The Base of the Upper Keweenawan, Michigan and Wisconsin

By WALTER S. WHITE

CONTRIBUTIONS TO STRATIGRAPHY

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A proposal to adopt the top of the Copper Harbor Conglomerate as the base of the upper Keweenawan in the Lake Superior region

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ABSTRACT

The top of the Copper Harbor Conglomerate (base of Nonesuch Shale) is a more satisfactory boundary between upper and middle Keweenawan rocks in northern Michigan and adjacent parts of Wisconsin than the various horizons that have been used hitherto without stratigraphic consistency from place to place. Irving's original boundary (1883) cannot be followed away from the Keweenaw Peninsula. The top of the Copper Harbor Conglomerate comes closer to marking the close of Keweenawan volcanism than other major boundaries and actually adheres more closely to Irving's original concept than the boundary that he himself chose. The top of the Copper Harbor Conglomerate is also more satisfactory from a practical standpoint because, thanks to exploration for copper at the base of the Nonesuch Shale, no other major stratigraphic boundary in the Keweenawan province is so precisely located over so large a fraction of its total outcrop trace. This paper proposes that the top of the Copper Harbor Conglomerate be adopted as the base of the upper Keweenawan and of the Oronto Group.

INTRODUCTION

The base of the "upper Keweenawan," a term applied to certain rocks of Precambrian Y[1] age in the Lake Superior region, has not been placed at the same stratigraphic horizon by all who have had occasion to use the term. Any of the possible definitions or redefinitions that might be adopted would be arbitrary, but light shed on the question by geologic and geophysical data gathered in recent decades now makes one of these choices seem more meaningful and more practical than the others.

[1] An interim scheme for the subdivision of Precambrian time, recently adopted by the U.S. Geological Survey:

Precambrian Z = base of Cambrian to 800 m.y.
Precambrian Y = 800 m.y. to 1,600 m.y.
Precambrian X = 1,600 m.y. to 2,500 m.y.
Precambrian W = older than 2,500 m.y.

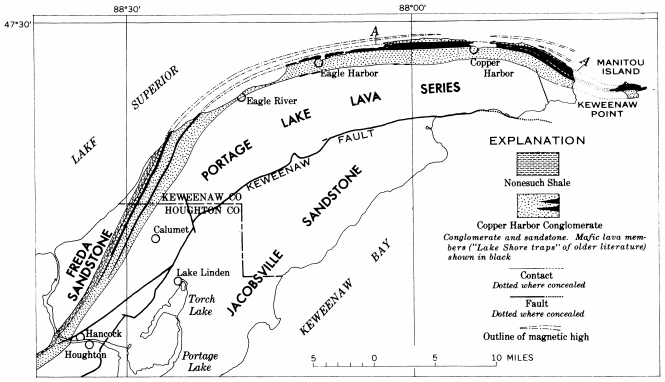

FIGURE 1.—Distribution of the Copper Harbor Conglomerate and included mafic lava members on the Keweenaw Peninsula of northern Michigan. Discontinuous lava units too thin to show without clutter lie about 500 feet below the lowest mafic lava member depicted on the map in the area west and north of Calumet and also between Eagle Harbor and Copper Harbor. Geology from 1:24,000 geologic quadrangle maps (Cornwall, 1954a, b, c; 1955; Cornwall and White, 1955; Cornwall and Wright, 1954, 1956a, b; Davidson and others, 1955; White, 1956; White and others, 1953; White and Wright, 1956; Wright and Cornwall, 1954).

