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AGE OF THE SANDSTONES AROUND LAKE SUPERIOR

By F. T. Thwaites and P. F. Oetting

final
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Fig 2 section R
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Fig 4 section E W
- No min.
Fig 5 dissection of
dip on Grand Island

Introduction. Deciphering the events of the long and complex history of the Earth is like trying to read a book whose pages have come loose. ^{It maybe} It is difficult to put them in ^{proper} order again, and some ^{part} have been irrecoverably lost. We may or may not be able from outside evidence to surmise what was on those missing pages. One of the old problems where there is little direct evidence is that of the age of the sandstones of the Lake Superior Basin. Are these more closely allied in age and origin to the older pre-Cambrian formations, or to the prevailingly horizontal sedimentary Paleozoic rocks of the Mississippi Valley to the south?

^{Previous investigations}
Historical. The problem outlined above has been a vexed one for many years. As remarked by Trowbridge and Atwater (Trowbridge and Atwater, 1934, p. 29), it makes a difference if a geologist approaches this problem from the standpoint of the student of the recognized pre-Cambrian or from the ^{view} standpoint of someone who is familiar with the marine strata of the Central Lowland. The rocks concerned are very little metamorphosed and ^{much} resemble the southern horizontal formations. On the other hand they are ^{grade} associated below ^{into} with a vast thickness of lavas and are ~~to some extent~~ involved in mountain-making earth movements ^{much} like those of the pre-Cambrian. It is necessary to strike a balance between these two different points of view. To complicate the problem still further, the entire region is covered with glacial drift so that, except for the cliffs of Lake Superior, outcrops are few and far between.

Not all of the sequence is exposed.

No attempt is made here to review the views of geologists prior to 1912.

Some of these ^{apparently} had their views colored by the ancient "Taconic Controversy". ^{of the eastern United States}

Prior to 1912, when the report by the writer appeared, the prevailing opinion

was that there is a break between two kinds of sandstone formations in the

Lake Superior Basin and that the upper group is either ^a the local phase of

the Upper Cambrian strata to the south or its downward extension, whereas

the lower one is pre-Cambrian. It was to study this problem that the writer

spent the summer of 1910 at a time when he was inexperienced, particularly

in igneous geology, and when studies of sedimentation were just beginning.

Such aids as color charts ^{air photographs,} and ^{and well writings} X-ray determinations were then unknown. Sig-

nificance of different types of bedding and ripple marks were then not appre-

ciated. (However, the gasoline engine was available, although reliable land

transportation by automobile was yet in the future. The writer covered all

of the lakeshore exposures with a small power boat and made many landings

upon them. ^{In 1912} A car was used ^{to save cost} in ~~1912~~. The exposures on the streams were

traversed on foot, many days hard work being devoted to some of them, as

well as to a search for ^{exposures} any not recorded by earlier geologists. After many

weeks in the field three exposures were discovered on streams tributary to

Lake Superior where there seems ^d to be a complete gradation between the two

types of sandstones. This conclusion then placed all the sandstones in the

Upper Keweenaw which was, by the definitions of the U. S. Geological Sur-

vey, regarded as pre-Cambrian (Thwaites, 1912, Van Hise and Leith, 1911,

pp. 415-416). Here the problem rested until it was reopened by G. O. Raasch

in 1950. The following discussion ^{is} ~~is a criticism of~~ ^{for the most part a} ~~his~~ generally fair and just

reappraisal of the scanty evidence, ^{but it} which was proposed without much field

work ^{by himself.} Hamblin of ^{the} University of Michigan restated the

sandstones of Michigan in 1955 ^{and} concluded that

the red ^{non-marine} sandstone of the ~~east~~ southeast side of Keweenaw Point

^(non-marine) is Middle or Lower Cambrian and ^{probably} (15) unconformable

on the upper Keweenaw sandstone. ^{below} and lower.

^{Four} ~~Three~~ answers could be found for the ^{the} age of the sandstones: (a) they are all definitely pre-Cambrian, (b) they are divided by an unconformity into two marked divisions, the upper Cambrian and the lower Keweenaw, ^{the inter sandstone} (c) ~~the~~ ^{unconformity} divides ~~deposits~~ ^{deposits} of two divisions of the Cambrian, middle ~~and~~ ^{Lower} and ~~traced~~ ^{traced} (d) the Keweenaw is not pre-Cambrian but is the downward extension of ^{upper Keweenaw} the recognized ^{Upper} Cambrian of the Mississippi Valley. Conclusions must of necessity be based on little direct evidence so that the personal bias of the geologist ~~will~~ ^{his} inevitably play a large part in ~~the~~ ^{his} result.

