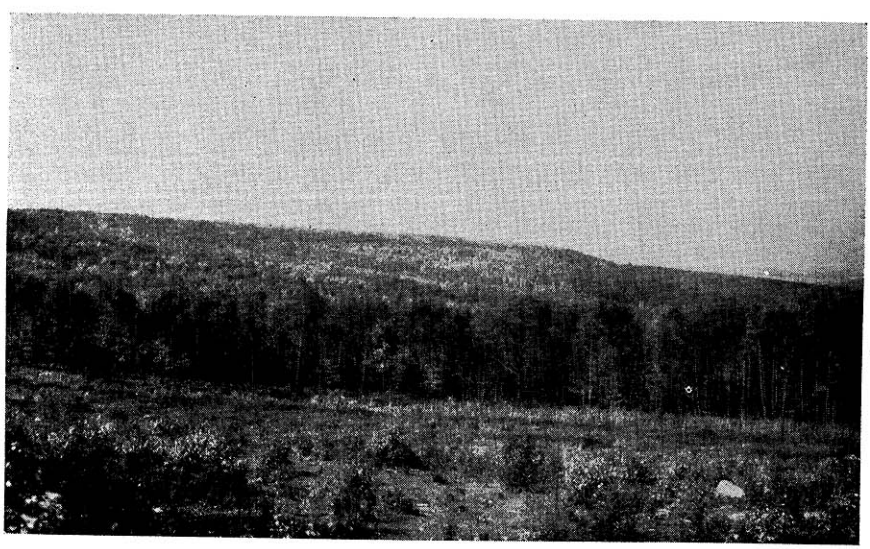

FIGURE 6. Summit plain on Happy Hill with terrace in quartzite on north. The terrace strikingly resembles a shore cliff.

with many cliffs, crags, and rock outcrops, coupled with their almost complete disregard of the structure of the quartzite. The type locality for this determination is Weidman Falls as shown in Fig. 2. Here the gorge below the falls is in sharp contrast with the smooth transverse profile of the Precambrian hogback seen in the foreground. The above criterion shows that the gorge of the Baraboo above Rock Springs is not of Precambrian age, although often claimed to be such. The same applies to the gorge of Narrows Creek farther to the southwest, the Devils Lake gap north of the open valley southwest of the lake which contains Cambrian sandstone, the Lower Narrows of the Baraboo, the entrance to Baxter Hollow, as well as several small valleys through quartzite ridges. Among these may be mentioned the quartzite outcrops at the quarry south of North Freedom and the cliffs along U. S. 12 at the foot of the sandstone hill south of the junction with Wisconsin 159. In Precambrian time Baxter Hollow drained east to the location of U. S. 12, north along that line and then discharged into the center of the syncline northwest of the ledges in an area where there are large sandstone hills. Weidman Falls is a fine example of superposition in a youthful stage because the stream has only a small drainage area. The falls are due to the vertical strata of the quartzite in this locality. In addition to the above criterion of age, both the Lower Narrows and the north part of Devils Lake gorge are unrelated to the form of adjacent exhumed quartzite hills. It is in these superimposed post Paleozoic valleys that most of the spectacular exposures which have been so commonly visited by geology students are situated. Exposures of the quartzite elsewhere are relatively poor.

Marine erosion of summit plain. The writer has previously (Thwaites, 1931, p. 745) suggested that the summit plain is the result of marine erosion during the submergence of the region. Acceptance of this hypothesis was hampered by the error on the Denzer quadrangle of 1898 which makes Happy Hill about two miles wide. Inspection of air photographs shows that the topographers were not allowed enough time to discover the deep valleys in the woods between the roads. They were even unable to cover all the roads, for there are such obvious errors in some places to prove that conclusion. The maximum width of the upland is less than three quarters of a mile. The upland is not exactly level but slopes gently toward the margins (Fig. 7). In following divides, several instances were discovered where there is locally a steeper slope so that it might be that the plain is multiple with distinct levels of different ages. If so, the elevation data presently available are not accurate enough to make definite correlations. Proof of the marine origin of the upland rests upon (1) presence of coarse boulder conglomerate which could have been derived only from strata above

FIGURE 7. The level upland of Happy Hill with clay soil containing both quartzite and chert stones.

