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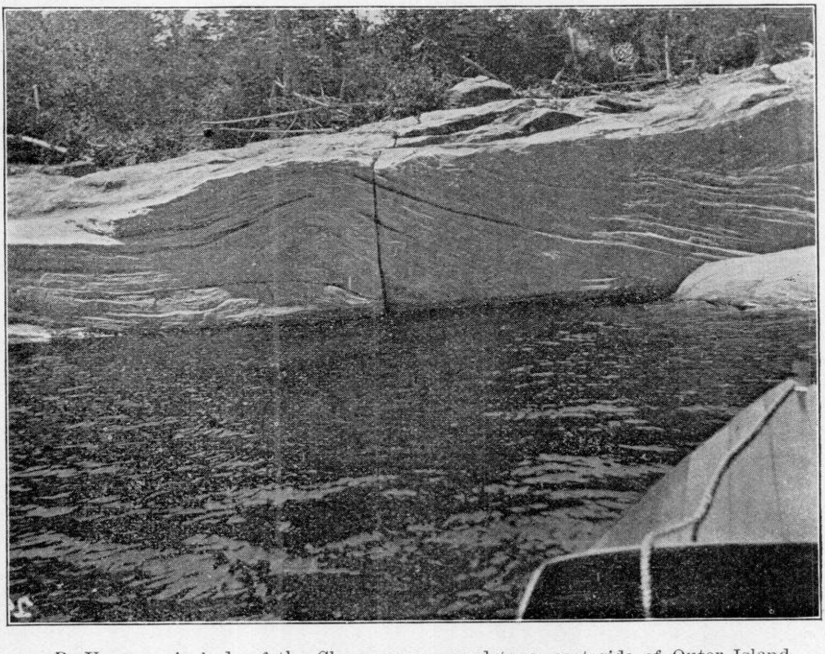
A. Beach of Lake Superior, at line between Bayfield and Douglas counties. The cliff exposes red clay, containing boulders. The beach is sandy and shows much magnetite sand. The launch used in making the survey, is shown in the foreground.



B. Up-curve in beds of the Chequamegon sandstone, east side of Outer Island. These phenomena may be due either to folding, concretionary iron banding, or original deposition (see p. 30).

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

E. A. BIRGE, Director **W. O. HOTCHKISS, State Geologist**

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SANDSTONES OF THE WISCONSIN COAST OF LAKE SUPERIOR

BY

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INTRODUCTION

Purpose of the Investigation. The study made by the writer in 1910, the conclusions of which are set forth in this report, was to determine, so far as possible, the age, origin, and stratigraphic relations of the red sandstones of the Wisconsin coast of Lake Superior. These rocks are, so far as known, entirely devoid of organic remains. They were at an early day divided into two great groups. Of these the older is characteristically composed of grains which are mainly feldspars and fragments of igneous rocks, and the strata are nearly always considerably tilted. On the other hand, the upper and younger group is almost wholly quartz sandstone, and its beds are in general approximately horizontal.

Former investigators recognized that the lower group was a part of the Keweenawan series, but opinions differed as to its relation to the upper; some held that they were conformable, while others maintained that an unconformity existed, and that the upper group probably corresponded to the Cambrian of southern Wisconsin, or its conformable downward extension.

Summary of Results. One of the main results of the present study was the discovery of the fact that there is a conformable downward gradation from the upper quartz sandstone sediments into red shales and arkose sandstones which possess the same characters as the main body of the recognized Upper Keweenawan sediments. At one locality it was found that highly tilted feldspathic sediments almost unquestionably belonging to the Keweenawan series grade conformably upward into quartzose beds, lithologically indistinguishable from and probably continuous with the upper group. Furthermore, no evidence was discovered which tended to indicate that the two groups are unconformable. While the evidence is not positively conclusive, owing to the scarcity of outcrops, it is believed that the facts warrant the conclusion that the sandstones form a single conformable series, so that what has heretofore been called the "Western sandstone" (here called the Bayfield group) is conformable with the underlying Upper Keweenawan arkose sediments (here called the Oronto group). The results of this work show that the contact of the upper, or Bayfield, group with the Middle Keweenawan traps is a fault. There is some evidence of unconformity at this contact. However, it is shown that if faulting took place prior to or during the deposition of the sandstone, the resulting local unconformity along the fault scarp would not demonstrate a great lapse of time between the deposition of the adjacent strata. Indeed, it seems certain that folding, faulting, and erosion went on during the deposition of the entire sandstone series, and that the upper beds therefore overlapped with slight unconformity upon the older strata of the same series. The difference in degree of folding of the two groups of sandstone is correlated with this fact and with the general structure of the region. Although no decisive opinion can at present be reached, it appears probable that both groups were deposited upon the land in a basin formed by the folding of the earlier Keweenawan rocks.

A detailed study of the lower sandstone group was not undertaken.

It seems probable that the so-called "red clastic series" which fills the continuation of the Lake Superior synclinal beneath the flat-lying Paleozoic rocks of Minnesota, is the continuation of the red sandstone of the Lake Superior coast. But, as no contact between these rocks and the recognized light-colored marine Upper Cambrian strata is known to be exposed, no definite opinion as to their relations can be formed. The results of this study, therefore, do not in any way affect the question of the age of the Keweenawan with reference to the Cambrian of the Mississippi valley. The evidence necessary to determine this question must be sought for along the extension of the upper sandstone group (Bayfield group) into Minnesota. However, the fact that the Bayfield group was involved in the profound deformations of the Keweenawan period, contrasts it sharply with the slightly disturbed strata of the recognized Cambrian of Wisconsin and Minnesota. It therefore appears from the evidence at hand that the Bayfield group is more closely allied to the Algonkian than to the Cambrian.

The question of the equivalency of the Bayfield group to the supposed Cambrian sandstones of the east side of Keweenaw Point is not considered in this report. Both formations are barren of fossils and are separated by a wide area of older rocks, so that no correlation can be attempted with the evidence now at hand.

Method of Field Work. The region in which the formations under investigation are situated is very sparsely settled, and hence only accesible with considerable difficulty. A light launch was designed especially for the Survey by Dr. Kent T. Wood of Madison. This novel craft weighed about 250-pounds when ready to run, but could carry three times that weight. An efficient and reliable gasoline engine gave it a speed of over seven miles an hour on a fuel consumption of one gallon for twenty miles. The launch was very seaworthy, even more so than many larger craft, and possessed the great advantage of light weight, permitting it to be drawn up on the beach out of the way of the sudden and violent storms. (See frontispiece, Plate I, A). Little time was lost on account of high winds; and the engine never failed to start, even when the boat was nearly swamped while being launched into the breakers. A further advantage was, that the light draught permitted running close to the shore. All of the coast exposures were examined in this manner, landings being made on the rocks whenever anything of interest was observed. About a thousand miles were travelled on the lake and its tributary streams in the three months devoted to field work.

Maps. On shore, the geologist working on a rapid survey is obliged to contend with the fact that there are no accurate maps of the region. The township plats of the Land Survey, while much better than nothing, are quite inaccurate, especially in Iron County. Section corners, except a few recently marked, can only be found with trouble and delay, and few roads or fences follow the land division lines. It is difficult to keep one's location at all accurately when following the rocky bed of a winding stream. All rivers and creeks on which any exposures were reported by former geologists or by present inhabitants of the district, were examined as thoroughly as the limited time available would permit and the importance of the formation seemed to warrant.

The base for the geological map is the general chart of the west end of Lake Superior, prepared by the U. S. Lake Survey.[1] This is accurate only so far as the navigation of large vessels requires. In shallow water and on shore it is unreliable. The township lines were adjusted to this base, the inland part of the map being based chiefly upon the plats of the U. S. Land Survey. The roads are corrected from observations by F. L. Musback of the Soils Division of the Geological and Natural History Survey and the writer, as well as from plats furnished by town clerks and others.

Acknowledgments. The writer was assisted by E. H. Toole of Baraboo, Wisconsin, then a student in the University of Wisconsin, who also spent some of his time in collecting plants and water life. For the last three weeks of the season, Thomas Turvill of Madison gratuitously contributed his services.

The work was carried on under the direction of W. O. Hotchkiss, State Geologist, and E. A. Birge, Director of the Wisconsin Geological and Natural History Survey. Much valuable information was obtained from F. L. Musback of the Soils Division of this Survey, who covered all the area east of Range 12 W. In the preparation of the report, most of those who have been interested in the question were consulted. The writer wishes to express his indebtedness to Prof. U. S. Grant of Northwestern University, Prof. F. F. Grout of the University of Minnesota, Prof. A. C. Lane, formerly State Geologist of Michigan, Prof. C. K. Leith of the University of Wisconsin, and Dr. Samuel Weidman of this Survey.

Acknowledgments are also due to Hon. S. S. Fifield, postmaster of Ashland, and his assistants, for much valuable aid at the beginning of the expedition; to Prof. J. A. Merrill of the Superior State Normal School for well-records and other help; to A. E. Appleyard, president of the Ashland Light, Power & Street Railway Co.; to J. E. Johnson, Jr., manager of the Lake Superior Iron and Chemical Co.; to F. N. Lang of Bayfield and

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[1] U. S. Lake Survey Office, Detroit, Mich., Chart 96.

C. N. Edin of Dedham—the last three having furnished well-records; to the officers and men of the John Schroeder and J. S. Stearns lumber companies, and the Good Land Company of Ashland, for information and assistance; to William Foley of Ashland, to whose infomation is due the discovery of the important outcrops on Fish Creek; and to many others, too numerous to mention, who treated our party with great kindness and hospitality.

Expedition of 1912. In June, 1912, the writer spent a week in re-examining several important localities. A detailed plane table map was made of the important exposures on the South Fork of Fish Creek, near Ashland, and a careful but unsuccessful search was made for exposures between these and the known area of the Bayfield group to the north. References to the results of this expedition have been incorporated in the text. No observations were made which materially changed any of the opinions formed as a result of the earlier survey.

CHAPTER I

THE TOPOGRAPHY OF THE WISCONSIN COAST OF LAKE SUPERIOR.

General Statement. In order to arrive at a better understanding of the geology of the Wisconsin coast of Lake Superior, a brief review of the main topographic features of the district is desirable.[1] This region may be divided into the following more or less well-defined districts:

The Southern Highland, including the Penokee Range, the plateau south of it, and the trap hills immediately to the north.

The Trap Ranges of Douglas County and the north coast.

The Bayfield Ridge, including the Pine Barrens to the southwest.

The Apostle Islands.

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[1] More detailed accounts of the topography and physiography will be found as follows:

Irving, R. D., Geology of Wisconsin, 1873–9, vol. III, pp. 60–211.

Sweet, E. T., Ibid, pp. 310–352.

Krey, J., Lake Superior and Mississippi Canal, House Doc. 330, 54th Congress, 1st Session, 1896.

Collie, G. L., Wisconsin Shore of Lake Superior, Bulletin Geological Society of America, vol. XII, 1901, p. 199.

Case, E. C., Wisconsin, Its Geology and Physical Geography, Milwaukee, 1907.

Martin, L., Geology of Lake Superior Region, Monographs U. S. Geological Survey, vol. LII, 1911, pp. 85–117.

The Western Plain.

The Eastern Plain.

The Southern Highland. The highest elevations occur at the southeastern corner of the area shown on the accompanying map and birds-eye view (Plate II, p. 8); but as seen from the lake this region because of its distance is not as impressive as some of the other features. The level skyline seen from the lake is formed by the southernmost ridge, sometimes known as the Gabbro Range, of Keweenawan traps, whose northward-dipping, steeply-inclined beds underlie the north slope of this highland. At its base is found a low escarpment, formerly known as the Copper Range, which marks the border of the traps where they are overlain by the sandstones of the lowlands to the north. The lower slopes are often heavily mantled with glacial drift, but at higher levels there appear bare ridges or hogbacks of rock. These culminate in the great escarpment, or Gabbro Range, which overlooks the longitudinal valley to the south, followed by the railway. This valley is underlain by slates, graywacke, and iron formation of Huronian age.

Beyond this, farther still to the south, rises the Penokee Range of slate, quartzite, and lean iron formation, the summits of which are some 1,200 feet above the lake or 1,800 feet above tide, exceeding but little the elevation of the trap ridge to the north. An abrupt slope on the south side of the Penokee Range leads down a hundred feet or more to the rolling upland underlain by Archean granites and metamorphic rocks. The streams having their sources in this area cross the ridges through deep gaps. The larger ones seldom follow the strike of the rocks for any great distance, though the strike determines the major lineaments of the country. The tumultuous descent of the streams usually ends in a high fall, where the soft sandstone is reached. Nearly all of these streams exhibit magnificent rock exposures, and outcrops are abundant throughout the Southern Highland district, only a portion of them being shown on the map.

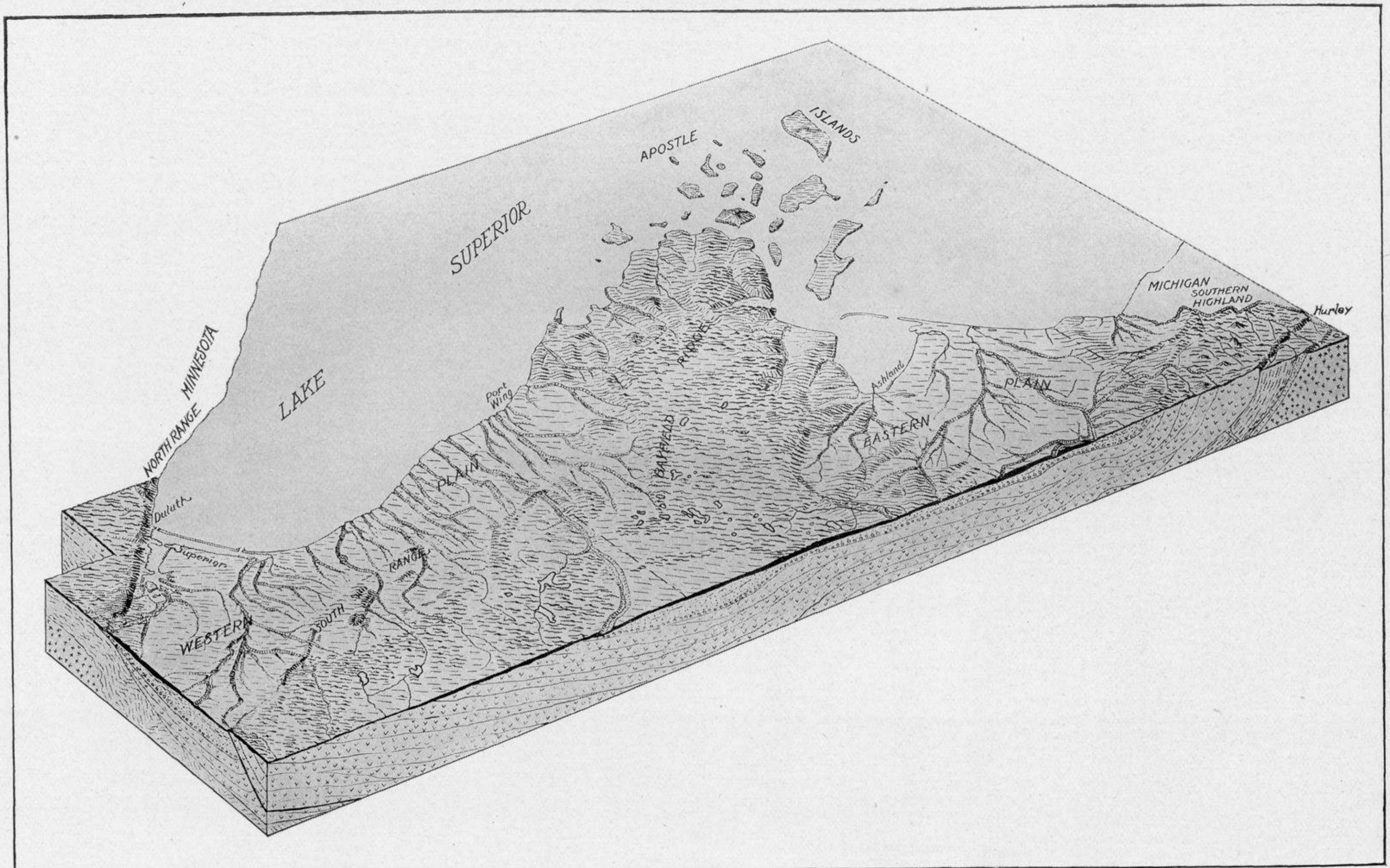
The Trap Ranges: Douglas County. Stretching across Douglas County in the western part of the district, is a comparatively low and much broken ridge, or rather a series of ridges, known as the "Douglas Range," "Copper Range," or "South Range." Its summits do not extend much over 500 feet above the lake, so that as seen from the coast it is not very striking. The southern slopes are rather gentle, but on the north is a descent of 50 to 300 feet to the plains which border the lake. This ridge is underlain by Keweenawan traps, moderately inclined to the southeast, and the escarpment marks the contact with the sandstones to the north. The streams cross through gaps and descend in falls to the lowlands.

North Range. Along the north coast in Minnesota occurs another range of similar rocks. also dipping to the southeast. It is higher than the South Range, and the serrated summits which are visible from the south coast on any clear day, form a very striking skyline. A few miles southwest of Duluth this range ends in a bold bluff about 450 feet in height. (See Duluth sheet, U. S. Geol. Survey, and Duluth plate, Geology of Minnesota, vol. IV, p. 566.)

The Bayfield Ridge. The broad peninsula which stretches out into the lake east of the Douglas Range, off the end of which lie the Apostle Islands, is for the greater part of its length the most conspicious topographic feature of the district. The average elevation of its summit is nearly 700 feet above the lake, or 1,300 feet above the sea. Topographically, it is a continuation of the Douglas Range and the high country to the south of it, but unlike the elevations previously described, the Bayfield Ridge so far as known consists wholly of drift. Except along the shore and a few of the deepest valleys, exposures of solid rock are absolutely wanting; and these are all of sandstone instead of igneous rocks.

The borders and the northeastern extremity of this ridge are cut up into ridges and isolated hills which have the appearance of land forms due to erosion. Up to a level of 500 to 550 feet above the lake are found terraces cut by the waves of former lakes held at these levels by the slowly retreating glaciers. These abandoned beaches run around the isolated hills and along the ridges, often producing the impression of rock escarpments. The slopes are cut by many deep ravines.

The summit of the Bayfield Ridge shows considerable areas of very rough, sandy, glacial moraine; the pits between the hummocks are among the largest in the state, being often over 150 feet in depth, and separated from one another by extremely nar-



Birdseye view of west end of Lake Superior, showing topographic divisions in relation to geological structure. Solid black on sections, indicates Pleistocene deposits (glacial drift).

row sharp ridges. Towards the southwest, this sandy country, called the "Pine Barrens," is of less relief. A striking feature of this entire upland is the absence of streams; lakes are found, however, the water being prevented from seeping away by the occurrence of a clay layer at a moderate depth. The Barrens present a most desolate appearance, now that all the timber has been cut. Only a few burnt stubs are left standing out mournfully above the sweet fern, scrub oaks, and low second growth.

The Apostle Islands. If we follow the Bayfield Ridge to the northeast, where it is broken up into separate hills, we will find that the same sort of topography extends beneath the surface of the lake, the summits of the hills forming the famous Apostle Islands. These islands were so named because once they were erroneously supposed to be twelve in number. Twenty-two islands now exist, one having succumbed to the attacks of the waves, and another having been cut in two since the coming of the first explorers. A study of the contours of the lake bottom (see map) and bird's eye view (Plate II, p. 8) shows the relation of the group to the topography of the mainland. There are a number of shoals which a slight fall of the water level would make into islands, and the same water stage would join some of the present islands to the mainland. On the other hand, the rise of the waters would submerge several islands and surround some of the hills near the coast. With the gradual lowering of the lake level since glacial times, there has been a progressive change in the composition of the Apostle group. The mainland has steadily been extended to the northeast, while lower and lower shoals have in turn become islands.

The present islands range in size from Madeline, twelve and one-half miles in length, to mere rocks, like Little Manitou. They vary from a height which is barely above the storm waves, to an elevation of 480 feet on Oak Island. Outer, Stockton, and Bear Islands are the only others to exceed 100 feet in altitude, most being flat and low. The higher ones are terraced by abandoned beaches, none of which, so far as known, exposes any rock.

The waves of the present level have cut deeper into the land than at any other stage, with the possible exception of the highest (see p. 13). Their work may be seen in the cliffs, bars, and beaches.

The cutting due to the present stage of the lake has exposed cliffs of the red sandstone. They do not exceed 60 feet in height, and are almost always capped with broken rock and drift. All are lined at the foot with fallen blocks, which, however, break up rapidly, so that there is little sandstone shingle. These fallen fragments, submerged ledges which sometimes form dangerous reefs, and the clean, reddish, sharp sands derived from their breaking up, may all be seen through the clear, cold, greenish waters of the lake. In thin-bedded layers only, have the waves worn any striking sea caves. The best are on Devils Island and near Squaw Bay to the southwest; but small ones, as well as deep coves along joint planes, are seen on the eastern end of Stockton Island and at a few other points (see Plates I, B, frontispiece; IV, p. 30; V, p. 40; XXIII A, p. 94).

A large portion of the shore line is drift. The materials exposed in the cliffs are mainly stony red clay, although the tendency of this material to slump down the bank gives one an undue idea of its abundance. Sandy till, gravel, and clean white or reddish sands are probably more abundant. So far as the writer's observations go, they underlie the red clay or clay till. Sand beaches are very common but are usually thickly strewn with boulders washed out of the drift. Huge fields of these, thickly paving the bottom, are frequently seen. Much of the ground marked as "rocky" on the chart is of this character. Spits of clear sand are found on the sides of the islands toward the mainland, that is, on the most sheltered side. These spits have usually been built out from both sides and often enclose a pond or swamp. At the outer ends is usually a rapid descent into deep water. Some seem to be now wasting away, as on Madeline Island, in which case they extend lakeward as shoals. Many bays have been cut off by beaches and in some cases the action of the waves has joined two rocky islands into one.[1]

The islands are nearly all densely wooded, some magnificent forest being seen in places. Hemlock, balsam, birch, and maple predominate. The dark foliage, together with the prevailing red

[1] The bar connecting Sand Island and the mainland does not appear to be wholly wave work. Cf. Collie, G. L., Wisconsin Shore of Lake Superior, Bull. Geol. Soc. Amer., vol. 12, 1901, p. 199.

color of the drift and rocky shores, give the islands a rather somber and forbidding appearance.

Permanent settlement is confined to Sand and Madeline Islands, but light-houses and fishing stations are found on most of the group. Now that the quarries are abandoned, sand is the only geological product (see p. 27). Several dredges take this material to Duluth from the spit on Oak Island.

The Western Plain. West from the little settlement at Herbster on the northwest side of the Bayfield peninsula, the main body of the great Bayfield Ridge leaves the coast. To the southwest stretches a broad sloping plain, broken at first by a few isolated hills like those near the end of the headland. For the most part of its length it is bounded on the southeast by the escarpment of the Douglas or South Range; but in some places where this is ill defined, it extends across the line of the traps up to the highest abandoned shore line which is found to the south upon the Pine Barrens. Near Superior the plain broadens, being bounded on the north by the North or Minnesota Range.

The surface of the plain is not level but slopes toward the lake at the rate of nearly fifty feet per mile; the inclination southwest of Superior, measured along the line of the axis of the lake basin, is much less.

No prominent beach terraces can be seen on the surface of this plain, which is broken only by slight marshy sags. It is dissected by narrow, steep-sided valleys cut by the numerous streams in the underlying soft red clay and fine sand. These valleys range from a few feet to over 100 feet in depth, with a flat bottom sometimes more than a quarter of a mile in width. The abundance of streams contrasts sharply with their rarity in the regions of porous sandy subsoil.

The lake shore (Plate I, A, frontispiece) is a steep cliff except at the mouths of rivers, where clean sand beaches occur. At the foot of this cliff is usually a stony beach. In the valleys of the streams and in the shore cliff are found infrequent exposures of the red sandstone underlying the drift.

At the head of the lake, southwest from Superior, is a very irregular shore line caused by the drowning of the valleys by the waters of the lake (see p. 13). Two long sandy beach ridges known as Minnesota and Wisconsin points, cross the end of the lake, enclosing Superior and St. Louis bays.

The Eastern Plain. In northern Ashland County, between the Southern Highland and the Bayfield Ridge, is a plain which differs only from the Western Plain in being more thickly dotted with sandy ridges and hills. The slope of this plain is about ten feet per mile in the middle, but it is steeper where it laps up against the highlands to the south. To the northwest it merges into the Bayfield Ridge, spurs of which extend out between the streams. The surface of the plain is cut by steep-sided valleys, some of which are over a half mile in width.

Between the irregular shore line of the Bayfield peninsula and the Apostle Islands, and the point where the Southern Highland strikes the lake at Clinton Point in Iron County, stretches a smooth sweep of sand beach. Its western extremity, known as Chequamegon Point and Long Island, separates a great depression in the shore line from the open lake; this is Chequamegon Bay. For the most part this bay is very shallow, especially on the east side where the bottom is a continuation of the low marshy country behind the beach ridge north of Odanah. The small break between the point and the island is called the Sand Cut and is said to have been first formed by a great storm in 1872.[1] As this low ridge alone protects the large bay from the violent northeast winds, it does not form a good harbor. A breakwater has been found necessary at Ashland.

Outline of Surficial Geology. The subject of the Pleistocene geology of this district is at present under investigation by Mr. Frank Leverett of the U. S. Geological Survey, and the Soils Division of this Survey is engaged in a study of the soils and agricultural conditions. The U. S. Bureau of Soils has published two reports upon the part of the area west from Range 12 West.[2] Although little time was given by the writer to the subject of the surface geology, a brief summary of its main points will be given.

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1 Irving, R. D., Geology of Wisconsin, 1873–9, vol. III, p. 71. Collie, G. L., Wisconsin Shore of Lake Superior, Bull. Geol. Soc. Amer., vol. 12, 1901, p. 199.

2 U. S. Dept. of Agriculture, Soil Surveys of the Carlton and Superior Areas, Field Operations, Bureau of Soils, 1904, 1905.

Deposits of Pleistocene and Recent age form a nearly continuous mantle, which with comparatively few exceptions conceals the hard rocks throughout the whole of the area. Only the Southern Highland, the Douglas Range, and the lake cliffs show many rock outcrops. The drift deposits range in thickness from nothing to nearly 600 feet. The maximum thickness is attained in buried valleys under the St. Louis River at Superior and south of Ashland, and in the Bayfield Moraine.

The materials of the drift are till, clay, sand, and gravel, nearly always of red or yellow color. Water-laid deposits are more abundant than ice-laid material. The deeply weathered character of the rocks at most points suggests that glacial erosion was not active, at least toward the end of the ice epoch. Far more detailed observations than any heretofore made will be needed before the complex history of these deposits is made known. The question of the origin of the west end of Lake Superior is considered on p. 95.

At one stage in the retreat of the last ice, the waters of Lake Superior[1] stood so high that they overflowed through a low col at the head of the Brule River, at an elevation of some 500 feet above the present level, into Lake St. Croix in Douglas County. This is known as the Lake Duluth stage. The outlets of the lower stages, whose beaches do not indicate as long a duration as that of Lake Duluth, are not yet definitely known. At the present time a slow tilting of the region along a northwest-southeast axis is going on, which is causing the water to advance upon the land at most places within this area, the movement probably being at a maximum in the vicinity of Superior. The large amount of post-glacial erosion as shown by the deep stream valleys, is due to the impervious character of the soft red clay which forms the surface of a large part of the area.

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[1] A brief summary of this subject will be found in an article by Frank Leverett, Outline of History of the Great Lakes, 12th report of the Michigan Acad. of Sci., 1910, p. 19.

CHAPTER II

PREVIOUS INVESTIGATIONS

Owen, 1847–50. The first competent geologists to make a careful examination of the Wisconsin coast of Lake Superior were David D. Owen and his assistants, J. G. Norwood, A. Randall, and C. Whittlesey.[1] Their explorations were made before the completion of the land survey, while the country was still known as the Chippewa Land District. This survey was made for economic purposes, since the question of the disposal of the public mineral lands was then a vexed one, as it is today. Owen was commissioned by the Treasury Department to classify the public lands with regard to their mineral and agricultural value. Taking into consideration the state of the country, and the progress of the science of geology at that time, this piece of work was remarkably accurate and thorough. The party explored all of the coast and most of the streams, mainly during the seasons of 1847 and 1848.

In his first report, in 1847, Owen concluded, chiefly from lithological evidence, that the Lake Superior sandstones were post-Carboniferous, for he regarded all the igneous rocks as intruded at a geologically recent date. However, in his final report of 1852 he withdrew this statement and advanced the

[1] For full titles with annotations refer to bibliography, p. 21.

Owen, D. D., Report of a Geological Reconnaissance of the Chippewa Land District, Senate Doc., 30th Cong., 1st Sess., 1847.

Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, etc. Philadelphia, 1852.

hypothesis, based on exposures along St. Croix river, that it was a downward continuation of the Mississippi valley Cambrian He drew no distinction between the different kinds of sandstone upon the lake. Owen also noted the gentle southeasterly dip of the strata in the Apostle Islands, and along the south coast, a fact which has escaped many subsequent observers.

Whittlesey, 1860. In 1860 Charles Whittlesey explored the eastern part of this district but owing to the abolition of the Wisconsin Geological Survey at the time of the war, his report was never published. An article entitled "The Penokee Mineral Range" was published by him in 1863; this gives a brief description of the district.[1]

Irving, 1873-78. Prof. Roland D. Irving was the first geologist to study the complex geology of the Lake Superior region in the light of modern knowledge. The eastern half of the district was surveyed under the personal direction of Prof. Irving, while the western portion was covered by E. T. Sweet. All of the known outcrops with the exception of those of Fish Creek and Oronto River were visited. The main fault of this excellent piece of work is the failure to show the outcrops upon the final maps. This deficiency is supplied in part from the text of the final and annual reports; but owing to the destruction of the field notes by fire, it is a serious handicap to the geologist who attempts to retrace the work.

Irving[2] naturally spent most of the short time at his disposal in a study of the Penokee Iron District, so that the sandstones received scant attention. Only a portion of the outcrop on Clinton Point, Iron County, was visited; and as the inclined beds were not seen, the rock was correlated with the horizontal sand-

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1 Whittlesey, Charles, The Penokee Mineral Range, Proc. Boston Soc. of Nat. Hist., vol. 9, pp. 235–44, 1863; reprint in part, Geol. of Wis., 1873–9, vol. III, p. 216.

2 Irving, R. D., Some Points in the Geology of Northern Wisconsin, Wis. Acad. of Sci. Trans., vol. 2, 1874, pp. 107–119.

—— On the Age of the Copper-Bearing Rocks of Lake Superior, etc., Amer. Jour. Sci. and Arts, vol. 8, 1874, pp. 46–56.

—— Geol. of Wis., 1873–9, vol. III, pp. 1–24, 53–238.

—— Copper-Bearing Rocks of Lake Superior, Mon. U. S. Geol. Survey, vol. V, 1883; see references below.

stones of the islands. In his preliminary articles, Irving mentioned horizontal sandstone and shale on Silver Creek near the modern village of High Bridge, Ashland County; but in his later monograph he stated that this was an error of Lapham's.[1]

In the Geology of Wisconsin, Irving affirmed that there were two great unconformable groups of sandstones. This statement was based first upon the horizontal attitude of the Bayfield sandstone group; second, upon the supposed unconformity complicated by slight faulting along the north edge of the Douglas Range; and third, upon the supposed equivalence shown by lithologic and structural similarity of the upper group to the Cambrian (Eastern, now Jacobsville) sandstone of Michigan. Therefore the Bayfield group (called Western by Irving) was assigned to that period. Irving was of the opinion that the Bayfield Ridge was a continuation of the Douglas Trap Range, although he recognized its morainic character.

Sweet, 1873-77. In 1873, 1875, and 1877, E. T. Sweet made his examinations of this area under Irving's direction. In the last year he made a trip along the south coast of Lake Superior from Ashland to Superior in the short space of two weeks.[2] Sweet was unable to understand the contacts of the traps and sandstones along the Douglas Range and so wisely confined himself to the statement that the sandstone was the younger. On Middle River he mistook the horizontal joints for bedding.

Irving, 1881. After further field work outside of Wisconsin, Irving completed a report upon the Copper Bearing Rocks of Lake Superior.[3] Although in this work Irving definitely asserted the existence of a concealed unconformity between the Bayfield and Oronto groups, he conceded that on structural grounds there was no reason to separate this upper group (called

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[1] Irving, R. D., Copper-Bearing Rocks of Lake Superior, Mon. U. S. Geol. Survey, vol. V, 1883, p. 411.

[2] Sweet, E. T., Some notes on the Geology of Northern Wisconsin, Wis. Acad. of Sci. Trans. vol. 3, 1876, pp. 40–55.

—— Ann. Rept. Wis. Geol. Survey, 1877, p. 4.

—— Geol. of Wis., 1873–9, vol. III, pp. 305–362.

[3] Irving, R. D., Copper-Bearing Rocks of Lake Superior, Mon. U. S. Geol. Survey, vol. V, 1883.

by him Western Lake Superior sandstone) from the underlying feldspathic rocks, since both should be horizontal in the vicinity of the Apostle Islands.[1]

Winchell, 1872-99. The work of the Geological and Natural History Survey of Minnesota was carried on within this area by N. H. Winchell. The final report was published in 1899[2] together with rather large scale maps showing 50 foot contours. Unfortunately these maps do not show outcrops, so that it is often difficult to see the basis of the distinction between the areas mapped as drift and those where the underlying formations are shown. Moreover, there are several serious errors in the drafting of the sheets covering the vicinity of Duluth.