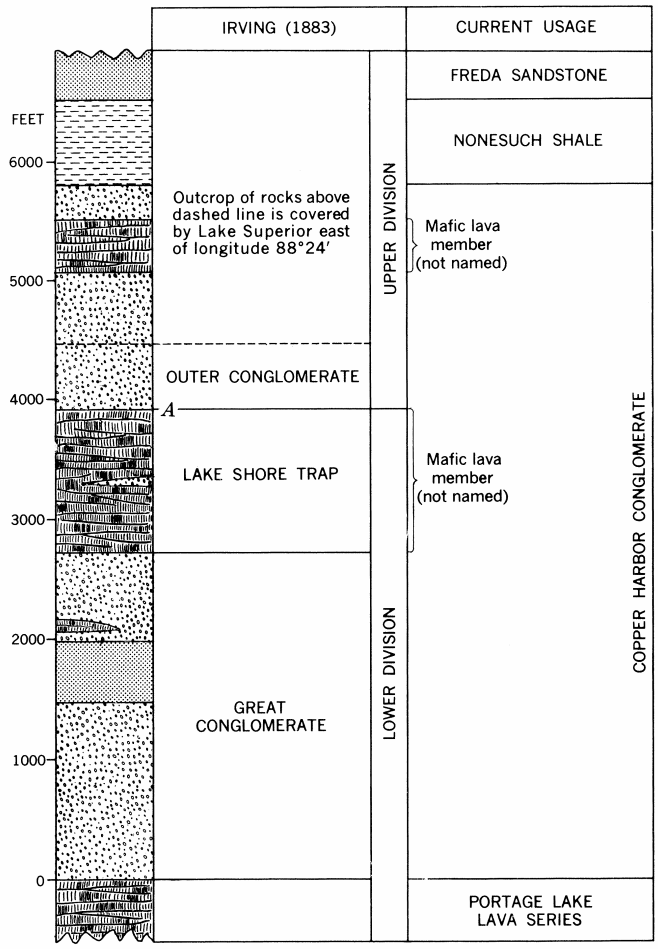

FIGURE 2.—Stratigraphic section of the Copper Harbor Conglomerate in the vicinity of Copper Harbor (from data of Cornwall, 1954b, c, 1955).

ACKNOWLEDGMENTS

I am very much indebted to N. K. Huber, who pointed out to me that when my colleagues and I (White and others, 1953) redefined the base of the upper Keweenawan on the Keweenaw Peninsula, we did not take formal notice of the departure from Irving's (1883) original definition, which was very explicit in his type area. Huber encouraged me to remedy this oversight, and this paper, though quite different from what I set out to write, is the result. I owe much to my colleagues Henry R. Cornwall and the late J. C. Wright for the years of joint endeavor that provided much of the background for this paper. And finally, the stratigraphic relations shown west of long. 89°15' in figure 3, so important a part of the argument in this paper, would have been most imperfectly reconstructed without the results from recent unpublished mapping by E. R. Brooks, H. A. Hubbard, R. F. Johnson, and J. T. Wilband (White and others, 1971), as can be readily seen by comparison of figure 3 with an earlier attempt to draw a similar section (White and Wright, 1960, fig. 3.2).

A most constructive critical review of the original manuscript by N. K. Huber led to substantial revision of parts of the text.

ORIGINAL DEFINITION AND USAGE

The reason for the problem has its roots in Irving's (1883) definition of what he called the "Upper Division" of the Keweenawan. The type locality for his classification is on the north shore of the Keweenaw Peninsula, in a belt extending a few miles east and west from Copper Harbor (fig. 1). Figure 2 shows a stratigraphic section of the Copper Harbor Conglomerate in this area and the names that have been applied to the various units by Irving (left-hand column) and more recent investigators (right-hand column) (see, especially, Cornwall, 1954b, c; 1955).

Irving (1883, p. 152) placed the boundary between his "Upper Division" and "Lower Division"[2] of the "Keweenaw Series" at the, "base of the outer conglomerate of Keweenaw Point—which [as he believed] corresponds to the top of the upper amygdaloid of the Porcupines, and to the base of the great conglomerate of the Montreal, and which is above any known occurrence of eruptive matter." This boundary was a very reasonable choice at the time and was later accepted by others (for example, Lane, 1911, p. 37-39; Van Hise and Leith, 1911, p. 413; Thwaites, 1912, p. 48 and geol. map) primarily for its presumed importance as the surface marking the close of volcanism in the region. The stratigraphic position of this surface of demarcation in the type area is indicated by the line labeled "A" in figures 1 and 2.