Origin of the sandstones. The writer concluded in his report of 1912 that all of the Wisconsin sandstones are non-marine and were ^{the} a filling of a deep and broad mountain valley with a scarcity of vegetation, ~~but in~~ which there was ^{there was} at times standing water. Reviewed after more than 40 years ^{in this depression with wave ripples and clean bottom} progress of a rapidly-growing science, this conclusion still remains without serious challenge. ^{sampled under this theory in 1958} Measurement of dips, the thicknesses deduced from them, and the division of the ^{strata} sequence into distinct ^{persistent} geological formations are all more open to doubt. Dip of the strata ^{was} could be easily observed from its relation to the lake level, but the ^{angles} dips measured with a Brunton compass from a moving boat are open to ^a the charge of exaggeration. Thicknesses ^{most} are uncertain because of ^{this} initial dip. It is, as was soon recognized, impossible in the sandstones of Lake Superior to trace ~~any~~ ^{any} given stratum for any considerable distance. The shales, ^{beds} for instance, are lenticular and pinch out within a short horizontal distance. ^h In view of the impossibility of discovering ^{could} persistent geologic horizons, it may be that the writer's division into formations was ill-advised. We can recognize definitely that the lower part of the sequence contains much more shale ^{substrata} and conglomerate than do the upper ^{strata} sandstones, so that the separation into Oronto and Bayfield groups appears sound. ^{whether or not they are impossible} The distinctive Devils Island sandstone formation was

actually traced for over 25 miles with little chance of error. A feature overlooked by readers of this report of 1912 is the presence, of quite similar ^{to the Devils Island} rock on Copper Creek far to the west (Thwaites, 1912, pp. 42-44).

Is it the same as the Devils Island or not? The Devils Island formation is certainly overlain by the red sandstone (Chequamegon), ^{at} above which is its type locality as shown in exposures on the south end of the island.

What is gained by trying to disprove this relation by faulting, as Raasch ^{suggested} does? ^{The in standing water} Correlation of the Hinckley sandstone with the Devils Island was suggested by the writer (Thwaites, 1912, p. 58) and has been the conclusion of later geologists who have visited the type locality of that formation.

It is necessary to recall that no fossils are available to confirm such a conclusion, which is of necessity based on lithologic resemblance and structure. ^{The Hinckley strata} ^{equally well} It could be correlated with the beds on Copper Creek. Tyler (Tyler, 1940, p. 1477) has shown by heavy mineral studies that the placing of the Eileen formation of the Oronto group below the Amnicon formation, which is exposed a short distance away on Fish Creek, may be an error. Thrust faults are there present. ^{in relation} If this was an error of the writer, it would reduce the estimated thickness of the Oronto group.

Contemporaneous deformation. The first geologists to study the relation of the Keweenaw lavas to the ~~upper or Bayfield group~~ of sandstones concluded there is an unconformity (Irving, pp. 351-366). ^{within the sandstones} ¹⁸⁸³ The great disturbance of the ^{Bayfield} sandstone by faulting was overlooked ^{because there is} in favor of the evidence of conglomerate along the fault. ^{recognized} It is now apparent that there could have been little or ^{no} any movement on these faults during Bayfield deposition because the Bayfield group of sandstones contains very little debris derived from the flows or intrusions in them (Tyler, 1940, p. 1481). Where did the

The name applies to the N. section sandstone and never ad to some other lithology which it was deposited in study with at in a relation which are clearly indicated

is or it is grades into marine origin above time now ended

debris go which was eroded from the upthrown sides of these great thrusts?

(Figure 1) That problem cannot be answered from information now available.

The conglomerates were undoubtedly faulted up from ^{conglomerate which lies below and may be} ~~Onto~~ beds like those either ~~Onto~~ or Bayfield. This conglomerate facies is well exposed in the ^{on St. Louis River and} of the northern exposures on Fish Creek near Ashland. A similar upturning (Hautw., 1958 pp. 26-33) of older strata occurs in the Wall Ravine of Michigan. Such upturning is

not present everywhere, and in fact one might be pardoned for incorrectly concluding that the flows are younger than the sandstones from the evidence

of some exposures. ^{in Michigan} It now seems clear that the extensive thrust faulting due to compression occurred later than the deposition of the Bayfield group.

It was an earth movement more ^{Anguliform} like those of the pre-Cambrian than anything which affects the Paleozoic of the Upper Mississippi Valley over such a wide area.

Gradation between the two groups of sandstones. Three localities were discovered in 1910 which seem ^{at that time} to demonstrate gradation between the Oronto and Bayfield groups. These are on Fish Creek, Middle River, and St. Louis Rivers. Raasch overlooks the last which ^{is} in the only section in which no concealed intervals are recorded. Further more, careful search failed to disclose any pebbles of Oronto type sediments enclosed in the Bayfield group, although pebbles of igneous and metamorphic rocks are common throughout its entire outcrop. The same applies to heavy minerals. The section on St. Louis River must now be largely concealed by a power dam, which had not yet been built in 1910. In passing, it is fair to remark that the section published by the writer agreed exactly with an older one by Winchell, so that Stauffer (Stauffer, 1927, p. 471) evidently did not read the text carefully and overlooked the addition to Winchell's column of strata which are exposed only in Wisconsin. The conclusion that there is conformity

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between Bayfield and Oronto rests wholly on these outcrops. Although it could be an error, there is ^{definite} no evidence in them to prove it is. ^{Hamblin reports} pebbles of a lower sandstone in the Jacobsville (Hamblin, 1958, p. 61-62)