Local details were published from time to time in the annual reports, and in 1895 Winchell published two articles which deserve especial attention.[3] These were of a distinctly controversial nature but many of the points were essentially sound. He described the conglomerates of the St. Louis River and divided them into two parts. The lower quartz pebble conglomerate he placed at the base of the Keweenawan, and the remainder. which contains trap pebbles, as contemporaneous with the last eruptions. This involves the assumption that an unconformity exists within the space of a few feet where the exposure happens to be covered by debris. He correctly argued that the mere presence of trap pebbles in a conglomerate does not imply a post-Keweenawan age, since such pebbles are found in all Keweenawan detrital rocks. In other words, folding and erosion must have gone on simultaneously with the deposition of sediments in other places. Winchell also threw some doubt upon the unconformity supposed by Irving to exist along the Douglas Range, suggesting that some of the conglomerate might be faulted up from lower horizons. In the second article entitled, "A Rational View of the Keweenawan," Winchell formulated the following series of objections to Irving's view as to the unconformity of the two sandstone groups. Although his object was to demon-

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[1] Irving, R. D., Ibid, pp. 154, 258, 365, 410, plate XXVIII.

[2] Winchell, N. H., Geology of Minnesota, 1872–99, vol. IV, pp. 1–24, 212–225, 550–580.

[3] Winchell, N. H., Crucial Points in the Geology of the Lake Superior Region, Amer. Geologist, 1895, vol. 16, pp. 75, 150.

strate that the entire Keweenawan was of Cambrian age, a question not considered by the present writer, it is worth while to quote these objections:

There is no permanent petrographic distinction between them [the two sandstone groups]. The red shale and red sandstone, which are said to prevail in the tilted beds [Oronto group], are found in great volume in the lower portion of the horizontal beds [Bayfield group]. This may be seen by consulting the sections of the horizontal beds [along St. Louis River] * * *.

The tilted beds [Oronto group] are sometimes horizontal, and the horizontal beds [Bayfield group] are sometimes tilted at high angles. [The author did not state the localities where this paradox is true.]

The top of the Keweenawan sandstones has never been observed.

The bottom of the overlying [Bayfield] sandstones has never been observed except where, by regional subsidence, it is non-conformable upon the tilted traps or the older rocks. [It may be noted that all known contacts with the traps are complicated by faulting.]

In various places the horizontal sandstone [of the Mississippi valley], even some of the higher magnesian limestones [no such case is known to the writer], have been seen non-conformable on the traps of the lower portion of the Keweenawan, indicating a progressive subsidence after the tilting of the traps.

The non-conformable contact which is assumed to have taken place between the base of the horizontal sandstones [Bayfield group] and the Keweenawan tilted sandstones [Oronto group] has never been observed.

The whole region in which this question centers is one of disturbance and eruptive action. Even since some of the horizontal sandstones were deposited there have been such movements [along the Douglas and Keweenaw Point faults] that the sandstones are broken and thrust in various attitudes in their relation to the trap.

The shortest observed interval between the horizontal and the tilted sandstones within which such nonconformity must exist, if it exist at all, is four miles, viz., between Montreal River and Clinton Point.[1]

If it were to be affirmed that there is no such non-conformable contact between these sandstones, the statement could not be disproved by any known facts.

If the statement were to be made that the upper part of the Ke-

[1] **The sandstones of Clinton Point are not horizontal and do not belong to the Bayfield group (see p. 55).**

weenawan [Oronto] sandstones passes conformably into the horizontal * * * [Bayfield] sandstones * * * in all places where they are in contact, such statement could not be disproved by any known facts, but would be in harmony with all that is known of the formation.

A figure given by Winchell showing a generalized section from Montreal River to Clinton Point may be mentioned, for the fact that it shows horizontal sandstone on Silver Creek in Ashland County, indicating that the author had overlooked Irving's denial of the existence of such a formation (see p. 16).

In his final report of 1899, Winchell expressed his opinion, based on the boring at Short Line Park near Duluth, that the sandstone of St. Louis River was deposited contemporaneously with the later igneous eruptions, the gradual dying out of which "rendered the sandstone more and more siliceous," so that "the upper strata are almost free from the shaley, red sediment which characterizes the lower portion." It was also stated that the sandstones here found are conformable beneath those of known Upper Cambrian age in the Mississippi valley. This conclusion was apparently based, although the evidence is nowhere clearly exposed, upon the apparent areal connection of the sandstones of the Lake Superior and Mississippi basins. The results of deep drilling at Stillwater[1] and other points in southeastern Minnesota showing a thick red sandstone series beneath the horizontal Cambrian, were also cited as supporting the contention that there was a complete and conformable transition between the Upper Cambrian and the Keweenawan traps.

Grant, 1899-1900. In 1899 Professor U. S. Grant of Northwestern University commenced a study of the Keweenawan traps of Wisconsin which were then being prospected for copper, as they have been at intervals of thirty or forty years ever since first discovered. After a slight amount of work in 1900 the survey was discontinued and the notes were never published in full. Much of this valuable material has been made use of by the writer for the first time.[2]

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[1] Winchell, N. H., Natural Gas in Minnesota. Minn. Geol. & Nat. Hist. Survey, Bull. V, 1889, p. 25.

[2] Grant, U. S., Preliminary Report on Copper-Bearing Rocks of Douglas County, Wis. Geol. and Nat. Hist. Survey, Bull. VI, 1900, 2nd ed. 1901.

In his report Grant did not touch upon the age of the sandstones, but in a later paper[1] he described the contacts which occur within the area he studied. He recognized the great amount of faulting which has taken place since the deposition of the sandstone, as shown by the fold on Middle River. At this place he perceived the true bedding, but assumed that the structure was anticlinal as he did not observe the ripple marks which conclusively demonstrate the overturning of the strata. He saw that the great Douglas fault was of the thrust type although he showed it as vertical on his structure sections. The evidence with regard to the unconformity along this fault he declared to be inconclusive.

Collie, 1900. In 1900 Prof. G. L. Collie of Beloit College, visited the region about Bayfield and made some steamer trips through the Apostle Islands. A paper[2] published by him describes mainly the physiography of the region. His observations of the Lake Superior sandstones were very meager, while the theoretical conclusions as to the geological history of the region are for the most part based upon misconceptions of the facts.

Hall, 1901-08. In 1901 Prof. C. W. Hall of the University of Minnesota described the Keweenawan area of the eastern part of that state.[3] Evidence was cited to show that the great fault of Douglas County extends far into Minnesota, but the sections are drawn on such an exaggerated vertical scale that the true relations are confused.

In 1908, Hall prepared a paper discussing the great series of red sandstones and shales which drill holes have discovered beneath the exposed Paleozoic rocks of southern Minnesota. These he stated to be conformable beneath the later sediments and to represent a transition between the Paleozoic and Algon-

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[1] Grant, U. S., Junction of Lake Superior Sandstone and Keweenawan Traps in Wisconsin, Bull. Geol. Soc. Amer., vol. 13, 1902, p. 6.

[2] Collie, G. L., Wisconsin Shore of Lake Superior, Bull. Geol. Soc. Amer., vol. 12, 1901, p. 199.

[3] Hall, C. W., Keweenawan Area of Eastern Minnesota, Bull. Geol. Soc. Amer., vol. 12, 1901, p. 313.

kian rocks. Unfortunately this paper was never published, an abstract only appearing in Science.[1]

Lane, 1908. In 1908 Professors A. C. Lane, then state geologist of Michigan, and C. K. Leith and Lawrence Martin of the University of Wisconsin, visited Clinton Point and parts of Montreal and Oronto rivers. They first observed some of the inclined beds at the former locality, Professor Lane giving it as his opinion that they are conformable upon the formations seen to the southeast.[2] It was suggested that a fault parallel to that on Keweenaw Point might pass through the belt of no expoures found on Montreal River and thus give an apparent thickness of sandstone much in excess of the fact.

Grout, 1910. The work of Professor Hall in Minnesota has been carried further by Professor F. F. Grout of the University of Minnesota. Writing in 1910, he gave a summary of the recent work.[3] He expressed some doubt as to the correlation of the sandstones north of the Douglas fault with the fossiliferous series of the St. Croix valley which overlie the tilted traps with evident unconformity. The areal connection is moreover doubted since a wide drift-covered interval occurs between the two areas of sandstone.

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1 Hall, C. W., The Red Sandstone Series of Southeastern Minnesota, Abstract. Science, vol. 27, 1908, p. 722.

2 Lane, A. C. & Seaman, A. E., The Geological Section of Michigan. Rept. State Board of Geol. Survey of Michigan for 1908, p. 23. A brief reprint is found in Journal of Geology, vol. 15, 1907, p. 680.

3 Grout, F. F., Contribution to the Petrography of the Keweenawan, Journ. Geol., vol. 18, 1910, p. 633.

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CHAPTER III

THE BAYFIELD SANDSTONE GROUP

Limits of the Group. The sandstones found along the Wisconsin coast of Lake Superior have long been divided into two groups. It is possible to draw a fairly definite line at the base of the prevailing quartz sandstones known as the Bayfield group, separating them from the underlying arkose sandstones and red shales which will hereafter be termed the Oronto group and which will be described in Chapter IV. The Bayfield group was formerly known as the Western Lake Superior sandstone. Because the correlation with the Lake Superior sandstone group of Michigan is uncertain, it seemed best to give the rocks in Wisconsin a new name.

Areal Extent. The Bayfield group is the highest rock formation of the area studied. It is the uppermost rock of all of the coast and islands from the mouth of Fish Creek at the head of Chequamegon Bay to the west line of the state; inland it is bounded by the Douglas Trap Range so that it underlies all of the Western Plain; how much of the Bayfield Ridge is underlain by sandstone is unknown on account of the heavy drift. So far as known, it never rises more than about 400 feet above the lake. The strata are, over most of this area, gently inclined to the southeast at low angles with a maximum of about five degrees. Apparently this dip decreases towards the southeast. Locally considerable folds are found (see p. 62), which bring to the surface rocks believed to belong to the underlying Oronto group. The Bayfield group extends into Minnesota and may possibly run beneath the Upper Cambrian sandstones, but its relations to them are as yet unknown.

Subdivisions. The present study has shown that the Bayfield group as seen in Wisconsin may be divided into the following formations, beginning at the top;

	Approximate thickness
Chequamegon Sandstone. Red and white sandstone composed predominantly of quartz grains, with thin lenticular beds of red sandy shale..........	1,000 feet
Devils Island Sandstone. Pink and white pure quartz sandstone with abundant ripple marks....	300
Orienta Sandstone. Like the Chequamegon in its upper part, but containing more feldspar grains especially towards the base......................	3,000
Total thickness, about	4,300 feet

Composition. Although predominantly a red sandstone, the Bayfield group is not wholly of that color. In many beds, and throughout most of the Devils Island formation, lighter colors prevail, ranging from pink, through yellow and light brown to gray and white. The very dark red "brownstone," widely known as a building stone, comprises only a small part of the group.

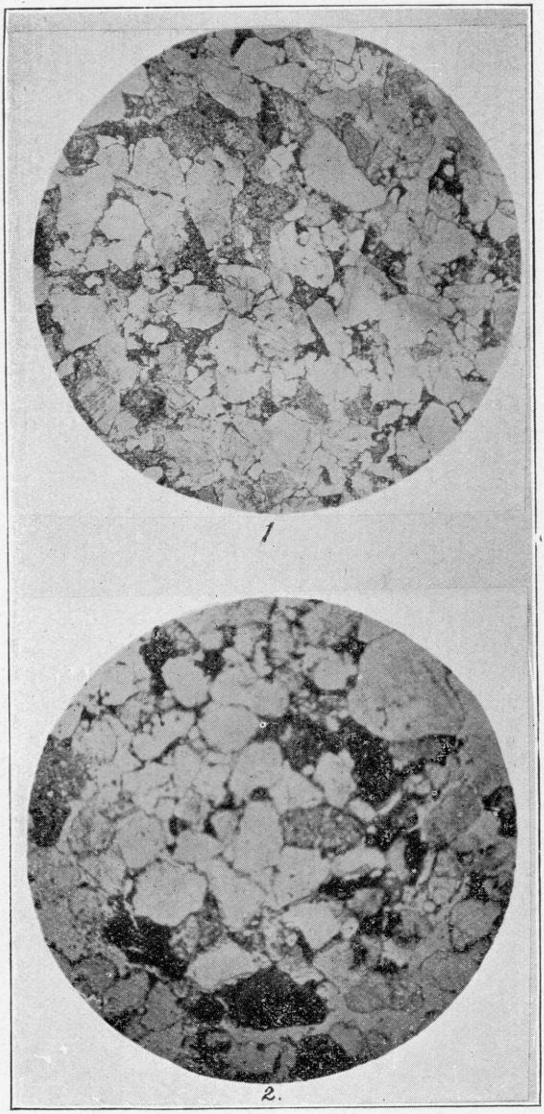
In size of grain the rocks vary from coarse pebbly grits down to shales, although very little fine clay occurs. (See Plates III, p. 26, and VI, p. 44). The coarse grits[1] are usually the lightest colored beds, and the thin bedded fine grained layers are usually the darkest in tint. The size of grain often varies very rapidly, but is usually coarsest near to bedding planes. The cement is generally quartz; the iron oxide, even where abundant, not being important as a cementing material. The iron usually coats the surfaces of the grains. Crystal faces due to enlargement of quartz grains, which are often so conspicuous in the sandstones of southern Wisconsin, are seldom observed. Enlargements of grains are nevertheless common but are nearly always quite irregular in form. The degree of rounding of the grains is

[1] In the use of the term "grit", the writer returns to its original meaning, a rock intermediate between sandstone and conglomerate.

PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS. (Buckley, Bull. IV, Plate LXV).

A

B



A. Chequamegon sandstone from quarry at Houghton, Bayfield County (specimen 4719). The light-colored grains, averaging .35 mm. in diameter, are quartz, and show irregular secondary enlargements, which have accentuated their angularity. The gray grains are mainly somewhat decomposed feldspars, and the black areas are ferric oxide.

B. Chequamegon sandstone from quarry on Basswood Island (specimen 4714). In this section, the grains are somewhat more rounded than in A. Feldspar is not as abundant. The grains run up to .40 mm. in diameter.

variable, the best rounded grains being those of the Devils Island formation, while in the other formations the grains are usually subangular.[1] They contrast sharply with the smooth grains of the sandstones in southern Wisconsin (see p. 101).

The materials of the sandstones of the Bayfield group are in order of abundance: quartz, feldspars (both orthoclase and plagioclase), micas, iron oxides (both magnetite and limonite), chert, and ferromagnesian minerals. Often the materials other than quartz comprise nearly one-fourth of the rock. Most of these minerals are end products of weathering, so that the rock is very resistant to the action of the atmosphere. The feldspars, however, are nearly always somewhat decomposed, and in the more porous sandstones have often been weathered into little specks of white kaolin. It appears probable that a large part of the decomposition has taken place since the deposition of the rock, since otherwise the forms of the grains would not have been preserved so perfectly. Sometimes sands largely composed of magnetite grains occur. The Devils Island formation is an exception to the most part of the group in being nearly pure quartz sandstone, of medium to fine grain.

The following chemical analyses confirm the results obtained by the examination of thin sections (Plates III, p. 26, and VI, p. 44). The amount of feldspar is considerable and appears to be greater in the lower members of the group.

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1 Irving, R. D., Geol. of Wisconsin, 1873–79, vol. III, p. 207.

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Note: It is this angularity of the grains which makes the sands derived from the sandstone valuable for concrete. Lake sands washed from the drift, like those of Minnesota Point, are much more rounded and hence less desirable. (See p. 11.)

ANALYSES OF SANDSTONES OF THE BAYFIELD GROUP[1]

CHEQUAMEGON SANDSTONE

Locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	H_2O	Total
1. Houghton............	86.57	8.43	1.55	......	......	2.36	.67	T	......	99.58%
2. Basswood Id.........	87.02	7.17	3.91	.11	.06	1.43	.22	......	T	99.92%
3. Basswood Id.........	89.76	......	......	not	given	......	......	......	......	....
4. Hermit Id............	91.64	......	......	not	given	......	......	......	......	....
5. Madeline Id	93.50	3.90	(Ca,	MgC	O_3—	1.00)	......	......	......	98.40

ORIENTA SANDSTONE

Locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	H_2O	Total
6. Port Wing............	89.33	6.05	1.41	T	T	2.12	.59	......	......	99.50
7. Siskowit Pt...........	90.86	4.76	1 58	.15	.59	1 06	.45	......	......	99.45
8. Eagle Id..............	84.13	... ..	......	not	given	......	......	......	......	....

Shale Beds. Small lenticular beds of shale, seldom over five feet in thickness, are found throughout the Chequamegon and Orienta sandstones. These are almost wholly of a sandy, micaceous character, little fine clay being found. In color they are usually the darkest parts of the rock, being a deep red tint, but are almost always streaked or spotted with yellow or white; less commonly, gray and green sandy shales are found. A very frequent accompaniment of these beds is a few inches of yellowish, coarse, and often pebbly sandstone above or below, or on both sides of the red bed. Sometimes pebbles occur in the shale itself. The shale beds are most common in hollows or troughs in the bedding, less often on inclined bedding planes' (Fig. 1). Their horizontal extent is always small; they either pinch out or grade into thin bedded sandstone or curve up so that the layers are cut off by the overlying sandstone bed.

[1] Nos. 2, 3, 4 and 8 by E. T. Sweet, Geol. of Wis., vol. III, p. 208. Nos. 1 and 6 by W. W. Daniells, Wis. Geol. and Nat. Hist. Survey, Bull. IV, p. 420. No. 7, Geol. of Minnesota, vol. I, pp. 200, 202. No 5, by J. G. Norwood, Chippewa Land District, 1847, p. 56; Geol. Survey of Wis., etc., 1852, p. 188.

Bedding. As a whole, the Bayfield group is very irregularly bedded, in contrast to the even bedded calcareous sandstones of southern Wisconsin. This fact makes it hard to describe the features satisfactorily. The individual beds range in thickness from a fraction of an inch to over twenty feet, but within these massive beds are minor bedding planes which are more evident on natural exposures than in the quarries. The

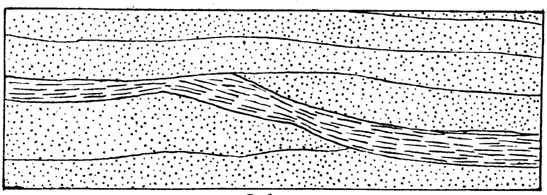


FIG. 1. Bedding in Orienta sandstone, Siskowit Pt., Bayfield County.

most striking and interesting feature of the bedding is what may be called "down curves." These are usually seen only in cross section so that their character in three dimensions can not be observed. They may be sections of curved cross bedding, or actual troughs. In width they range up to 200 feet, but most are of far less size. Two of the clearest seen are shown in Plate IV, p. 30, and Fig. 2. The first shown is not over twenty-five feet across and is filled with curved beds. Sometimes the filling is a bed of red shale, or beds of horizontal sandstone, usually thin-

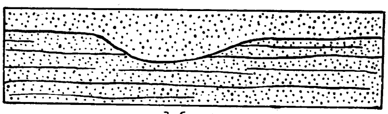


FIG. 2. Channel in sandstone layers—Quarry northeast of Washburn, Bayfield County.

ner-bedded than the rock below. Oftentimes the relation of the down curve to the underlying rock is not clear; but in the instance shown in Plate IV, B, the underlying rock is cross bedded; here it is seen that the depression cuts through the previously deposited layers. In other instances the down curve appears to be an actual bend in the bedding.

The origin of these interesting features is thought to be in part curved cross bedding (cf. p. 30) and in part **erosion by** streams or currents of beds previously deposited. In this case the hypothesis of subaerial origin of the formation is favored. The great diversity of forms, often incomplete in development, leads one to think that different agencies caused the various forms.

A less common feature is an upward bending of the strata as shown in Plate I, B, frontispiece, and Fig. 3. Sometimes even sharper forms occur, but most are comparatively gentle domes or ridges.

Cross bedding is very common, scarcely an exposure being free from it. Every gradation from the normal type to the pecu-

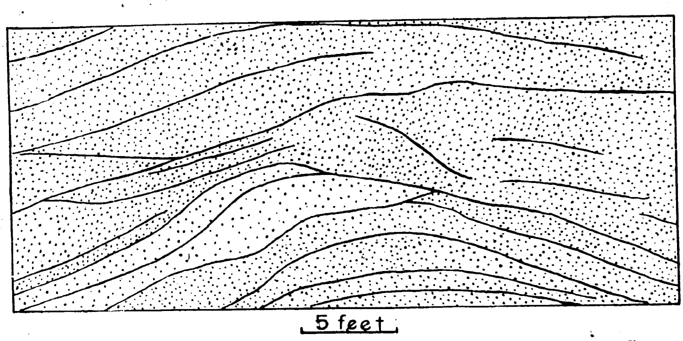
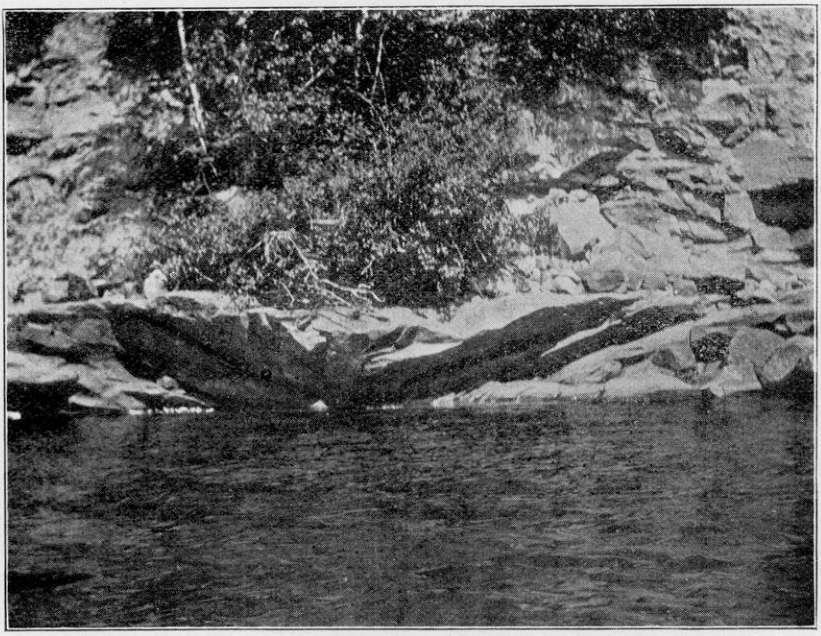


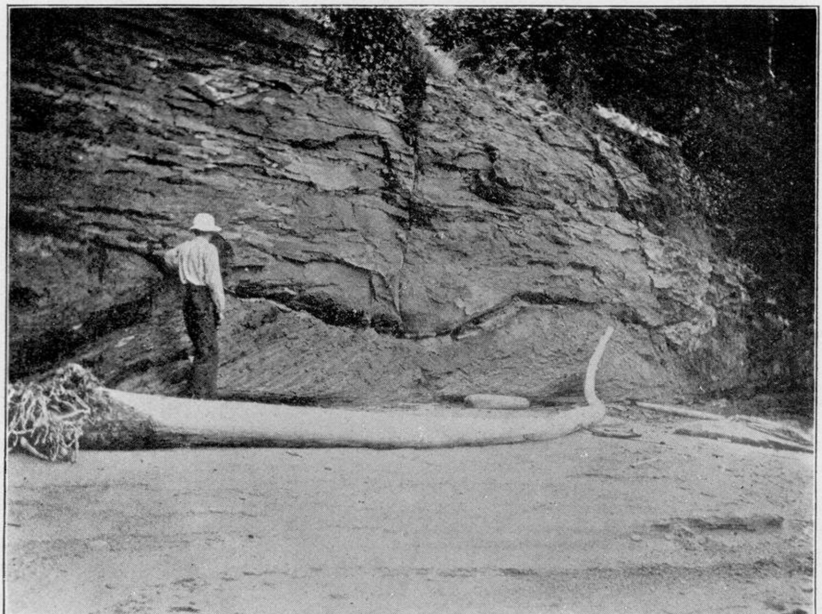
FIG 3. Bedding in Orienta sandstone, Amnicon River, Douglas County.

liar features described above can be found. Usually the inclined layers do not extend through more than a few feet of stratigraphic thickness, but some long gently inclined partings may represent cross bedding developed on a huge scale. At some places, where the waves have washed off a large terrace along the shore, cross bedding may be seen in three dimensions. Then the inclined layers are often found to be curved into sags, domes, and other irregular forms; as suggested, many down curved layers may be simply cross sections of this kind of cross bedding.

The dip of the inclined beds is often rather steep, but no cross bedding of the type usually ascribed to wind action was observed. The direction of dip was observed with some care. It is almost always toward a northerly or easterly direction. In the Devils Island sandstones alone are southerly or southwesterly dips at all common, although they are found occasionally in all the lower strata. The significance of this fact is the presumption



A. Down-curve in upper beds of Orienta sandstone, west side of Sand Island, Bayfield County.



B. Horizontal sandstone beds, filling channel in cross-bedded layers, Orienta sandstone, west of Herbster, Bayfield County.

that the material for this formation was brought mainly from the northeast, while that of most of the group came from the opposite direction.

Iron Banding. In noting the colors of the Bayfield group the observer is often confused by the tendency of the red beds to weather white, while many white beds are discolored to a brown shade on the surface or are stained red by iron from overlaying rocks or drift. Much more light colored sandstone exists than is generally supposed. The rapid variations of color are often very striking. When the change takes place along a joint it gives the appearance of a fault which is often very deceptive. In general it may be said, that the coarse grained and often the thick bedded layers are lightest in tint, while the thin bedded and shaley beds are both darkest and most varied in color, although most affected by spots and streaks of lighter tint. Mottling and irregular blotching of red and white, however, is not confined to these beds. When this kind of rock is seen below water, where the surfaces are cleaner and the colors brighter than where exposed to the air, the effect is very striking. Sometimes red circles are seen in white sandstone, inclosing spots of white. Often very irregular markings occur. Fine banding along the bedding is by far the most common, but one seldom has to follow the bands far before they leave the planes of deposition to form irregular curves. True concretions of iron oxide are, however, not very common.

The origin of these varied features is evidently the work of ground water, but the reason for the curious forms is not known. It appears probable that most of the iron was originally deposited in the thin-bedded, fine grained layers and in the massive brownstones, and that it has spread from them into the rest of the rock. The light color of the coarse grained sediments suggests either the action of leaching of these more porous beds, or that the iron was never deposited in them. A striking instance of secondary coloration was observed in a cross bedded layer near Pikes Quarry, Bayfield County, in which the upper half was red and the lower nearly white, the line of junction thus cutting the bedding. Although the iron oxide is not an important cement in the firm brownstone, it may be the dominant cement in some of the less indurated sandstones, no thin sections of which have been examined. The writer is inclined to believe that such curious forms as are shown in Plate I, B, frontispiece, are due to partings along the lines of iron banding. Generally these apparent folds or sharp basins occur along joints, thus strengthening the suggestion of an origin due to irregular cementation, although, however, all are not to be explained in this manner.

Pebbles and Clay Pockets. In a formation entirely devoid of fossils, like the Bayfield group of sandstones, the derivation of the pebbles in the conglomerates is a subject of considerable importance. No thick beds of conglomerate occur within the group, but pebbles are found very commonly on both normal and cross bedding planes and to a less extent scattered through the sandstone or even through the shale. The Devils Island sandstone, however, is free from them. In size these pebbles average about an inch in diameter, the largest being some four inches across. All are well rounded. By far the greater portion of the pebbles are porphyries and amygdaloids with some basic traps; these were obviously derived from the Middle Keweenawan. Next follow in order of their abundance, vein quartz, red and white quartzite, iron formation, chert, slate, and granite, all derived from the Huronian and older rocks.[1] It should be noted that all the pebbles with the exception of the traps are of very resistant rocks, while even those are the hardest parts of the formations from which they were once worn. No debris from the recognized Keweenawan sediments (Oronto group, etc.) could be discovered.

Often associated with the pebble deposits are small cavities which when seen in fresh sandstone are found to contain red or green clay. Many of these show remnants of decomposed trap pebbles making their origin at once evident. Others are larger and of irregular shape. Yet others are small and flattened, appearing at first sight much like the casts of shells. But again, in fresh rock they are always found to be filled with clay. A common feature of clay pockets occuring in red rock is a surrounding rim of white.

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[1] Owing to weathering, the identification of many of the small trap pebbles is quite difficult.

The origin of the irregular or flattened clay pockets must be nodules of clay laid down with the rock[1]. Such clay lumps are often found in recent deposits. They are formed of flakes of somewhat indurated clay which will not mix with sand, or washed out by streams, or dried and broken up by sun and wind in connection with mud cracks. Mud cracks are not often found in the Bayfield group of sandstones, owing to the scarcity of clay and the ease with which they are overlooked in natural exposures.

Chequamegon Sandstone

General Character and Extent. The youngest formation of the group is the Chequamegon sandstone, so named from the exposures in the now almost idle quarries on Houghton Point on Chequamegon Bay, Bayfield County. In areal distribution, this formation underlies all the Apostle Islands southeast of a line drawn from Sand Point to Devils Island. How far it extends beneath the thick drift of the Bayfield Ridge is a matter of conjecture. The Chequamegon formation consists mainly of brown quartzose sandstone.

Thickness. As the initial dip of the formation could hardly have been over one degree, or about 100 feet per mile, and that presumably towards the northeast (cf. p. 102) we may compute a thickness of nearly two thousand feet; but in order to allow for the probable lessening in dip towards the southeast, as well as a tendency to overestimate the degree of inclination, a thickness of 1000 feet is regarded as nearer the truth.

General Section. The Chequamegon sandstone may be divided into several more or less distinct members as follows:

Washburn beds. Soft red and white sandstones with much banding and mottling of the colors; beds usually thin with few pebbles or shale layers, which sometimes show mud cracks.

Quarry or Brownstone beds. Heavily-bedded dark brown ferruginous sandstone with pebbles and clay pockets; between heavy beds are thin-bedded layers and lenses of red, micaceous shale.

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[1] The writer did not observe any evidences of decomposing trap boulders. Cf. Irving, R. D., Geol. of Wis., 1873–9, vol. III, p. 209.

3

Main beds. Much the same as the brownstone but with more irregular bedding, cross bedding, light colored and coarse pebbly sandstone, and red shale beds. (It may be that the quarry rock is only a phase of this division.)

Basal beds. Thick, cross-bedded layers of white or brownish sandstone with pebbles; lenses of red and yellow thin-bedded rock; some ripple marks.

LOCAL DETAILS.

The youngest or Washburn beds of the Chequamegon sandstone are seen in the shore cliffs south of Washburn on Chequamegon Bay. Here are exposures up to nearly 40 feet in height of soft sandstone of all colors. There are many rapid variations from white to the darkest red, while mottling is very common. No pebbles were observed. The beds range from several feet in thickness down to a fraction of an inch in the dark red sandy shale beds.

At the Barksdale works of the E. I. Du Pont Denemours Powder Co. a well shows the greatest thickness of the Chequamegon sandstone known at one locality. It is clear that the Devils Island sandstone was not reached.

LOG OF WELL AT BARKSDALE POWDER WORKS

Drilled in 1906. Situated in sec. 23, T. 48, R. 5 W. at elevation of about 750 ft. A. T. Samples sent by courtesy of U. S. Geological Survey.

Sample No.	Thickness Feet	Depth Feet
Pleistocene:		
1 Grayish-red, sandy, non-calcareous clay......	70	
2 Very calcareous reddish-gray "hard-pan" or sandy cemented till	20	90
Chequamegon sandstone:		
3 Soft medium grained light reddish quartz sandstone	18	
4 The same, slightly darker and harder.......	27	
5 Pinkish white coarser and subangular grained quartz sandstone	25	
6 Soft, finer grained reddish quartz sandstone	20	
7 Soft, very coarse gritty or conglomeritic red sandstone mixed with some finer sandstone	20	

8	Soft, nearly pure quartz sandstone, grains subangular and of medium size...........	30	
9	Sample missing. Said to be same as last...	15	
10	Soft fine to medium grained pinkish quartz sandstone	15	
11	Much the same as the last but with somewhat more rounded grains	20	
12	Nearly pure white sandstone, otherwise same as last	20	
13	Sample missing. Said to be soft red sandstone	45	
14	Sample missing. Said to be white conglomerate with much water..................	30	375
	Depth of well	375	375

At the quarry just north of the city very similar rock is seen. (see Fig. 2, p. 29). Between the thicker beds occur thin-bedded and shaley partings which sometimes show mud cracks. These exposures show a dip of about one degree to the south.

Only comparatively small exposures occur on Madeline Island, the best being on the northernmost point. These beds show a darker color, together with red shaley beds, and pebbly layers. They appear to be a portion of the quarry beds.

The now virtually idle quarries on Houghton Point north of Washburn are in heavily-bedded brownstone.[1] Between the heavy layers is frequently found a foot or more of thin-bedded or softer sandstone, while lenses of red micaceous shale often occur. At other places the bedding planes are marked by coarse yellowish grits or layers of pebbles. Clay pockets also occur. Plate III, A, p. 26, shows a thin section from this locality.

Pike's quarry south of Salmo shows the greatest vertical extent of the formation so far as known in any single exposure. The following section, from top down, shows the downward gradation of the quarry beds (numbers 7 to 9) to the less regularly bedded and variable colored layers of the main beds:

[1] Buckley, E. R., Building and Ornamental Stones of Wisconsin, Wis. Geol. & Nat. Hist. Surv., Bull. IV, 1898, pp. 187–192.

SECTION AT PIKE'S QUARRY, SEC. 33, T. 50, R. 4 W.

		Thickness
9	Weathered and broken brownstone	23 feet
8	Thin bedded and cross bedded red shaley sandstone with yellow streaks	6
7	Heavily bedded brownstone with very few clay pockets, the best quarry rock	33
6	*Unexposed* below level of railway track	15
5	Heavily bedded brownstone in lake cliff, the top much broken up	35
4	Thin bedded, red, shaley sandstone	8
3	Heavy layer of brownstone	8
2	Gray to deep red, yellow, and white sandstone, varies from shaley to pebbly with much cross bedding, the coarser phases having the lighter colors	12
1	Heavily bedded coarse pebbly brown sandstone	20
	Total thickness, about	150 feet

Immediately south of the docks at Bayfield is a good exposure of brown sandstone in the cliffs. The usual thin bedded and sandy shale partings occur between the beds, and in one place is found a small lense of pure clay shale, a foot or two in thickness. This is of varying shades from deep red to gray and green, and grades into the usual sandy shale; the associated yellow sandstone layers are also seen.