[2] The rocks immediately below the base of upper Keweenawan have been called "lower Keweenawan" (lower division of the Keweenawan) by some authors and "middle Keweenawan" by others. For the purposes of this paper, it makes no difference which usage is followed, but it should be pointed out that a threefold division of the

Keweenawan appears far more useful than a twofold in the light of what is now known about the stratigraphy throughout the Lake Superior region (Van Hise and Leith, 1911, p. 366-367; Halls, 1966, p. 5; Hubbard, 1968; Books, 1968).

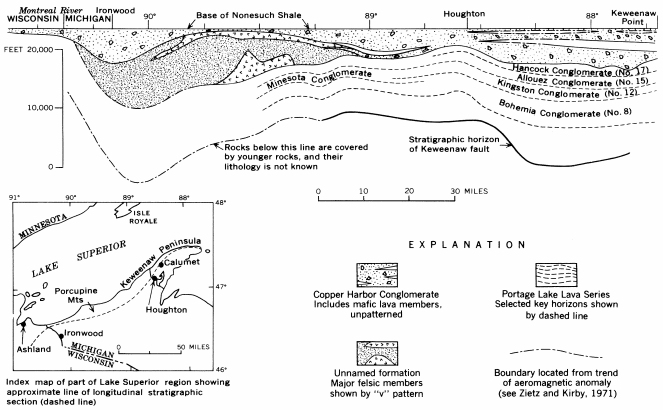

FIGURE 3.—Longitudinal stratigraphic section of Keweenawan rocks below the base of the Nonesuch Shale from Keweenawan Point to the Montreal River. All data projected to an east-west line. Dashed lines within the Portage Lake Lava Series represent individual horizons that can be traced with confidence between the indicated points, largely by correlation of drill-hole sections. Thickness east of long. 89°15' from sources listed in figure 1 and from Butler, Burbank, and others (1929, pl. 15); thickness west of long. 89°15' calculated from unpublished maps by E. R. Brooks, H. A. Hubbard, R. F. Johnson, W. S. White, J. T. Wilband, and J. C. Wright.

Figures 1 and 3 clearly show some of the problems that stem from Irving's choice. As Lane (1911, p. 39; see also Lane and Seaman, 1907, p. 690) clearly recognized from his own subsequent work, practical difficulties attend any effort to follow Irving's boundary away from Keweenaw Point. If the base of the upper Keweenawan is defined as the time-equivalent of Irving's boundary on the Keweenaw Peninsula, it does not coincide with any recognized lithologic unit or break beyond the point where the highest so-called "Lake Shore trap" of the Keweenaw Peninsula pinches out north of Hancock (fig. 1). There is no theoretical or practical reason, today, to correlate the "Lake Shore traps" of the Porcupine Mountain region (Wright and Lane, 1909) or of the Black River (Gordon and Lane, 1907, p. 430) with those of Keweenaw Point, and there is no way, at present, to identify beds in westernmost Michigan or Wisconsin, for example, that might be contemporaneous with the top of the "Lake Shore traps" of Keweenaw Point.

If, on the other hand, the base of the upper Keweenawan is defined as the top of the highest lava flow, regardless of stratigraphic position (which is what authors attempting to follow Irving rigorously have actually done in practice), its stratigraphic position can change abruptly by as much as 2,000 feet at places where the highest lava flow pinches out (fig. 3). At the many places where no "Lake Shore trap" flows are recognized, authors have placed the boundary at the top of the Portage Lake Lava Series.

Other problems caused by acceptance of Irving's boundary have only become obvious in recent decades as a result of detailed geologic mapping and magnetic surveys. One is that the base of what Irving took as his "Outer Conglomerate" of Keweenaw Point is actually 1,500-2,000 feet below the top of the highest lava flow in that area, as can be shown by geologic projection and airborne magnetometer survey (fig. 1). Another is that the end of volcanism was almost certainly later than the highest known lava flow; I have found water-laid tuff, probably representing ash falls, in drill core within 25 feet of the base of the Nonesuch Shale (sec. 33, T. 55 N., R. 34 W.)