Extent of the Bayfield group outside the Lake Superior Basin. Raasch ^{Rauch 1950,} presents a map (Figure 1, p. 138) ^{showing} to show a vast extent of the Bayfield group outside of that of the Oronto group which is confined to the basin of Lake Superior. This map is based on ^{The} an interpretation ^{of the lower parts} of the great ~~thickness~~ of the Mt. Simon formation (or member) ^{of the lower parts} of Upper Cambrian age. Correlation of the ^{ac} deeply-buried red sandstones ^{of the lower parts} of northern Illinois, some of which are arkosic ("granite-wash") (Templeton, 1951), with the Keweenawan ^{suggested} was made by the writer in 1923. ^(Thwaites, 1923, pp. 554-555) Subsequent study of cuttings from very deep wells (Knappen, 1926) ^{PRS4-36} served to disprove that suggestion, although it ^{was} appears ~~to have been~~ revived by Bays (Bays and others, 1945), Raasch, (Raasch, 1950) and others so that the new map of Illinois revives Winchell's long un-used local term of "Fond du Lac" for the basal portion of the Cambrian of Illinois. Since these concealed beds ^{definitely} seem to grade into the known Upper Cambrian above, the inference was drawn that the Bayfield group of sandstones must also be ^{upper} Cambrian. The name "Fond du Lac" is ~~most~~ unfortunate for (a) it never had any general usage, (b) the ^{distance} gap from the type locality at Fond du Lac, Minnesota, is long with no conclusive subsurface tracing, and (c) it could easily be confused with the much better-known city of Fond du Lac, Wisconsin. The writer suggests that the name be dropped. The "Red Clastic series" found in wells in Minnesota along the extension of the Lake Superior syncline is the only provable extension of the Bayfield group. Correlation by color alone is very hazardous, ^{for} There are many red Cambrian sandstones. ^{in many} ^{localities} ^{places} ^{interbedded with lighter colored sandstone.}

Late Keweenaw sedimentation. The similarity of sedimentary conditions during Keweenaw time to those of the Snake River Plain in Idaho (Figure 2) is very striking and explains many phenomena which at first sight seem puzzling. In Idaho the basalts rest upon an older series of rhyolite flows which locally project through them. The Tertiary and Quaternary lavas are confined to a basin in the older igneous and metamorphic rocks (Stearns, 1936). Whether this is tectonic or erosional is ^{very important for this problem} beside the point. On top of the basalts the present-day ^{mountain} streams from the mountains are depositing sandy alluvium. This alluvium overlaps the margin of the flows and ^{must} could contain pebbles both from the exposed rhyolite knobs and from the much older rocks of the Northern Rockies. There have been no recent faults to complicate the picture. This Idaho example shows exactly the condition ^(omitting) ~~(save for the water~~ faults) which existed in the Lake Superior region during Keweenaw time. The fact that the pebbles of the Bayfield group, as well as in most older conglomerates, are rhyolite instead of basic rock is exactly matched in these modern deposits. Overlap of the lavas in relatively short distances is obviously not the result of erosion following tilting but is an original feature. The Bayfield sandstone is in fault contact with the lavas on Keweenaw Point, whereas a few miles away at L'Anse it lies on Huronian slate ^{with} ~~(with possibly a~~ glaciated contact. If this is the result of glaciation in the nearby Huron Mountains of that time, ^{The water could fill} there is no distinct till to confirm it. ^{This is a possibility} (Murray, 1955) ^{Figure 3 shows the contrast between overlaps of organically deposited marine sediments and those produced by early filling.}

Fig 2

Fig 2

Fig 2

Fig 3

Fig 3

Fig 3

Figure 3

Insert on page 7

In the gorge of Sturgeon River below the falls in section 17, T. 49 N., R. 35 W., about a mile and a half southeast of Silver Mountain. ^{is an exposure which} So far as the writer can find this locality ^{has never been} described in print. It was brought to his attention by W. K. Hamblin, ^{by Hamblin (Hamblin, 1958, pp. 47-48, 61-62)} who was a student at the University of Michigan, and it was visited by the writer in August, 1958, but rain prevented close examination.

The sandstone is of the Bayfield type much like that exposed at Jacobsville on the shore of Keweenaw Point. According to a letter from Hamblin of 26 March, 1957, the sandstone lies on a highly irregular surface cut into the trap rock together with a zone of weathering about 10 feet thick. ^(Hamblin, personal communication to me, 1957) The locality is near the concealed ^{east} border of the Middle Keweenawan flows which appear to dip ^{west} west about 10 degrees at that place. ^(Hamblin, 1958, pp. 62) The entire Oronto group of shaly arkosic sandstone is missing so that the contact ^{represents} is one of overlap on the border of the basin in which the flows ^{accumulated} occur. As the basin was filled with sediment it is reasonable to conclude that it would be unconformable on all older rocks. ^(see fig 3)

Age of Lake Superior faults.