FIGURE 8. Air photograph of Dinosaur Bluff. Spurs to the north were eroded by migration of a stream down the sloping quartzite. The dark circles identify section corners.

the present level. (2) competence of waves to make such a level surface, and (3) the improbability of any other agent making so regular a nearly level surface. Elevations ascribed to this plain on the Denzer and Baraboo quadrangles are extremely inaccurate with known errors up to 160 feet. The Baraboo quadrangle was surveyed in 1892 and has been shown to be in error by many later surveys. The bluffs at Devils Lake are given about 100 feet too high and are not correctly located or delineated. If the base of the Platteville formation of Ordovician age is projected northward to the Baraboo Bluffs, it is found to coincide with the summit plain. This horizon has been shown to be that of a very extensive marine transgression where the Platteville rests upon St. Peter sandstone in Wisconsin to where it lies on the Precambrian in Ontario. Conditions were favorable to reduce the relatively small islands of quartzite to such a plain of marine erosion (Thwaites, 1935, pp. 396, 401–402). The only direct evidence in favor of marine erosion is the presence of several exposures of conglomerate along the edges of the upland plain. The boulders of this conglomerate must have come from strata which lay higher than the present plain and which were removed by wave action. Criticism based on supposed weak wave action during deposition of sandstone adjacent to the islands is also disproved by discovery of initial dips up to 11 degrees near Rock Springs. Such an inclination indicates quite deep water close to the ancient shores. (Raasch, 1935; Wanenmacher and others, 1934)

Terrace problem. The hypothesis of marine erosion of parts of the quartzite during burial is supported by the discovery of a marked terrace about 200 feet below the summit plain. This terrace is shown in Fig. 6 which shows the northeast part of Happy Hill. The terrace is best developed on north-facing spurs although fainter examples have been discovered on south slopes. Its inner margin is distinctly steeper than most Precambrian slopes on quartzite. Locally it strikingly suggests a shore cliff. The outer slope is gentle and is in many places covered with a thin plaster of Paleozoic conglomerate. At the far southwest, one of these terraces contains an outlier of the lower strata of the Prairie du Chien dolomite, the main body of which formation occurs at about the same level to the west. In the glaciated area the terraces are difficult to distinguish and correlation is indefinite. At Rock Springs there is a local terrace making the top of the hogback ridge at elevation about 1100 feet. This terrace is thinly covered with basal Franconia sandstone conglomerate. Objection (unpublished) was raised because of the good preservation of this terrace for such a long period of time. The answer is that it was soon buried under Paleozoic sediment and has been exhumed only in relatively recent geologic time. The inter-

pretation of the terrace as a marine feature strengthens the theory of marine origin of the summit plain.

Post Paleozoic

Erosion forms of Paleozoic sediments. Following the elevation of the land above the Paleozoic sea erosion started. There is no direct means of finding the age of this uplift or the age of the youngest covering strata. Aside from the immediate vicinity of the quartzite islands, the Paleozoic strata are nearly horizontal. The land forms developed on them are, for the most part, flat-topped, and the texture of the drainage is much finer than in the more resistant quartzite. Some physiographers have related drainage texture to amount of infiltration of the rainfall, but this relationship cannot hold here. It is obvious that the widely spaced drainage of the Precambrian landscape required larger drainage areas to make valleys. Air photography demonstrates that the upland plateaus shown on the Denzer quadrangle are much smaller. Many are very narrow divides. Topography of these younger and softer Paleozoic sediments is closely related to lithologic differences. The oldest formation exposed is the Galesville member of the Dresbach formation. This sandstone is thickbedded and for the most part white; hence it develops striking cliffs and steep slopes which are best observed in the unglaciated part of the district both south of and within the quartzite bluffs. Overlying this formation is the dolomitic fine-grained Franconia sandstone, of which the Mazomanie facies is here best developed. It forms a bench with local cliffs and crags. Its green-gray color is in striking contrast to the light colored cliffs below. Among the scenic features is Natural Bridge near Leland. (Salisbury and Atwood, 1900, pl. XXVI, p. 69) The arch resulted from undercutting of one side of a very narrow cliffed ridge. Weathering was probably more important than stream erosion in making the arch. Over the Franconia lies the siltstone, dolomite, and sandstone of the Trempealeau formation. This formation makes cliffs and part of the upland in the west end of the district, where all the overlying Prairie du Chien (Oneota or Lower Magnesian) dolomite has been removed. At the southwest, this dolomite with overlying residual cherty clay caps broad rolling uplands, which many geologists regarded as remnants of a peneplain which also accounted for the terrace on the north face of the quartzite bluffs. (Trowbridge, 1917, p. 253, 1921, p. 85) The youngest Paleozoic formation preserved within the district is the St. Peter sandstone. This weak formation case-hardens and forms some cliffs. It is found in the far southwest where it makes no distinctive topography and in the eastern part of the district in Pine Bluff near the Lower Narrows of the Baraboo River. This bluff may have some of the overlying