ORONTO GROUP

Thwaites (1912, p. 48) introduced the term Oronto Group for "a great thickness of arkose sandstones and shales" overlying the lavas and underlying more quartzose sandstone formations, to which he gave the name Bayfield Group. Following Irving's precedent, he took the base of the Oronto Group as "the base of a thick conglomerate called the Outer Conglomerate, above which horizon no igneous rocks occur." His definition and the explanation for the map accompanying his report clearly equate the base of the Oronto Group and the base of the upper Keweenawan, and this identity seems to have been accepted by all those who have had occasion to use the term Oronto Group, even where there might be disagreement or inconsistency, from area to area, about where the boundary should be placed stratigraphically. It should be recognized, therefore, that any redefinition of the base of the upper Keweenawan should apply also to the base of the Oronto Group.

ALTERNATIVES FOR STRATIGRAPHIC PLACEMENT OF THE BASE OF THE UPPER KEWEENAWAN

The name "Outer Conglomerate," used rather informally by Irving, has unfortunately become formalized by subsequent usage, despite the fact that, from a practical standpoint, its base cannot be followed west from the Keweenaw Peninsula. Because the "Outer Conglomerate" has only local significance it seems inappropriate both as a formal stratigraphic name and as unit defining the base of the upper Keweenawan. Lane (1911, p. 37-39) clearly recognized that the discontinuity of the lavas known as the "Lake Shore traps" made it impractical to separate the "Outer" and "Great Conglomerates" outside the Keweenaw Peninsula, and he therefore collectively grouped all conglomerates above the Portage Lake Lava Series and below the Nonesuch Shale into the "Copper Harbor Conglomerates." Lane continued to accept the base of the "Outer Conglomerate" as the base of the upper Keweenawan, however, and thus the lumping of Irving's "Outer" and "Great Conglomerate" into a single formation has, as Lane (1911, p. 39) recognized, the disadvantage

of placing the base of the upper Keweenwan within a formation.

From a hierarchical point of view, it seems most undesirable to have a boundary of major rank fall within a unit of lesser rank. Inasmuch as the base of the upper Keweenawan (and of the Oronto Group) does fall within a formation that cannot be subdivided on any theoretical or practical grounds that are valid and consistent on a regional basis, the most obvious alternatives are to place the base of the upper Keweenawan at either the top or base of the Copper Harbor Conglomerate.

TOP AND BOTTOM OF THE COPPER HARBOR CONGLOMERATE AS UNCONFORMITIES

If either the top or bottom of the Copper Harbor Conglomerate, but not both, were known to be a pronounced unconformity, the unconformable contact should, with little question, be adopted as the base of the upper Keweenawan. On this basis, unfortunately, there is little to choose between them.

Both boundaries are more or less gradational. The conglomerate and sandstone beds between lava flows of the Portage Lake Lava Series differ little from those of the Copper Harbor Conglomerate, both on the Keweenaw Peninsula and on Isle Royale (Lane, 1898; Huber, 1971). Sedimentary beds are more abundant in the uppermost 1,000 feet or so of the Portage Lake Lava Series than below, and the choice of the top of the highest lava flow as the formation boundary, though logical and practical, is quite arbitrary. The transition between the formations reflects a gradual decrease in volcanic activity and growing dominance of a sedimentary regime rather than an abrupt time or environmental break.

Similarly, sandstone and dark-gray siltstone to shale are inter-bedded and interlaminated in the lowermost 20 feet of the Nonesuch Shale, and the basal contact (top of the Copper Harbor Conglomerate) is arbitrarily placed at the base of the lowest thick (several feet) unit containing dark-gray siltstone and shale. This boundary does reflect a relatively abrupt change from a subaerial to a shallow subaqueous environment.

Both boundaries are only slightly transgressive. Maps of part of the Keweenaw Peninsula by Cornwall (1954b) and Cornwall and Wright (1954) suggest that the stratigraphic position of the base of the Copper Harbor Conglomerate may locally rise toward the west, but the rate of rise is very small. Even where the Copper Harbor Conglomerate laps up on the unnamed formation (fig. 3), the contact does not appear to be notably unconformable and may have much intertonguing. Gradual transgression of the base of the Nonesuch Shale is clearly shown in north-south sections of the base of that formation in the Porcupine Mountain region (White and Wright, 1966, fig. 2), but it is barely detectable without considerable vertical exaggeration.