On the south end of Basswood Island is an abandoned quarry which shows about 25 feet of brownstone in heavy layers.[1] The bedding planes are curved both up and down from the normal. A shale layer is found between the brownstone beds in the quarry and the same material is said to have been reached by boring not far below the bottom of the quarry. Pebbles and clay pockets are abundant. Plate III, B, p. 26, shows a thin section of this rock.

A small quarry was once operated on the northeast corner of Hermit or Wilson Island.[2] The neighboring shore cliff shows thin bedded and cross bedded yellow and white mottled layers be-

1 Ibid., pp. 178–182.

2 Ibid., p. 185.

tween the heavy beds of brownstone. A thin section shows fairly well rounded grains averaging nearly 0.4 mm in diameter. About a fourth is altered feldspar including much microcline, although orthoclase is predominant.

Stockton Island shows extensive outcrops on its eastern end. There the waves from the open lake have worn some striking caves and deep coves along the joints. The sandstone is somewhat redder in color than the quarry beds. A few shaley layers are seen but most of the bedding is heavy. Some long partings dipping gently to the south resemble huge cross bedding, but are probably inclined joints. Cross bedding is common. At the southeastern end of the exposures occurs hard, cross bedded, white sandstone. Similar rock is also seen on Presque Isle Point.

Near the southwest corner of Stockton Island is a large abandoned quarry which shows a thickness of 73 feet of brownstone in the main opening.[1] Above this another excavation discloses rock which is mottled with white. The upper layers all show clay pockets. The partings are often shaley and show cross bedding. They pinch out rapidly, never having any great horizontal extent. Sometimes they end on downward pitches of the bedding, but in other places the layers bend up and are cut off by the heavy layer above as cross bedded layers are.

Outer Island exhibits a fine exposure along almost the entire length of its eastern side. The sandstone is much varied in color, ranging from the usual brownstone to pure white. The changes are very rapid and often take place along joints. In general the coarse grained cross bedded layers are lightest in tint. Plate I, B, frontispiece, represents a curve in the bedding seen near the southern end of the island; others occur but are not so distinct.

Some interesting exposures occur on the east side of Oak Island. At the northeastern corner, heavy beds of brownstone with interbedded dark shaley layers are seen. Coarse yellow grits also occur. Toward the south, lenses of thin bedded yellow and white banded sandstone appear, and also some hard white and brown coarse pebbly layers.

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[2] **Ibid., p. 183.**

On Point Detour and the adjacent headlands[1] occur beds of brown sandstone with the usual shaley partings. The depth to which weathering here extends is unusual, being often 20 feet or more.

North Twin Island shows strata near the bottom of the Chequamegon formation. White to brownish heavy cross bedded layers with occasional large ripple marks occur.

Bear Island shows on its eastern coast a very good section. The southeasterly dip is here more pronounced than it is to the southeast, so that some 400 feet of the stratigraphic thickness is apparently seen. However, the layers pinch out and vary so rapidly that an exact determination is impossible. As we go north we descend to successively older and older strata. At the south, brown sandstone with irregular cross bedding and lenses of thin bedded yellow and pink sandstone occur. But towards the north end the color becomes gradually lighter until hard cross bedded white beds take their place. These basal beds show a few ripple marks. At some points wide terraces of rock have been washed clean by the storms so that an excellent opportunity is given to study the curious forms of the curved cross bedded layers (see p. 30).

On York Island, at the northwestern cape, is a fine exposure of the basal layers in a clean wave-swept terrace. White and reddish sandstone, with grit and conglomerate, occur as well as small lenses of thin bedded red and pink layers.

At the south end of Devils Island, which is entirely surrounded by a rock cliff, the light colored basal layers of the Chequamegon sandstone are seen. There are interbedded layers similar to the main body of underlying Devils Island sandstone, so that no very sharp line of demarkation can be drawn.

Devils Island Sandstone.

General Character and Extent. The formation of the Bayfield group, which conformably underlies the Chequamegon sandstone, is called the Devils Island standstone, from the excellent exposures on the island of that name. It is distinguished

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1 Owen, D. D., Chippewa Land District, p. 54; Geol. Survey of Wis., etc., pp. 268, 305.

from the other formations of this group by its thin bedding, well rounded, medium sized quartz grains, which are almost free from any coating of iron oxide, by ripple marks, and by its pink and white color. Banding and mottling of the colors is frequent. A few iron concretions occur. No shale beds, feldspar grains, clay pockets or pebbles are known in this formation. The formation is much more porous and friable than the others of the group. For that reason more striking and larger sea caves have been worn in the Devils Island sandstone than in any other horizon.

The Devils Island sandstone outcrops along a narrow belt stretching for twenty-five miles southwest from the island from which it takes its name. Fine exposures occur in the cliffs of Sand Island and Squaw Bay (Plates V, B, XXIII, A, p. 94).[1] Lesser ones are seen on Siskowit River and Lost Creek near Cornucopia. Twenty-five miles to the southwest an isolated exposure on Brule River corresponds so closely in character, that there is little doubt that it is to be placed in this formation. According to the writer's interpretation of the structure of the district, this formation must lie immediately beneath the drift south of Washburn, but no exposures of it are there known. It may pinch out or otherwise disappear in the interval.

Thickness. The thickness of the Devils Island sandstone cannot be directly measured, but a computation based upon the width of outcrop and average dip places the figure at about 300 feet.

Ripple Marks. The only portion of the Bayfield group which shows ripplemarks in any abundance, is the Devils Island sandstone and some of the beds immediately above and below. The accompanying diagrams show the most common types. Most have symmetrical ridges, little if any sharper than the intervening troughs. The other type has one side of the ridge much steeper than the other, as shown in Fig. 4, c, and Fig. 5, p. 40. Few were observed which show the subordinate ridge in the hollow, such as is often seen in modern ripple marks formed on the lake bottom (Fig. 4, b). This is, however, a

[1] Owen, D. D., Chippewa Land District, p. 55; Geol. Survey of Wis., etc., p. 268.

feature which is readily overlooked. The ripple marks occur both on cross and normal bedding planes, and where marked by a cement of iron along the bedding the effect upon the outcrop is very striking (Fig. 5). In size they average one to two inches from crest to crest, but occasionally much larger ones are seen.

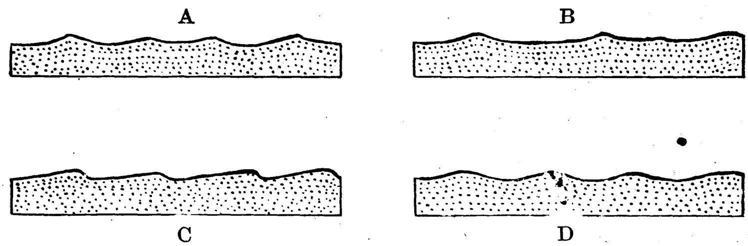


FIG. 4. Types of ripple marks.

It is believed that the symmetrical ripplemarks are the result of wave action in standing water; and that the unsymmetrical form (Fig. 4, c) was formed by currents, either of water or air.

Cross Bedding. The common cross bedding of the Devils Island formation is more regular than much of that in the other members of the Bayfield group. The curious irregular curved forms there noted are seldom seen. The direction of

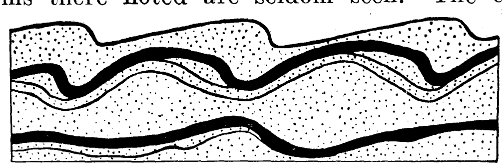
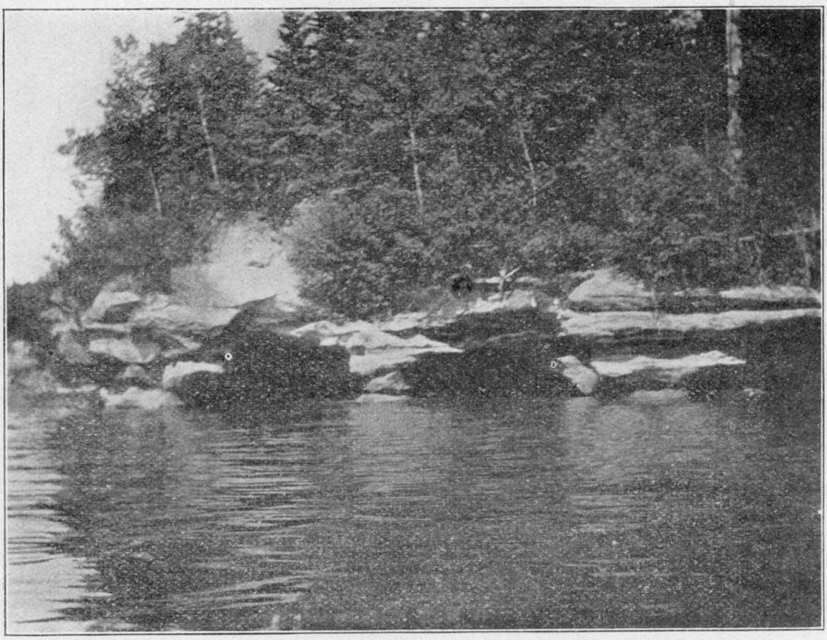
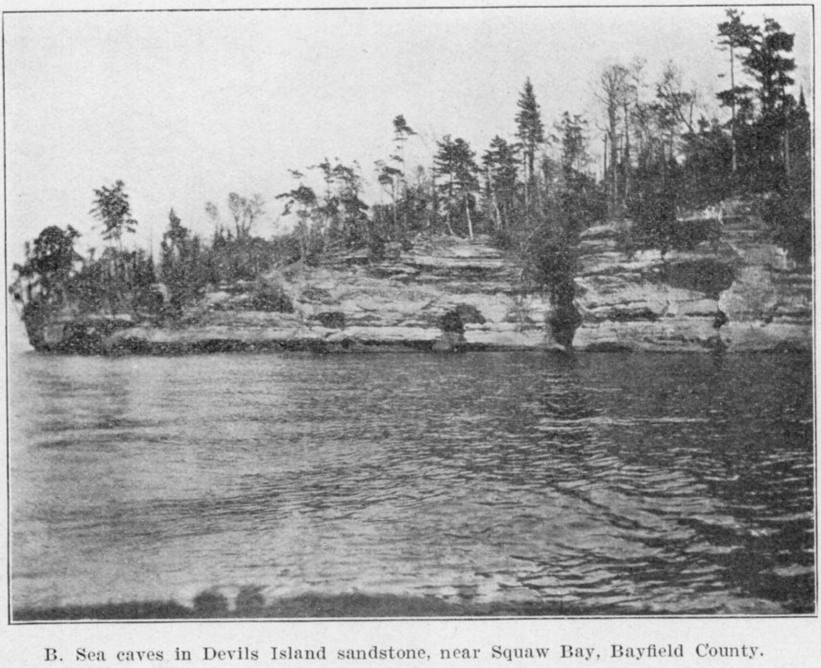


FIG. 5. Ripple marks marked by iron banding in Devils Island sandstone (Specimen 11,058). One-half size.

dip of the layers is usually to the south or southwest but there are some exceptions, although on the whole it is conspicuous for being in a direction opposite to that prevailing in the other formations. This fact is thought to mean that the material of the Devils Island sandstone was brought from a different direction.



A. Sea caves in upper beds of Orienta sandstone, west side of Sand Island.



B. Sea caves in Devils Island sandstone, near Squaw Bay, Bayfield County.

Orienta Sandstone

General Character and Extent. Underlying the Devils Island sandstone occurs the lowest formation of the Bayfield group, the Orienta sandstone, so called from its exposure in the quarries near the village of that name. In its upper portion this formation resembles the Chequamegon sandstone very closely, so that the possibility of repetition of that formation by faulting was considered. It is seen, however, that in the vicinity of Cornucopia the uppermost beds of the Orienta pass beneath the Devils Island sandstone, although the actual contact is not exposed so far as known. Moreover, there is no repetition, so far as could be discovered, of the Devils Island formation to the west. In its lower portion, and indeed to some extent throughout, the Orienta contains more feldspar, mica and magnetite grains than the younger formations, the relative amount increasing towards the bottom, as do beds of red shale.

The Orienta sandstone underlies the Western Plain, extending from the line of outcrop of the Devils Island formation, all along the south coast north of the Douglas Range and into Minnesota. Folding brings it up near Ashland, where rock believed to be a part of it outcrops on the South Fork of Fish Creek, and it is found beneath the thick drift in deep wells.

Thickness. As with the Chequamegon, there is no direct means of measuring the thickness of the Orienta sandstone. A computation based on a uniform dip of but one degree places the thickness on Brule River at about 1000 feet. This section is not good enough to be correlated with that shown on Middle River, where the formation is turned up by the thrust fault of the Douglas Range, exposing some 2,700 feet. As the Devils Island formation does not occur there, it appears certain that the Middle River section is all Orienta sandstone, thus placing the total thickness of the formation at 3,000 to 3,500 feet; 2,495 feet of this formation is penetrated by the deep well at Ashland (see p. 65), and 1,110 feet is exposed on Fish Creek.

General Section. The following section shows the subdivisions of the Orienta sandstone from the top down. In the future it is possible that some parts may be distinguished as separate formations:

	Approximate Thickness
Upper beds. Mainly white and red sandstone with a few ripple marks	300–400 feet
Upper brownstone (of Port Wing)	500–700
Copper Creek beds. White and pink fine grained sandstone with magnetite and mica grains and a few ripple marks	75–100
Main beds. Brown, red, and white sandstones, becoming progressively more felspathic towards the bottom, with thin beds of red shale	1800–2000
Total thickness, about	2700–3200 feet

LOCAL DETAILS

Aside from the small exposure believed to belong to this formation, on Fish Creek near Ashland Junction, which will be described in Chapter V, the easternmost exposure of the Orienta Sandstone is on Sand Island. Here and on Eagle Island[1] and Squaw Point (Plate V, A, p. 40) to the west, occurs white cross-bedded, ripple-marked sandstone much resembling the basal beds of the Chequamegon formation. A few layers of red sandstone occur and there is much banding of the colors. A considerable amount of decomposed feldspar is seen among the sand grains.

To the west, on Siskowit Point, the downward gradation of this type to the brownstone beds may be seen. Lenses of red shale also appear (Fig. 1, p. 29). A small quarry formerly operated here produced red and white sandstone. Similar sandstone with red, shaley, and yellow gritty layers occurs on Bark Point, across a bay by that name to the west.

Just west of the little settlement at Herbster is a bold rocky point projecting out from the sandy coast cliffs.[2] Here the sandstone is pebbly and cross bedded. Plate IV, B, p. 30, shows an interesting trough in the bedding seen here. A quarry was once started at this locality.

The quarries at Port Wing are still operated at times and produce some of the best brownstone in the region. This rock is heavily bedded, free from clay pockets, has few pebbles, and

[1] Irving, R. D., Geol. of Wis., 1873-9, vol. III, p. 208.

[2] Owen, D. D., Geol. Surv. of Wis., etc., 1852, p. 269.

is of a somewhat redder and more cheerful tint than the brownstone of the Chequamegon sandstone. In the quarry some pebbles were observed along the bedding planes, together with black magnetitic layers, and a little white sandstone.[1] Plate VI, A, p. 44, shows a thin section of this rock. About a fourth is feldspar, mainly orthoclase, but including some microcline and plagioclase. The locality is notable for the unusual fact that the rock is sound clear up to the top and shows glacial striae.

Another good quarry was formerly operated on the east bank of Iron River near Orienta, in the western part of Bayfield County.[2] The southeasterly dip of the formation, combined with the fall of the river, brings one to successively higher and higher strata in ascending the stream. We pass from the heavily bedded brownstone up to thin bedded white and red banded rock. Near the road crossing, occur white and yellow heavier beds with thin layers of green shale.[3]

West of the mouth of Iron River no exposures occur on the coast. Only two small outcrops occur on Brule River below those of the Devils Island sandstone. On Poplar River are good outcrops for several miles above the mouth, but as the dip here is generally less, no great thickness can be observed. The rock is thought to be part of the upper brownstone. Much is thin bedded and grades to coarse yellow sandstone. The magnificent section seen on Middle River shows the lower portion of the formation and will be described in detail in Chapter V.

West of Middle River, exposures are much less satisfactory. The Copper Creek and main beds are the only ones found. On Amnicon River for about three-fourths of a mile below the falls, at the contact with the trap, occur good sandstone exposures. The dip is southeasterly, except close to the trap, and some 275 feet of beds is thus exposed. Of these the lower 200 feet is mainly heavily-bedded brownstone, which once was quarried to

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1 Buckley, E. R., op. cited, pp. 201–205.

2 Ibid., p. 209.

3 Owing to bad weather the survey of Iron River was not completed. No exposures were seen or reported where we would expect to find the Devils Island sandstone (see map). Sweet, E. T., Geol. of Wis., vol. III, 1873-9, p. 322.

a considerable depth.[1] Associated white and yellow pebbly phases and magnetitic bands occur. These features serve to distinguish the beds from the upper brownstone of the Port Wing quarries, although the possibility of lateral change in the formation must be taken into account. Above these layers occurs a gradual transition to the Copper Creek beds. These are mainly thin bedded pink or red and white fine grained sandstone. Much cross bedding, sometimes curiously curved, occurs (Fig. 3, p. 30). No ripple marks were observed, and this fact, taken in connection with fine grain, magnetite grains, and small thickness lead the writer to regard this as a part of the Orienta sandstone rather than a lateral change in the Devils Island formation. It is also simpler on structural grounds to assume this correlation, for it is entirely possible that these beds occur under one of the unexposed intervals in the Middle River section to the east.

Similar beds appear to occur at two small exposures which were not visited by the writer. One of these is in Sec. 30, T. 48, R. 10 W. and was not discovered by any of Prof. Grant's party.[2] Another outcrop in Sec. 7, T. 47, R. 13 W., was examined by one of Prof. Grant's assistants and a sample preserved, which shows the rock to be very like that at the falls of the Amnicon River. It is a pebbly reddish and white sandstone.

On Copper Creek next to the contact with the traps, a small thickness of thin-bedded, ripple-marked, red and white spotted sandstone is exposed, which in many respects resembles the Devils Island sandstone. It is, however, much darker in color and is therefore thought to belong to the same horizon as the rocks described above.

Farther to the west, below the lower falls of Black River (Plate XIX, p. 80) occurs red and white spotted irregularly colored sandstone varying much in bedding and coarseness of grain. The dip may be sufficient to expose as much as 200 feet of strata, showing a somewhat similar seccession as at Amnicon River (see p. 43). No true brownstone was observed and there is a comparative abundance of magnetite, micas, and ferromagnesian

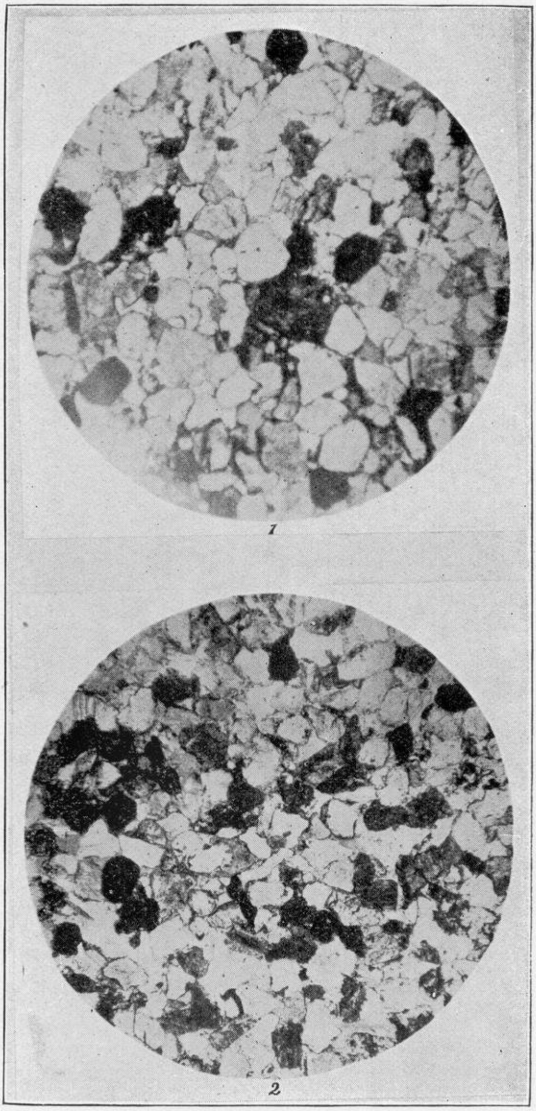
1 Buckley, E. R., op. cited, p. 208.

2 Sweet, E. T., Geol. of Wis., 1873-9, vol. III, p. 348.

PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS. (Buckley, Bull. IV, Plate LXIV).

A

B



A. Orienta sandstone (specimen 4717) from Port Wing. The section shows more feldspar (mainly orthoclase, but including some microcline and plagioclase), iron oxide, and ferromagnesian minerals, than those from the Chequamegon sandstone, although not notably different from Plate III, B, p. 26. The cement in this specimen is partly iron.

B. Orienta sandstone (specimen 4718) from quarry on St. Louis River, in bed 1 of section on p. 70. Nearly one-fourth of the rock is feldspar, mainly orthoclase, but including as usual some microcline and plagioclase. The cement is in part argillaceous, being composed of the alteration products of the feldspars.

minerals. Ripple marks occur but rarely and cross bedding is not very abundant, but many clay pockets and pebbles were observed. Some of the thicker beds are of yellowish to white quartz sandstone. One such was observed to fill a hollow in the thin bedded red layers. The latter type of rock appears to be more abundant in the upper part of the section but often occurs as lenses in the heavier bedded sandstones.

In Sec. 29, T. 47, R. 14 W., occur several small exposures of yellow and white fine grained hard sandstone, very much like some of the beds exposed on Copper Creek. A well at Foxboro in Sec. 6, T. 46, R. 15 W., almost on the west line of the state, shows the same kind of rock,[1] as do some small exposures near Holyoke visited by Professor Grout.[2]

A small exposure of sandstone is said to exist on the Nemadji River in the NE¼ Sec. 27, T. 48, R. 14 W., but was not visited by the writer.[3]

The exposures of the Orienta sandstone on St. Louis River are described on p. 69.

Economic Products. The only product of economic value derived from the Bayfield group is building stone.[4] This is obtained from the most ferruginous phase of the sandstone which is commonly known as "brownstone." Apparently this rock is found only in certain more or less well defined horizons. It will be noted that the quarries, especially those in the Apostle Islands, are arranged in a nearly straight line along the strike of the formation. Therefore but one horizon of good quarry rock is believed to exist in the Chequamegon formation, although good stone was seen at many scattered points. Less is known about the Orienta sandstone. The best brownstone is that found at Port Wing and Orienta, but it is most probable that the brownstone quarry on Amnicon River is at a lower horizon.

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1 Drillings sent by C. N. Edin, Dedham, Wis.

2 Personal communication.

3 Sweet, E. T., Geol. of Wis., 1873-9, vol. III, p. 318.

4 A full description of the quarries, including a list of buildings constructed with Lake Superior stone, is found in Bull. IV, Wis. Geol. and Nat. Hist. Survey, Building and Ornamental Stones of Wisconsin, by E. R. Buckley, 1898, pp. 167-219.

The quarry at Fond du Lac does not produce a true brownstone, the rock being firmer, more felspathic, and irregularly colored red and white.

Condition of the Quarry business in 1910. When the writer visited the district, no quarry happened to be in operation. The Port Wing quarries, which alone are operated on an extensive scale, closed down about the first of July. A very little stone had recently been quarried at Houghton. The Fond du Lac quarry is operated whenever the height of water in the river permits shipments, but is not equipped to furnish anything but rubble and irregular blocks.

Causes of Decline. The causes of the almost complete abandonment of this once apparently flourishing industry do not lie wholly in the character of the stone itself.[1] A few decades ago brownstone was a very popular building material in the eastern part of this country, so that when a similar stone was discovered in Wisconsin it was at once exploited. Between 1868, when the first quarry was opened on Basswood Island,[2] and 1893 the business continued to grow. A few years before 1893, a boom took place at the head of the lakes. As in all other business enterprises, speculators then rushed into the brownstone industry. Stone, often of inferior quality, was put out at ruinously low prices. The bad results from the use of this low grade material naturally reflected upon the reputation of the good. Then came the inevitable panic, resulting from the unnatural expansion of business. The demand for stone decreased greatly and never again reached its former extent.

In the meantime, the brownstone buildings of the east had begun to look shabby and a cheerful light stone was demanded. This was supplied by the Bedford limestone, which is nearer the best markets and possesses the great advantage of softness. Tools dull much more rapidly in cutting sandstone, a fact witnessed by the extensive blacksmith shops of the Lake Superior quarries. Before the Lake Superior companies could recover from the results of their folly before the panic, this light stone had captured the market. By 1897 very little stone was being

1 Buckley, E. R., op. cited, p. 211.

2 Irving, R. D., Geol. of Wis., 1873–9, vol. III, p. 209.

taken out and today only two quarries are producing first class building stone. Plants representing an investment between two and three million dollars are now idle; some have been burned; in most the machinery is rusted and useless and the buildings are falling to pieces. At several quarries large piles of cut blocks ready to ship remain unsold.[1] Perhaps now that business at the head of the lakes is developing upon a more sane and wholesome basis than formerly, quarrying will be resumed; for the stone has a useful field for buildings in smoky cities, as it does not show dirt like the lighter toned materials now in fashion.

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1 In 1912 some of these were being shipped.

CHAPTER IV

THE ORONTO GROUP AND OLDER FORMATIONS, AND THE EXTENSION OF THE SANDSTONE GROUPS IN MINNESOTA

Nomenclature. Beneath the Bayfield sandstone group described in the last chapter, is a great thickness of arkose sandstone and shales, nearly all red in color, and for the most part occupying a highly tilted position wherever exposed. On account of these differences, these rocks were separated by the former Geological Survey of Wisconsin from the overlying horizontal quartzose sandstone (see p. 16). At its base this arkose group is interbedded with the traps, thus showing that it is a part of the Keweenawan series; but the bottom of this upper division of the series is assumed to be the base of a thick conglomerate called the Outer Conglomerate, above which horizon no igneous rocks occur.

With the exception of the basal portion, this group has not heretofore been divided into formations. Professors Lane and Seaman have recently applied the name Freda to the sandstone immediately overlying the black shale beds (Nonesuch formation) just above the Outer Conglomerate.[1] As this formation (sometimes known as the Western sandstone of Michigan) is only a small portion of the entire thickness of sediments below the Bayfield group which have not yet been studied in

[1] Lane, A. C., and Seaman, A. E., Geological Section of Michigan, Rept. of State Board of Geol. Survey, 1908, p. 23; Jour. of Geology, vol. 15, 1907, p. 36.

detail, it seems best to give a new name to the entire group and retain the name Freda for this formation. It will therefore be termed the Oronto Group, from the excellent exposures near the bay of that name in the northern portion of Iron County. The limits of the group may be fixed at the bottom of the Outer Conglomerate as a base, and the top of the highest thick beds of red shales and well-marked arkose sandstones as the top.

General Character. The Oronto Group is composed of conglomerate, sandstone, and shale; the last probably predominating, although not often exposed. In color it is usually some shade of red, but a characteristic feature is banding, streaking, and spotting with greenish white. The white beds are seldom more than a few inches thick. Often the light color also extends along the joints. In the material of the component grains it differs mainly from the Bayfield group in having a greater proportion of undecomposed minerals, feldspars, micas, and ferromagnesian compounds, as well as more magnetite and calcium carbonate. Quartz grains are, however, present in considerable quantity; but are never, so far as known, predominant throughout any considerable thickness of strata. The shale is usually sandy and micaceous, but there are considerable beds of fine clay shale. Nearly always the shale beds are more brightly colored than the coarser grained strata.

Areal Extent. In areal extent the Oronto Group underlies all of the Eastern Plain (see p. 12), between Ashland and the Southern Trap Highland, but it is exposed at but few points. It is probable that only the harder beds are exposed, since these would form the ridges now buried beneath the drift, which is usually so thick that only a few very deep wells enter the rock. It here forms a series of open folds (see p. 92). Isolated areas of rocks believed to belong to the Oronto Group occur also on Middle and St. Louis rivers in Douglas County, and rock of the same type is penetrated by deep wells in Superior. The Oronto Group is believed to extend far into Minnesota, for rocks of the same type have been found by drilling to lie beneath the Paleozoic sediments.

Thickness. The thickness of the Oronto Group can only be determined by computations based upon discontinuous exposures. The sum of the stratigraphic thicknesses actually exposed is nearly 10,000 feet, but evidently the total must be much greater. On Montreal River it is possible that a thrust fault, dipping to the north, might cause a repetition; but no direct evidence indicating its existence was discovered.[1] Computation places the thickness of the Freda sandstone between the top of the Nonesuch shales and Lake Superior at 12,600 feet. Should an initial dip of even 10 degrees be subtracted, (which is much too great), the result would be 11,700 feet. On Fish Creek to the west, where there is every probability that the strata are thinner, since they thin rapidly in that direction at all lower horizons,[2] a thickness of fully 8,000 feet is indicated. There the jointing and shearing (see p. 93) do not indicate that the thickness is expanded by faulting. Since the rocks of this locality are believed to lie at a horizon above those of Montreal river, a total thickness of the Oronto Group of some 21,000 feet is indicated. This figure agrees with other computations based upon the dip, and appears to be conservative—provided lateral variations in the character of the strata along the strike, and concealed faulting have not confused the true sequence to a greater extent than now seems probable.

Subdivisions. The Oronto Group may tentatively be subdivided into the following formations; the basis of the division is in part structural but is mainly lithologic, and therefore rather unsatisfactory, owing to the possibility of lateral variation as mentioned above:

	Thickness
Amnicon Formation. Red and greenish shales, arkose sandstone, and some conglomerate (1050 feet exposed)	5,000 feet
Eileen Sandstone. Red and white somewhat quartzose sandstone (1800 feet exposed)	2,000
Freda Sandstone. Fine-grained red and greenish arkose sandstone with a little conglomerate at top and bottom (about 8000 feet exposed)	12,000

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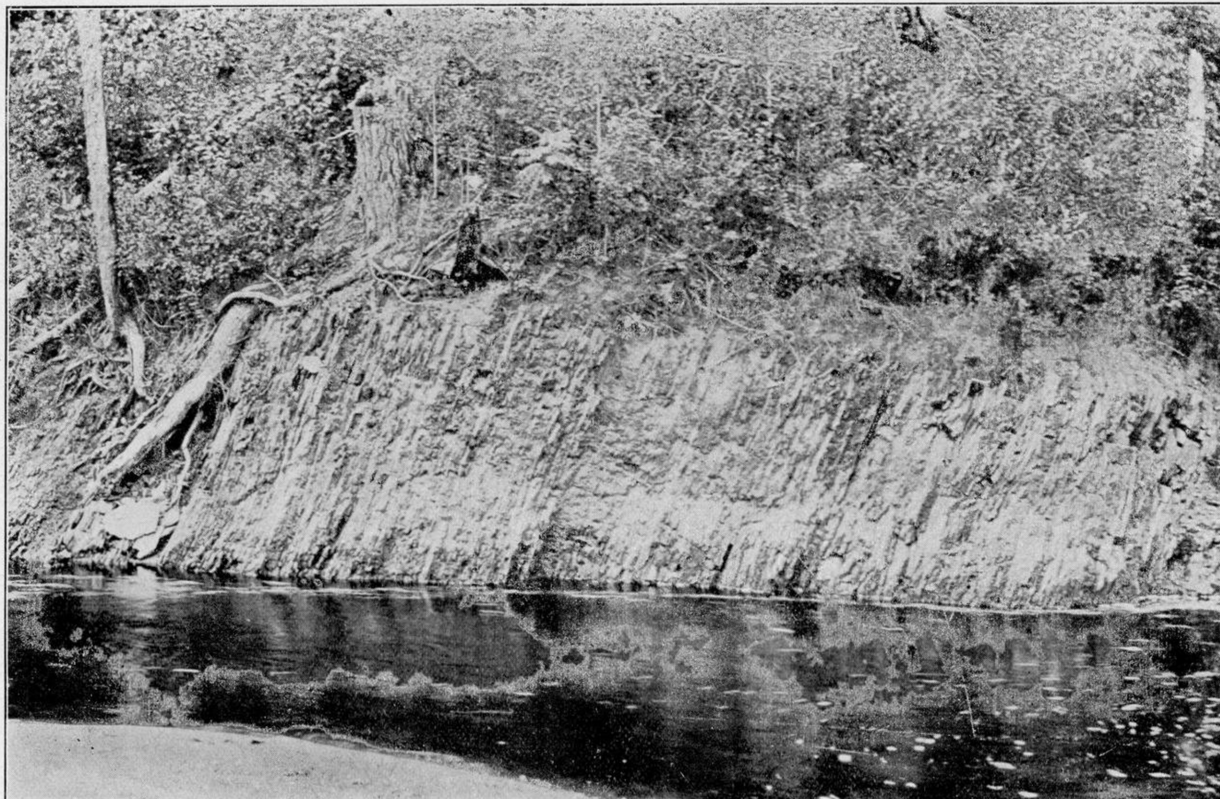
1 Lane, A. C., and Seaman, A. E., Geol. Section of Mich., Report of State Board of Geol. Survey of Mich., 1908, pp. 33, 38.

Personal communications.

2 Irving, R. D., Geol. of Wis., 1873-9, vol. III, p. 12.

—— Copper Bearing Rocks, Mon. U. S. G. S., vol. V, pp. 153-230.



Amnicon Formation—Middle River, near east end of exposure (see Plate XIII). The rock is hard, green, and red, very fine-grained sandstone, in beds varying in thickness from a foot to a fraction of an inch. The green phase is calcareous (see page 52, and Plate XVI A, p. 72). The bedding planes show abundant ripple marks of the symmetrical type, as well as mud cracks. These beds dip south at high angles and are shown by ripple marks to be overturned. (Grant, Bull. VI, Plate VI.)