Platteville formation beneath the drift cover, for a few feet of this dolomite is found on Gibralter Bluff south of Wisconsin River.

Dinosaur Bluff. A phenomenon noted (Salisbury and Atwood, 1900, p. 62) long ago is the lateral movement of a valley which cuts down along the slanting upper surface of the quartzite. This phenomenon is well developed all along the south border of the quartzite and reaches its most striking example in what the writer has termed Dinosaur Bluff, west of Badger. In this case the lateral stream work cut away all northern spurs (Fig. 8) of a sandstone hill, leaving the outline of a gigantic dinosaur. This bluff is best seen from the air, for it is very crudely contoured on the Denzer quadrangle. Valleys along the contact are all best seen on the air photographs.

Peneplain theory of summit plain. It has been postulated that the summit plain of the Baraboo district is a peneplain developed during the erosion of the Paleozoic strata (Trowbridge, 1921, pp. 64–65). The same objections may be raised against this theory as were applied to the similar origin in Precambrian time. Besides, the presence of Paleozoic chert in the residium on Happy Hill and elsewhere is almost positive proof that this plain existed prior to the deposition of the covering dolomite. If eroded later, all remnants of the younger strata should have been removed. We can here refer to the gravel and potholes on East Bluff at Devils Lake where they occur through a vertical range of 80 feet. In order to make the potholes, which contain much chert gravel, the water must have had a considerable velocity and on top of the bluff this could only have come by fall from higher now-vanished dolomite strata. These gravels furnish no evidence of the origin of the upland plain, but are simply an incident of the superposition of drainage on the quartzite (Thwaites and Twenhofel, 1921, pp. 296, 302–303). The youngest fossils in the gravel are Silurian. Salisbury (1895) (Chamberlin, 1874) reported gravel in a dug well north of the bluff margin but extensive test-pitting (Alden, 1918, pp. 99–102) and examination of the side of the well failed to confirm this. The original information might have been obtained by asking "leading questions." The gravels have been referred to the Windrow Formation whose age is unknown but may be Cretaceous. The bulk of the mantle rock on top of East Bluff is clearly residium from dolomite and not gravel. It has been termed the Baraboo silt loam (Geib and others, 1925). (See also Andrews, 1958)

Other peneplains. Trowbridge (1921) and other authors (Salisbury and Atwood, 1900, pp. 50–55, 62–69) have postulated that subequality of summit levels in different parts of the district is evidence of the occurrence of two or more dissected peneplains formed