It is conceivable that the uppermost beds of the Copper Harbor Conglomerate represent sands reworked by the waters in which the Nonesuch Shale was deposited and that the apparent near-conformity of these beds masks or blurs a more profound angular unconformity between the Nonesuch Shale and the Copper Harbor Conglomerate as a whole. Stratigraphic relations within the Copper Harbor Conglomerate are not well known because of poor exposures and few drill holes, but meager information that is available suggests that there is no significant angular unconformity between the two. The relations shown in figure 3, particularly near Houghton, suggest that much of the local angular discordance between the Portage Lake Lava Series and the Nonesuch Shale is due to tectonic movements during rather than before or after Copper Harbor time.

Finally, neither boundary represents any profound change in the basic pattern of sediment dispersal, for as Hamblin and Horner (1961, p. 210) point out, the same pattern, implying highlands to the south or southeast of the western Lake Superior region, persisted from Portage Lake through Freda time. Hite (1968) reached a similar conclusion for the Copper Harbor Conglomerate and higher formations that he studied in northeastern Wisconsin.

In summary, therefore, the magnitude of the unconformities represented by the top and base, respectively, of the Copper Harbor Conglomerate provides little reason for considering one of the contacts more suitable than the other to be taken as the base of the upper Keweenawan. Some other basis must be sought.

BASE OF THE COPPER HARBOR CONGLOMERATE

The principal argument for placing the base of the upper Keweenawan at the base of the Copper Harbor Conglomerate is the weight of prior usage, even though this usage has commonly involved an unwitting departure from the original definition. In the many areas where no “Lake Shore traps” are recognized, authors have unfailingly placed the boundary at the base of the Copper Harbor Conglomerate (for example, Van Hise and Leith, 1911, pl. 1; Leith and others, 1935, pl. 1). Some authors, particularly in Wisconsin (Thwaites, 1912; Aldrich, 1929; Tyler and others, 1940; Ostrom, 1967; Hite, 1968), have semantically resolved this departure from Irving’s definition by simply using the name Outer Conglomerate for all the rocks between the Portage Lake Lava Series and the Nonesuch Shale. Although for Wisconsin, in particular, this correlation is not inconceivable, the relations shown in figure 3 do not provide much support for it, and the correlation is certainly not valid in areas such as that shown in the southwestern part of figure 1.

On the Keweenaw Peninsula, this usage adopted elsewhere cannot be reconciled with Irving’s usage, and a choice must be made between the two. White,

Cornwall, and Swanson (1953) chose to follow the usage accepted for the region as a whole rather than Irving's definition when, on maps of the Keweenaw Peninsula, they placed the base of the upper Keweenawan at the base of Lane's (1911) "Copper Harbor Conglomerates." The more conventional singular form was used by White (1952) and White, Cornwall, and Swanson (1953) when they adopted Lane's term as a formation name. Several more recent authors (Hamblin and Horner, 1961; Hamblin, 1961; Halls, 1966; Kelley, 1968) have followed suit, using the term Copper Harbor Conglomerate for the whole conglomerate sequence and accepting the top of the Portage Lake Lava Series as the base of the upper Keweenawan on the Keweenaw Peninsula as well as in the areas where this usage had become more or less established.

From the foregoing, it might appear simplest, therefore, to follow this revised usage that has gained general acceptance, and to place the base of the upper Keweenawan at the top of the main body of lavas, including within the upper Keweenawan those flows within the Copper Harbor Conglomerate that have been called "Lake Shore traps." Recent work in western Michigan, however, has greatly complicated this otherwise straightforward solution.

As shown by figure 3, the horizon that marks the top of the Portage Lake Lava Series can be located very closely by reference to the internal stratigraphy of that formation (Butler, Burbank, and others, 1929, pl. 15; White, 1968, fig. 3). As this horizon is followed southwestward from the Keweenaw Peninsula, it passes beneath an unnamed formation consisting of a thick series of felsic and generally nonophitic mafic flows (fig. 3). In the region south of the Porcupine Mountains, this overlying sequence of flows attains a thickness of at least 8,000 feet, whereas the Copper Harbor Conglomerate shows complementary thinning; in places, the total thickness of sandstone and conglomerates of the Copper Harbor is less than 200 feet. The sequence of flows between the top of the Portage Lake Lava Series and the overlying Copper Harbor Conglomerate appears to be a volcanic pile (White and Wright, 1960), and the rocks just below this pile are probably more or less contemporaneous with rocks just below the base of the Copper Harbor Conglomerate on Keweenaw Peninsula.