The great faults south of Duluth and on the southeast side of Keweenaw Point have always been thought of as pre-Cambrian. Raasch correctly points out that at Limestone Mountain, west of L'Anse, faulting and tilting affects strata at least as young as Silurian ^(Hamblin, 1958, pp. 122-124) (Thwaites, 1943). This local disturbed condition has lowered these Paleozoic ^{or possibly Precambrian}

remnants below their expectable position. Similar ^{local} disturbed areas are known at Glovers Bluff, Wisconsin, Des Plaines, Illinois, Kentland, Indiana, and many other places throughout the Mississippi Valley. They are called "cryptovolcanic" by some geologists but display no evidence whatever of ^{either} hot waters or intrusive igneous rock. They ^{probably are due to} ~~may be~~ local renewed movement on old faults. The writer suggests that the north-south fault inferred east of Limestone Mountain may be a fault from Silver Mountain to the southwest which to the north joins the main Keweenaw Point thrust. Silver Mountain is the easternmost portion of a southern range of upturned lavas. When visited by the writer and P. F. Oetking, no ideas could be obtained on its structure ^{but} from a distance it looks like a tilted fault block. ~~If the low country around it is underlain by sandstone, there are neither outcrops nor well data to prove it.~~ ^{apparently} ~~as shown in the Sturgeon river gorge~~ ^{concludes} The writer suggests that the evidence of Limestone Mountain is not at all conclusive on the age of the major thrusts.

Erosion surfaces. Correlation by erosion surfaces, often termed peneplains, is at best very uncertain. The Upper Cambrian of central and ^{see Fig 4} northwestern Wisconsin lies on a surface of moderate relief which bevels across all pre-Cambrian structures ^{see} (Figure 3). Its evenness has been much overstressed by many writers. It is a curved ^{rolling} surface which forms the dome of the Northern Highland of Wisconsin and is obviously continued on the northwest side of Lake Superior. On that shore it has Cretaceous sediments resting on it. Glacial drift ^{lies} rests upon almost all of it. It bevels the upraised sides of the great thrusts and, as noted above, it is impossible to ^{tell} ~~say~~ what became of the material eroded from these. Without entering here on the problem of the origin or origins of this vast erosion surface, it seems logical to conclude that it is mainly, if not wholly, of pre-Upper Cambrian age and bevels all older uplifts. The great thrusts of the Lake Superior

region must be older and have been locally sharpened ^{up} in horizontal outline by glacial erosion during the Pleistocene. ^{This surface} It cuts across the

depressed belts in which the Bayfield and Oronto sandstones were preserved. ^{Figure 4 in a stratigraphic section along the Lake Michigan shore to the west of Munising - It shows a marked wedge at the base of the upper Cambrian} This general relation strongly suggests that the Keweenawan, including the Bayfield sandstones, is much older than the Upper Cambrian.

If the Keweenawan is the time equivalent of Middle and Lower Cambrian in a non-marine basin, we would have to account for (a) so much erosion prior to Upper Cambrian time and (b) the occurrence of so much vulcanism during the time that none is recorded in the areas of older Cambrian both to east and west of Lake Superior. The pre-Cambrian correlation of the Bayfield sandstone, therefore, still appears probable, although we must admit that final conclusive proof is not present. The outliers of horizontal upper Cambrian described by Atwater ^{in north-west Wisconsin} lie upon folded Oronto sandstones not on the Bayfield.

Relation

Contact in Michigan. In northern Michigan the Jacobsville red sandstone appears so much like the Bayfield group that its correlation has always been taken for granted. ^{Certainly there is little to disprove the old conclusion} Upon ^{evenly bedded} it lies a rather thin section of Munising light-colored ^(Hawkins, 1958, pp 71-74) marine but unfossiliferous sandstone. The base of the overlying Munising is marked by a well-bedded conglomerate with stream-rounded pebbles, which are apparently a concentrate from the older Jacobsville pebbles (Thwaites, 1934, 1943). This region has ^{was} been studied in detail by Phillip F. Oetking ^{never} who has not yet reported on it in print. ^{Hawkins duplicated his work some years later} Two explanations of the contact are possible: (a) there is an unconformity and the overlapping Upper Cambrian ^{See Fig 4} contains only the upper portion of the section found to the south, or (b) the Jacobsville sandstone is a local and probably non-marine red phase of the lower part of the Cambrian section as known in southern Wisconsin and northern

Illinois

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9A

Correlation. The correlation and division of the red sandstones of the Lake Superior basin divides itself into two parts: (1) the relation of the red sandstone to the light-colored obviously Cambrian sandstone of the Munising region and (2) ^{the problem of whether or not} are the older sandstones divisible into two unconformable groups?

Relation to the white sandstone above. ^{overlying} The only known contacts of the red sandstones (Jacobsville or Bayfield) with the overlying white sandstone are in the vicinity of Munising from which the white sandstone received its ^{name} name.

Figure 5 shows that there is a slight angular unconformity between the two kinds of sandstone. This fact was long ago noted by Houghton who allowed himself to be talked out of the obvious result of his own observations.

~~For this reason~~ ^{he} ~~he~~ reversed himself and ^{his} the field observations were lost sight of for many years. A difference in strike is more important than this small

difference in dip. The Munising sandstone now recognized as in part Galesville and in part Franconia (Driscoll) ^{pp 51, 13-156} is evidently Cambrian and dips southeast ^{to} into the Michigan basin at an average of about 40 feet per mile or half of one degree. The strike of

the Jacobsville is east-west with a dip of a few degrees to the north into the Lake Superior basin. Hambling fails to describe a marked white layer

below the conglomerate of the Munising. This layer is clearly shown in his Figure 34 p. 65 from which Figure 5 of this paper was redrawn. It is material from this bed that fills the clastic dikes in the top of the Jacobsville.