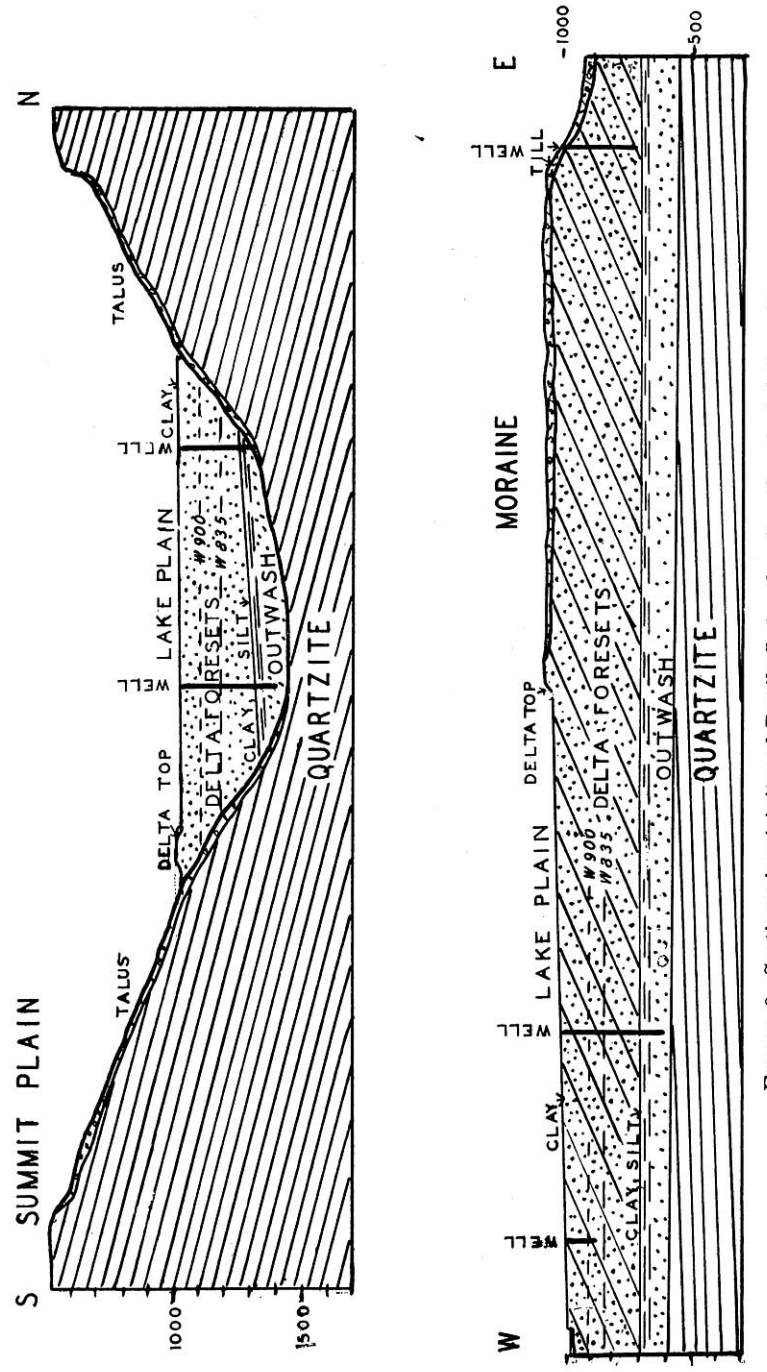

FIGURE 9. Sections in vicinity of Devils Lake showing the glacial deposits.

during the removal of the Paleozoic cover. None of the evidence thus far presented, however, is regarded as conclusive by the writer. Apparently these physiographers thought of peneplains as valley widening only and hence as growing upstream during the time that remnants of older erosion surfaces survived nearer the divides. They did not consider either removal of interstream ridges by reduction in slope or weathering. The terrace in the quartzite is clearly not related to peneplanation.

Preglacial topography. It was long ago demonstrated (Alden, 1918, pp. 105–107) that the Wisconsin River north of the Baraboo district must have had a preglacial course east of the present one as far south as the Lower Narrows of the Baraboo (Fig. 1). From there the river could only have flowed south of west to the Devils Lake gap, for there is no other possible course. The cause of this five mile detour is not evident. It might have been due to the partial exhumation of the quartzite by the time the river assumed its course although this idea does not check with the evident superposition of the north part of the gap. Possibly the cause lies in the initial dip of the Paleozoic strata. The Wisconsin River turned south just east of a buried Precambrian valley west of the lake. At the south end of the lake it discovered a Precambrian valley which contains sandstone. This valley must have discharged east. Although the only sandstone in this valley is near the eastern extremity, many of the tributaries (very poorly contoured on the Baraboo quadrangle) hang above the rock floor. It seems most probable that the river was diverted by this belt of weak rock, although it later deepened and widened the Precambrian valley. The ancient course of the Baraboo River west of Baraboo prior to glaciation is well known from exploration drilling for iron ore. The records given probably show the depth of casing below the surface, for they were not based on samples so far as known. Owing to the soft character of the preglacial rock surface it may be that many indicate too great a depth of fill. The maximum recorded is 260 feet. East and south of Baraboo the preglacial surface is not known with as much detail. No well has ever reached the rock bottom of the Devils Lake gap. The deepest appears to be the new supply well not far from the railroad (Fig. 9), 383 feet in depth with no rock. It is safe to conclude that the bluffs where Devils Lake is now situated rose fully 900 feet above the preglacial river. South of the quartzite the river course must have approximated its present location below Merrimac. The maximum depth of drift shown by samples is 260 feet in the Badger Ordnance Works. Very few well records are recorded on the glaciated part of the quartzite bluffs, but it is known that the drift is locally quite thick although the average depth may be small.