This new development materially affects the attractiveness of the base of the Copper Harbor Conglomerate as a location for the base of the upper Keweenawan. On Keweenaw Peninsula and probably in northeastern Wisconsin, the base of the Copper Harbor Conglomerate and the top of the Portage Lake Lava Series are one and the same contact. In the Porcupine Mountain region, they are not, and there is a difference between adopting the base of the Copper Harbor Conglomerate, on the one hand, or the top of the Portage Lake Lava Series, on the other, as the base of the upper Keweenawan. Exposures are poor in this region, and the amount of interfingering between the Copper Harbor Conglomerate and the unnamed formation is not yet known. The question of whether or not the unnamed formation is contemporaneous with any or most of the Copper Harbor Conglomerate is, therefore, unresolved. The complementary changes in thickness shown in figure 3 strongly suggest at least some overlap in time. If the base of the upper Keweenawan is drawn to approximate a time line, therefore, as it probably should be, it should be drawn at the top of the Portage Lake Lava Series. The boundary between a predominantly extrusive sequence below and a predominantly sedimentary sequence above, although convenient for mapping purposes, is seen to have little meaning as a time line. The same is true farther west in Wisconsin. The Portage Lake Lava Series, for example, cannot yet be correlated with the sequence of lavas immediately below the Copper Harbor Conglomerate southwest of Ashland, Wis., (fig. 3, index map). The boundary between the extrusive and overlying sedimentary sequence, now commonly accepted there as the base of the upper Keweenawan, therefore, cannot be assumed to be contemporaneous with the base of the Copper Harbor Conglomerate on the Keweenaw Peninsula.

Although the problem of approximating a time line can be resolved, at least for the Porcupine Mountain area, by drawing the boundary at the top of the Portage Lake Lava Series, beneath the unnamed formation (fig. 3), this solution has two major drawbacks. First, a sequence of lava flows as much as 8,000 feet thick is included with the upper Keweenawan rocks, and any significance the boundary might have as a reflection of change is lost. Secondly, as a practical matter, it may prove difficult to follow this boundary with any accuracy through areas of poor exposure west of long. 89°50' W. The boundary as drawn in figure 3 is based to a considerable extent on a projection parallel to the traces of aeromagnetic anomalies (Zietz and Kirby, 1971).

TOP OF THE COPPER HARBOR CONGLOMERATE

The top of the Copper Harbor Conglomerate has much to recommend it as an alternative location for the base of the upper Keweenawan.

First, as a time line, this contact comes very close indeed to fulfilling Irving's concept that the base of the upper Keweenawan should mark the close of active volcanism in the Lake Superior region. Northwest of Calumet (fig. 1), the boundary that Irving (1883, pl. 17) did draw is only 300 feet stratigraphically below the Nonesuch Shale. Lava flows and tuff beds almost at the top of the Copper Harbor Conglomerate in the Keweenaw Peninsula area show that volcanism persisted through almost all of Copper Harbor time, even though this cannot be demonstrated in most areas because the flows themselves did not cover all parts of the sedimentary basin.

Second, the top of the Copper Harbor Conglomerate makes a better boundary than the base for practical reasons. Even though the Nonesuch Shale is not well exposed in most areas, the occurrence of copper at the base of that formation has encouraged a great deal of exploratory drillling in recent years, and the location of the intersection of the top of the Copper Harbor Conglomerate (base of Nonesuch Shale) with the bedrock surface is now known within a few feet to tens of feet over large areas and within 500 feet at most places. Drilling by the Bear Creek Mining Co. has even delineated the approximate trace of this boundary throughout the area of deep drift cover south and west of Ashland, Wis., (Moerlein, 1963; White, 1966). Today, at least, no other major stratigraphic boundary in the entire Keweenawan province is so precisely located over so large a fraction of the total length of its outcrop (or suboutcrop).