Nonesuch Formation. Black, gray and red arkose and shale (maximum)	350
Outer Conglomerate, coarse conglomerate (maximum)	1,200
Total maximum thickness, about	21,550 feet

Composition. The rocks of the Oronto Group are mainly composed of angular to subangular fragments, derived from igneous rocks without much chemical decomposition. The only marked exceptions are some of the red clay shales. At the base in the Nonesuch formation, occur many layers of black sandstone composed of nearly unaltered fragments of trap, so thoroughly cemented with calcite that they are readily mistaken for igneous rocks. Higher in the group there appears a greater proportion of debris from quartzose rocks. In the conglomerates there is little difference in the source of the pebbles from those found in the Bayfield group. They comprise traps of many varieties (porphyries probably predominating), quartzite, iron formation, chert, vein quartz, slate, and granite. In the coarse arkose grits, fragments of igneous rocks of both basic and acid varieties are plainly seen, but these rocks were not studied in detail. In most of the group the grain is so fine that the microscope is needed to determine the material; and as no detailed study was made, information is available for only a few varieties of rock. This will be found under the head of local details, page 54. The component grains are mainly feldspars (both orthoclase and more basic varieties, the latter being often too much altered to determine), quartz, mica, magnetite, ferromagnesian minerals and fragments of fine-grained igneous rocks. On the whole, the grains are less rounded than those of the Bayfield group and although extremely variable, appear to average considerably smaller in size. Often a somewhat clayey reddish or greenish matrix is seen, perhaps derived from these fine-grained porphyries, from the decomposition of feldspar, or sometimes mainly composed of iron oxide. The cement is often calcium carbonate, but enlargements of the feldspar and quartz grains are probably the dominant cement. Red oxide of iron is also quite abundant.

An interesting rock which was examined is the greenish calcareous sandy shale of the Amnicon formation, found on Middle River (see p. 66, Plate VII, p. 50, and Plate XVI, A, p. 72). In the thin section, calcium carbonate was found to separate the very fine angular quartz grains, but on analysis this proved to be less than 20% of the rock. These ripple-marked and mud-cracked shales are interbedded with and merge into red noncalcareous shales and sandstone. Red spots also occur within the greenish rock and greenish within the red. It cannot be determined whether or not the calcium carbonate is original or has been introduced into the rock by underground waters from the adjacent traps.

The following chemical analyses are the only ones available for Wisconsin; unfortunately they mainly represent the Nonesuch formation, which is wholly composed of basic debris; none are typical of the great body of the group:

ANALYSES OF SANDSTONE OF THE ORONTO GROUP.[1]*

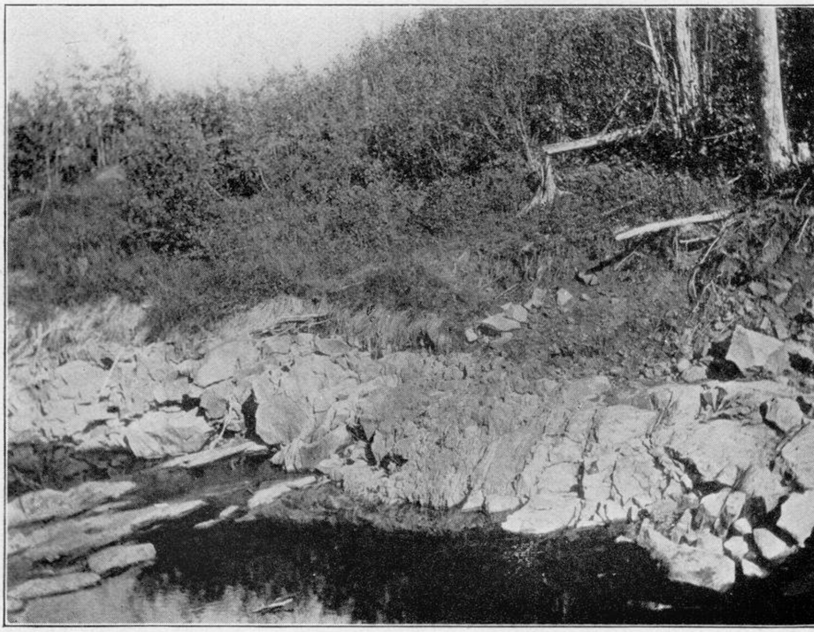
Locality.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2	Total
NONESUCH FORMATION									
Bad River	54.50	......	......	......	......	......	......	......	......
Bad River	49.14	......	......	......	......	......	......	......	......
Montreal River	55.91	......	......	......	......	......	......	......	......
Bad River (shale)	51.98	......	......	......	......	......	......	......	......
FREDA SANDSTONE									
Bad River	75.24	......	......	......	......	......	......	......	......
White River Falls	68.91	......	......	......	......	......	......	......	......
AMNICON FORMATION									
Bad River Falls	69.78	15.43	7.93	.49	1.17	2.64	2.42	......	99.86
Bad River Falls	72.14	......	......	......	......	......	......	......	......
Middle River	......	......	......	10.71	.12	......	......	8.55*	......

* Calculated.

[1] Geol. of Wis., 1873–9, vol. III, p. 203. Last by Victor Lehner, 1911.

EILEEN FORMATION, SOUTH FORK OF FISH CREEK, SEC. 19, T. 47, R. 5 W., TOWN OF EILEEN, BAYFIELD COUNTY.

A. Vertical beds of red and white streakel feldspathic sandstone, showing horizontal joints (see Plate X, B, p. 56). The strike is nearly east and west.



B. Vertical beds of red and white sandstone and sandy red shale. Looking southwest.

Bedding. The bedding of the Oronto Group varies from shaley to layers several feet in thickness (Plates VII, p. 50; VIII, p. 52, XI, p. 58; XVII, A, p. 74); but in general it is thinner and more regular than that of the Bayfield sandstones. However, the difference may in part be accounted for by the fact that the exposures of this group are smaller; and being of steeply-inclined layers, they expose to view less of the horizontal variability of the beds. A very striking feature of much of the group is the extremely rapid variations from very coarse grit or conglomerate to fine shale. Shale is very often interbedded with conglomerate through a considerable thickness of strata, the sharpness of contacts and scarcity of sandstone being remarkable (see pp. 62, 106). Cross-bedding is abundant, but usually small; no prevailing direction of dip was discerned. Curved beds are often met with, some being shown in Figs. 6,

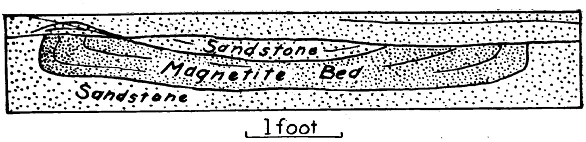


FIG. 6. Magnetite sand bed in Eileen sandstone, Fish Creek, Bayfield County.

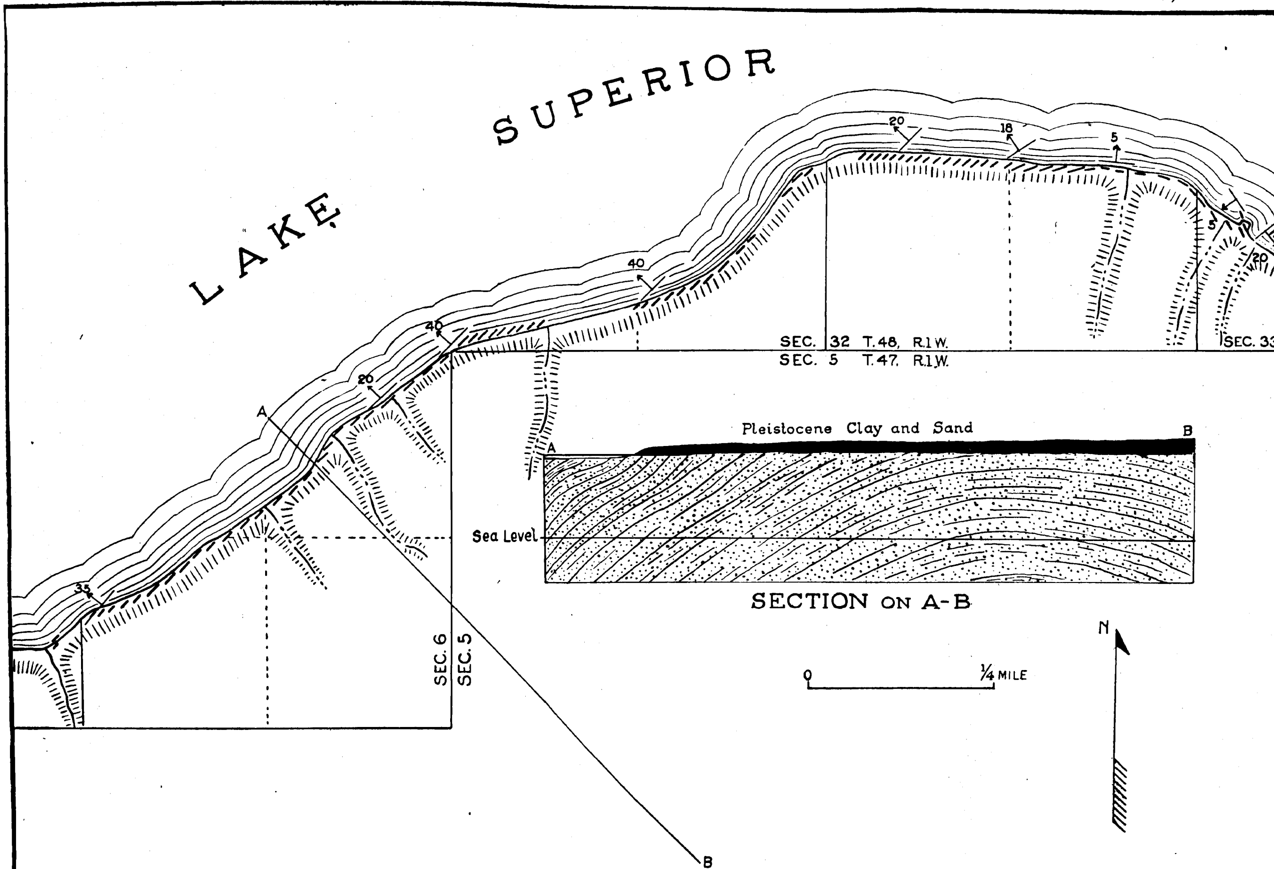
and 7, p. 55. Channels in the top of shale beds, filled with sandstone, are very common; an example is given in Fig. 9, p. 69. Ripple marks are very abundant, being mainly of the symmetrical type and rather small in size (see Fig. 4, p. 40). These occur in the finer grained rocks, especially shales, the surfaces being often greenish or red shale, or decidedly ferruginous sandstone. In some localities mud cracks are extremely abundant; but they are readily overlooked, for they do not show on weathered surfaces. This remark also applies to rain prints, which were observed at but one point. Frequently none of these features are of such character that they may be utilized to determine the top of the strata. In the case of mud cracks, the filling often adheres to the nearest hard sandy layer, whether it is above or below the original surface. When developed in typical form, cross-bedding is the most reliable guide to the structure (see Fig. 8, p. 63 and Plate XIc, B, p. 64). Clay pockets and scattered pebbles are not common. Most of the former are of the small flattened type and grade into small lenses of shale. Veins of calcite are abundant.

LOCAL DETAILS

Amnicon Formation. The top of the Amnicon formation may be observed on Fish Creek, near Ashland, and on Middle and St. Louis rivers in Douglas County. These interesting exposures and their correlation will be described in the succeeding chapter. Aside from these the highest known beds are those seen at the lower falls of Bad River, in sec. 25, T. 47, R. 3 W. About 750 feet of greenish and red coarse arkose sandstone, with interbedded red shales, are there exposed.[1] Microscopic examination shows that the rock is composed mainly of small fragments of porphyry, although the debris of basic rocks is also seen. This is confirmed by the chemical analysis on p. 52. In some beds considerable quartz is seen. The section is probably near the base of the formation.

Eileen Sandstone. In secs. 20 and 21, T. 47, R. 5 W., Town of Eileen, Bayfield County, the valley of the South Fork of Fish Creek exposes about 1800 feet of sandstone in vertical beds. The bedding varies from heavy to shaley with a little clay shale as shown in plate VIII, p. 52. The colors range from brick red, or occasionally even deeper shades, to clear white and show much mottling and banding of red and white. Beds composed almost exclusively of magnetite are also seen. Some are as much as eighteen inches in thickness but have only a slight lateral extent. Ripple marks, cross-bedded and irregularly bedded or domed beds occur, as shown in Figs. 6 and 7. Pebbles are not very common. Microscopic examination (Plate X, B, p. 56) shows that only a third of the rock is quartz. Feldspars (mainly orthoclase with some microcline and plagioclase, more or less altered), magnetite, mica, iron oxides, and rarely altered ferromagnesian minerals make up the larger portion of the rock. The grains are decidedly angular. as is usual in all the sandstones of the region. Were it not for the structural relations, however (see

[1] Irving, R. D., Geol. of Wis., 1873-9, vol. III, pp. 14, 202; Copper-Bearing Rocks, Mon. U. S. G. S., vol. V, p. 132. Irving states that 2000 feet of strata were then seen, but the writer was able to find but the one exposure, about three-eighths of a mile long. No map of the river is accurate.



Outcrop map of Clinton Point, Iron County. Most of the ledges shown on this map, are covered at high water. Those showing southeasterly dips can be seen only from the top of the bank, as they are in water several feet deep. The rocks are arkose sandstones and red shales, undoubtedly belonging to the Oronto group (see Plate X, A, p. 56), although once correlated with the Bayfield group.

section, p. 63, and structure sections on map) these rocks might be regarded as the lower part of the Orienta formation.

On the west side of Clinton (locally known as Marble, or sometimes Graveyard) Point, are low ledges dipping at a moderate angle to the northwest, exposing some 1,300 feet of fine-grained and somewhat shaley to heavily bedded sandstone (Plate IX, p. 54). In general character, it most resembles the last described beds and so is correlated with them. It is, however, not greatly different from the rocks exposed on Bad River (see p. 54). Ripple marks, cross-bedding and contorted

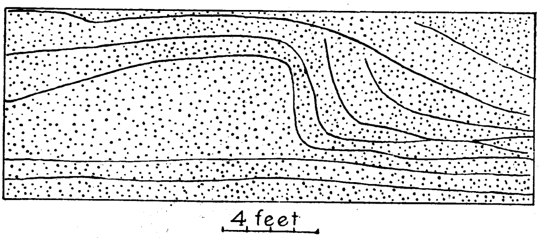


FIG. 7. Bedding in Eileen sandstone, Fish Creek, Bayfield County.

bedding, as well as indistinct mud cracks are observed. A thin section (Plate X, A, p. 56) from a representative phase shows not over a quarter of the rock to be quartz; the remainder is feldspar, about half orthoclase and half plagioclase, as well as ferromagnesian minerals and micas.[1] The minerals show considerable secondary enlargement. The cement is quartz, feldspar, and calcite. These rocks were formerly correlated erroneously with the Bayfield Group (see pp. 15, 18).

At Mason, in eastern Bayfield County, the well at the mill of the White River Lumber Co. penetrates, beneath 145 feet of drift, 650 feet of sandstone with occasional beds of red sandy shale, presumably belonging to the Eileen formation.

Freda Sandstone. Below the dam across White River, in sec. 6, T. 46, R. 4 W., is an exposure of some 300 feet of strata, as shown in Plate XI, B, p. 58. This rock consists of coarse, red and greenish arkose alternating in rather thin beds, with red

[1] Irving, R. D., Geol. of Wis., 1873–9, vol. III, pp. 16, 209. Copper-Bearing Rocks, Mon. U. S. G. S., vol. V, p. 366.

Lane, A. C., and Seaman, A. E., Geol. Section of Michigan, Report State Board of Geol Survey of Mich., 1908, p. 33.

and green micaceous shales. Some poorly developed ripple marks and mud cracks were observed. Lithologically, this section might be assigned either to the horizon of the Bad River rocks, or to the top of the Amnicon formation, as seen on Fish Creek five miles to the north (see p. 62); but on structural grounds (see section E-F on general map) it is simpler to assume that it lies at the top of the Freda sandstone, in the gap between the Oronto Bay and Fish Creek sections (see p. 50)[1]

In the valleys of the streams that flow into Oronto Bay, in Iron County, occur numerous excellent exposures of the Freda sandstone (Plate XI, A, p. 58). The prevailing rock is red, fine grained arkose. Some thin greenish beds occur. There are also numerous beds, usually rather thin, of markedly micaceous red shale. Toward the base of the formation, the grain becomes coarser, and there is found a 100-foot layer of conglomerate. The exposures represent a thickness of over 12,000 feet, but they are separated into two groups, with an unexposed interval of some 4,000 to 5,000 feet of stratigraphic thickness. As assumed in the case of the other interval of no outcrops, it is most probable that the lack of exposures is due to the softness of the rock (see p. 21). Microscopic examination[2] shows that less than a fourth of the rock is quartz, the bulk being feldspars and fragments of porphyries and basic eruptives with reddish decomposition products, micas, ferromagnesian minerals, and magnetite. The cement is usually red oxide of iron,[3] but in some cases it is calcium carbonate, and to some extent quartz. The quartzes and feldspars show secondary enlargements.

The Freda sandstone is also exposed on Potato River, within the area of the map, but this locality was not visited by the writer.[4]

Nonesuch Formation. Exposures of the Nonesuch formation of the Oronto group occur on the Montreal, Oronto, and

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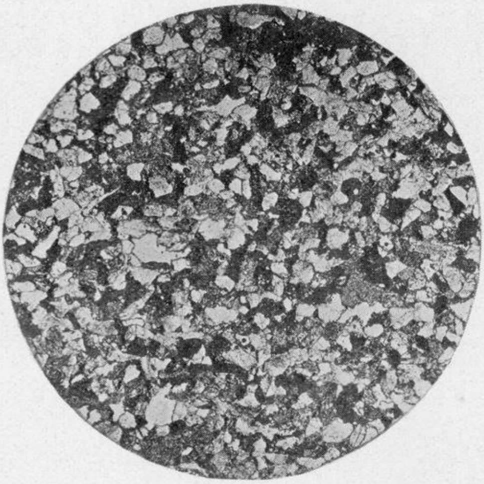
1 Irving, R. D., Geol. of Wis., 1873–9, vol. III, pp. 14, 202.

2 Irving, R. D., and Chamberlin, T. C., Observations on the Junction between the Eastern Sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, U. S. G. S. Bull. 23, 1885, p. 82.

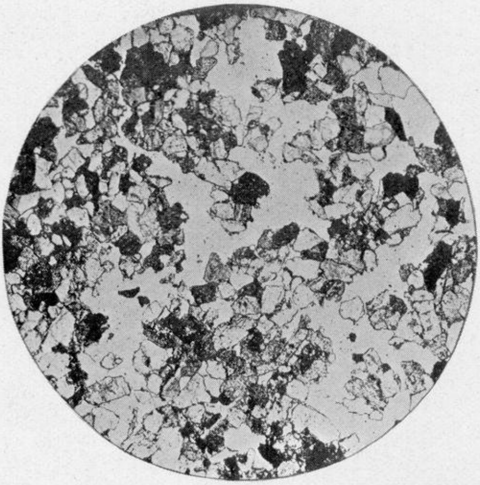
3 Irving, R. D., Geol. of Wis., 1873–9, vol. III, pp. 12, 199. Copper Bearing Rocks, Mon. U. S. G. S., Vol. V, pp. 133, 226.

4 Irving, R. D., Geol. of Wis., 1873–9, vol. III, pp. 188, 202.

PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS.



A. Fine-grained arkose sandstone from Clinton Point, Iron County (specimen 11,124). The grains run from .1 to .3 mm. in diameter. About 25 per cent are quartz. The remainder is about half orthoclase, the other half being microcline, plagioclase, ferromagnesian minerals, mica, and iron oxide. Calcite is in some places seen forming a cement. Most of the cementation is, however, due to enlargements of the quartz and feldspar grains. This section should be compared with those of the Bayfield group shown in Plates III, p. 26, and VI, p. 44, the rock having formerly been placed in that group.



B. Medium-grained red sandstone from Eileen formation on South Fork of Fish Creek, Bayfield County (specimen 11,369). This rock differs mainly from A, in the size of grains, which average nearly .3 mm. About a third of the rock is quartz, the remainder being mainly orthoclase. Some plagioclase, micas, and ferromagnesian minerals are found. The large white areas are holes in the section.

Potato rivers. This member is composed of red, gray and black arkose and shale, often with calcareous cement. Microscopic examination shows that the rocks are composed of virtually unaltered debris of basic eruptives. The thickness on Montreal River is about 350 feet, lessening rapidly to the west.[1]

Outer Conglomerate. Beneath the Nonesuch shale is found the great Outer Conglomerate, which is 1,200 feet thick on Montreal River, but thins to only 800 feet on the Potato. On the former stream, it outcrops in magnificent cliffs over 200 feet in height. The conglomerate is composed of pebbles averaging four or five inches in diameter—some measure fifteen inches or more. They are from the diabase, porphyry, gabbro, and other rocks of the Middle Keweenawan series, with subordinate amounts of Huronian quartzite, iron formation, slate, and chert, as well as granite and vein quartz, probably derived mainly from the Archean. There is practically no matrix of sand, and the bedding is only apparent where there are thin layers of coarse arkose sandstone. As in the higher beds, calcite veins are common.[2]

OLDER FORMATIONS

The Traps. Beneath the base of the Outer Conglomerate is found a great series of interbedded traps, conglomerate, sandstone, and shale. This reaches a thickness of some 1,200 feet on the Montreal, but to the southwest thins out to nothing within a few miles. Below this occur the traps of the Middle Keweenawan, including both extrusive and intrusive rocks. These rocks also occur in the Douglas Range.[3]

The Pre-Keweenawan Rocks. Still farther to the southeast, the Huronian sediments are found in a position stratigraphically below the eastern traps; and then in turn the older Archean granites, schists, and greenstones (see p. 7).

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1 Irving, R. D., Geol. of Wis., 1873–9, vol. III, p. 200. Copper Bearing Rocks, Mon. U. S. G. S., vol. V, 1883, pp. 133–226.

2 Irving, R. D., Geol. of Wis., 1873–9, vol. III, pp. 12, 202.

3 In S. E. ¼ of N. E. ¼ sec. 19, T. 47, R. 4 W., near Ashland, a huge mass of trap 60 feet across rises from the clay plain. As no rock is found in neighboring wells, the writer believes that this is simply an enormous boulder, and not an outcrop as believed by some.

Economic Products. So far as known, no products of economic value are found in the Oronto group. In contrast to the earlier sedimentary series of the Lake Superior region, it contains no iron formation. Thin lenses of nearly pure magnetite occur in places, especially along Fish Creek; but they are hardly greater in amount than the magnetitic sands of the modern lake beaches, or the drift. Most of the rock, with the possible exception of parts of the Eileen sandstone on Fish Creek is entirely unsuited for building stone. Occasionally, however, some of the red shale has been used for paint rock. Traces of copper and silver have been found in the Nonesuch formation,[1] but no concentration of these minerals or the abundant ferric oxide is known to have taken place in Wisconsin.

The rocks of the Oronto group carry little water and such little as is found is often salty (see pp. 66, 73, 102).

The Extension of the Sandstone Groups into Minnesota. The Bayfield and underlying Oronto groups of sandstones extend into Minnesota, as shown by Hall[2], between the continuation of the Douglas Trap Range to the southeast and the Huronian and Archean rocks to the northwest. The drift is so thick along this narrow strip, however, that the actual continuity with the Paleozoic sediments to the south is somewhat doubtful.[3] Nevertheless, a brief discussion of this question is not out of place.

Most of the rock exposed in this belt is a well indurated, rather fine to medium grained, quartz sandstone pinkish to yellow or gray in color. This, the rock of the well known quarries of the Kettle River region, is much like the sandstones found near the falls of Black River in Douglas County[4] (see p. 45).

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1 Irving, R. D., Geol. of Wis., 1873–9, vol. III, p. 206.

2 Hall, C. W., Keweenawan Area of Eastern Minn., Bull. Geol. Soc. America, vol. XII, 1908, p. 313.

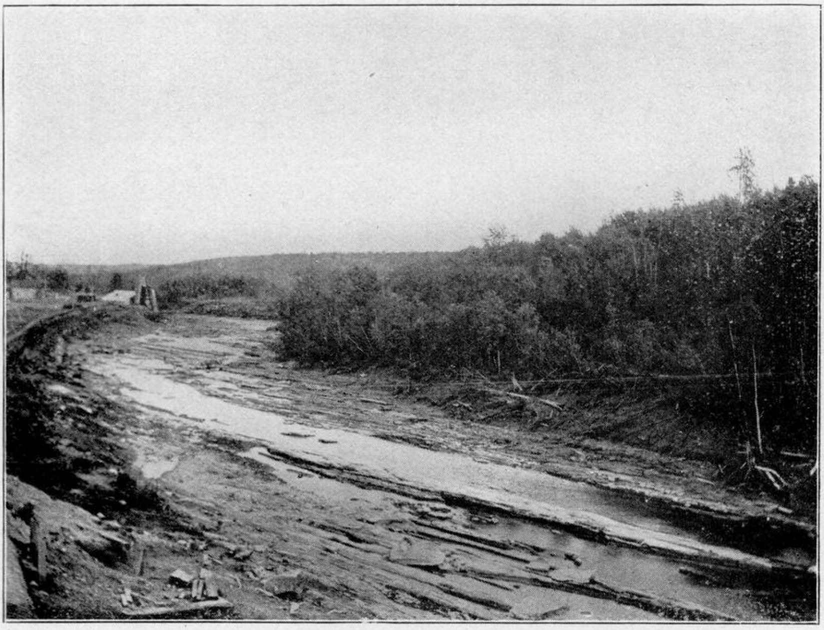
3 Grout, F. F., personal communications.

4 Grout, F. F., personal communications.

Weidman, S., personal communications.

It may not be too great a stretch of the imagination to suggest that these light colored rocks may be equivalent to the Devils Island sandstone of the Apostle Islands.

A. Red and greenish arkose sandstone and shale of Freda sandstone, on east bank at mouth of Oronto River, Iron County.



B. Red and green shale and arkose grit of Freda formation, below dam of White River electric plant, Sec. 6, T. 46, R. 4 W., Ashland County. The northeasterly strike is plainly indicated by the outcropping ridges; the dip is 25 degrees to the southeast, away from the observer.

Still farther to the south and southeast, in the valley of the St. Croix River, appear flat-lying, yellowish or pinkish quartz sandstones, bearing fossils of Upper Cambrian age. These rocks (the Potsdam sandstone of Wisconsin) rest with pronounced unconformity upon both the tilted traps of Keweenawan age and the older Pre-Cambrian rocks. The known Cambrian rocks are separated from those of the Kettle River district by a considerable drift-covered interval, probably underlain largely by trap and granite, as well as by the great fault of the Douglas Range which is known to extend far into Minnesota, forming the northwestern border of the traps.[1]

In many places deep drilling has shown that the Potsdam rests upon a great thickness of red clastic rocks. These red rocks fill a great depression in the surface of the Pre-Cambrian crystalline rocks.[2] The thickness of these red rocks varies from nearly 2,500 feet in the center of the basin down to nothing at both sides of the trough and to the south, where the Potsdam rests directly upon the Pre-Cambrian igneous and metamorphic rocks. But few wells have penetrated the entire thickness of the red clastic series near the center of the basin. At Minneapolis they are found to rest upon granitic rock, while at Stillwater, apparently at the center of the trough, Keweenawan diabase lies beneath (see p. 60).

The red series is studied with difficulty as it is not known to reach the surface. The only information is derived from churn drill records and is hence rather unsatisfactory. N. H. Winchell[3] believed they were a conformable connection of the Cambrian with the Keweenawan. More recently C. W. Hall restudied the question, reaching the same conclusion (see p. 20).[4]

The red clastic series consists of red shale and sandstone while some fragmental volcanic rocks are thought to exist. The sand-

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1 Hall, C. W., Keweenawan Area of Eastern Minn., Bull. Geol. Soc. America, vol. XII, 1901, p. 313.

2 Hall, C. W., Meinzer, O. E. and Fuller, M. L., Geology and Underground Waters of Southern Minnesota, U. S. G. S. Water Supply Paper 256, 1911, pp. 32, 48.

3 Winchell, N. H., Geol. of Minn., vol. I, 1882, pp. 422, 424, 537.

4 Hall, C. W., The Red Sandstone Series of S. E. Minn. Unpublished manuscript not available. Abstract, Science, vol. 27, 1908, p. 722.

stone is mainly composed of quartz grains, but much of it contains more or less feldspar and is very frequently calcareous. It is not always red, for occasionally white sand is reported.

The following record of the well at Stillwater gives a good idea of the lithologic character of the series:

LOG OF STILLWELL DEEP WELL [1]

		Thickness
Pleistocene		
Glacial drift		18 feet
Cambrian		
Mendota limestone		85
Potsdam sandstone; calcareous sandstone of gray to yellowish color and some gray shale		592
Upper Keweenawan		
Dark red, sandy calcareous shale	13	
Coarse quartz sandstone	5	
Fine dark red calcareous shale	11	
Fine dark red calcareous sandstone with some calcite and pink feldspar grains	2233	2262
Middle Keweenawan		
Diabase		450
Depth of Well		3447 feet

In general, these rocks are exactly like those of the Upper Keweenawan series of the Lake Superior basin, whose continuation they must be; while beyond doubt the basin in which they lie is part of the Lake Superior syncline which passes up Chequamegon Bay. and thence southeasterly across Wisconsin (see p. 88). The portion in southeastern Minnesota is probably everywhere separated by the traps of the north side of the basin, from the belt northwest of the fault in which lies the lighter colored

[1] Hall, C. W., Meinzer, O. E. and Fuller, M. L., Geology and Underground Waters of Southern Minnesota, U. S. G. S. Water Supply Paper 256, 1911, p. 366.

Meads, A. D., The Stillwater Deep Well. Bull. Minn. Acad. Nat. Sci., vol. III, No. 2, 1891, pp. 274–7.

Winchell, N. H., Natural Gas in Minnesota. Minn. Geol. and Nat. Hist. Survey, Bull. V, 1889, p. 25.

sandstones of the Kettle River region. A connection west of the fault, through the heavily drift-covered region of Anoka County, Minnesota, is nevertheless possible.

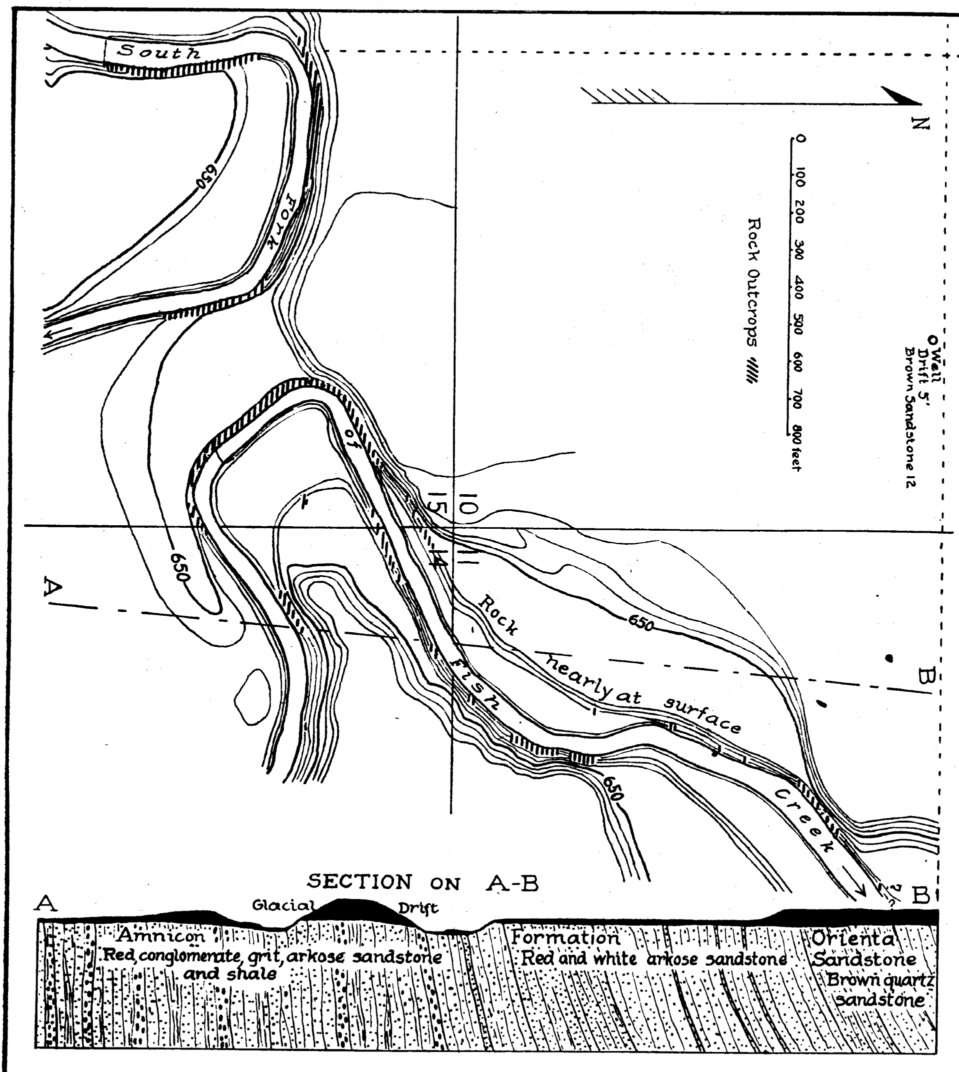
Whether or not these buried red rocks are conformable beneath the Upper Cambrian marine sediments is a question beyond the scope of the present report. On the whole, the ocurrence of the red series in a basin, overlapped on both sides by the overlying horizontal sediments which rest with pronounced unconformity upon the tilted Keweenawan traps, favors the view that an unconformity also exists between the sandstones (see p. 103). Such an unconformity probably could not be recognized in the records of churn drill holes.

CHAPTER V

THE RELATION OF THE BAYFIELD AND ORONTO SANDSTONE GROUPS

General Statement. The study of the relation of the Oronto and Bayfield groups of sandstones was the principal object of the present investigation. Outcrops are so scarce that we can at no place trace the two sandstone groups to a point of contact where their relations may be absolutely determined. But it is possible to find exposures at points where we should expect to to find the contact of the Bayfield and Oronto groups. At all of these localities there is a conformable gradation from quartz sandstone of the general type of the Bayfield group downward into red shales, and arkose sandstone or conglomerate of the same general type as the main body of the Oronto group. Sections showing this general stratigraphic succession are found on the south fork of Fish Creek, near Ashland, not far from the main area of the Oronto group, in the deep well at Ashland, on Middle and St. Louis rivers in Douglas County, and in deep wells in Superior. This widespread stratigraphic sequence shows a gradation between the two general types of sandstone formations and is believed to indicate that the Bayfield and Oronto groups are conformable.