Pleistocene

Extra glacial surficial deposits. Pleistocene deposits west of the terminal moraine shown in Fig. 1 consist of several classes: (1) a mantle of residual material both from Paleozoic rocks and from quartzite (Baraboo soil series), (2) non-glacial alluvial deposits, (3) wind-blown silt (loess), (4) talus, and (5) lake sediments. Within the glacial boundary we can distinguish (1) terminal moraine, (2) ground moraine, (3) outwash, and (4) lake deposits.

Residual mantle. A mantle of clay and rubble covers the quartzite hills and extends down the slopes to end against the adjacent plains. Locally on U. S. 12 there is a strong suggestion of a dissected alluvial fan of rubble. Some of the surficial material may be loess although most of it contains many angular stones, chiefly quartzite. Some of the larger stones may have been mistaken for outcrops of bed rock. The problem is to determine to what extent this mantle is the product of mass movement, solifluction, running water, or mud slides under periglacial conditions. That the conditions of accumulation of the mantle were different from those of the present is demonstrated by modern erosion. Such erosion by wet-weather streams is producing "stone rivers", concentrations of quartzite boulders. In the spring of the year one can hear water running through these removing the finer material (Smith, 1949). Only locally is there any suggestion of movement of these boulders where they are higher than the adjacent slopes. Whether or not these "stone rivers" required a climate different from that of today is debatable, for snow is often found among the stones quite late in the spring. In places the parallel ravines in the mantle have left narrow, comparatively straight ridges which students have mistaken for eskers.

Old terrace gravel. Gradational from the mantle described above are poorly sorted stream-laid gravel deposits. These may form part of the fan on U. S. 12 but have been definitely discriminated only near Plain and on a sandstone plateau on the Galesville sandstone north of Denzer. The gravels contain quartzite (Alden, 1918, p. 170) pebbles derived from conglomerate and possibly some diorite from the diorite outcrop north of Denzer. The Denzer locality was mistaken by Weidman for glacial drift (Weidman, 1904, p. 102). Such deposits can be interpreted in more than one way: (1) remnants of valley fill consequent upon glacial outwash of pre-Wisconsin age in the main valleys, (2) a periglacial phenomenon due to scarcity of vegetation on adjacent hills, or (3) an interglacial accumulation due to aridity with scanty vegetation. It is not possible with existing knowledge to decide between these hypotheses (Thwaites, 1928).

Loess. Where stones have not been introduced by overturning trees, burrowing animals, and soil creep it is easy to distinguish loess by (1) lack of pebbles, (2) its silty composition, and (3) its lighter color than that of dolomite residium. We need not here discuss the different opinions of the origin and derivation of loess. It is noteworthy that the loess mantle of the Baraboo district rests upon older residual clay from dolomite with no bleached A horizon at its top and no accumulation of chert pebbles. This indicates the soil profile of a warmer climate than that of the present which developed the modern soil profile in the loess.