(Hambling 1958, pp 131-134) It is these clastic dikes ^{which demonstrate earth movement} which give better evidence of a time lapse than does the slight bevel ^{by} the conglomerate.

The pebbles of the conglomerate and ⁿ rounded like those of streams and are a concentrate of the scattered pebbles found in the entire Jacobsville

These pebbles appear to indicate fairly rapid ^{source} streams and therefore a hilly to mountainous source area for the sediments of the Bayfield group, an area

unlike that which furnished the debris ^{much of} of the older Oronto group. (Hambling, 1958)

~~fig~~ (fig 57, p 136.)

Ontario group of definitely Keweenawian sediments. The primary objective of the writers survey of 1910 and 1912 ^{in Wisconsin} was the ~~relationship~~ ^{sandstone} determination of the relationship of these two groups of sediments. After almost the whole of the season of 1910 ^{late in the season of 1910} three sections were discovered which appeared to show a contact between sandstone of the Bayfield type, that is high in quartz and feldspathic sandstone, conglomerate and siltstone beneath. After recent examination of ^{above} ~~basal~~ the rocks of the Ontario group the writer concluded that these rocks are part of that group. The localities were: (1) St. Louis River on the Minnesota border where the section terminates below on the Tomson Slate. The Ontario rock is largely conglomerate ^{largely siltstone} (2) Middle River where about 3000 feet of sediments are upturned by the Douglas County fault, and (3) Fish Creek near Ashland where the inferred ^{and the Ontario sediment is 285 feet of pebbles and shale} ~~and were turned up to a vertical dip by a probable thrust fault~~ Ontario sediments are chiefly conglomerate. All of these sections showed a perfect gradation from Ontario to Bayfield type although only the first displays no covered intervals. Hamblin (Hamblin, 1958, p.) places the conglomerate beds as a phase of the Jacobsville instead of ^{in the} Ontario but in view of the scarcity of exposures of this group in Michigan such a difference of opinion is expectable. The writer, however, made the correlation as Ontario mainly on the sandstone and shale layers within the sequence. At no place did Thwaites find any pebbles of Ontario sediments in the Bayfield group although Hamblin (Hamblin, 1958, p. 61) reports that such occur in Michigan. The siltstone of the Ontario group made largely of comminuted felsite could be readily confused with original felsite. Hamblin also reports (Hamblin, 1958, p. 62) that in the vicinity of Sault Ste. Marie (the Soo) an older series of siltstones dip at a higher angle than do sandstones of the Jacobsville type. He admits however that an angular unconformity is not ^{expressed so the evidence is of far from conclusive} ~~definitely known~~ for there is considerable distance between the outcrops. ^{Moreover} ~~Add to this~~ ^{is a} the possible differences in initial dip especially between sediments derived from different sources and this suggested evidence may be disregarded as inconclusive. It must be admitted that the identification of the basal beds of the three section ^{in Wisconsin} as Ontario is merely an opinion based on similarity as determined by visual observation including use of thin sections,

In this connection it is worth while to quote verbatim the conclusions of the writer in 1912. These statements do not include Michigan (Thwaites, 1912, p. 74)

1. The same conformable downward gradation from more quartzose into more feldspathic sandstone and red shale is found at several widely scattered localities within the district.
2. At most of these localities the identification 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 than those of the Oronto group, thus showing that the materials of the Bayfield group must in any ~~case~~ 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 synclinalorium and hence is usually nearly horizontal but near Superior all along the great fault of the Douglas trap ranges 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 Keweenaw series. //

indistinct - single space

The passage of nearly half a century since the ~~work~~^{ap} was written has disclosed nothing ~~important~~ to change the opinion of the writer. The Sturgeon Falls exposure of the unconformity of the Jacobsville sandstone on the Middle Keweenaw lavas is as explained above not decisive, for it represents the ^{re} ~~an~~ overlap of Case II in Fig. 3 where the unconformity is the normal result of spread of debris up the sides of a valley or depression progressively covering ^{of} ~~ro~~ different rock types. Evidence of discordant dips noted by Hamblin in the Soo region is admittedly indecisive and the weathering ^{of the flows} might be the result of ground water work at the contact of impermeable and permeable rocks. A question still remains as to the disposal of the debris from the flows for there is only a relatively small amount in most of the Bayfield group. The bulk of that group appears to have been derived from granitic rocks. (Thwaites, 1912, p. 57)

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Conclusions. ^{It is possible even if improbable that} The red quartzose sandstones of the Bayfield group of Wisconsin are ~~probably~~^{not} equivalent to the Jacobsville sandstone of Michigan. These sediments are the concluding phase of a period of filling of an intermontane valley due to subsidence of the Middle Keweenaw flows. ^(Fig 4) By the time they were laid down the flows were concealed (almost wholly) so that the younger sandstone is unconformable on ^{the} ~~all~~ Middle Keweenaw ^{lavas} flows and on older pre-Keweenaw formations. ^{as at L Anse.} Apparently little material was derived from the lavas above the horizon of the Nonesuch formation (Thwaites, 1912, p. 57). Later than that time sediments were mainly derived from the rhyolites and the pre-Keweenaw rocks. The exposure on Sturgeon River showing unconformity of the younger sandstones on the Middle Keweenaw lavas is without stratigraphic significance for it is the ^{consequence} ~~expectable~~ result of overlap with filling of the Lake Superior basin. ^{See Fig 2} It is interesting to note that its discovery ^{of Sturgeon Falls} was forecast by the writer in the following words: ^(Thwaites, 1912, p. 107) "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."