Fish Creek. Beginning at the east, there is found an exposure of the supposed base of the Bayfield group, in the town of Eileen, near Ashland Junction, in eastern Bayfield County. Here the valley of the South Fork of Fish Creek exposes rock in sections 11, 14, and 15, T. 47, R. 5 W. These exposures have never been described previous to the present study. The beds are ver-



Plane-table map (10-foot contours) of rock exposures on South Fork of Fish Creek, Secs. 11, 14, and 15, T. 47, R. 5 W., Town of Eileen, Bayfield County. The exposures are thought to represent a conformable gradation from the red conglomerates and arkose sandstones of the Amnicon Formation of the Oronto group, to the brownish quartzose sandstones of the Orienta sandstone of the Bayfield group.

tical or inclined steeply to the north, decreasing from 90° at the south to 70° at the north end of the section, while the strike is approximately east and west (see p. 93). (See Plates XI b, p. 62, and XI c, p. 64). The following section is based upon a chained

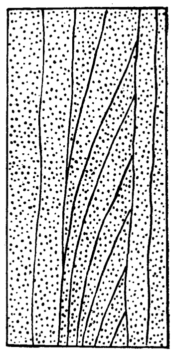


FIG. 8. Diagram showing the use of cross-bedding, in determining top of vertical strata. The top is to the right.

plane table survey made by the writer in 1912, as shown in Plate XI a. The thickness are therefore accurate. Although the exposures are not continuous, the rock is everywhere so near the surface that abundant fragments permit the general character of the strata to be determined.

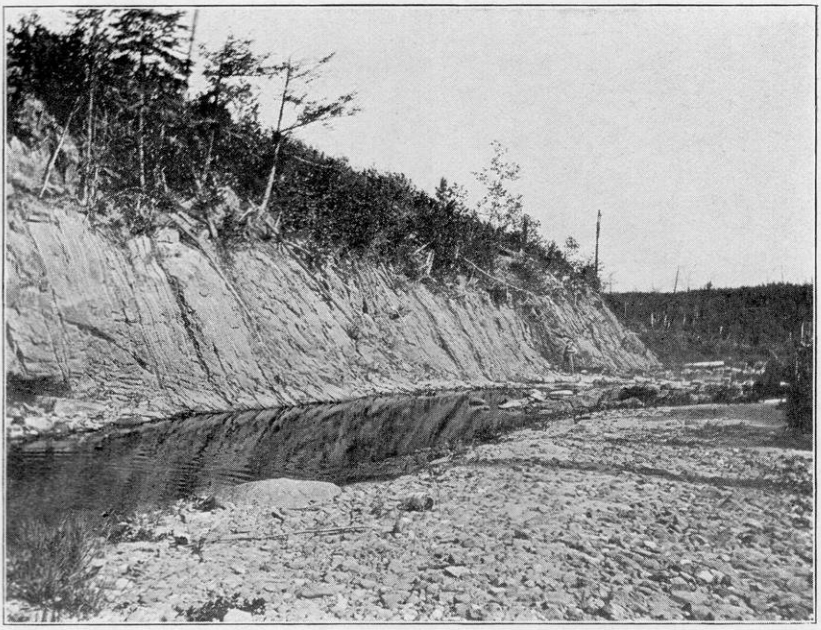
SECTION ON SOUTH FORK OF FISH CREEK, BAYFIELD COUNTY

Bayfield Group: Orienta Sandstone.	*Thickness* Feet.
14. Heavy to thin-bedded medium grained brown quartz sandstone, often cross bedded. This rock is of the typical Bayfield type, being apparently *nearly all quartz*, but with some mica flakes and feldspar grains. Is pebbly in places	50
13. Red and white spotted, thin to medium bedded and cross bedded quartzose sandstone. A thin section (Plate XII, p. 66) shows that *three quarters of the rock is quartz*, the remainder being mainly orthoclase	75
12. *Unexposed*, but shows abundant fragments of red grit and coarse red and white sandstone	150
11. Red grit in small ledge	5
10. *Unexposed*, but shows fragments as before . .	65

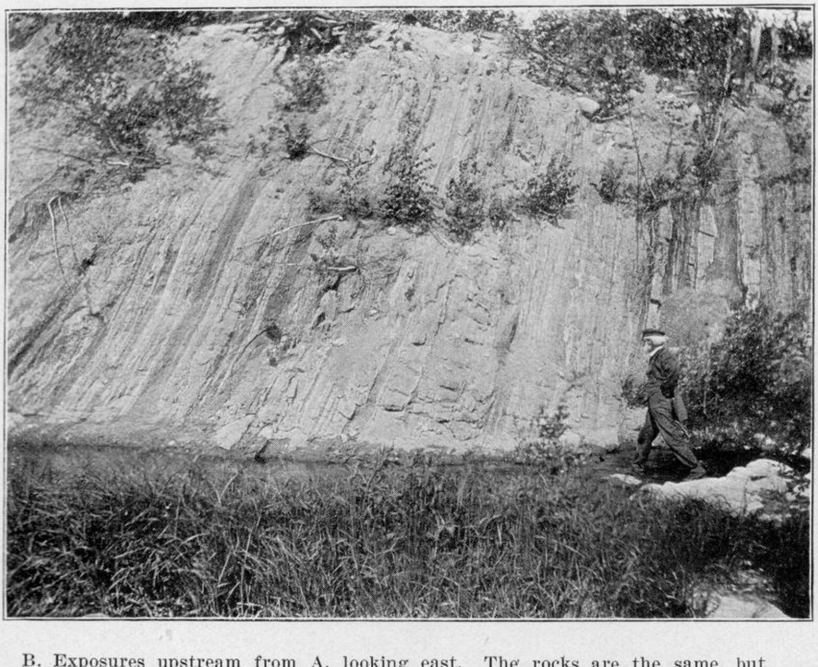
9. Red grit in place	5
8. *Unexposed*, but shows fragments as before	130
7. Red grit and red and white sandstone	10
6. *Unexposed*, but shows fragments as before	190
5. Medium to heavily bedded coarse brownish red and white (often in spots) sandstone with red and greenish shaley partings and some red grit. A thin section from the coarse sandstone, with minute layers and pockets of shale, shows that it is not greatly different from the higher strata. Most of the feldspar is orthoclase but some microline, plagioclase, and mica are seen. Most of the section (Specimen 11401) is red shale composed of fine grains of quartz cemented by iron oxide and the decomposition products of feldspars, etc. A thin section (Plate XII, B) from the coarse white sandstone shows that *less than half the rock is quartz*. The grains are angular and vary from 2. mm to below .25 mm in diameter. Mica is abundant	230
4. *Unexposed*, but shows fragments of rock like the last	100
3. Thin to medium bedded shaley to gritty red and white sandstone	15
2. *Unexposed*, but shows fragments like the adjacent rocks	85
Oronto Group: Amnicon Formation.	
1. Coarse red and white spotted arkose grit. Conglomerate with pebbles seldom over 3 inches in diameter of trap, vein quartz, quartzite, slate, iron formation, and chert. The beds vary from a foot to 15 feet in thickness with subordinate layers of coarse arkose sandstone and red and greenish shales. There is some cross bedding (see Plates XIb, XIc)	1,050
Total thickness	2,160

An unexposed interval of nearly 5,000 feet separates this section from the outcrop of the Eileen sandstone in Secs. 20 and 21.

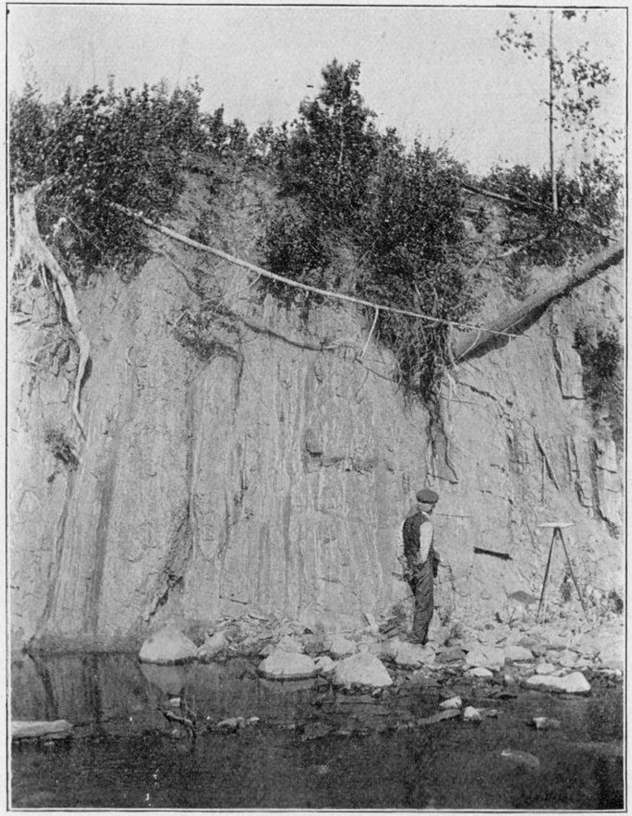
This section is quite important, since it throws new light on the structural relations of the sandstone groups. It is but five miles from the area of rocks undoubtedly belonging to the Oronto group. The lowermost beds of this section are as highly tilted as any of the recognzied Oronto group, and match it ex-



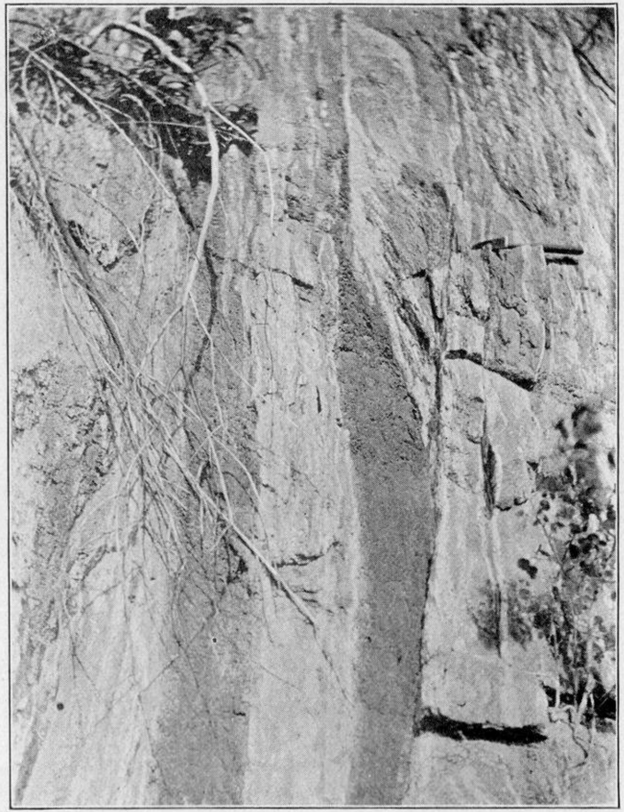
A. General view, looking southeast, on South Fork of Fish Creek, NE ¼ of NE ¼, Sec. 15, T. 47, R. 5 W., Bayfield County. The rocks are red conglomerate and grit, with some red shale, and are correlated with the Amnicon formation. The dip is to the north and varies from 70° to 90°, while the strike averages N. 85° W.



B. Exposures upstream from A, looking east. The rocks are the same, but with more layers of red shale.



A. Vertical beds of Amnicon Formation, on South Fork of Fish Creek, Bayfield County. The rock is conglomerate and grit, red in color, but with some streaks and spots of white. There are also partings of red shale.



B. Cross-bedding in red and white grit, near the place shown in A. By means of cross-bedding, it may be determined which was the top side when the strata were still horizontal. In this case it may clearly be seen that the cross-bedded layers merge into the others at the right or south side, while they are sharply cut off by the layer at the left. This shows that the left or north side was uppermost before folding.

actly in lithologic character. The anticline of which they form part of the north limb involves at least 8,000 feet of strata. This fold must belong to the general system of Keweenawan folds (see p. 95), since there is no known subsequent period of deformation with which it could be correlated. The correlation of the lower horizons of the Fish Creek section with the Oronto group seems therefore to be very well established.

The correlation of the upper quartzose beds with the Bayfield group is much less definite. A drift-covered interval of about three and one-half miles exists between the most northerly exposure on Fish Creek and the outcrops of the Chequamegon sandstone on Wayman Point. This belt was carefully explored but no exposures could be discovered, and the inhabitants of the region unite in saying that none exist. The evidence on which the upper layers are correlated with the base of the Orienta sandstone depends on three factors:

1. The lithologic likeness is complete and can be better appreciated in the field than in a description. The bedding is also characteristic of the upper group, being frequently very heavy, but giving way rapidly to thin cross-bedded layers.

2. The dip of the beds decreases towards the north end of the section, thus indicating a probable flattening out of the beds to the north (see structure section E-F, on map).

3. The deep well at Ashland encounters a very similar succession of beds to that shown in the section on Fish Creek, and indicates a pronounced flattening of the beds to the north.

Ashland Well. At the plant of the Lake Superior Iron and Chemical Company in Ashland three miles to the northeast of Fish Creek, is a well 3,095 feet in depth. Although not situated in direct line between the most northerly exposure on Fish Creek and the nearest exposures on the northwest shore of Chequamegon Bay, nevertheless if the position of the well is projected parallel to the probable strike of the rocks, it will be found to occupy a position well to the north of the Fish Creek exposures, thus serving very well to fill in the unexposed interval. If the red shales there encountered represent even approximately the horizon of those seen on Fish Creek, from which they differ only in lacking the conglomerate beds, a flattening out of the beds toward the north is indicated (see structure section E-F). While it cannot be positively stated that any of the beds encountered in the well belong to the Bayfield group, it is nevertheless shown that the usual stratigraphic succession of sandstone grading down into red shales is here found.

LOG OF "JUMBO" WELL AT ASHLAND

Drilled in 1889 at works of Lake Superior Iron and Chemical Company, near west ¼ post of Sec. 5, T. 47, R. 4 W. Elevation of curb, 660 ft. A. T. Record from original log, furnished by Mr. J. E. Johnson, Jr., manager, 1910.

	Thickness Feet	*Depth* Feet
Pleistocene:		
Red clay	40	
Till with boulders	43	
Red sand	92	175
Bayfield Group: Orienta Sandstone.		
Principally fine grained sandstone of red color with few white beds, and bands of red shale from one to ten feet thick. A soft stratum 30 feet thick, 825 feet from the top, furnishes most of the water. The flow did not increase below it. The water is said to be salty	2,495	2,670
Oronto Group: Amnicon Formation.		
Red shale	425	3,905
Depth of well	3,095	3,095

Middle River. On Middle River, in eastern Douglas County, occurs perhaps the most interesting exposure in the entire district. Here over 3.000 feet of strata are exposed in a great overturned fold. The structure of the locality is shown in Plate XIII, p. 66, which is based on a paced survey made by Grant in 1899.[1] (See also Plate VII, p. 50; Plate XVII, B. p. 74; and Plate XXI, 90).

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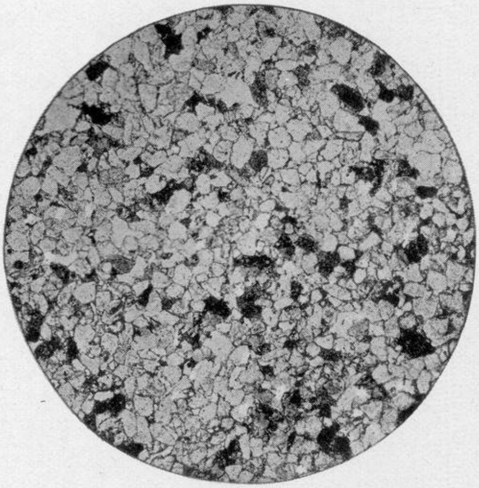
[1] Grant, U. S., Copper-Bearing Rocks of Douglas County, Wis. Geol. and Nat. Hist., Survey, Bull. VI, 1900, pp. 18, 20.

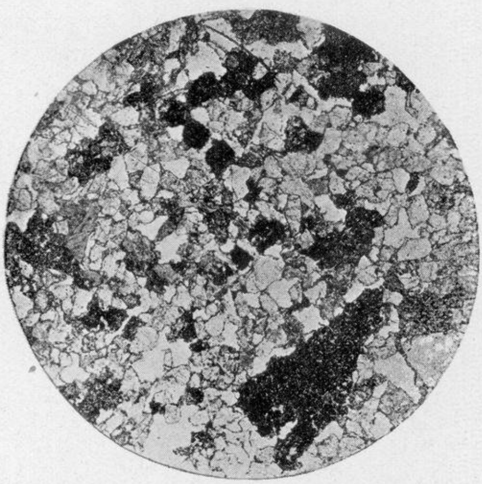
Personal communications.

Sweet, E. T., Geol. of Wis., 1873–9, vol. III, p. 347.

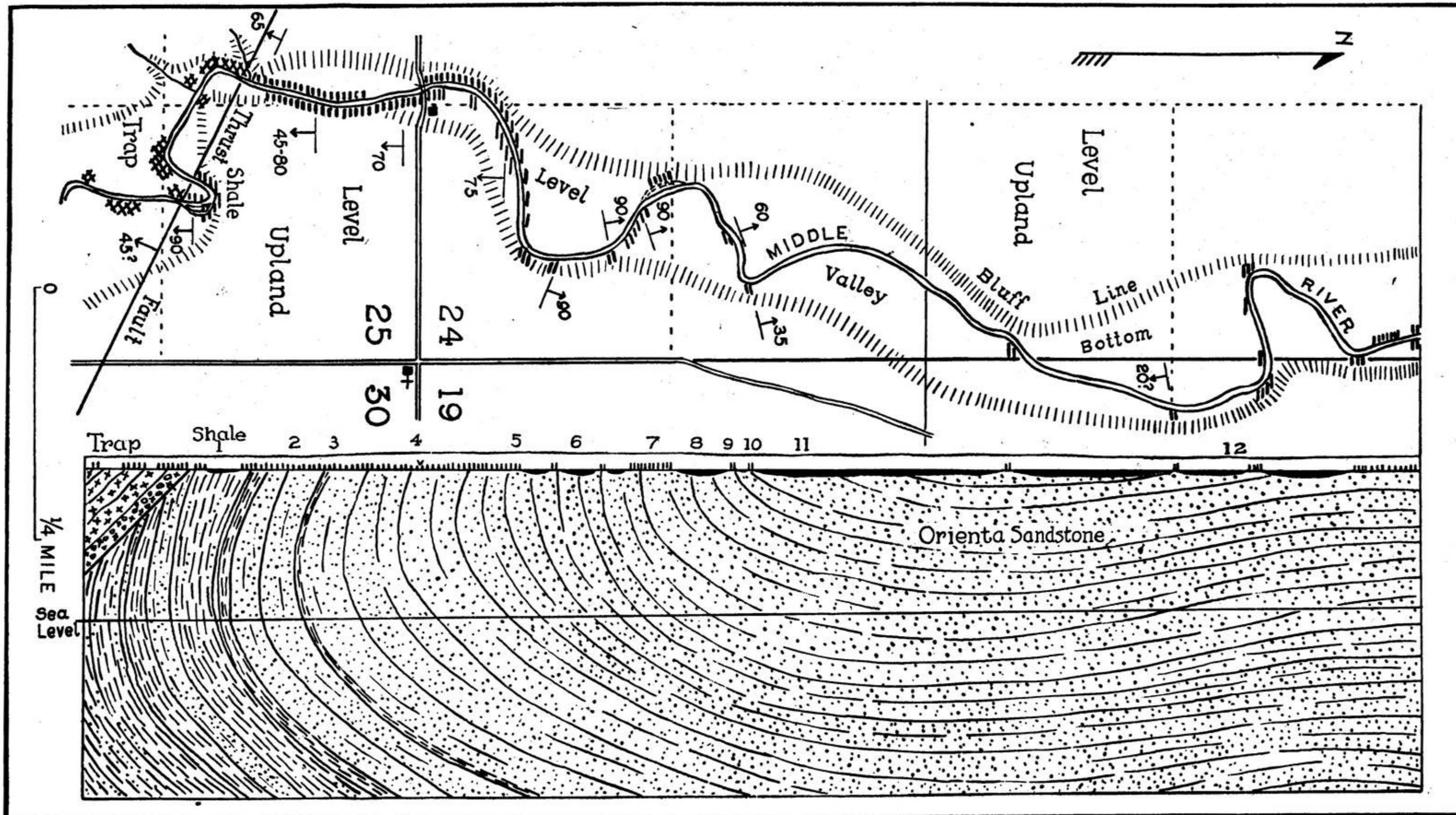
PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS.



A. Medium-grained feldspathic sandstone (specimen 11,404), from South Fork of Fish Creek, Sec. 11, T. 47, R. 5 W., Bayfield County. Average diameter of grains .35 mm. Seventy per cent of the rock is quartz, the remainder being feldspars (mainly orthoclase, but some microcline) and iron oxide. The cement is quartz. It should be noted that the rock does not differ greatly from those of the Bayfield group, Plates III, p. 26, and VI, p. 44.



B. Coarse-grained white arkose sandstone (specimen 11,397), from a lower horizon than A. The average size of the grains is .5 mm, but the largest (of microcline) is 2.0 mm. long. Quartz makes up half of the rock; the remainder is mainly orthoclase, but there is much plagioclase; little iron oxide is present. The coarseness and angularity of the grains, as well as the greater proportion of feldspar, should be compared with A.



Outcrop map of part of Middle River, Douglas County, based on survey by U. S. Grant, 1899; structure section by F. T. Thwaites, 1910. Ripple marks show that the south-dipping layers are overturned. The numbers are those of the different beds in the section given on p. 67. The lower bed (1) is believed to belong to the Amnicon formation of the Oronto group. A conformable contact between the Bayfield and Oronto groups is thus indicated.

SECTION ON MIDDLE RIVER, DOUGLAS COUNTY

	Thickness Feet
Orienta Sandstone.	
12. Horizontal thick-bedded light pinkish brown sandstone; grains are of medium size and appear to be *mainly quartz.* The banding with red and white (see p. 31) often gives the impression of folds. Estimated thickness	225
11. *Unexposed,* but showing fragments of thick-bedded brown sandstone	100
10. Thin-bedded reddish sandstone apparently *containing a larger proportion of feldspar.* Dips 35° N.	50
9. Coarse white sandstone with pebbles of trap and quartz; some is very calcareous (Spec. 11243) Dips 60° N.	50
8 *Unexposed,* probably contains the Copper Creek beds	300
7. Medium to coarse grained pebbly, brown sandstone; beds very heavy and hard to make out, but appear to be vertical. Shows iron banding. It may correspond to the brownstone of Amnicon River (see p. 43). Grains of feldspar and mica are apparent to the unaided eye. Under the microscope (Specimen 11240), it is seen that these constitute not over a quarter of the rock, the remainder being quartz. Microcline and plagioclase are distinguishable, although most of the feldspar is orthoclase. Biotite is also seen	250
6. *Unexposed*	200
5. Fine grained red sandstone, apparently containing more feldspar and mica than higher beds; coarse, soft, brown sandstone; reddish, medium-grained, more feldspathic sandstone in vertical beds. The coarser rock was examined microscopically (Plate XIV, A, p. 68) and found to be *over two-thirds quartz.* The subangular grains average .35 mm. diameter. Some large microcline fragments were discovered. It is not notably different from the brownstone at Port Wing (see p. 42 and Plate VI, A, p. 44). The cement is alteration products derived from the feldspars	250

4. Medium to fine-grained pinkish or brownish sandstone with frequent greenish bands and spots. Pebbles and clay pockets are not common. Some beds are cross-bedded or show curious curved forms; most are in heavy layers making the stratification difficult to determine (see Plates XVII, B, p. 74 and XXI, p. 90). Towards the base a few thin layers of red shale occur. Two thin sections from the top and bottom of the horizon were examined (Specimens 11233 and 11235). The grains average less than .3 mm. in diameter and are slightly more angular than in higher strata. *Quartz constitutes from a third to a half of the material.* The remainder is almost wholly much altered feldspar, mainly orthoclase. Occasionally microcline is seen, as well as a few altered ferromagnesian minerals and mica. The cement appears to be quartz and feldspar enlargements, with some iron oxide . . . 1,000

3. Red shale, dips about 70° S. 10

2. Fine-grained thin-bedded hard red and greenish gray spotted sandstone. Dip varies from 45° S. to 80° S. Under the microscope this is seen to be little different from the lower part of the bed above (Plate XIV, B, opposite). *Less than half is quartz.* The grains average about .25 mm. diameter and are cemented by quartz and feldspar. Microcline and plagioclase may be distinguished in the feldspars but most of them are much altered, generally to kaolin. Ferromagnesian minerals and mica can also be seen 275

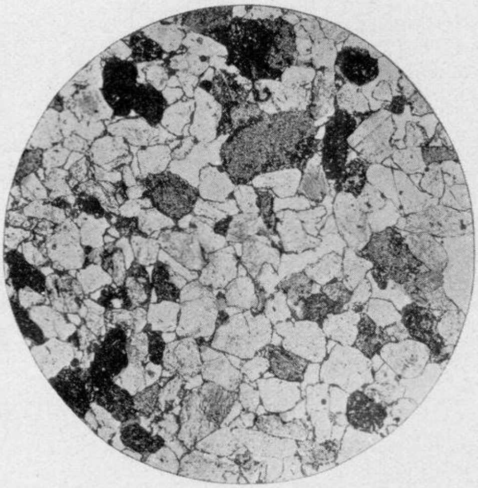
Total thickness of Orienta sandstone 2,735

Amnicon Formation.

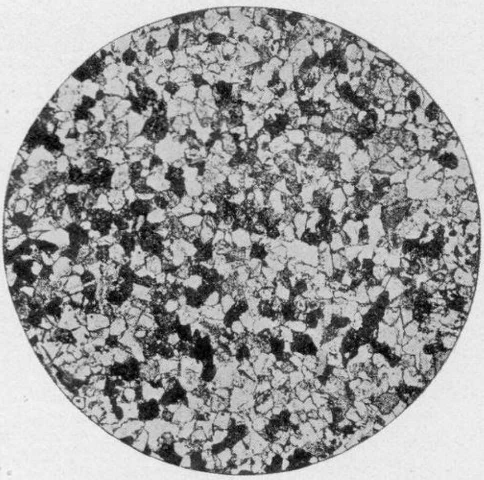
1. Purplish red and light-greenish-gray very fine-grained sandstone to sandy shale, in beds seldom over an inch thick. Dip varies from 60° S. to vertical. Ripple marks and mud cracks are decidedly abundant. There is scarcely any cross bedding. In but one place were found ripple marks by which the inversion of the strata could be demonstrated[1] (see

[1] Most of the ripple marks are of the symetrical indeterminate type.

PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS.



A. Coarse friable brownstone (specimen 11,236) from bed 5, Middle River, Douglas County. The grains are fairly well rounded as compared with the older sandstones, and average about .35 mm. in diameter. The rock is over two-thirds quartz. The remainder is, as usual, feldspar, in which some large microcline fragments are conspicuous. The cement is composed of alteration products from the feldspars.



B. Fine-grained pink feldspathic sandstone (specimen 11,232) from bed 2. The grains are somewhat more angular than in A, and average .25 mm. in diameter. Less than half of the rock is quartz. Most of the feldspar is orthoclase, but microcline and plagioclase are also abundant. Ferromagnesian minerals, including micas, also occur. The cement is quartz and feldspar, stained with iron. This section should be compared with A, as well as with Plates X, p. 56, and XII, B, p. 66.

p. 90). A thin section (Plate XVI, A, p. 72) from one of the greenish layers was examined. It consists of extremely fine angular grains of quartz (diameter about .01 mm.), with a few feldspars, imbedded in a matrix of crystalline calcite which forms over a third of the slide, but analysis shows that it is less than 20% of the total (see p. 52). Mica flakes are seen in places, being concentrated on some bedding planes. The red noncalcareous phase was not examined microscopically . . 365

Total thickness 3,100

In the field the lithological likeness of the lower beds of this section to the upper part of the known Amnicon formation of the Oronto group is more striking than any description can make it, so that the writer has no reasonable doubt of the correlation as given. However, it must be remembered that the distance from undoubted outcrops of the Oronto group is considerable.

St. Louis River. At the extreme northwest corner of the state, on St. Louis River. and extending for a short distance into Minnesota, is an exposure of about 730 feet of conglomerate, sandstone, and shale. These beds are prevailingly red in color but are spotted and streaked with white or greenish-gray. They contain much feldspar, decreasing in amount towards the top of the section (Plates VI, B, p. 44, and XVI, B, p. 72). Ripple marks, mud cracks, and rain prints are abundant (Fig.9).

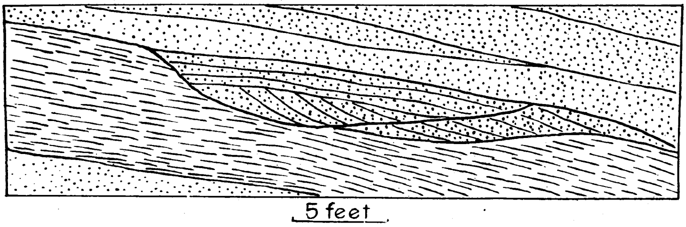


FIG. 9. Bedding in Amnicon formation, St. Louis River, Minn.

In all their characters they are like the upper part of the Oronto group, and insensibly grade upward into rock like that of the lower part of the Orienta sandstone.

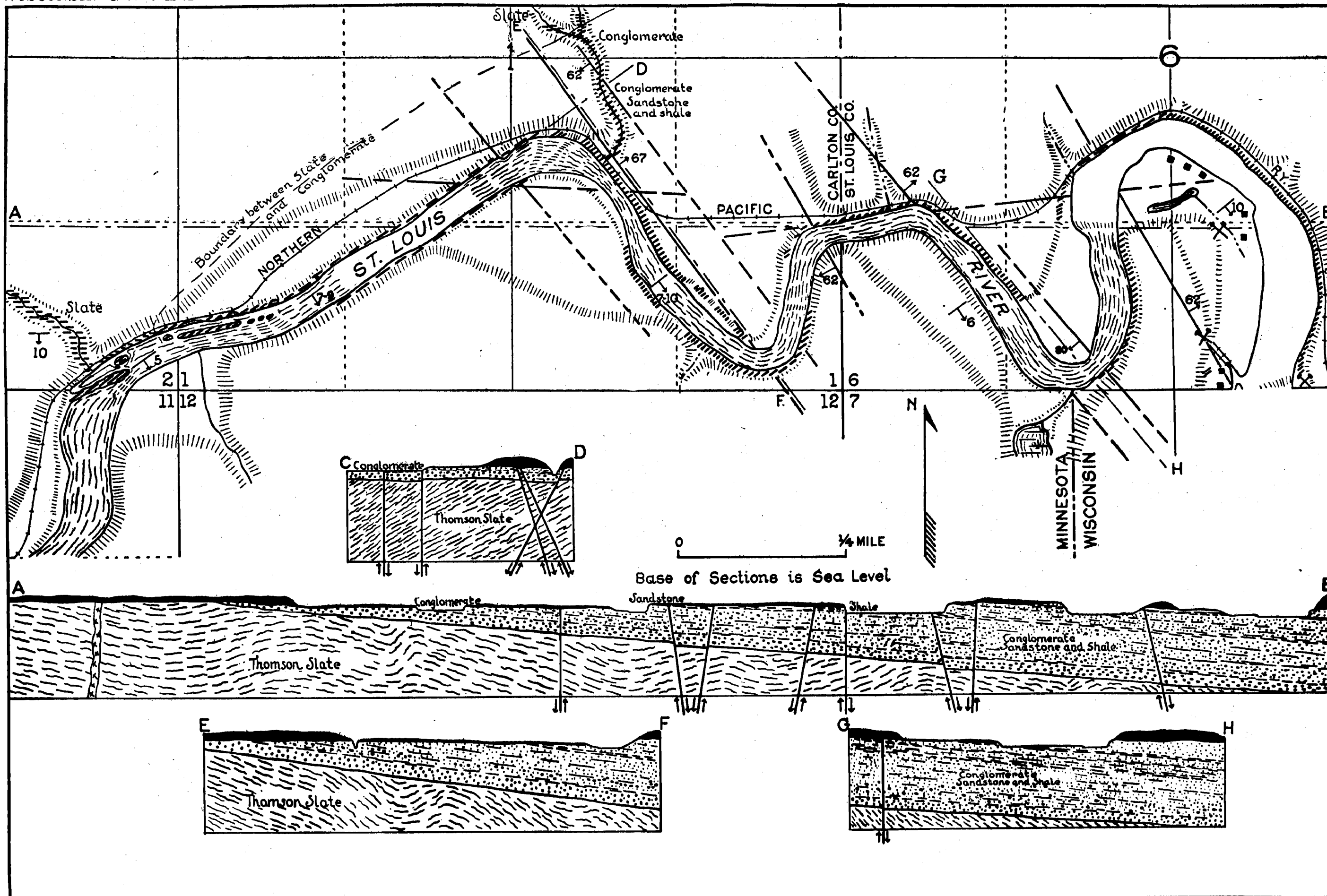
The following detailed section is based upon one given by N. H. Winchell of the Minnesota Survey, supplemented by the observations of the writer.[1] The dip varies from 3° to 10° to the southeast (see Plate XV, opposite).

Winchell was inclined to assume the existence of an unconformity between the lowest conglomerate, which is mainly composed of pebbles of vein quartz, and that which overlies it and is composed of basic trap pebbles. He found a pebble in the latter which he supposed to have been derived from the pyritiferous quartz conglomerate. The writer found no evidence for such a division. A large pebble of Keweenawan porphyry (Specimen 11272) was found in the lower conglomerate, and there is a complete gradation between the two types (see p. 17).