Talus. Coarse talus with little or no fine material occurs mainly in unglaciated narrow youthful valleys of streams superimposed on the quartzite. Boulders in this type of talus are large, angular, well settled, and overgrown by lichens. It is safe to step on almost all of them without danger of their rolling or sliding. Two distinct opinions have been expressed about the talus: (1) Martin (Martin, 1932, p. 123) held that the formation of the talus is so slow that there has not been time since glaciation for very much to form. This agrees with the fact that there is little talus on top of the glacial lake sediments of the vicinity of Devils Lake. The lake sediments have sunk into previously formed talus leaving depressions such as the Alaskan Grotto where cold air emerges from the talus in warm weather. In a few places the talus has been filled up so that water descending under the talus forms springs. (2) H. T. U. Smith regarded talus formation as an accompaniment of glaciation due to frequent freezing when the ice was near. This theory also fits with the observed slow formation of today and the scarcity of talus in glaciated valleys. One would think, however, that talus formation should then have followed the retreating ice margin resulting in heavy accumulations along the ice margin. Such accumulations are not present. Both theories, themselves not entirely incompatible, neglect the normal reduction of rate of talus accumulation as the cliffs became buried. Preservation of so much unaltered talus is explicable by the extreme resistance of quartzite to weathering, although there has undoubtedly been much breaking up of quartzite beneath the mantle of clay as shown by the large number of angular fragments in the mantle rock of the unglaciated district.

Pre-Wisconsin glaciation. Although it is now known that all the evidences presented by Weidman (Weidman, 1904, pp. 99–102) to demonstrate glaciation of the Baraboo region prior to the ice advance which formed the recognized terminal moraine are invalid, there is distinct indication of such glaciation nearby. In a test hole at the Baraboo City Waterworks organic material was found in a clay layer in sand at a depth of 145 feet. This clearly demonstrates

an interruption of deposition of the valley filling which may indicate an interglacial interval. In the well at the Waterstreet resort north of Devils Lake a weathered zone in sand was found at 215 feet. Neither of these occurrences proves that the earlier ice extended as far west as the longitude of Devils Lake, for no pre-Wisconsin till has been recorded. The writer must, therefore, endorse Weidman's general conclusion although he rejects his evidence.

Lake sediments. As has long been realized, the presence of glacial ice in the east end of the Baraboo bluffs blocked the drainage and resulted in extensive lake sediments. Salisbury and Atwood describe (Salisbury and Atwood, 1897, 1900, pp. 120, 129, 134; Alden, 1918, pp. 222, 226, 245–276) many of these and discriminated several lake basins. The principal basin was the valley of Baraboo River now known to have been confluent with Glacial Lake Wisconsin north of the quartzite bluffs. The second was an expanded Devils Lake enclosed between the two crossings of the gap by glacial ice (Fig. 1). Smaller lakes have been discovered (1) northeast of Devils Lake and (2) southeast of the lake in a tributary valley. The maximum level to which Devils Lake was raised probably depended upon leakage along the ice front northwest of the lake and not upon the divide west of the lake. There is no evidence of any overflow despite reports of glacial boulders near to this level (Trowbridge, 1917, p. 366; Alden, 1918, p. 246). The highest delta front is at elevation 1040 or about 80 feet above the lake. Some instructors tried to show students the sloping plain at the southeast side of Devils Lake as an outwash plain. As a matter of fact it is underlain by clay with quartzite and other boulders which overlies delta sand and gravel (Fig. 9). It must be an erosional surface not depositional, but just why the clay cover was deposited is not clear. It seems to be lake clay with ice rafted boulders, but its exact distribution has not been determined. In the Baraboo Valley the lake sediments are fairly well exposed. Where seen they are clay, but it is not unlikely that there is stream-laid sand and gravel below. Weidman (Weidman, 1904, pp. 100–102) did not accept the lake origin because there is no marl and peat, deposits which could not be present in a glacial lake bed. Weidman regarded the ice-rafted glacial stones as direct glacial deposits. Those he reports are all below the level of 980 of the maximum lake elevation. The position of the lake level is determined from isolated shore deposits plus the level of the delta fronts. One of those mentioned by Salisbury and Atwood is northeast of North Freedom and consists of a spit of tabular pebbles from the Trempealeau siltstone with ice-rafted glacial boulders (Salisbury and Atwood, 1900, p. 130). The pebbles of this deposit were driven north by waves from their origin in the

rock spur. Some of the localities they mention were located so indefinitely that they could not be found. Others are now concealed by loess and crept material but were observed when roads were first graded. An excellent spit of siltstone pebbles, now almost entirely dug away as a county gravel pit, occurs on Wisconsin 23 just south of Reedsburg outside the district shown in Fig. 1.