Although we ~~may not~~ ^{we do not} today think that the ^{great thrust} faults were formed concurrently with deposition, it is ^{the} post-sandstone bevel of the upthrown sides of these vast displacements ~~which~~ ^{is} the ^{most} important evidence of the pre-Upper Cambrian age of the Bsyfield group of sandstones. This erosion is clearly an event of the formation of the erosion surface below the known Upper Cambrian strata ^{to the south} and the ^(Fig 4) disposition of the eroded debris is unknown. The writer can find no definite evidence which contradicts his conclusions of 1912. ~~Add about accompanying~~

Revised with
(1) deletion to
main body
(2) addition of
note M

~~3 Bsyfield sandstones~~

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AGE OF THE SANDSTONES AROUND LAKE SUPERIOR

F. T. THWAITES

Introduction. Deciphering the events of the long and complex history of the Earth is like trying to read a book whose pages have come loose. It is difficult to put them in order again and some have been irrecoverably lost. We may or may not be able ~~for~~ outside evidence to surmise what was on those missing pages. One of the old problems where there is little ~~if any~~ direct evidence is that of the age of the sandstones of the Lake Superior Basin. Are these more closely allied in age and origin to the older pre-Cambrian formations or to the prevailing horizontal sedimentary rocks of the Mississippi Valley to the south?

Historical. The problem outlined above has been a vexed one for many years. As remarked by Trowbridge and Atwater (Trowbridge, 1934, p. 29) a geologist ~~as remarked by Atwater~~ it makes a difference if ~~you~~ approach this problem from the standpoint of the student of the recognized pre-Cambrian or the standpoint of ~~the geologist~~ ^{someone} who is familiar with the marine strata of the Central Lowland. The rocks ~~are~~ concerned are very little metamorphosed and ~~resemblance to~~ ^{in that} the southern horizontal formations. On the other hand they are associated below ~~with~~ with a vast thickness of lavas and are to some extent involved in mountain-making earth movements like those of the pre-Cambrian. It is necessary to strike a balance between ^{these} two different points of view. To complicate the problem still further the entire region is covered with glacial drift so that ^{except for the cliffs of Lake Superior} outcrops are few and far between. No attempt is made here to review the views of geologists prior to 1912. ^{Some} Many of these had ^{their} views colored by the ancient "Taconic Controversy". Prior to 1912, when the report by the writer appeared, the prevailing opinion was that there is a break between ^{two} ~~two~~ kinds of sandy ^{stone} formations in the Lake Superior Basin and that the upper group is either the local phase of the Upper Cambrian strata to the south or its downward extension. ^{where the lower one is pre-Cambrian} It was to study ^{this problem} ~~the evidence of this~~ that the writer spent the summer of 1910 at a time ^{when} ~~that~~ he was inexperienced, particularly in igneous geology and when studies of sedimentation were just beginning. ^{Such aids as} Color charts and X-ray ^{determinations} ~~studies~~ were then unknown. ^{Signature of different types of bedding and ripple marks were then not appreciated}

However, the gasoline engine was available although ^{reliable} land transportation by automobile was yet in the future. The writer covered all of the lakeshore exposures with a small power boat and made many landings upon them. ^{A car was used in 1912.} The exposures on the streams were traversed on foot, many days hard work being devoted to some of them as well as to a search for ^{any} ~~those~~ not recorded by earlier geologists. After many weeks in the field three exposures were discovered on streams tributary to Lake Superior where there seems to be a complete gradation between the two types of sandstones. This conclusion then placed all the sandstones into the Upper Keweenaw which was by the definitions of the U. S. Geological Survey, ^(Chamberlain, Van Hise and Leith, 1911, pp 415-416) regarded as pre-Cambrian. Here the problem rested until it was reopened by G. O. Rasch in 1950. The following discussion is a criticism of his generally fair reappraisal of the scanty evidence. ^{which was, however} without much ~~personal~~ field work ^{by himself}.

Three answers could be found for the age of the sandstones. (a) They are all definitely pre-Cambrian, (b) They are divided by an unconformity into two ^{the upper Cambrian and the lower Keweenaw,} marked divisions, and (c) ~~The Keweenaw is not pre-Cambrian~~ but is the downward extension of the recognized Upper Cambrian of the Mississippi Valley. Conclusions must of necessity be based on little direct evidence so that the personal bias of the geologist will inevitably play a large part in the result.