SECTION ON ST. LOUIS RIVER FROM FOND DU LAC TO THE POWER HOUSE

	Thickness Feet
Orienta Sandstone.	
1. Upper Sandstone Beds. Reddish brown sandstone of medium grain (about .4 mm.) spotted with and grading into white. Contains pebbly bands, and micaceous shaley layers. The pebbles are trap, vein quartz, and quartzite. The bedding varies from thick to thin and cross-bedded. The quarries are on this bed. Under the microscope, the grains are seen to be subangular. *About two-thirds of the rock is quartz*, the remainder being more or less altered feldspar, mainly orthoclase (see Plate VI, B, p. 44). Microcline, plagioclase, mica, magnetite, and various ferromagnesian minerals appear. Specks of red iron oxide also appear, but the cement is quartz	200
2. Dark red shale, with greenish layers and spots . .	18
3. Lower Sandstone Beds. Sandstone much like 1. Is somewhat finer grained and contains more mica, shaley beds, red and green clay pockets, and beds	

[1] Winchell, N. H., Amer. Geol., vol. 16, 1895, pp. 75, 150; Minn. Geol. & Nat. Hist. Survey, 10th Ann. Rept., 1881, pp. 30, 91; Id., 23rd Ann. Report, 1894, p. 239; Geology of Minn., 1899, vol. IV, p. 15.



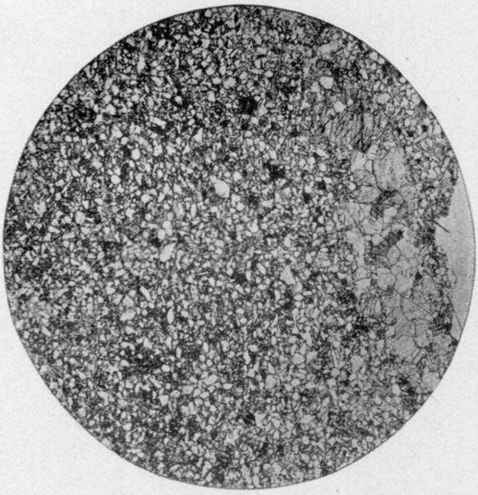
Outcrop map of part of St. Louis River, near Wisconsin-Minnesota line. This section shows a conformable gradation from arkose sandstone, conglomerate, and red shale, to brown quartz sandstone at the top. It is believed that this succession indicates that the Bayfield and Oronto groups are conformable.

of magnetitic rock. Under the microscope (Specimen 11328) shows little difference from 1, except that *not much over half is quartz* and there is more mica	70
Total Orienta sandstone	288
Amnicon Formation.	
4. Red shale, like 2	10
5. Alternating beds of sandstone and red shale. Thickness not accurately known. Under the microscope (Specimen 11326) shows medium-sized (about .3 mm. diameter) grains; all are subangular. *Not much over half are quartz,* the remainder being mainly altered feldspars of all kinds, orthoclase being most abundant, but some microcline can be distinguished	75
6. Red shale	10
7. Thin-bedded red and white sandstone, finer grained than the higher layers. Under the microscope (Plate XVI, B, p. 72) it is seen that *less than half is quartz.* The orthoclase feldspars are much altered, but some plagioclase was seen. There is considerable mica. The cement is mainly calcite . .	3
8. Main Shale Bed. Red shale with thin partings of hard greenish sandstone, and some grit towards the base. Thickness not accurately known on account of faulting (see Plate XVII, A, p. 74) . . .	45
8M[1]. Red and green shale with ripplemarks . .	4.5
9. Grit and shale series. Grit	.5
10. Red shale	3.0
11. White grit	3.0
12. Red shale with greenish spots, ripple marks and rain prints (Specimen 11316)	14.0
13. Grit, mostly light colored	.75
14. Red shale	.25
15. Grit	2.0
16. Red shale	.25
17. Grit	.35
18. Red shale	.35
19. Grit	1.0

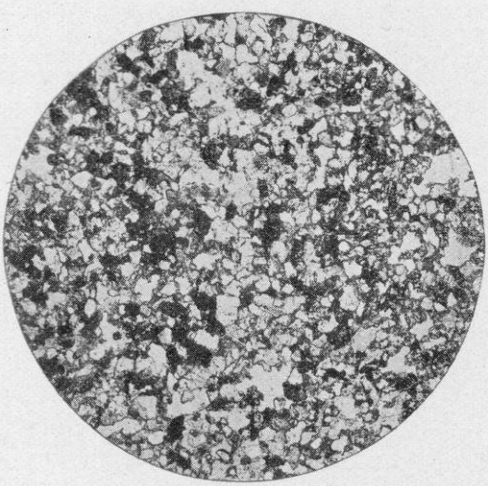
[1] Below this the numbering of the beds agrees with Winchell's section.

20.	Red shale, mud cracks	3.5
21.	Grit, white, quite calcareous from decomposition of basic feldspars	1.5
22.	Red shale and shaley sandstone, with green layers and ripple marks	14.0
23.	Light red sandstone	3.0
24.	Red grit, some white	4.5
25.	Shaley red sandstone, very hard; some white . .	10.0
26.	Red grit	3.5
27.	Dark red shale and shaley sandstone . . .	9.0
28.	Lighter colored sandstone (white and red) . .	8.0
29.	Green shale, ripple marks	5.0
30.	Red shale and shaley sandstone, ripple marks . .	9.0
31.	Grit with shale layers	4.0
32.	Red and white mottled cross-bedded sandstone . .	5.0
33.	Grit and conglomerate, coarsest in middle . . .	7.0
34.	Shaley micaceous sandstone; pinches out . . .	.75
35.	Grit	.85
36.	Red shale	.35
37.	Grit	2.0
38.	Red shale	.2
39.	Greenish grit	.5
40.	Red and white sandstone, pinches out into conglomerate. Under microscope (Specimen 11300) shows that *over three-quarters of the rock is quartz.* Remainder includes feldspars, mainly orthoclase, although both microcline and plagioclase were distinguished, mica, and rarely ferromagnesian minerals. Average size of the grains is about .25 mm. but there is much variation. All are subangular . . .	1.2
41.	Red grit passing below into coarse light colored sandstone; cross-bedded	3.5
42.	Red conglomerate, coarser below; pebbles up to two inches	7.0
43.	Red shale with green spots; some conglomerate .	1.5
44.	Firm light-colored conglomerate with enclosed layers of cross-bedded sandstone	3.0
45.	Green and red shale, micaceous	.7
46.	Sandy shale	1.0
47.	Fine red shale, ripple marks	15.0
48.	Quartz Conglomerate. Coarse hard pyritiferous conglomerate. Color usually white to greenish. In-	

PHOTOMICROGRAPHS IN ORDINARY LIGHT, MAGNIFIED 12 DIAMETERS.



A. Very fine-grained greenish calcareous shaley sandstone from Middle River, bed 1, Amnicon formation (specimen 8611). The light-colored grains are fine angular quartzes, averaging .01 mm. in diameter. An occasional feldspar is seen, and mica is visible in the hard specimen. The matrix of the rock is crystalline calcite, which in one place forms a vein in which its characteristic cleavage may be seen. A chemical analysis shows CaO 10.71%, MgO 0.12%, which would require 8.55% CO, making a total of about 19% of carbonate (see p. 52).



B. Fine-grained arkose sandstone from Amnicon formation, bed 7, St. Louis River (specimen 11,321). Quartz constitutes a little less than half of the rock. The remainder is feldspar (mainly orthoclase, but some more basic varieties), with iron oxide, a little mica, and calcite cement.

cludes layers of shaley sandstone, red conglomerate and red or green shale	50
49. Conglomerate, somewhat coarser and very hard. The pebbles are of vein quartz, slate, quartzite, and iron formation. But one trap pebble was found. A foot of green shale is found in places next to the underlying slate	100
Total thickness	727
Total thickness computed from dip and allowing for faults	730
Huronian	
50. Thomson slates. Gray slate	Unknown

A number of wells in Superior[1] disclose a similar succession. The result of the southeasterly dip of the sandstones is that while in East Superior solid brownstone is found, along the St. Louis River to the west there is only discovered red sandy shale, carrying a little salt water. The deepest well of which the record was obtained, is Patterson's, in N. E. ¼ of N. E. ¼ of Sec. 24, T. 49, R. 14 W. (see general map). This penetrates 185 feet of dry drift, below which was found over 700 feet of red sandy shale, undoubtedly belonging to the Amnicon formation.

Summary. The exposures described above show that the stratigraphic sequence of a downward gradation through progressively more and more arkose sandstone into red shales, sometimes interbedded with conglomerate and grit, is found throughout the district. In the case of the exposures on Middle and St. Louis rivers it is practically certain that the upper beds belong to the Bayfield group. On the other hand, in the case of the Fish Creek section, farther east, the lower beds plainly belong in the Oronto group, and are seen to grade upward into sandstones which are correlated with the Bayfield group. These facts indicate that the Bayfield and Oronto groups are conformable and hence should both be placed in the Upper Keweenawan series.

[1] Records furnished by J. A. Colwell, a well-driller, 1900, and Prof. J. A. Merrill, 1910.

The only alternative is to suppose that the Bayfield group rests unconformably upon the Oronto group, somewhere beneath the drift-covered interval at the head of Chequamegon Bay. While this cannot be disproved, there is nevertheless no evidence of any kind to indicate that such is the case and on such an hypothesis must rest the burden of proof.

Categorically the evidence may be stated as follows:—

1. The same conformable downward gradation from more quartzose into more feldspathic sandstone and red shale is found at several widely separated localities within the district.

2. At most of these localities the indentification of the upper beds with the Bayfield group is indisputable.

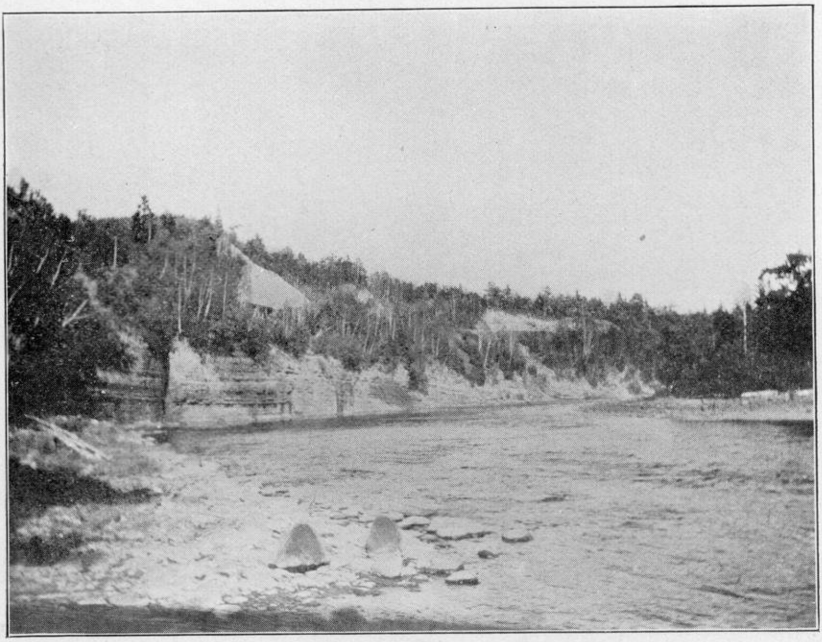
3. On Fish Creek the correlation of the lower beds with the Oronto group is almost equally definite, thus indicating that the lower beds at other places are presumably the top of the Oronto group.

4. No debris worn from the rocks of the Oronto group has been found in rocks of the Bayfield group. For the most part the younger sandstones are made up of grains which average somewhat larger in size than those of the Oronto group, thus showing that the materials of the Bayfield group must in any event have been largely derived from other sources than those of the Oronto group.

5. There is no universal structural difference between the two groups. The Bayfield group lies in the center of the Lake Superior synclinorium and hence is usually nearly horizontal; but near Superior, all along the great fault of the Douglas trap range, and apparently on Fish Creek, it was involved in the extensive folding and faulting formerly supposed to be confined to the Oronto group.

6. If the Bayfield group is unconformable upon the Oronto group, then its lowermost exposed member is indistinguishable on lithologic or structural grounds from the recognized Oronto group.

There is, therefore, no reason to place the Bayfield and Oronto groups in different periods, and the evidence at hand drives us to the conclusion that the Bayfield group is a part of the Upper Keweenawan series.



A. North bank of St. Louis River, near line between St. Louis and Carlton counties, Minnesota. The cliff exposes red shale, with thin greenish sandstone partings. This is a part of the Amnicon formation. A normal fault of at least 40 feet displacement passes through the east end of the exposures (see p. 91).

B. West bank of Middle River, Sec. 25, T. 18, R. 12 W., Douglas County, showing contact between the Middle Keweenawan traps at left of ravine, and overturned beds of red and greenish feldspathic sandstone and shale of the Amnicon formation to right (see I 'ate XIII, p. 66).

CHAPTER VI

THE CONTACT OF THE BAYFIELD GROUP WITH THE TRAPS

General Statement. All along the south coast of the west end of Lake Superior the Bayfield group of sandstones comes into contact with the traps of Middle Keweenawan age, with dip to the southeast at angles varying from 10 to 70 degrees. At the head of the lake, on St. Louis River, near the western border of the state, the conformable downward extension of this group. the Amnicon formation, appears from beneath the younger sandstones and is plainly in unconformable contact with the underlying slates of Huronian age.

Douglas Fault. It has long been recognized that the contact of the Bayfield group with the traps of the Douglas (or South) Range is marked by a fault. With regard to the age, extent, and significance of this displacement there has been much diversity of opinion. As explained in Chapter III, Irving was of the opinion that the contact was an unconformity along a fault scarp complicated by slight recent movement on the same plane. Since that time, Grant recognized that an enormous displacement has taken place since the deposition of the sandstone, and that the fault is of the thrust type (see p. 89).

LOCAL DETAILS

On Iron River, near the eastern boundary of Bayfield County, is the most easterly known exposure of the traps of the South or Douglas Range. Several miles west of this small outcrop, the crest of the Douglas trap range rises above the plain of Pleistocene deposits (see p. 7, and Plate II, p. 8). Where Brule River crosses through a deep gap in this ridge, the contact of the sandstone and trap is not exposed; it occurs beneath a covered space of about a fourth of a mile. No distinct evidence of faulting or other disturbance appears at this point in either formation. A contact showing fine conglomerate was reported by Sweet[1] (see p. 44), in Sec. 30, T. 48, R. 10 W. This locality was visited by Grant's party, but the exposure was not found.

Middle River Contact. Ten miles west of the Brule, Middle River exposes the contact of the traps and the Amnicon formation, which conformably underlies the Bayfield group (see p. 66). Berkey, Van Hise, and Grant visited this locality in 1899 and made the map which is the basis of Plate XIII. They recognized the true bedding of the sandstone, which Sweet had not,[2] and assumed that the structure was anticlinal. (See also Plate XVII, B, p. 74, and Plate XXI, p. 90).

The writer decided that this interpretation must be an error, since the stratigraphic sequence observed in other localities is exactly opposite to that required by such an hypothesis (see section on p. 67). No evidence could be detected of a small syncline next to the fault at the eastern exposure,[3] such as would be expected below a thrust fault. The fault cuts the E-W strike of the fold, the layers in which are somewhat broken near the contact. Furthermore, as explained on p. 68, ripple marks are found, which clearly demonstrate that the southward-dipping beds have been overturned. The structure deduced from these facts is that of an overturned and broken anticline, a normal structure in connection with a thrust fault; while that described by Grant would be unusual.

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1 Sweet, E. T., Geol. of Wis., 1873–9, vol. III, p. 348.

Irving, R. D., Copper-Bearing Rocks, Mon. U. S. G. S., vol. V, 1883, p. 257.

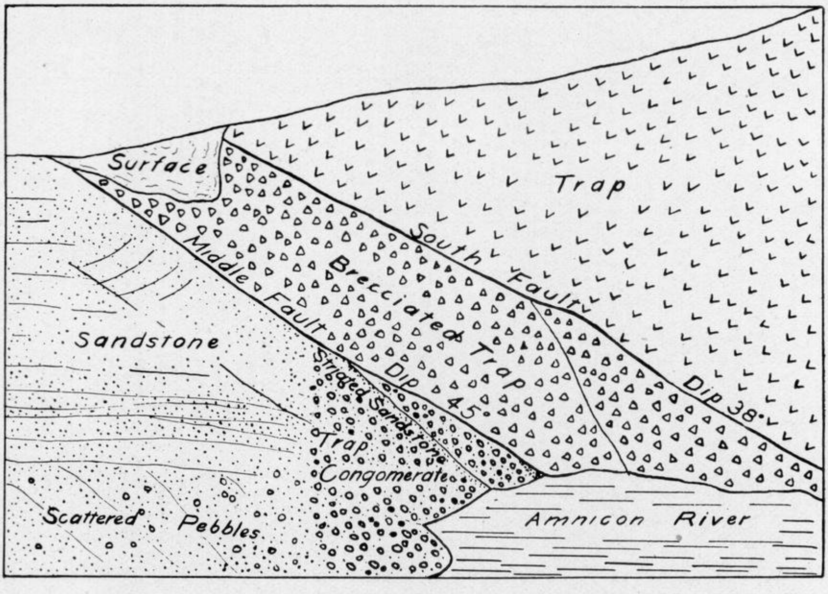
2 Sweet, E. T., Geol. of Wis., 1873–9, vol. III, p. 347.

3 Grant, U. S., Copper-Bearing Rocks of Douglas Co., Wis. Geol. & Nat., Hist. Survey, Bull. VI, 1901, structure section C–D on Plate IX, p. 31.

—— Junction of Lake Superior Sandstone and Keweenawan Traps in Wis., Bull. Geol. Soc. of America, vol. 13, 1906, p. 8.

Personal communications.

A. East bank of Amnicon River, Sec. 29, T. 48, R. 12 W., Douglas County, showing thrust fault, which brings the traps into contact with the Orienta sandstone.



B. Key to the foregoing photograph.

Amnicon River Contact. Where Amnicon River crosses the fault, occur good exposures which bring to light the actual plane of contact.[1] Changes in the course of the stream have resulted in uncovering the formations for a considerable distance, as shown in Fig. 10. These exposures are particularly interesting, in that they show the direction of the fault to change abruptly from nearly E. and W. to N. 70° E.

The eastern exposure, which doubtless was at one time a channel of the river, is in a deep and narrow ravine following the

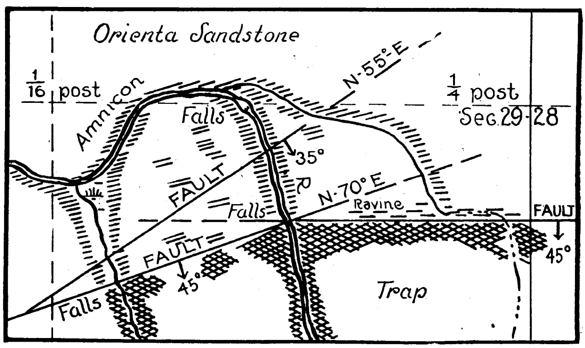


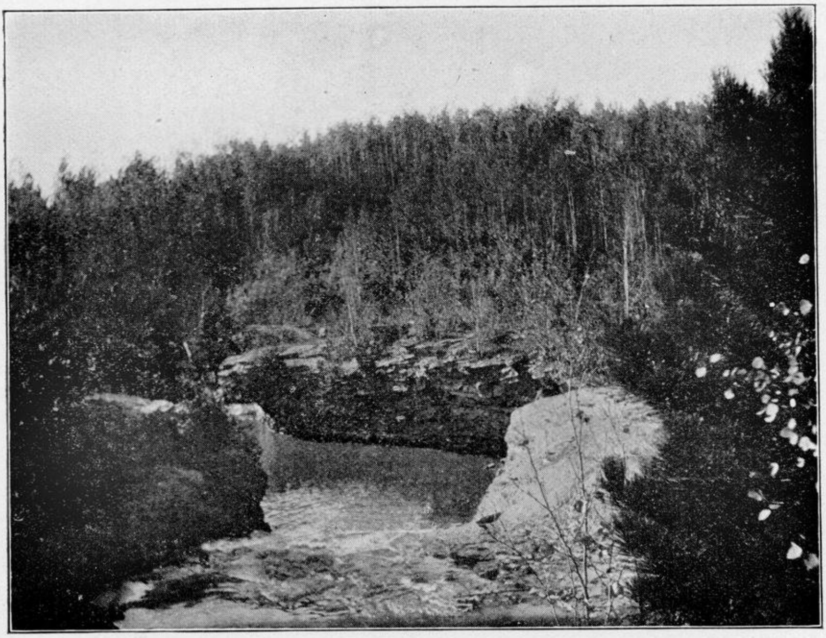
FIG. 10. Sketch map showing contact of trap and sandstone on Amnicon River, Douglas County.

contact for some distance. The actual junction is covered with but a few inches of soil. The south side of the ravine is an overhanging wall of brecciated trap. In the bottom, occasionally rising into ridges, and on the north wall, occur exposures of conglomerate with interbedded layers of sandstone. The dip of the beds varies from vertical to about 45° N.; but the exact relation of the horizontal sandstone farther to the north could not be determined because of fallen debris and the irregular shearing that conceals the true bedding. It is probably marked by faulting, as will presently be explained. The conglomerate is composed of trap pebbles, usually much weathered, averaging an inch or two in diameter, but with occasional specimens a foot in diameter. All are well rounded, and, so far as was ascertained, composed mainly of porphyry and amygdaloids. The

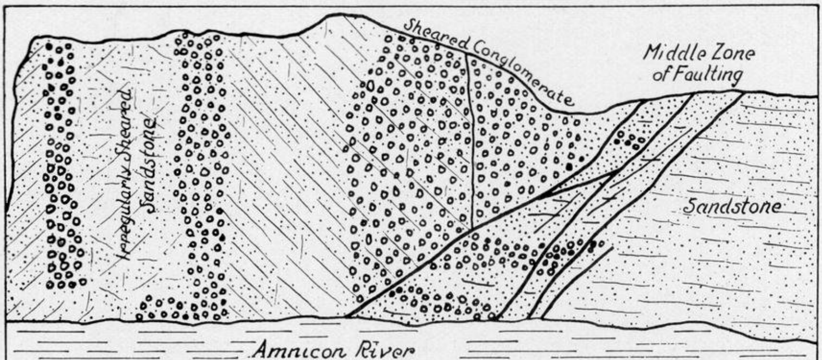
[1] Sweet, E. T., Geol. of Wis., 1873-9, vol. III, p. 346.
Grant, U. S., Copper-Bearing Rocks, p. 19.

sandstone matrix and interbedded layers do not differ, except in coarseness of grain, from the rock exposed to the north (p. 43); some, however, appear to contain more small fragments of trap. At the west end of the ravine is exposed a thin layer of hard ferruginous sandstone. It forms the face of the north wall, dipping south at approximately the same angle as the fault (about 45°), thus cutting across the vertical layers of conglomerate and sandstone beneath. On the upper surface of this layer are two sets of grooves; one is parallel to the dip, the other is inclined at an angle of about 30° in a NE–SW direction.

The exposures are naturally much better on the present banks of the stream to the west (Plate XXII, B, p. 92). That this present course has not been occupied by the river for a great length of time, is shown by the fact that the fall of about 15 feet, just at the fault line, has receded but slightly into the traps. Plate XVIII shows the eastern wall of the gorge. Two faults are seen, of which the upper or southern one dips 38° S. with an E–W strike; the lower 46° S., strikes N. 72° E. They are separated by a zone of trap breccia, such as also occurs beneath much of the bottom of the ravine to the east, as above described. It consists of angular and subangular fragments of weathered trap, some of them several feet across. North of the lower fault occurs a wedge of conglomerate, bounded on the north by an approximately vertical plane. In this conglomerate are two thin sandstone layers striking parallel to this fault, and dipping south at a somewhat steeper angle than the fault. The southern one is almost quartzite, and the other carries scratches like those noted to the east. The bedding of the conglomerate is otherwise indistinguishable. In places to the north it appears to be vertical, as shown by an interbedded sandstone layer; but there, with no appearance of fracture, the conglomerate gives way above to horizontal thin-bedded quartz sandstone, and below to cross-bedded pebbly white sandstone, among the pebbles of which are some of quartz and quartzite. There an appearance of gradation is presented, but above the contact is sharp. Shearing makes the relations difficult to determine. Above the top of the conglomerate the foot wall of the fault is composed of much fractured sandstone. About 100 feet to the north a small thrust fault of undetermined throw is seen in the sandstone, as shown



A. Lower Falls, Amnicon River, Douglas County (see Fig. 10, for location). Looking north, showing Copper Creek beds of Orienta sandstone.



B. Diagram (drawn from a photograph) of part of west bank of Amnicon River, Douglas County, just north of contact of trap and sandstone (south of the falls shown in A)—for location, see Fig. 10. This exposure shows the dying out of the middle fault into a confused zone of fractures which separates the vertical conglomerate layers from the horizontal sandstone to the north—shown at the right. The shearing planes in the vertical layers are very complex, and are but partly represented.

in Plate XXII, A, p. 92; the dip is 38° S., the strike about N. 55° E.

The west bank is not so well exposed, owing to a recent fall of the overhanging wall of trap, thus concealing the main fault. Two other zones of displacement may be seen to the north. The southernmost of these is important since it shows the relation of the vertical sandstone and conglomerate to the horizontal sandstone beds.

It is not clear just how the middle fault is related to that described on the other side of the river. The two there seen, appear to join beneath the water, so that no well-defined breccia is seen on the west bank, the actual contact being marked only by an inch or so of red shale. The middle fault of the west bank branches out from the others beneath the river. It is composed of several irregular planes of fracture, as is shown in the plate Between the two faults is found conglomerate with irregular interbedded sandstone layers, all much sheared, as is imperfectly shown in Plate XVIII a, B, p. 78. A remarkable feature is the sudden ending of one of the conglomerate layers against sandstone below, with no appearance of fracture. Whether or not the alternation of conglomerate and sandstone represents bedding, is not known; but it is worthy of note that no conglomerate is found in undisturbed sandstone beds, while most of the layers occupy a vertical or highly tilted attitude and are much sheared. This intense shearing is quite irregular; no permanent system could be discovered, although many of the planes of fracture dip toward the fault at a low angle. In the western bank the northernmost fault is again seen, dipping to the south at an angle of 28°.

There are but poor exposures in the wide valley that crosses the fault to the west of the river. The inclined conglomerate beds reappear, but their relation to the horizontal beds to the north is not clear on account of the intense shearing; no pebbles extend beyond their limits. Fractures approximately parallel to the fault are most abundant, apparently representing the dying out of the middle fault. The strike of the contact is here N. 70° E. while that of the conglomerate is N. 50° E.[1]

[1] About a quarter of a mile to the west is a valley which crosses the contact and is believed to show exposures; the writer was, however, unable to visit it.

Copper Creek. In sec. 15, T. 47, R. 14 W., Copper Creek crosses the contact of the sandstones with the traps. The actual junction is covered by a few feet of debris, so that the attitude of the fault plane is difficult to determine.[1] Sweet's section shows it dipping to the north, but the writer was inclined to believe that the dip is about 60° to the south. The sandstone is sheared and sharply flexed for a distance of less than a hundred feet from the contact, thus indicating an upward movement of the igneous rocks. No conglomerates or other unusual features are found in the sandstone.

Falls of Black River. What is probably the best known exposure of the sandstone-trap contact is that in the S. E. 1/4 sec. 21, T. 47, R. 14 W., at the picturesque falls of Black River. The locality is, however, more attractive for its scenery than for its rocks, for the latter are not everywhere well exposed.[2] Plate XIX is a map of this locality made by Grant in 1899, and shows the complex relations of the formations more clearly than could any description.

Conglomerate is found in but two places. The pebbles are decayed acid lavas, vein quartz, and red quartzite, preserving about the same proportions as the pebbles in the main body of the sandstone. The sizes, however, average somewhat larger, pebbles six inches in diameter being found.

On the east bank, not far above the stream and beneath trap layers higher up the bank, is a ledge of conglomerate with two interbedded sandstone layers which dip 30–40° N. This is quite close to the main fault (which here dips some 50° S.) and to the supposed cross fault. Above the conglomerate, sandstone, bearing but occasional pebbles, approaches close to the fault.

On the west bank of the stream is a larger ledge of conglomerate and sandstone. The dip here is reversed, being about 10 to 20 degrees to the southeast. This feature is shared, as may be seen in the diagram, by a number of sandstone exposures to the

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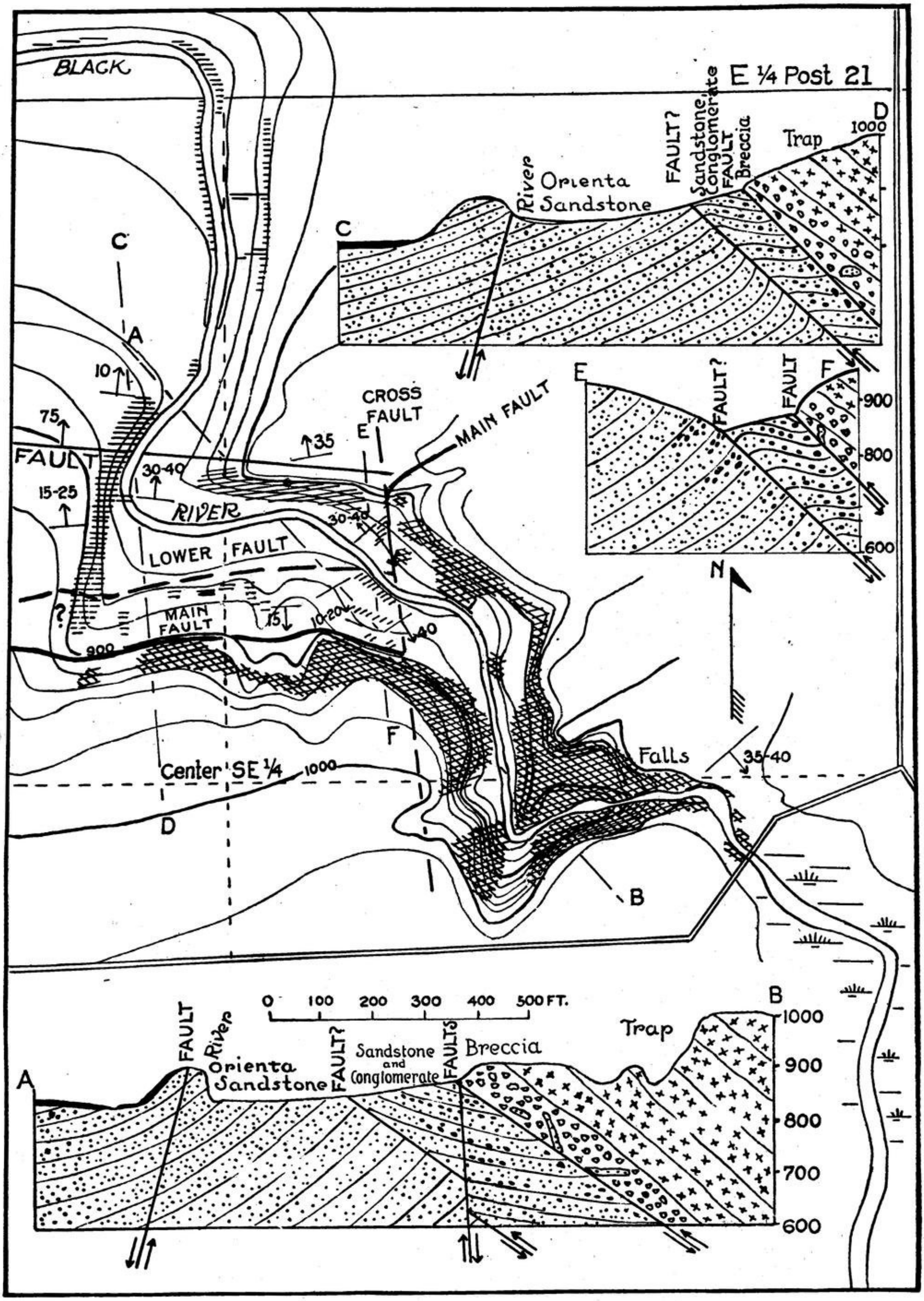
1 Sweet, E. T., Geol. of Wis., vol. III, 1873–9, p. 344.
Grant, U. S., Copper Bearing Rocks, p. 19.

2 Sweet, E. T., Geol. of Wis., vol. III, 1873–9, p. 340.
Grant, U. S., Copper Bearing Rocks, p. 19.



Map of vicinity of Lower Falls of Black River, Douglas County, showing contact of Middle Keweenawan traps and Orienta sandstone. Map by U. S. Grant, 1899; sections by F. T. Thwaites, 1910. Contour interval, 20 feet; elevations, 11 feet too high.

west. All of these rocks are quartzose, like those to the north, the only difference being that they are considerably harder.

Above these exposures rises a cliff of trap breccia, in which are included several large pieces of red quartzite. The extent of the brecciation is much greater than noted elsewhere, extending several hundred feet from the contact. The dip of the fault here cannot be measured, but appears to be not very steep.

The sandstone north of a line bounding these south-dipping exposures, as usual dips to the north. These beds are described on p. 44.

A study of the detailed map shows that the reentrant in the fault line must be the cause of the abnormal features here noted, just as the bend in the reverse direction at the Amnicon River is accompanied by peculiar phenomena. There must be a cross fault to account for this reentrant angle in the border of the trap; the excessive brecciation is doubtless due to its presence. It is most probable that the south-dipping layers of sandstone are separated from the north-dipping by a continuation of the fault to the east of this break. This fault probably passes through the poor exposures on the west side of the valley, although they are so obscure that nothing can be stated positively; it may, however, join the main or southern fault beneath a covered space farther to the east. The writer could distinguish no definite evidence of unconformity, or of this reentrant being a sinuosity of an ancient shore line, as supposed by Irving.[1]

In the S. E. 1/4 of the N. W. 1/4 of sec. 29 of the same township occurs a small exposure of the contact. Irregularly-sheared sandstone occurs within two feet of trap breccia and dips about 40° N. for a short distance from the contact.

Interpretation of Exposures. Irving believed that the phenomena above described represented an unconformity along a fault scarp, complicated by a slight amount of recent faulting on the same plane. Grant discovered the great amount of throw (at least 3,000 feet; see p. 66) which the fault possesses, and declared the evidence to be not conclusive in favor of uncon-

[1] Irving, R. D., Copper-Bearing Rocks, Mon. U. S. G. S., vol. V, 1883, p. 441.

formity. All former investigators have assumed that the sandstone was a marine deposit, a fact now regarded as decidedly doubtful.

The following evidences favor the older view:

1. The presence of conglomerates, often of large pebbles mainly, if not sometimes wholly, derived from the rocks of the adjacent trap series.