North Freedom kettle hole. The "typical kettle similar to the depressions and sags in terminal moraine 'located' in the coarse drift on the south slope of a sandstone hill about one-half mile southwest of North Freedom" (Weidman, 1904, p. 102) is far from typical. It is rimmed with Franconia sandstone on three sides and on the fourth by clay. We have already mentioned this depression under the theory that it could be due to collapse of the deeply buried Precambrian dolomite with the conclusion that this theory appears to be an inadequate explanation. Another suggestion is that it was a narrow ravine or cave in the sandstone blocked at the entrance either by Pleistocene lake deposits or by landsliding. No drift other than lake clay could be found either in or near the depression. Although unsupported by borings, the crevice theory appears the more plausible.

Glacial erosion forms. The invasion of the eastern part of the district by glacial ice occurred in the Cary substage of the Wisconsin stage of glaciation. We have already demonstrated that Weidman's conclusion (Weidman, 1904, p. 102) that an earlier ice advance extended much farther west is not supported by acceptable evidence. The erosive action of the ice so close to the margin appears to have been slight. It is doubtful that on the quartzite it did little but smooth and round some of the hills and remove the talus. In the sandstone area little effect can be seen save at Owls Head Bluff near Merrimac, which shows a gentle side toward the direction from which the ice came, compared with cliffs on the other or west side. Field examination showed, however, that much of the supposed shaping by ice is due to accumulation of drift and not to erosion.

Terminal or end moraine. The moraine at the maximum of the Cary ice invasion was mapped and described by Salisbury and Atwood many years ago (Salisbury and Atwood, 1897, 1900, pp. 102–111; Alden, 1918, pp. 214–216) and very little can now be added to their description of the effect of topography on the position of the ice margin. The inaccuracies of the old topographic maps make their estimates of slope of the margin too high. During the survey of the glacial geology of the eastern part of the quartzite bluffs by Alden, it was a source of disappointment that the end moraines within the glacial margin are so weak and doubtful. Con-

siderable areas of topography with many small depressions do occur but their distribution is irregular and not demonstrative of definite ice margin. The outer moraine was traced by so many students through such a period of years that its crest was marked over long stretches by a veritable footpath. It is possible, although not checked in the field, that some of the lower areas mapped by Alden as terminal moraine are really pitted outwash. Much of the moraine south of the quartzite strongly suggests overridden pitted outwash. Some well logs support this idea. An exposure at the dam of the Wisconsin Power and Light Company where the outermost moraine crosses Wisconsin River shows outwash beneath till.

Ground moraine. Much of the area inside the outermost end-moraine is classified as ground moraine or till deposited when the ice melted. It shows no characteristic topographic form. Such till mantles many rock hills, preserving their former topographic form. In this connection it must be realized that much of the area shown on most geologic maps as quartzite in fact has a considerable cover of Paleozoic sediments.

Outwash and deltas. It appears from perusal of older literature on the Baraboo district that the phenomenon of deltas in the margin of standing water could not have been understood by all geologists. Deltas formed at the margin of the ice sheet consist of sand and gravel layers which dip about 25 degrees into adjacent standing water. Some till masses slid from the ice. As the delta grew wider, such events could not occur. The outer margin of the delta plain displays a sharp break from subaerial beds (topset) on the plain to inclined layers (foreset) on the slope of the face. Such a condition is well displayed north and south of the quartzite range and along Baraboo River. At Devils Lake the case is not as clear. The moraines on both sides show from old gravel pits plus sample-controlled well logs that the layers of sand, gravel, and till dip toward the lake. These segments of the moraine are certainly deltas. Outwash could only be deposited above the level of the lake enclosed in the gorge. Apparently there are no remnants of topset beds. The only place which has a flat top is the little hill southeast of the old railroad station which rises 80 feet above the lake to 1040 feet elevation. This hill is now isolated and the front of the moraine north of the railroad track is indented by two valleys leading west to the low plain near the lake. Test pits disclose that this ridge is sand and gravel. The plain noted above is underlain by sand and gravel of glacial origin overlain by at least 15 feet of dense unstratified clay with abundant glacial boulders. This clay extends east up the flanks of the moraine to a higher elevation than the inferred delta top. The writer offers the following hypothesis. After the Cary ice