Origin of the sandstones. The writer concluded in his report of 1912 that all of the Wisconsin sandstones are non-marine and were a filling of a ^{ashland mountain} deep valley ^{with a} ~~under conditions of~~ scarcity of vegetation but in which there was at times standing water. Reviewed after more than 40 years progress of a rapidly-growing science, this conclusion still remains without serious challenge. ^a Measurement of dips, ^{The} thicknesses deduced from them, and the division of the sequence into distinct geological formations are ^{all} more open to doubt. Dip of the strata could be easily observed ⁱⁿ ~~from~~ relation to the lake level but the dips measured with a

Brunton compass from a moving boat are open to the charge of exaggeration. ^{These are uncertain because of initial dip.} It is as was soon recognized impossible in the sandstones of Lake Superior to trace

any given stratum for any considerable distance. The shales, for instance, are lenticular and pinch out within a ~~xxx~~ short horizontal distance. In view of the impossibility of discovering ~~a~~ ^{horizons} persistent geologic section may it not be that the ^{writers} division into formations was ill-advised. We can recognize definitely that the lower part of the sequence contains much more shale and conglomerate than do the upper sandstones so that the separation ^{into} of Oronto and Bayfield groups appears sound. The distinctive Devils Island sandstone ^{formation} was actually traced for over 25 miles with little chance of error. A feature overlooked is the presence of

^{quite} somewhat similar rock on Copper Creek far to the west ^{Thwaites} (1912, pp. 42 ~~43~~ ⁴⁴) Is it the same as the Devils Island or not? The Devils Island ^{formation} is certainly overlain by the ^{sandstone} redder rocks ^(Chequamegon) above as shown in exposures on the south end of the ~~Island~~ ^{which is its type locality}. What ~~point~~ is gained by trying to disprove this relation by faulting as

Raasch does? Correlation of the Hinckley sandstone with the Devils Island was ~~in fact~~ suggested by the writer ^{Thwaites} (1912, p. 58) and has been ^{the conclusion of} ~~concluded~~ by later geologists who have visited the type locality of that formation. It is necessary to recall that no fossils are available to ~~confirm~~ ^{such a} ~~this~~ conclusion which is

of necessity based on lithologic resemblance, and structure. Tyler has shown by ^{IT could be correlated with the beds on Copper Creek} heavy mineral studies that the placing of the Eileen formation of the Oronto

group below the Amnicon formation, which is exposed a short distance away on Fish Creek, may be an error. Thrust faults are there present. If this ^{was} ~~is~~ ^(of the writers) an error it would reduce the estimated thickness of the Oronto group.

Contemporaneous deformation. The ~~a~~ first geologists to study the relation of the Keweenaw lavas to the upper or Bayfield group of sandstones ~~definitely~~ ^{concluded there is} ~~concluded~~ ^(Imms, 1983, pp 351-366) an unconformity. The great disturbance of the sandstone by faulting was overlooked in favor of the evidence of conglomerate ~~abxxx~~ along the fault.

It is now apparent that there could have been little or any movement on these ^{during Bayfield deposition} faults because the Bayfield group of sandstones contains very little debris derived from the flows or intrusions in them. ^(Tyler, 1940, p. 1481) Where did the debris go which was eroded from the upthrown sides of these great thrusts? ^(Fig 2) That problem cannot be answered

from information now available. The conglomerates were undoubtedly ~~fa~~ ^{faulted} up ~~from~~

from Oronto beds like those of the northern exposures on Fish Creek near Ashland. A similar upturning of older strata occurs in the Wall Ravine of Michigan. Such upturning is not present ~~everywhere~~ and in fact one might be pardoned for ^{concluding} that the flows are younger than the sandstones from the evidence of some ^{exposures} sections. It now seems clear ^{that} the extensive thrust faulting due to compression occurred later than the deposition of the Bayfield group. It was an earth movement more like those of the pre-Cambrian than anything which affects the Paleozoic of the Upper Mississippi Valley over such a wide area.

Gradation between the two groups of sandstones. Three localities were discovered in 1910 which seem to demonstrate gradation between the Oronto and Bayfield groups. These are on Fish Creek, Middle River, and St. Louis ^{pebbles} rivers. Raasch overlooks the last which is in the only section in which no concealed intervals are recorded. Further more, careful search failed to disclose any ^{fragments} of Oronto type sediments enclosed in the Bayfield group although pebbles of igneous rocks ^{and metamorphic} are common throughout its entire outcrop. ^{The same applies to heavy minerals.} The section of St. Louis River must now be largely concealed by a ~~lower~~ power dam ^{had} which was not yet built in 1910. In passing it is fair to remark that the section ^{published} by the writer agreed exactly with an older one by Winchell so that Stauffer ^(Stauffer, 1927, p. 471) evidently did not read the text carefully and overlooked the addition to Winchell's column of ~~some~~ strata which are exposed ^{only} in Wisconsin. The conclusion ^{that there are 15} of conformable relations between Bayfield and Oronto rests wholly on these outcrops. Although it ^{could} ~~may~~ be an error there is no evidence ^{in then} to prove ^{is} ~~that it is from their evidence.~~