2. The striking difference in the amount of folding and metamorphism of the two groups of rocks, which implies that most of the deformation of the traps must have taken place before the deposition of the younger sandstones.

3. The enormous throw and subsequent erosion required by the fault hypothesis.

4. No strata are known from which the conglomerates might have been faulted up; these is little to show definitely that they have been faulted up more than a few feet.

5. The dip of the fault plane to the south, giving it a large horizontal component of motion, would have cut away a large part of the coarse deposits adjacent to the fault scarp, thus explaining the absence of conglomerate at some points.

6. As the fault is part of the Keweenawan deformation, representing a broken fold, it is quite probable that faulting began before the time of deposition of the adjacent sandstone, and perhaps continued through the time of its formation.

7. The Bayfield sandstones may be areally continuous with the horizontal light-colored sandstones of the Mississippi valley (cf. p. 58), which are separated from the tilted Middle Keweenawan by a considerable unconformity.

The following facts support the idea that the faulting is in large part, if not wholly, later than the deposition of the sandstone:

1. Well defined conglomerates occur at but two localities out of the eight known exposures (less definite ones occur at two others).

2. They are never found over a few rods from the contact.

3. They do not clearly grade into the adjacent sandstone.

4. They occur only at points of unusual minor faulting in the sandstone.

5. No patches of sandstone are found resting uncomformably upon the trap.

6. The amount of conglomerate is not sufficient, nor are the pebbles large or angular enough, to be regarded as either a subaerial or marine deposit along a fault scarp.

7. In many cases the pebbles are one-third vein quartz and quartzite; these could only have been supplied from a distant source, and would not be likely to occur along a fault-scarp. The trap pebbles were not usually derived from the immediately adjacent rocks.

8. The inclination of the fault plane involves a large horizontal component, approximately equal to the vertical one. If faulting took place during or just prior to the deposition of the sandstone, this would involve a shifting northward of the scarp line, thus supplying a large amount of fresh unweathered sediment. No such amount of sediment of that character is found in the upper beds of the sandstone.

9. The throw of the fault since the deposition of the sandstone is certainly great; it must be at least 3,000 feet, since that thickness of strata is involved on Middle River.

10. The total displacement involved, even if the traps are as thick as was formerly supposed (see p. 89), is not greater than that of many well-known thrust faults. The uplifted rock may readily have been eroded during the long time that has since elapsed.

11. The conglomerates that occur are so intensely sheared that they may represent material from lower conglomerates which has been dragged up along the fault and worked into the sandstone, like the layers of sandstone that have been found included in the trap breccia (see p. 81). This hypothesis would explain some of the peculiar features of the conglomerates, found only at points of intense faulting. We have no knowledge of the stratigraphy of the lower beds of the sandstone in this part of the area, but conglomerates almost undoubtedly occur at lower horizons.

12. At several points, cross-bedded layers in the sandstone dip toward the fault. This would be an unusual occurrence if the rocks occupied the same relative positions at the time of the deposition of the sandstone, as they do today.

13. The areal connection of the Bayfield group with the Cambrian sandstones of Minnesota is not proved; the age and structural relations of the red sandstones beneath the light-colored Potsdam of Minnesota are unknown (cf. p. 58).

14. If the supposed fault scarp was being eroded during the deposition of the sandstones, then the sandstones must have been formed very soon after, if not during a period of regional deformation. This contrasts them sharply with those of the recognized Cambrian of southern Wisconsin, which were evidently formed under quiescent conditions (cf. p. 101).

15. The sandstones adjacent to the fault (Bayfield group) are apparently conformable upon those which overlie the traps (Oronto group) and elsewhere are folded with them. They all belong to the same period of deposition. Therefore it is very improbable that the exposures described above represent an unconformity involving any great lapse of time. If there is any unconformity, it is rather a local matter formed by slight movements of the fault during the deposition of the sandstones.

The writer concludes that inasmuch as deformation appears to have been more or less continuous throughout Keweenawan time, the probabilities are, that while most of the movement on the fault may have been accomplished before the deposition of the sandstones now exposed, that slight movements may have occurred during their deposition, while a considerable amount has demonstrably occurred since. This hypothesis agrees best with all that is known of the phenomena (cf. p. 108).

North Coast Contact. Near Duluth, several supposed contacts of the sandstone with the trap came to the notice of the writer. Upon investigation they proved to be either red syenite, cemented drift, or interbedded Middle Keweenawan sediments. But as explained on p. 107, it is entirely possible that an unconformable contact may yet be found.

St. Louis River Contact. Although on St. Louis River the Amnicon formation of the underlying Oronto group is seen in contact only with the Huronian slates, the presence of basic trap pebbles in such abundance implies a nearby exposure of Keweenawan igneous rocks during deposition, and hence a possible unconformity. Less than a mile from the exposures on Mission Creek, near Fond du Lac, hills of intrusive gabbro rise to a level some 500 feet above the exposures. About the middle of the interval between these exposures, some real estate speculators at one time drilled a deep hole in search of natural gas, the log of which is here given:

LOG OF CHURN DRILL HOLE NEAR SHORT LINE PARK, MINN.

Situated on S. line Sec. 32, T. 49, R. 15 W., in a ravine at elevation 900 feet A. T. (After N. H. Winchell, Natural Gas in Minnesota, Minn. Geol. and Nat. Hist. Survey, Bull. V, 1889, p. 31; Geology of Minnesota, Vol. IV, 1899, p. 567.)

	Thickness, feet
Pleistocene.	
Drift (clay?) no samples	100
Keweenawan	
2. Rock, said to be soft, no samples	131
3. Brownish red shale (called tuff by Winchell)	12
4. "Decayed trap", perhaps conglomerate	33
5. No samples, presumably same as above	104
6. "Surface eruptives", perhaps conglomerate	37
7. The same, samples appeared to be in part fragmental, hence is probably a conglomerate	31
8. Gray slate or shale, said to be misplaced in record, but is possibly one of the greenish siliceous shales of the Amnicon formation	15
9. Pink to purple quartz sand with some trap fragments	5
10. The same but coarser and pyritiferous with pebbles of trap	5
11. "Gray slate", probably shale rather than slate misplaced in the record	17
12. "Gabbro"	16
13. Conglomerate of soft trap pebbles	2
14. Pink and gray quartzose, pyritiferous conglomerate and quartzite containing pebbles of slate, and probably layers of shale	20
15. "Surface lavas like those at Duluth." These rocks are clearly igneous	91
Huronian–Thomson Slate	
16. Gray and black quartzose slate	930½
Depth of hole	1,517½

A little salt water was found, but no gas.

The interpretation of the foregoing record is difficult. Winchell[1] correlated No. 14 with the similar white quartzose, pyritiferous conglomerate which is exposed on the banks of St. Louis River, to the west. He believed that the conglomerate seen in the river valley was older than the Keweenawan lava flows, since it contains no trap pebbles. (One large one was found by the writer, see p. 70). The red conglomerates and shales of the St. Louis River section, which at that point immediately overlie the pyritiferous conglomerate, he held to be either separated by an unconformity from the pyritiferous conglomerate or to have been deposited contemporaneously with the traps. The interbedding of traps and conglomerates, which he believed was shown in the above drill record, fits with either hypothesis.[2] A single pebble of pyritiferous conglomerate found by him in the red trap conglomerate, was believed to come from the underlying conglomerate and therefore to indicate an hiatus between the deposition of the two conglomerates, the upper one of which he believed to be of pyroclastic origin. This view is illustrated in Plate XX, A.

Winchell's views were not borne out by the writer's investigations. It seems clear that there is no unconformity between the two types of conglomerate on St. Louis River. The pebble of pyritiferous conglomerate found in the upper conglomerate, may well have been derived from some other similar formation. Furthermore, no evidence of contemporaneous volcanic eruptions was discovered in the Amnicon beds of St. Louis River and Mission Creek. These sediments do not differ essentially in character from the other parts of the Oronto group. It would therefore appear probable that the pyritiferous conglomerate found in the drill hole is not the same as that on the river, but is a part of the Middle Keweenawan trap series with which it is interbedded. The scarcity of coarse trap debris, especially of the gabbro, in the conglomerates of St. Louis River, suggests that faulting since the formation of the sediments has brought the traps into their present position, so that they rise 500 feet or more above the river level.

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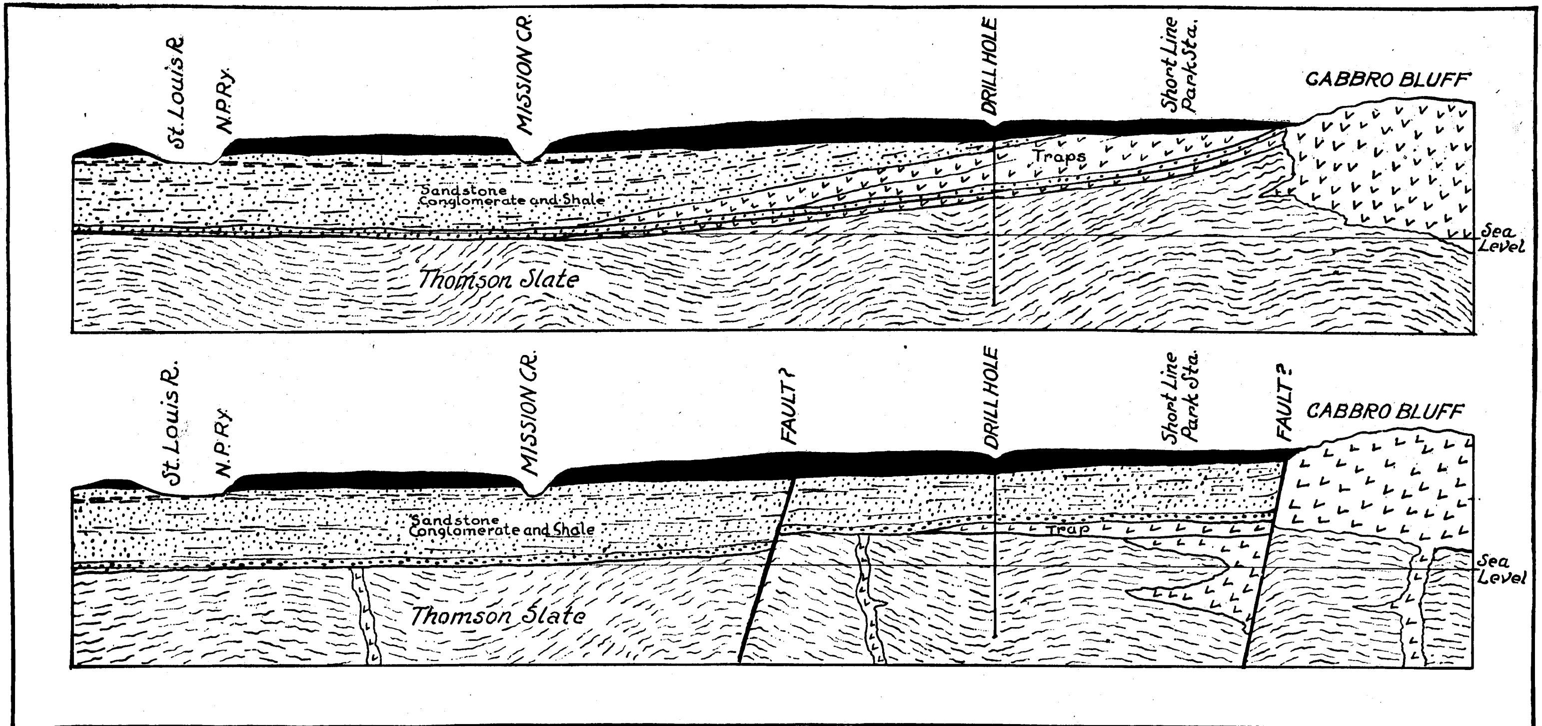
1 Winchell, N. H., Geol. of Minn., vol. IV, 1899, p. 15.

2 Hall, C. W., Keweenawan Area of E. Minn., Bull. Geol. Soc. of America, vol. 12, 1901, p. 342.

STRUCTURE SECTIONS FROM ST. LOUIS RIVER, AT FOND DU LAC, MINN., TO SHORT LINE PARK BLUFF, MINN.



Upper section. Interpretation of geology, as given by Minnesota Geological Survey. The quartz conglomerate is shown interbedded with the traps, according to this interpretation of the drill record. The conglomerate was correlated with that shown at the left end of the section, just above the Thomson slate, thus indicating an interbedding of the Amnicon formation and the traps.

Lower section. A different interpretation of the geology. All of the material above the quartz conglomerate, is believed to be sedimentary, the drillings having been wrongly identified. The conglomerate found in the drill hole just above the trap, is still believed to be the same as that found just above the slates farther to the west. The Amnicon formation overlaps the edge of the traps, and may either be unconformable against the gabbro bluff or have been faulted against it, as shown in the section.

Still another explanation of the ambiguous record of the Short Line Park drill hole is, that all the strata above No. 15 are sediments, the drillings from coarse conglomerates having been mistaken for traps by Winchell. The large amount of fragmental material noted in his descriptions of the drillings, supports this view. Moreover, a resident of the vicinity who watched the drilling informed the writer that a daily progress of 10 to 12 feet, presumably in a single shift, was maintained with the use of 1,500-pound tools. Such a rate would favor the view that little or no solid trap was penetrated. If this view (see Plate XX, B) is correct, there may not be any fault between the drill hole and the gabbro bluffs, the conglomerates having been deposited at the base of the trap hills. The scarcity of gabbro pebbles in the drill hole, however, strongly indicates that a fault occurs between the drill hole and the bluff. Such an hypothesis best explains the present relation of the gabbro in the bluffs to the north, and the sediments found in the drilling.

Contact with the Slates. The contact of the Amnicon formation with the Thomson slate, on St. Louis River, demonstrates a progressive overlap. As shown in section A–B, on the general map, the traps must thin out and be overlapped in the space between the Douglas Range and this point. The same phenomenon must also occur in the short distance between Mission Creek and the Short Line Park bluffs (see p. 84).

As noted in the last chapter (p. 72, we find between the trap conglomerates on St. Louis River and the underlying slate a pyritiferous quartz and slate pebble conglomerate, which is clearly part of the Amnicon formation. The surface of the slate is rough, several small knobs showing through the conglomerate (see Plate XV, p. 70).

CHAPTER VII

THE STRUCTURE OF THE WISCONSIN COAST OF LAKE SUPERIOR

General Statement. The basin of Lake Superior is a broad and flat synclinorium. Toward the west end of the lake, this structural trough turns inland up Chequamegon Bay, and thence crosses Wisconsin in a great curve to the St. Croix valley[1] and into Minnesota (see p. 60). The southward-dipping Douglas or South Trap range divides it from the far western end of the lake, which is bounded on the north by the south-dipping traps of the Minnesota or North range.

The Bayfield and Oronto sandstone groups occupy the narrow strip between the north escarpment of the faulted Douglas Range and the lake, lapping across the course of the traps in the promontory of the Bayfield Peninsula and the Apostle Islands, and extending into the basin of the main syncline to the east. On the south shore the sandstones have a low southeasterly dip, a continuation of the inclination of the traps of the north coast, passing to the southeast into a series of broad open folds which occupy the bottom of the synclinorium. The major structural features of the region are the Douglas Fault, the North Coast

[1] Irving, R. D., Geol. of Wis., 1873–9, vol. III, p. 1.

—— Copper-Bearing Rocks. U. S. G. S. Mon. V, p. 410, with structure map and natural scale sections.

Hall, C. W., Keweenawan Area of E. Minn., Bull. Geol. Soc. of America, vol. 12, 1901, p. 313.

Grout, F. F., Contribution to the Petrology of the Keweenawan. Jour. Geol., vol. XVIII, 1910, p. 633.

Fault, and the folds within the Lake Superior synclinorium south of Ashland.

Douglas Fault. The exposures of the great fault along the northern edge of the Douglas or South Range have been described in detail in the last chapter—the conclusion being there reached that the displacement is in large part later than the deposition of the sandstones, although movement may have taken place before or during their formation. The fault plane dips to the south at angles varying from 38° to about 60°, and the south side is raised relatively to the north side, this fact showing it to be a thrust fault. Its origin is a broken anticline, as shown by the overturned fold of sandstone thrown up at one locality, and apparently it is allied in point of age with the period of Keweenawan folding. The displacement on this fault must be enormous, over three thousand feet being known at one locality. This can only be a fraction of the total, which must be equivalent to the sum of the thickness of the traps above the horizon at which the fault occurs and of the sandstones. The former rocks were estimated by Sweet[1] to be at least 36,000 feet thick, above the lowest horizon faulted up, provided that unknown faults have not duplicated the exposures. It seems probable that from 4,000 to possibly 15,000 feet of sediments overlie the traps (see structure sections on general map) in the vicinity of Superior. Since the displacement along the fault plane is greater than the stratigraphic thickness between the horizons on each side of the fault, a throw of from six to twelve miles is estimated. This figure is truly enormous, but is no greater than the absolutely proven displacements of many thrust faults. The shortening represented by the folds between Madeline Island and the Penokee Range is computed from structure sections E–F and J–K to be at least five miles, agreeing closely with the lower estimate given for the fault.

In its course (see general map in pocket), the fault does not exactly follow the northeast strike of the traps and sandstones, but turns in a zigzag line in a general E–NE direction, thus cutting across the strike of both series. Following it to the southwest, the fault thus progressively brings older sandstones in contact with younger traps.

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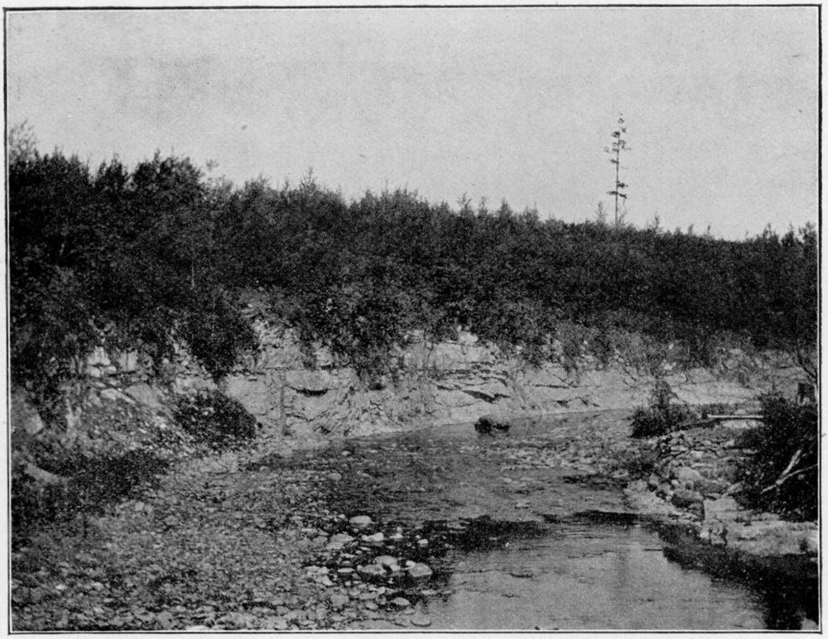
1 Sweet, E. T., Geol. of Wis., 1873–9, vol. III, p. 338.

The Douglas fault does not pass through the Apostle Islands, but appears to die out into a fold which in turn becomes gentler and finally flattens out beneath the drift-covered area of the Bayfield ridge. The dying out of the fault is to be correlated with the northeastward pitch of the minor folds (see p. 92), and the general broadening of the synclinorium in northern Ashland County. The compressive stress which to the west was relieved by the thrust fault, was there relieved by folding. It is very probable that this dying out is accompanied by normal faulting perpendicular to the strike. Such dip faults are known to occur at some of the angles in the course of the thrust fault (see p. 81). As indicated by the topography, the fault appears to follow a nearly straight line from where the trap outcrops on Iron River, to the southwest, where the Trap Range becomes ill defined; and finally, in the vicinity of Maple, in Douglas County, is entirely buried beneath the Pleistocene deposits. Where exposed on Middle River, the fault has a strike of N. 65° W., thus showing that there is a reentrant in its course beneath this unexposed gap. In this reentrant is found the great overturned fold of Middle River (see p. 66). This fold is apparently a local feature associated with the change in direction, but unfortunately the exposures on Poplar River are not sufficient to allow its eastern extension to be examined. Cross faulting may also occur.

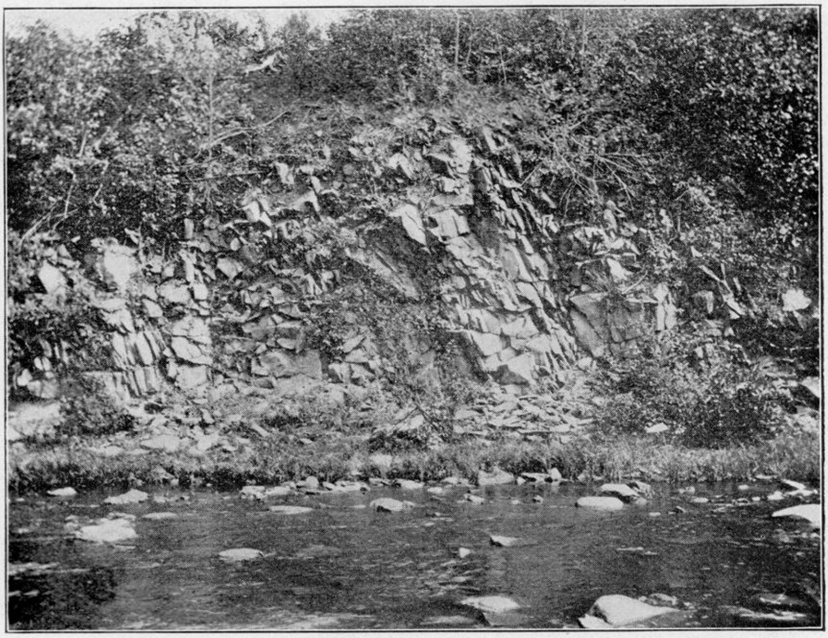
Plate XIII, p. 66, represents the structure of the rocks exposed on Middle River, to the north of the fault; its general features have already been explained. Jointing in the sandstone is best developed along nearly horizontal planes (Plate XXI opposite). In some cases these show faulting, the upper blocks having moved a few inches to the north. The actual junction with the trap is not exposed, but is associated with no marked breaking or crushing of the sandstone. The trap is, however, considerably brecciated. The thickness of strata of sandstone involved in the fold shows that there has been at least 3,000 feet of movement on the fault at this point.

Between Middle and Amnicon Rivers, the fault takes a course nearly due west. Just at the crossing of the latter stream it resumes a southwesterly direction. This exposure is described in detail on pp. 77–79. It would appear that the confused fault-

MIDDLE RIVER, DOUGLAS COUNTY.



A. Vertical beds of red feldspathic sandstone of Orienta formation, showing horizontal joints formerly mistaken for bedding. Just north of bridge on south line of Sec. 24, T. 48, R. 12 W.



B. Overturned beds just south of the bridge, from which A was taken.

ing along planes essentially parallel to the main displacement, is due to this change in direction. Because of this, the striations seen on the sandstone (see p. 78) have little weight in disclosing the history of the displacement.

Southwest of Amnicon River, the fault follows the more or less marked escarpment of the trap range, to where it crosses Black River. The only good exposure of this portion, on Copper Creek, shows that the plane of movement dips about 60° to the southeast. The sandstone is sharply flexed and sheared for less than 50 feet from the junction.

Another reentrant occurs at the falls of Black River (Plate XIX, p. 80). This is marked by normal dip-faulting, as well as by faulting in the sandstone, parallel to the main plane of displacement, which is seen to dip about 50° to the south. The trap is intensely brecciated. A small normal fault of E–W strike is found in the sandstone still farther to the north.

West of Black River, only slight bends interrupt the southwesterly course of the fault. The only known exposure in Wisconsin (see p. 81) shows a sharp flexure of the sandstone and considerable brecciation of both formations.

In Minnesota, Hall[1] has shown that the great fault extends far to the southwest, nearly to St. Paul, but its age has not been satisfactorily determined.

North Coast Fault. For various reasons, the evidence being mainly physiographic, it has long been thought that the abrupt descent from the nearly level uplands of Minnesota to the deepest part of Lake Superior was marked by a fault.[2] Moreover, at Superior, deep wells show a considerable thickness of shale, across the river from the high trap hills. The dip of the formations here is not known, however, so that it might readily be steep enough to carry the sediments over the traps.

St. Louis River. On St. Louis River there is observable a dip of 6° to 10° to the southeast, together with a complex system of normal faults (see Plate XV, p. 70). These faults are un-

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1 Hall, C. W., Keweenawan of Eastern Minnesota, Bull. Geol. Soc. of America, vol. 12, 1901, p. 313.

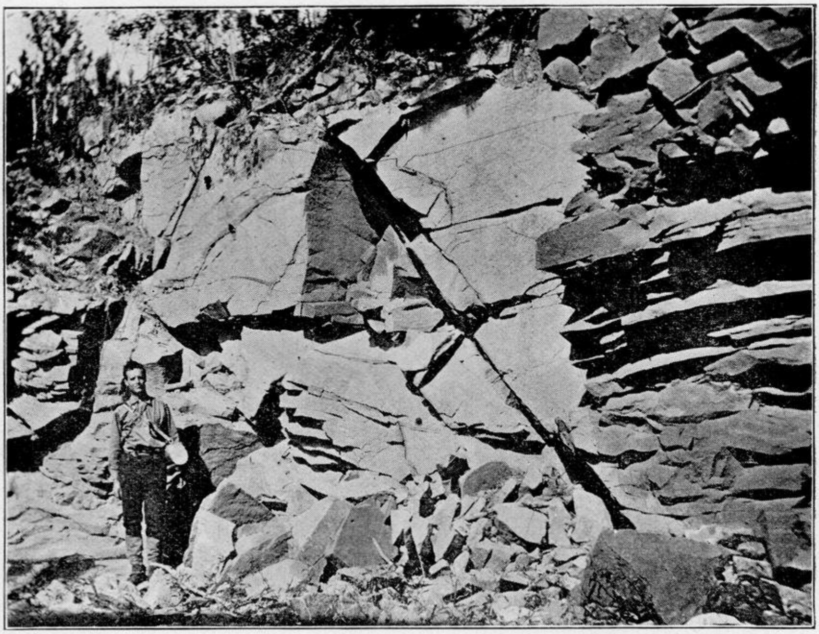
2 Martin, L., The Geology of the Lake Superior Region, Mon. U. S. Geol. Survey, vol. LII, p. 112.

usually well exposed (see Plate XXIII, B, p. 94), so that the exact plane of movement can usually be observed. This varies in dip from vertical to about 60° toward the downthrow side. This displacement varies from a few inches up to about 40 feet; the fault shown in Plate XXIII, B, has a throw of about 14 feet. The strike of most of the faults averages about N. 35° W., but a few have a nearly E–W direction. Occasionally, slickensides occur; these indicate more or less of a horizontal component to the motion. As already mentioned (p. 87), it appears necessary to assume the existence of a fault between the sandstones of Mission Creek and the trap bluffs at Short Line Park; but the drill record (see p. 85) near the latter locality is so ambiguous as to afford small help in locating the displacement.

Folds Near Ashland. Beneath the eastern plain southeast of Ashland, occur the most interesting structural features of the district. Unfortunately, however, few outcrops exist, so that much of the structure remains obscure. But sufficient evidence has been discovered to show that we have to deal with the south half of an asymetric synclinorium, in which the southward dips are comparatively gentle while the northerly dips are steep. The southern side of the synclinorium carries more minor folds than the northern (see structure sections on large map). These minor folds appear to pitch to the east and northeast.

The strata of the Apostle Islands represent the gently-dipping north limb of the great depression, while the faulted anticline of the Douglas trap range is a subordinate eastward-pitching fold on this limb. If the map were continued farther south, we should find (see Atlas Plate XXII, Geology of Wisconsin, 1873-79) that as the axis of this great Lake Superior synclinorium passes inland near Chequamegon Bay, it suffers a rather sudden bend from its northeast-southwest direction to a course slightly north of west. Farther to the west, however, as shown on the map by the line indicating the probable course of the synclinal axis, it resumes its usual southwesterly direction.

In the vicinity of Oronto Bay are good exposures of the southern limb of the main fold. Here the strike averages N. 53° E. with a northwesterly dip of 45° to 90°, the average being about 65°. Minor undulations are not common, nor are joints especially numerous (see table on p. 96). Small dip faults



A. Minor thrust fault of unknown displacement, in Orienta sandstone just north of main fault on east bank of Amnicon River, Sec. 29, T. 48, R. 12 W., Douglas County. This is the most northerly plane of faulting (see p. 77, and Fig. 10).

B. General view, looking south, of falls of Amnicon River, at contact of traps and Orienta sandstone. The falls are just on the fault (see Plate XVIII, p. 76, and Plate XVIIIa, p. 78).

occur in places, with striae showing that the movement has been mainly horizontal; the displacements are apparently not over 45 feet. Slickensides also occur on some of the beds, while inclined fractures dipping toward the northwest combine to give an impression that there has been strike faulting with the down-throw towards the lake. Inclined fractures striking parallel to the dip also occur, but the details were not worked out.

Northwest of Oronto Bay, the first minor fold of the synclinorium has its crest at the apex of Clinton Point. This locality is figured in detail in Plate IX, p. 54. The beds which dip to the southeast are submerged, hence are only visible when the water is clear and calm, and then are seen at their best from the top of the bank. Most of the exposures to the west are almost aswash, so that it is not surprising that former visitors have misinterpreted the structure (see p. 15). The inland continuation of the fold is unknown, the deep well at Birch not having struck rock at a depth of 300 feet; but apparently the anticline merges into the south limb of the main fold, as shown on the map.

Close to the north side of the anticline, runs the axis of a syncline, which must lie between it and the southeasterly-dipping rocks on Bad and White rivers. At the former locality the dip varies from 27° to 55° to the southeast with a strike of about N. 50° E; at the other, the strike is about the same, with a dip averaging about 25°. The rocks have not been greatly affected by the folding. Joints are not abundant, and most of them follow the strike (see table).

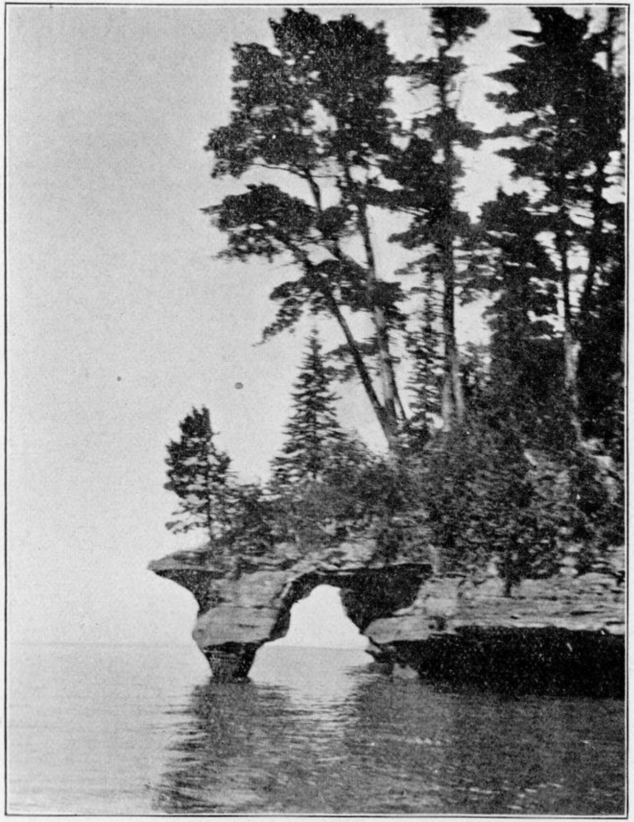
Passing again to the northwest, the next known exposures are those on the South Fork of Fish Creek, near Ashland. Here the strike averages N. 85° W., corresponding to that of the rocks of the south limb of the synclinorium farther to the south, while the dip is northerly at angles varying from 70° to 90°, the inclination lessening towards the north (see Plates VIII, p. 52, XI a, p. 62, XI b, p. 64, XI c, p. 64). There is no repetition of beds by close folding. Horizontal or slightly inclined joints are most common. On some of these there has been differential movement, so that the upper side has moved north. The maximum displacement noted was about four feet. A small thrust fault, dipping 20° S., was observed, but there was no evidence of a displacement of more than 15 to 20 feet (see Plate XI c, A, p. 62). The strike of the fault is the same as that of the beds.

Between the north-dipping rocks of Fish Creek and the exposures on White River, five miles to the southeast, there must exist an anticline which may possibly be faulted like that of the Douglas Range. It is difficult to decide on which side of the center of the synclinorium this axis lies; but the evidence appears to favor the view shown on the map—that it is on the southern side, merging with the main south limb near the bend to the southwest. On account of the absolute lack of exposures west and northwest of Fish Creek, the distribution of the formations shown on the map is mainly hypothetical.

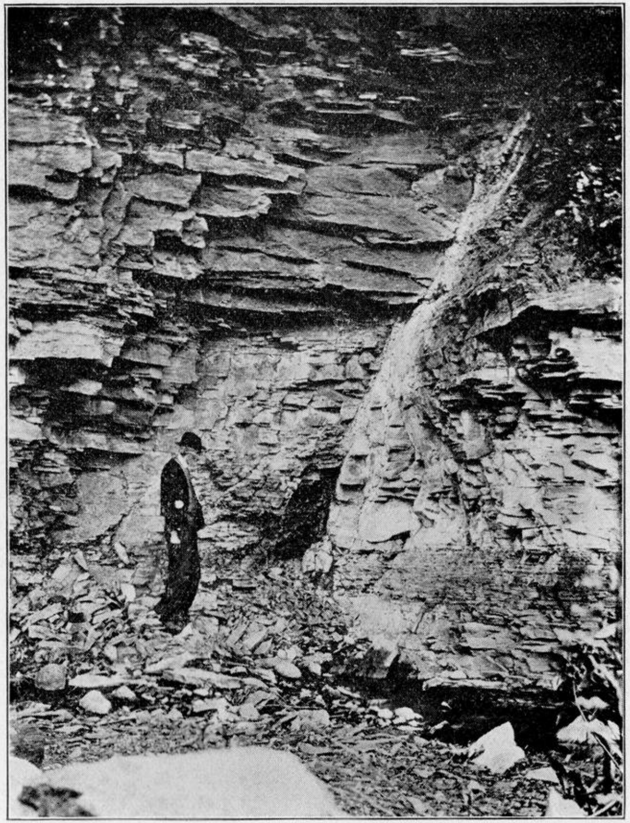
Structure of the Bayfield Group. The strata of the Bayfield group are in general but slightly inclined. The dip varies from nothing up to a maximum of about 5 degrees, except where the strata have been affected by the Douglas fault, and towards the edges of the synclinorium, on Fish Creek and St. Louis River, where greater dips are found. In spite of the fact that this dip is higher than the average for the flat-lying rocks in southern Wisconsin, joints are not as abundant as in the latter region. In most cases the fractures are irregular and often end at bedding planes (see Plate IV, B, p. 30). For the most part, only well-defined fractures were measured by the writer, since the minor ones are often curved or run in such a variety of directions that measurements are meaningless.