first advanced deltas were deposited at both ends of the enclosed lake with a water level of about 1040. How far the topset beds extended into the lake is unknown. Following this the ice melted back from the moraine at the north end of the lake and the glacial lake drained out to the lake in the Baraboo Valley which lay at elevation about 980. This erosion initiated the valley followed by the railroad north of the lake which had a creek which originally drained into Baraboo River until an artificial dam diverted part of the discharge through a canal into Devils Lake. Next the ice readvanced and blocked this valley for a short time. No younger moraine across it can be discovered. At this time the water level rose higher than before and the clay with ice-rafted stones was deposited. This hypothesis is admittedly without sufficient supporting evidence. It could be that the second moraine at the north end of the lake was eroded away when the ice finally left both of the two moraines.

Pre-lake outwash. An interesting light on events in the Devils Lake gap was the discovery of outwash gravel below the bottomset silt and clay beds of the delta at the south end as shown in Fig. 9. This records through drainage in the gorge before the formation of the delta moraines at both ends. Three distinct water levels may be distinguished: (1) Devils Lake which is a perched body of water held in by its own sediments at elevation about 960, (2) a shallow water table, also perched, in the delta sand and gravel at elevation about 900, and (3) a deeper and more important water level in the deep outwash at level about 835. This level is slightly higher than the land to north and south suggesting recharge by leakage of local higher ground water. Bretz has described (Bretz, 1950) Glacial Lake Merrimac, a body of water enclosed in Wisconsin River valley above the end moraine. He ascribes a body of deltaic bouldery gravel near the east end of the quartzite bluffs as the product of the initial discharge when the glacier freed the east end of the bluffs. The lack of any scoured area on the bluffs suggests that the discharge must have been very short lived. Thwaites (Thwaites, 1943, p. 127) describes a valley eroded in the drift when the waters of Glacial Lake Wisconsin stood at an elevation of about 835 feet. No sediments have been discovered which record either the later eastward extension of Lake Wisconsin north of the Baraboo bluffs or Lake Merrimac. Although the writer has seen both deltas and lake clays only north of the quartzite area, glacial lake waters must have remained in the east part of the Baraboo valley until drift dams were eroded. Presence of a kettle hole in the outwash just south of Badger has long been a puzzle, for such normally indicate that glacial ice was present in the area not long before its formation. The finding of the layer of till in a well within the kettle appeared to substantiate

this theory, but no till could be found at that level in the samples from a number of wells inside the Badger Ordnance Works. It has also been suggested that water just outside the moraine was deep enough prior to deposition of the delta to float out a large iceberg. The till might have come from its melting. In conclusion it may be explained that most of the glacial lakes of the Baraboo region are proved mainly by their level bottoms and sediments, for examples of shore features are rare.

Drainage outlets. Definite drainage outlets for glacial waters are not common in the Baraboo region. The best example is near the south side of Badger Ordnance Works where there is a break in the moraine which is continued west by a shallow channel in the outwash plain. Just north of the quartzite range a low fan on the outwash indicates discharge through a depression in the moraine.

Recent

Postglacial erosion. Since the glacial ice melted away, there has locally been considerable erosion. This has been mainly along the major streams, the Wisconsin and Baraboo where the slope was greater than that needed to carry the load from above. The total depth of erosion along the Wisconsin appears to have been close to 100 feet. The material eroded was largely sand. On the steeper slopes of the quartzite range and its covering drift many ravines have been eroded. Most famous of these are the glens: Parfreys, Durwards, and Fox. The last two are not shown on Fig. 1. All of these gorges are in part eroded in Paleozoic rock. A ravine south of the railroad southeast of Devils Lake is about 80 feet deep in till. South of this the soft sediments of a minor glacial lake are dissected intricately by gullies.

Postglacial shorelines. Devils Lake appears to have become stabilized at a level several feet higher than the normal maximum of today. The cause of the later recession could be either climatic change or increased leakage to the ground water below.

Postglacial deposition. Devils Lake has received a considerable thickness of mud (Twenhofel and McKelvey, 1939) which is very black and seen through the water is mistaken for a "bottomless" depth. As a matter of fact the normal depth of the lake is only a little over 40 feet. Alluvial fans, some of them very bouldery, are common below ravines where the grade of the surface changed abruptly. The swamps contain considerable depths of peat.

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