Extent of the Bayfield group outside the Lake Superior Basin. Raasch ^(fig. 1, p. 138) presents a map to show a vast extent of the Bayfield group outside of that of the Oronto group which is confined to the basin of Lake Superior. This map is based ^{on} an interpretation of the great thickness of the Mt. Simon formation (or member) of Upper Cambrian age. ^{some of which are argillite} In fact such a correlation of the deeply-buried red sandstones ^{(Templeton, 1931) ("Granite wash")} of northern Illinois with the Keweenaw was made by the writer in 1923. Subsequent ^(Knappen, 1926) study of cuttings from very deep wells serves to disprove that suggestion although

(Bays and others, 1945) 5
(Raasch, 1950)

it appears to have been revived by Bays, Raasch, and others so that the new map of Illinois revives Winchells' long-disseminated term of Fond du Lac for the basal portion of the Cambrian of Illinois. Since these concealed beds seem to grade ^{into} down from the known Upper Cambrian ^{above} the inference was drawn that the Bayfield group of sandstones must also be Cambrian. The name "Fond du Lac" is most unfortunate for ^(a) it never had any general usage, ^(b) the gap from the type locality at Fond du Lac, Minnesota, is ^{long} great with no conclusive subsurface tracing, and ^(c) it could easily be confused with the much better-known city of Fond du Lac, Wisconsin. The writer suggests that the name be dropped. The ["]Red Clastic series found in wells in Minnesota along the extension of the Lake Superior syncline is the only ~~possible~~ provable extension of the Bayfield group. Correlation by color alone is very ^{hazardous}. There are many red Cambrian sandstones.

Late Keweenawan sedimentation. The similarity of sedimentary conditions during Keweenawan time to those of the Snake River Plain in Idaho (figure 1) is very striking and explains many phenomena which at first sight seem puzzling. In Idaho the basalts rest upon an older series of rhyolite flows which locally project through them. ^{# Tertiary and Quaternary} The lavas are confined to a basin in the older igneous and metamorphic rocks. ^(Stearns, 1936) Whether this ~~is~~ is in part tectonic or in part erosional is beside the point. On top of the basalts the present-day streams from the mountains are depositing ^{sandy} alluvium. This alluvium overlaps the margin of the flows and ^{could} ~~must~~ contain pebbles both from the exposed rhyolite knobs and from the much older rocks of the Northern Rockies. There have been no recent faults to complicate the picture. ^(Idaho example shows) This ~~is~~ exactly the condition ^T (save for the faults) which existed in the Lake Superior region during ~~the same~~ Keweenawan time. The fact that the pebbles of the Bayfield group, as well as in most older conglomerates, are rhyolite instead of basic rock is exactly matched in these modern deposits, ~~the oldest of which are probably of Quaternary age.~~ Overlap of the lavas in relatively short distances is obviously not the result of erosion following tilting but is an original feature.

The Bayfield sandstone is in fault contact with the lavas on Keweenaw Point whereas a few miles away at Lanse it lies on Huronian slate with possibly a glaciated contact.

If this is the result of glaciation, in the ^anerby Huron Mountains of that time there is no distinct till to ^{confirm} prove it. ~~It may be~~ ^{could it} horizontal faulting? (Murray, 1955)

Age of Lake Superior faults. The great faults ~~of~~ south of Duluth and on the southeast side of Keweenaw Point have always been thought of as pre-Cambrian. Reasch correctly points out that at Limestone Mountain west of L¹anse faulting and tilting affects strata at least as young as Silurian. ^(Thwaites, 1943) This local disturbed condition has lowered these Paleozoic remnants below their ^{expectable} ordinary position. Similar disturbed areas are known at Glover's Bluff, Wisconsin, Des Plaines, Illinois, Kentland, Indiana, and many other places through ^{out} the Mississippi Valley. They are called 'cryptovolcanic' by some geologists but display no evidence whatever of hot waters or intrusive igneous rock. They may be local renewed movement on old faults. The writer suggests that the north-south fault inferred east of Limestone Mountain may be ~~the~~ ^{to the southwest} course of a fault from Silver Mountain which to the north joins the main Keweenaw Point thrust. Silver Mountain is the easternmost portion ~~of~~ of a southern range of upturned lavas. ^{R.F.} When visited by the writer and Oetking no ideas could be obtained on its structure. From a distance it looks like a tilted fault block. If the low country around it is underlain by sandstone there are neither outcrops nor well data to prove it. The writer suggests that the evidence of Limestone Mountain is not at all conclusive ~~on~~ on the age of the major thrusts.

Erosion surfaces. Correlation by erosion surfaces, often termed peneplains, is at best very uncertain. The Upper Cambrian of central and northwestern Wisconsin lies on a surface of moderate relief which bevels across all pre-Cambrian structures. (figure 2) Its evenness has been much over stressed by many writers. It is a curved ~~at~~ surface which forms the dome of the Northern Highland of Wisconsin and is obviously continued on the northw^{est} ~~side~~ ^{side} of Lake Superior. On that s^{hore} it has Cretaceous sediments resting on it. Glacial drift rests upon almos^t all of it. It bevels the upraised sides of the great thrusts and as noted above it is impossible to say what beca^{me} of the material eroded from these.

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