The accompanying table and diagram show that the best developed joints approximate an E–W direction; next in importance follow those which strike a little east of north, while northwest and northeast joints are occasionally noted. It will be seen that there is little relation to the direction of the strike and dip of the bedding, or to the main lineaments of the country. Many of the E–W joints are inclined, usually at a steep angle to the north.

Occasionally, beds are found that are much more fractured than those above or below. An instance of this is found near the northeast corner of Oak Island, where a shaley bed a few feet in thickness is cut into small slabs and sometimes long slivers, by a set of N–S and E–W joints. On Point Detour, Poplar



A. Sea caves in Devils Island sandstone, near Squaw Bay, Bayfield County (see p. 39).



B. Normal fault of 14 feet displacement, in arkose grits and sandstones of Amnicon formation. Gully just above railway bridge, Sec. 1, T. 48, R. 16 W., Carlton County, Minn.

River, and North Twin Island occur other sheared layers of sandstone. The fragments are usually subangular and consist of the adjacent sandstone, but they are always much weathered. They much resemble conglomerate on the weathered surface, but lack a decisively sedimentary character; while the layers often pinch out or run into irregularly broken rock. Presumably these phenomena are due to shearing and in part to concretions of iron (cf. p. 31).

Age of the Deformation. There is no direct means of determining the age of the deformation of the sandstone groups. It will be pointed out, however (see p. 101, in the consideration of their origin, that it is quite probable that earth movements went on simultaneously with the deposition of sediments of the Oronto group. It is also probable that the movements which formed the Douglas fault, continued throughout the period of deposition of the Bayfield group, for there has been a great amount of displacement since its beds were hardened. The Orienta sandstone, a member of the Bayfield group, is involved in the general regional folding in the vicinity of Ashland. In many places it would appear from the lack of secondary structures due to folding (see p. 92), that the deformation took place before the rocks were entirely indurated. This supposition agrees with the scarcity of joints throughout most of the area. Many faults, although formed after hardening, are now entirely recemented, while secondary fractures unrelated to folding are quite common. There is, however, no evidence of any marked deformation since that which produced the folds and faults. This deformation appears to have continued throughout all of the Keweenawan period.

Origin of West End of Lake Superior. The main body of Lake Superior occupies a great structural as well as topographic depression. It would appear probable that the deformation of the rocks took place mainly during and shortly after the Keweenawan period, and that the present depth of the topographic basin, slight compared with its width, is due to subsequent erosion (by what agency is unimportant for this discussion) of the relatively soft Upper Keweenawan sediments that occupied its center. Turning to the western portion of the lake, especially westward of the Apostle Islands, there is found little evidence

Table showing direction of Joints and Faults.—West End of Lake Superior

	Locality	Strata			Joints			Faults			
		E. of N.	W. of N.	Dip	E. of N.	W. of N.	Dip	E. of N.	W. of N.	Dip	Displacement
Bayfield Group	Washburn			S-5-1°	85°	0, 82°	90°				
	Houghton			S-5-?	0, 45, 90	45, 83	"				
	Pikes Quarry			S-5-?	0, 18-25, 8', 90	7?-82	"		75°	90°	?
	Big Bay			?		60, 75	"				
	Basswood Id.				0, 90						
	Stockton Id.				0, 5-'0, 90						
	Hermit Id.				0, 10-15, 90						
	Oak Id.	45°		SE-1°-5°	13-22, 45, 70, 80-84	65-70, 85-89					
	Devils Id.	45		SE-1 -3		80					
	Sand Id.	45		SE-1 -5	80-82	12					
	Eagle Id	45		SE-5	50						
	Siskowit R	45		SE-?	74						
	Port Wing	45?		SE-?	0	10, 55					
	Brule R.	45		S-SE-2-3	0, 5, 30, 87						
	Poplar R.			S-0-6	65, 75-80						
	Amnicon R.	45-83		SE-E-1-10	38	5, 34					
	Copper Cr.				45	75					
	Black R.	55		SE-5	75						
[illegible] Group	Oronto Bay	45-53		NW-50-75	33, 45, 60, 90	20-35, 40-45, 60			20-35, 40	90	5ft-45ft
	Clinton Pt	38-48		NW-12-40	35, 50	30, 50, 65	50 W. dip, NE crest anticline 38 dips 60° NW				
	Bad R.	45-55		SE-27-55	60, 75 2, 38, 50	15, 45, 80					
	White R.	50-65		SE-25-28	50						
	Fish Cr.		78-88	N -70-90			Horizontal		85	S20	Thrust
	St. Louis R.	50-60		SE- 5-10	0, 10, 15-18, 32-35 53-67, 70-85, 90	10-25, 58, 78-87		85-90	30-10, 87	62-90	½ft-40ft

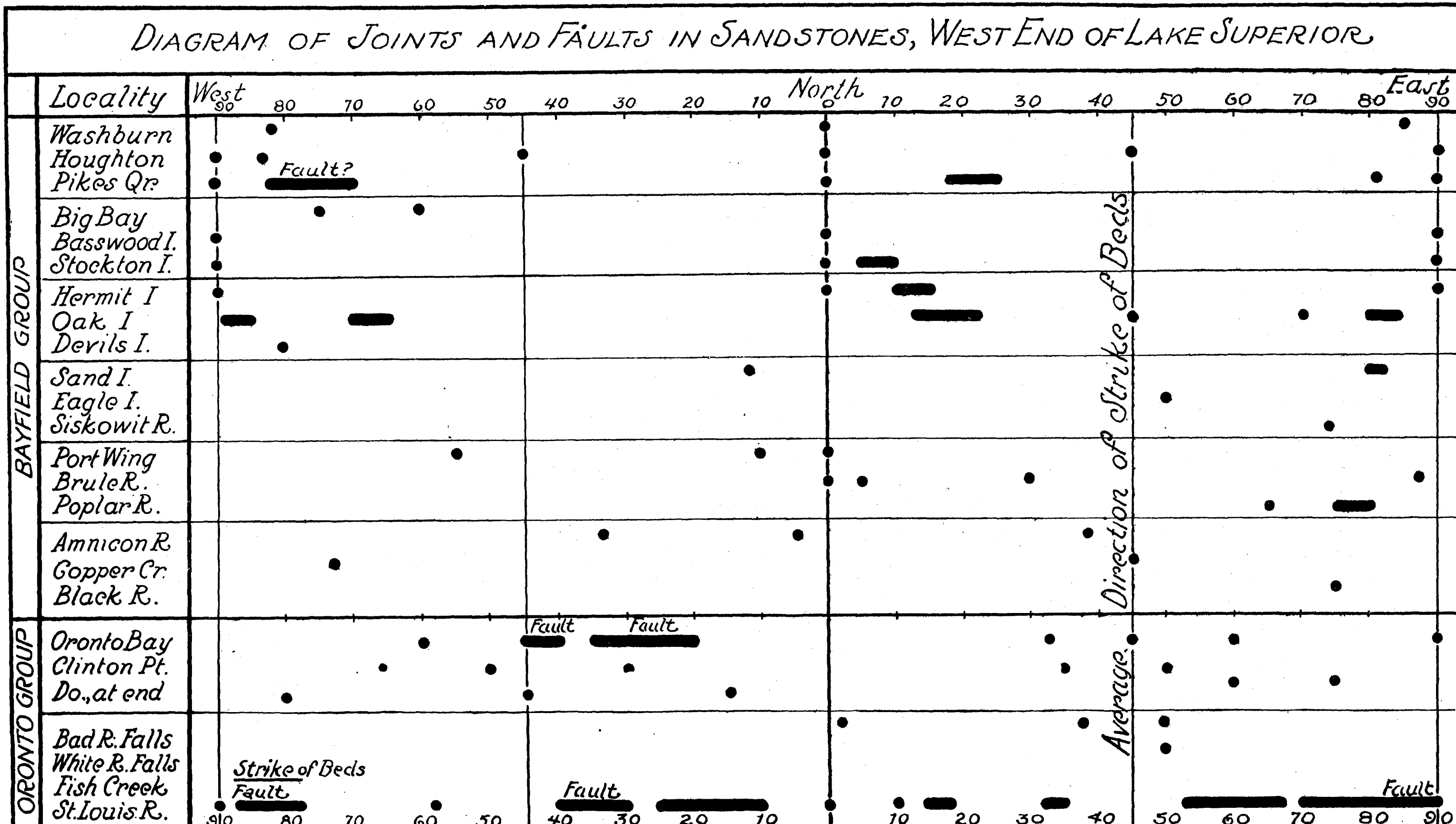


DIAGRAM OF JOINTS AND FAULTS IN SANDSTONES, WEST END OF LAKE SUPERIOR
Locality
West
North
East
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
BAYFIELD GROUP
Washburn
Houghton
Pikes Qr.
Fault?
Big Bay
Basswood I.
Stockton I.
Hermit I
Oak I
Devils I.
Sand I.
Eagle I.
Siskowit R.
Port Wing
Brule R.
Poplar R.
Amnicon R.
Copper Cr.
Black R.
Average Direction of Strike of Beds
ORONTO GROUP
Oronto Bay
Clinton Pt.
Do., at end
Fault
Fault
Bad R. Falls
White R. Falls
Fish Creek
St. Louis R.
Strike of Beds
Fault
Fault
Fault
7

of a structural origin of the present topography, although the rock fractures of the Oronto Bay region do indicate a depression of the lake bed since the completion of the folding. Indeed, the lake does not extend so far up the main syncline south of the Bayfield Peninsula as it does north of the Douglas Range toward Superior. On the south side of this great western extension of the lake, we find no vestige of a structural origin, for the sandstone universally dips away from the lake.[1] (See structure sections on general map, in pocket.)

The explanation must lie in differential erosion. We can clearly discern that the Bayfield Peninsula must owe its origin primarily to different causes than the trap ridge of Keweenaw Point, which it resembles in outline. It may be supposed that the influence of the soft shales of the Amnicon formation is responsible for the development of the Superior-Duluth arm of Lake Superior. A study of the depth of the water shows that the deeper part, which is not over 900 feet, is confined to the neighborhood of the north coast, where this formation is believed to outcrop (see p. 73). At Superior, well records show that this ancient valley lies upon the shales next to the foot of the Minnesota trap range. It is known to have been eroded at this point to a depth of over 500 feet below the present lake level. In the case of the Chequamegon Bay region, the structure was more complex, so that beds of varying hardness and attitude were exposed by erosion. Buried valleys, almost as deep as those at Superior, are known from the records of wells south of Mason and in Ashland County.[2]

The Bayfield Peninsula, then, is a ridge of flat-lying, comparatively resistant sandstone, left as an erosion remnant between two areas mainly composed of shales and soft arkose. The outline of the islands is approximately that of the pre-glacial hills into which this ridge was cut. Some of the ancient valleys between them (as east of Outer Island) appear to have escaped filling by the glaciers which deposited the huge interlo-

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1 Owen correctly observed this feature. Geol. Survey of Wis., etc., p. 270.

2 These records and many others are on file in the office of this Survey.

bate moraine upon this dividing ridge, thus giving to it its present height. That the erosion of this part of the Lake Superior basin was the work of streams, rather than of ice, therefore appears most probable.

CHAPTER VIII

CONCLUSIONS

General Statement. No fossils have been, or seem likely to be, discovered in either the Bayfield or Oronto groups of sediments, by means of which they may be assigned to a definite geologic period. They must therefore be correlated on the basis of lithologic characters, origin, and general stratigraphic and physiographic relations.

Summary of Lithologic Characters. The sandstones and shales of the Wisconsin coast of Lake Superior comprise an enormous thickness of sediments, amounting possibly to nearly 25,000 feet. In composition they show a progressive change, with but minor alternations, from sediments composed of poorly assorted and almost unaltered fragments of igneous rocks, to dominantly siliceous sandstone, which represents a marked degree of weathering and assortment of the original material.

The greater part of the lower, or Oronto group, may be placed in the first class. It is composed of debris of igneous rocks which usually was but poorly assorted, and little weathered or worn before deposition. In the Bayfield group, the forces of decomposition and sorting had greater effect, so that a much greater proportion of more resistant minerals are found. The dominant source of the sediments, moreover, had changed. The material of the older group was mainly, although not wholly, derived from the Middle Keweenawan traps, while the siliceous sands and orthoclase feldspars of the Bayfield group represent the debris of older sediments, granites, gneisses, and schists. Both groups differ from the older sedimentary series of the

Lake Superior region in containing, so far as known, neither iron formation nor distinct pyroclastic material.

Comparison with Sandstones of Southern Wisconsin. The differences of the rocks of the Oronto group from the sandstones of southern Wisconsin are clearly apparent. The Bayfield group, although in some horizons much like the southern rocks, differs in many important respects. Its color is usually some shade of red; while the southern sandstones, where they contain iron, are prevailingly yellowish. The dominant cement of the latter rocks is calcium carbonate, and this is almost entirely absent in the Bayfield group, its place being taken by silica and iron oxide. The sand grains are almost universally much less rounded, and the secondary enlargements are very irregular. Nevertheless they are more indurated. Much more feldspar, mica, magnetite, and other minerals derived from rather basic rocks are found. Clay pockets, and pebbly bedding planes, as well as irregular and curved bedding, are characteristic of the northern sandstones. But little clay shale, or clean quartz sandstone, and no fossils, occur in these rocks. All these facts point to different conditions of origin, as well as a somewhat different source of material, from that of the sandstones of the southern part of the state.

Origin of the Sandstones. The facts bearing on the conditions of origin of the Oronto group are numerous and almost indisputable. That it is a non-marine deposit is disclosed by mud-cracks, abundant ripple marks (often of the type produced by currents), rain prints, angular sand grains, poor assortment, absence of fossils, and by channels in shale beds filled with sandstone. All of these are features characteristic of stream deposits, laid down by shifting and variable currents of water, probably, but not necessarily, under desert conditions. The flat clay pockets are believed to be associated with the mud-cracks, being dried films of clay broken up and then buried in the sands. Another feature of fluviatile deposition is the abundant and irregular cross-bedding, dipping in various directions. The exact origin of the light-colored spots, so conspicuous in many localities, is unknown; until this is determined by chemical work, little can be concluded from the color of the rocks. They may be due to particles of either organic matter or iron pyrite. The prevailing red color is generally believed to represent aridity at the time of deposition. Taken in connection with the absence of fossils, it certainly does denote a scarcity of life, the remains of which would have bleached the ferric oxide; but as iron was so abundant in the traps from whose debris the sediments were built up, this conclusion is rendered doubtful. Apparently, conditions were favorable to the oxidation, but not to the chemical concentration of iron, the magnetite beds being the result of purely mechanical processes. Likewise conditions were unfavorable for the chemical concentration of copper derived from the traps. The salty water often found in the rocks of the Oronto group is without significance, since both marine and non-marine sediments are salty.

Passing to the overlying Bayfield group, we again find nearly all of the features of terrestrial deposits mentioned above. Naturally mud cracks are not as common as in the more shaley rocks of the older group, but are occasionally found at almost all horizons. The flat clay pockets and eroded channels are abundant, but the latter differ in being often cut in sandstone and filled with shaley rock. Rain prints were not noted. No distinct evidences of wind action were discovered, although it is possible that some of the peculiar cross-bedding may be of dune origin. The angular character of the sand grains, however, does not favor such an hypothesis. Neither can any definite conclusion be drawn from the ferric oxide which gives the predominant color. It has been so thoroughly redistributed by the action of ground water that its original state is a matter of doubt. All that can be said is, that most probably it was originally confined to the finer grained beds. The irregularly scattered pebbles — concentrated only on bedding planes, and never forming beds of any thickness—are also believed to favor the hypothesis of fluviatile origin. No deposits like those at the foot of sea cliffs are found along the Douglas fault, although movement probably took place during the deposition of the sandstone.

Age of the Bayfield Group. The age of the Bayfield group cannot be definitely stated, as it could were fossils present. It must be correlated by the same methods that are used with the other non-fossiliferous series of the Lake Superior region. In the past it has been considered to be of Cambrian age: first, because of the supposed striking difference in degree of folding from the recognized Upper Keweenawan sediments (Oronto group); and second, because of its likeness to the eastern Lake Superior (Jacobsville) sandstone of Michigan, which is believed to be Cambrian. In later years the probable areal connection of the Bayfield group with the red clastic series of southeastern Minnesota has been appealed to in order to prove the Cambrian age of the entire Keweenawan series. The possibilities are, then:

1. The Bayfield group may be unconformable upon the Oronto group, and be conformable with the Potsdam of the Mississippi valley. It may be either the same thing as the southern sandstone, or its conformable downward extension.

2. The Bayfield group may be unconformable upon the Oronto group, and be unconformable below the recognized Cambrian. It would then belong to an unknown and unrecognized period.

3. The Bayfield group may be conformable upon the Oronto group, and conformable with the known Cambrian. This would involve the assumption that the period of Keweenawan deformation and terrestrial deposition continued until the advancing Cambrian sea reached the Lake Superior basin, so that the two types of deposition merged into one another.

4. The Bayfield group may be conformable upon the Oronto group, and unconformable below the Cambrian. The time relations to the Cambrian could not then be ascertained.

The writer has sought to demonstrate in the foregoing chapters that there is no reason to believe in the existence of an unconformity between the Oronto and Bayfield groups. Both are a part of the Upper Keweenawan, none of the sedimentary rocks of which display much more metamorphism than do the Paleozoics to the south. The Bayfield group has moreover been shown to be horizontal, merely on account of its position in the center of the Lake Superior synclinorium. Locally it is involved in the more pronounced Keweenawan folds and faults, thus contrasting sharply with the relatively undisturbed Cambrian rocks of southern Wisconsin.

It seems highly probable that the red clastic series which fills the continuation of the Lake Superior syncline beneath the Paleozoic rocks of Minnesota, is the equivalent of part or all of the Upper Keweenawan rocks of Lake Superior; although they may now possess no areal connection with them, either by way of the main syncline or by way of the strip of sandstone adjacent to the Douglas fault, west of Lake Superior. The known thickness of these red sediments in Minnesota is much less than that of the equivalent rocks in the Chequamegon Bay region, so that it may be that they represent only a portion of the series.

The areal connection of the Bayfield group with the lighter colored quartz sandstones of the Kettle River region appears highly probable. But the age of these rocks is unknown, since they too are barren of fossils and are separated by a fault from the traps which intervene between them and the known Cambrian of the St. Croix valley, and are separated by a drift-covered interval from all other strata of known age. A connection with the red clastic series, is, nevertheless, possible.

It therefore appears that the Bayfield group is much more closely allied to the Upper Keweenawan than to the Cambrian. Nevertheless, we must recognize the possibility that it may have been deposited in an inland basin, in part at least contemporaneously with the lower parts of the Cambrian series, and may later have merged into the marine strata when the advancing sea entered the Lake Superior basin. The slight degree of metamorphism exhibited by the Keweenawan sediments as compared with that of the older rocks of the region, supports this view. However, the overlapping of the upper Cambrian strata over the red sandstones in southeastern Minnesota appears very much like an unconformity. Such a discordance could naturally not be recognized in the churn drill records which form the only source of information regarding these deeply-buried rocks.

The equivalence of the Bayfield group with the Jacobsville sandstone ("Eastern sandstone") of Michigan cannot be proved on account of the lack of areal connection, but the lithologic likeness is complete. The Jacobsville is believed by Lane and Seaman of the Michigan Survey to be conformable beneath the light-colored sandstones (Munising) of known Cambrian age (see p. 16). The two areas of sandstones are separated by a wide area of older rocks and may well be of widely different ages. Therefore none of the results of this study should be applied to the question of the relative ages of the Michigan formations.

The question of the relation of the Keweenawan to the Cambrian cannot be here entered upon.[1] It is sufficient to say that so far as Wisconsin is concerned, there is no reason for separating the Bayfield group from the Oronto group, the upward continuation of which it undoubtedly is. Therefore, the Bayfield group, according to all observations we could make, is of Upper Keweenawan age.

Summary of Geologic History. The Huronian formations of the western end of Lake Superior were brought substantially to their present condition before the deposition of the earliest Keweenawan sediments. Their sandstones had become indurated to quartzites, their shales largely metamorphosed to slates, while the iron formations had been greatly weathered. In Wisconsin, however, much of the deformation appears to belong to the same period as that of the Keweenawan.[2]

The first Keweenawan sediments were quartzose sandstone and conglomerate, derived from the erosion of these older rocks. After a slight thickness of this had accumulated, volcanic activity commenced. Lavas of varying types were poured out until a thickness of many thousands of feet had been built up in the structural basin now occupied by Lake Superior. Most of these flows were of basic composition. and none show the characteristics of submarine deposition. Interbedded with the igneous rocks are layers of conglomerate and sandstone, derived from the erosion of adjacent flows. These are mainly composed of debris from acid rocks, since those probably formed greater elevations than the more fluid basic varieties. In the latter part of the eruptive period, enormous masses of gabbro were intruded into the surface flows.

During the deposition of these Keweenawan igneous rocks, folding and faulting went on. In the pebbles of the Outer Con-

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1 For a fuller discussion see Van Hise, C. R., and Leith, C. K., Geology of the Lake Superior Region, Mon. U. S. G. S., vol. LII, 1911, pp. 378–415.

2 A full statement of these facts will be found in Ibid., p. 366.

glomerate, just above the highest flow of the series, are found representatives of all the older rocks, including the deep-seated intrusives. This plainly indicates that tilting and erosion proceeded simultaneously with deposition in the lower parts of the great structural basin. Although the lowermost Keweenawan rocks now exposed were thus not subjected to the weight of all the strata stratigraphically above them, there is no reason to doubt that an enormous thickness was laid down in the middle of the Lake Superior synclinorium.

Oronto Group. Following the deposition of the lava flows, the volcanic activity ceased and sedimentary rocks alone were formed. These rocks, like those interbedded with the traps, were laid down by the streams that eroded the upturning edges of the great basin, and deposited their load upon the floor of the depression in order of the coarseness of the particles. The same process may now be seen going on in the enclosed basins of modern mountains. Whether or not standing water occupied any of the syncline, or the sea entered, is unknown; for it should be recognized that the only rocks now visible are those that were deposited near the edges.

A comparison with modern alluvial fans, shows that the grade of the depositing streams probably decreased as they left the mountains. Near the foot of the surrounding elevations, conglomerate was deposited where the streams just began to spread out and deposit the coarsest portion of their load. Farther out, the gradient lessened still more, and sands and clays were deposited on a slope of probably less than a hundred feet per mile. Floods and shifting of channels, however, mixed the various kinds of material, giving us such sharp changes as between mud and gravel. When the deposits were not covered by water, mud cracks developed and hardened sufficiently to be preserved under the next layer of sediment, which may often have been blown over them by the wind—although there is no recognizable evidence that any large dunes existed. At other times the shifting streams formed temporary lakes, in which ripple marks were formed by the waves, although many such marks appear to have been formed by currents. Again, changes in the currents eroded troughs in previously-deposited sediments. These were later filled, often with somewhat coarser material than that below.

We must, therefore, recognize that deposits of varying lithologic character were formed simultaneously, so that such formations represent not periods of deposition of different materials but the shifting of the zones of deposition, due to the filling up of the basin. The material of the higher beds was progressively more and more weathered, a fact to be correlated not only with this process of shifting zones, in which the material deposited farthest from its source was better weathered, but also with a very probable lessening in the rate of erosion and transportation, and possibly with increase of vegetation on the uplands—both factors favoring chemical decomposition.

Further, it appears quite probable that as time went on, the soft basic traps were eroded to low levels and covered more and more by the spreading sediments. Thus the older sediments, granites, and other more siliceous rocks furnished a relatively greater portion of the material brought down by the streams. It will further be seen that the sediments thus overlapped unconformably upon the previously-eroded lower slopes of the trap mountains, so that although no exposure of such a contact is known, one may yet be found; but this would not prove that the sandstone was much younger than the trap.[1] As the Douglas fault is structurally a part of the general Keweenawan deformation, it is entirely probable that along it more or less movement may have taken place throughout the time of deposition of the sediments.

Bayfield Group. No stratigraphic or sharp lithologic break occurs between the Oronto and Bayfield groups of sandstones, so that no cessation of deposition or radical change in conditions could have occurred. The further extension of the processes outlined above, brought about the change from little-weathered feldspathic sands and clays to fairly-clean quartz sands with very little clay. The greater abundance of acid trap and quartzite pebbles shows that as time went on those rocks furnished more and more material. The red coloration and peculiar bedding,

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1 It appears probable that the red clastic series of Southeastern Minnesota overlaps the traps of the center of the basin upon the granitic rocks of both sides of the basin, and gradually thins out between them and the overlying Paleozoics.

troughs, and so forth, are all found in the Bayfield group, thus indicating conditions of deposition similar to those which previously prevailed. It is unwise, however, with the present imperfect knowledge of the interpretation of different types of bedding, to attempt to state what parts of the formations are fluviatile and what subaqueous. There is little evidence that any is strictly aeolian. There is a strong probability, however, that the Devils Island sandstone differed in manner of deposition from the beds above and below. The prevailing dip of the cross-bedding indicates a northern source for the material, while the lighter color and abundant ripple marks may be indicative of a subaqueous origin. There is insufficient coarse and unweathered sediment in the neighborhood of the Douglas fault to render it certain that there was any considerable movement on that displacement, with the necessarily consequent rapid erosion, during the period of the deposition of the Bayfield group. However, as deformation continued, so that there has been over 3,000 feet of movement since that time, it is not impossible that faulting took place at intervals. The date of the latest movement cannot be ascertained; but as the lower part of the Bayfield group was involved in the Keweenawan folds, it is evident that the deformation continued at least to that time.

As no formations older than the Pleistocene overlie the Bayfield group in Wisconsin, we cannot ascertain how long sedimentation continued. Presumably the entire Lake Superior basin was filled up, thus checking the erosion of the surrounding highlands. Whether or not the deposition of the Bayfield group merged into the Cambrian, when the sea invaded the continent, is unknown. The entire Lake Superior region was doubtless covered by Paleozoic sediments, which have since been almost wholly worn away. It may thus be seen that the basin of the present lake, as distinct from the structural basin of the Keweenawan rocks, does not differ essentially in origin from the basins of the other Great Lakes (see p. 95).

Summary of Conclusions. The Bayfield group of sandstones is conformable upon the recognized Upper Keweenawan sediments, and is therefore a part of that series.

The contact of the Bayfield group with the Middle Keweenawan traps is along a thrust fault, on which great movement has taken place since the deposition of the sandstones. It is probable, however, that as this fault is to be correlated with folding in which the Bayfield group participated, that some movement took place during its deposition; but that such unconformity if it exists, does not represent any considerable lapse of time.

Folding and probably faulting went on contemporaneously with the deposition of both the Oronto and Bayfield groups. The sediments accumulated in the sinking middle portion of the great Lake Superior syncline, while the edges were being relatively upraised and eroded. As the sediments accumulated, they overlapped unconformably upon the feet of the surrounding elevations. Such unconformable contacts have been largely eroded away, but may yet be found. The relation of the sandstones to the traps at Duluth may be of this character, but is probably complicated by faulting.

Both the Oronto and Bayfield groups of sediments are largely if not wholly of non-marine origin, having been laid down by streams in an enclosed basin, not necessarily, although very likely, under desert conditions and probably in part under standing water. The climatic conditions were favorable to the oxidation of iron, a fact denoting a scarcity of vegetation.

The age of the Bayfield group cannot be determined without determining the relation to the Cambrian of the Mississippi valley, with which no areal connection is definitely known. It is possible that non-marine deposits in the Lake Superior basin may have merged into the marine deposition of the Cambrian sea.

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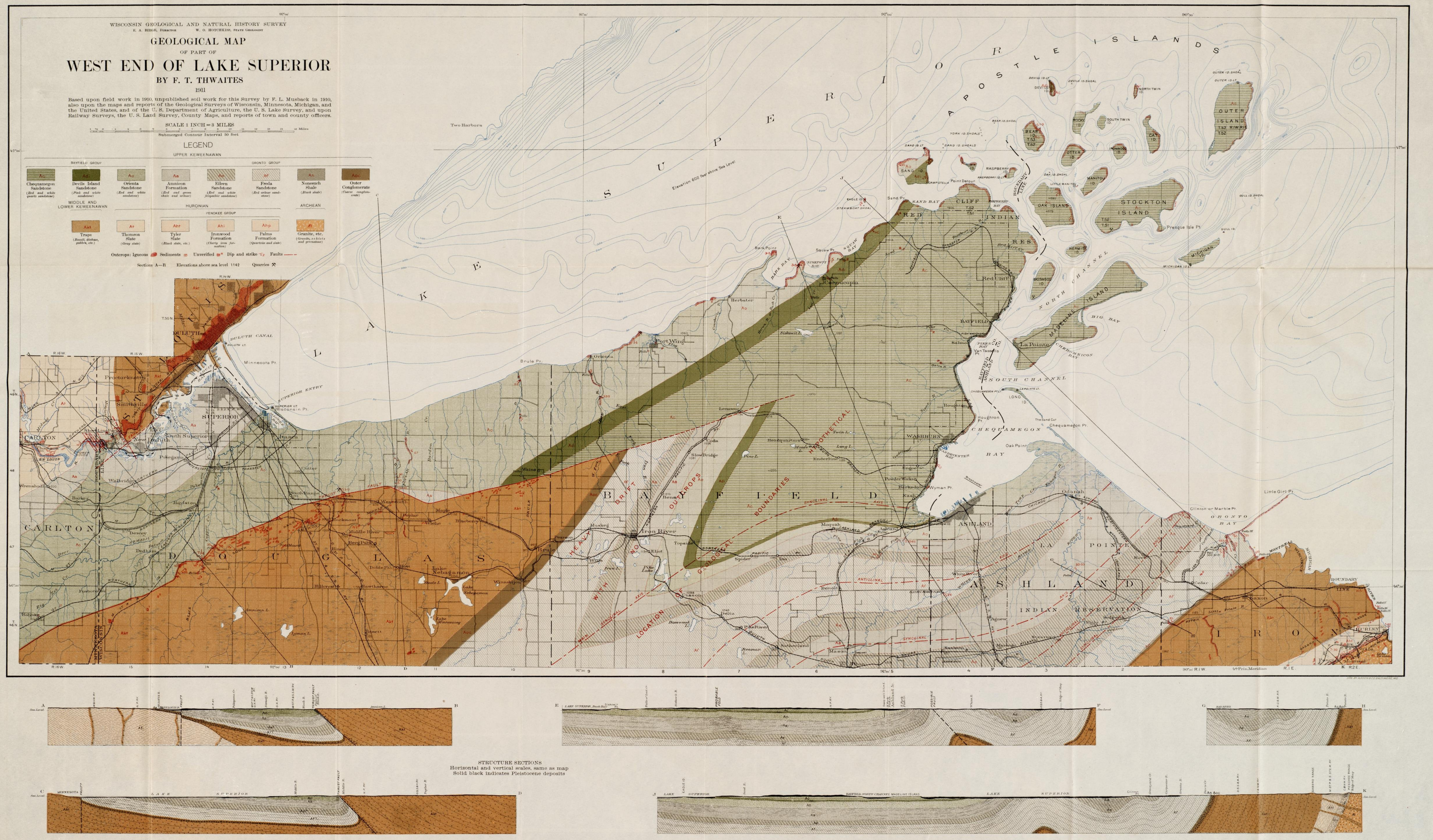
(Includes Plates)


WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
E. A. BIRGE, DIRECTOR W. O. HOTCHKISS, STATE GEOLOGIST
GEOLOGICAL MAP
OF PART OF
WEST END OF LAKE SUPERIOR
BY F. T. THWAITES
1911
Based upon field work in 1910, unpublished soil work for this Survey by F. L. Musback in 1910, also upon the maps and reports of the Geological Surveys of Wisconsin, Minnesota, Michigan, and the United States, and of the U. S. Department of Agriculture, the U. S. Lake Survey, and upon Railway Surveys, the U. S. Land Survey, County Maps, and reports of town and county officers.
SCALE 1 INCH = 3 MILES
Submerged Contour Interval 50 feet
LEGEND
UPPER KEWEENAWAN
BAYFIELD GROUP
ORONTO GROUP
Chequamegon Sandstone (Red and white quartz sandstone)
Devils Island Sandstone (Pink and white sandstone)
Orienta Sandstone (Red and white sandstone)
Amnicon Formation (Red and green shale and arkose)
Eileen Sandstone (Red and white felspathic sandstone)
Freda Sandstone (Red arkose sandstone)
Nonesuch Shale (Black shale)
Outer Conglomerate (Coarse conglomerate)
MIDDLE AND LOWER KEWEENAWAN
HURONIAN
PENOKEE GROUP
ARCHEAN
Traps (Basalt, diabase, gabbro, etc.)
Thomson Slate (Gray slate)
Tyler Slate (Black slate, etc.)
Ironwood Formation (Cherty iron formation)
Palms Formation (Quartzite and slate)
Granite, etc. (Granite, schists and greenstone)
Outcrops: Igneous Sediments Unverified Dip and strike Faults
Sections A—B Elevations above sea level 1142 Quarries
LAKE SUPERIOR
APOSTLE ISLANDS
CARLTON
DOUGLAS
BAYFIELD
ASHLAND
IRON
LA POINTE INDIAN RESERVATION
DULUTH
SUPERIOR
ASHLAND
BAYFIELD
STOCKTON ISLAND
OUTER ISLAND
MADELINE ISLAND
CHEQUAMEGON BAY
STRUCTURE SECTIONS
Horizontal and vertical scales, same as map
Solid black indicates Pleistocene deposits