The location of the base of the Copper Harbor Conglomerate, on the other hand, is much less precisely known. It can be located magnetically within a few tens or, at most, hundreds of feet in many areas of poor exposure because of the good magnetic contrast between many mafic lava flows and sedimentary rock. In areas of fairly deep overburden, however, magnetic methods give inconclusive results where the rocks near the base of the Copper Harbor Conglomerate consist of an alternation of thin lava flows and sandstones, as they do in many places. And where the rocks beneath the lowest thick conglomerate beds are felsic flows, as they are in much of western Ontonagon County, attempts to locate the boundary magnetically have proved fruitless.

Third, the top of the Copper Harbor Conglomerate represents a somewhat more pronounced lithologic change than the base, at least in some areas. The base, to be sure, represents a very large change in the ratio of effusive rocks to relatively coarse grained sedimentary rocks, but both these constituents are found above and below the contact. The top, on the other hand, marks a boundary above which no effusive rocks are known to occur and below which the amount of gray siltstone and shale (the predominant rock for several hundred feet above the contact) is vanishingly small. Qualitatively, therefore, the top is the boundary representing the greater lithologic change.

The main disadvantage of placing the base of the upper Keweenawan at the top of the Copper Harbor Conglomerate is that this is a significant departure from current usage, even though it comes much closer to fitting Irving's original boundary than does the current usage.

Before we proceed to a summary of pros and cons, a brief review of geophysical evidence relating to the choice is desirable.

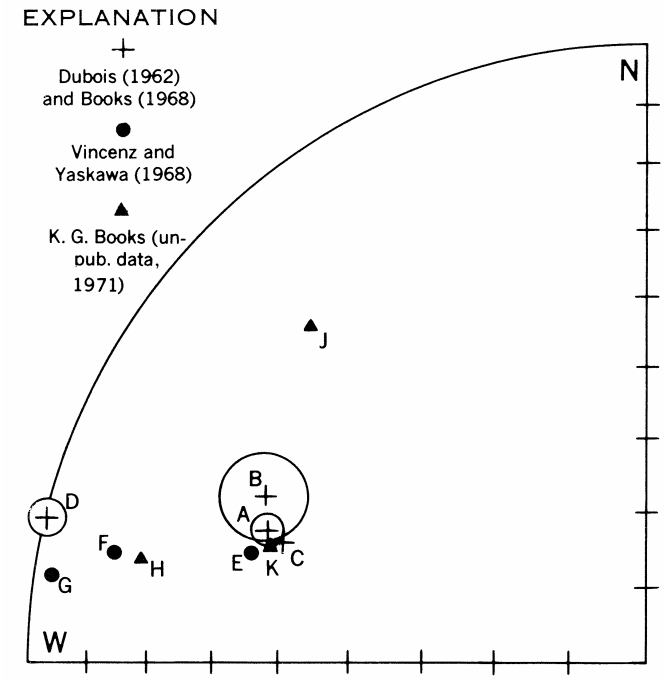

FIGURE 4.—Mean directions of magnetization for some Keweenawan rocks. A, Portage Lake Lava Series, with radius of confidence circle (95 percent) (Books, 1968, table 1); B, Copper Harbor Conglomerate, sandstones and lavas, with radius of confidence circle (DuBois, 1962, table 18); C, Copper Harbor Conglomerate, mean of 13 samples of lava (calculated from data of DuBois, 1962, table 4); D, Nonesuch Shale and Freda Sandstone, with radius of confidence circle (DuBois, 1962, table 18); E, Portage Lake Lava Series, mean of 14 site means (Vincenz and Yaskawa, 1968, table 2); F, lavas from Copper Harbor Conglomerate, mean of six site means (Vincenz and Yaskawa, 1968, table 2); G, Nonesuch Shale and Freda Sandstone, mean of five site means (Vincenz and Yaskawa, 1968, table 2); H, J, and K, lavas from Copper Harbor Conglomerate, individual site means, five samples per site (K. G. Books, unpub. data). Directions are recalculated to values that equivalent dipole would produce at lat 45° N. long 90° W. Equal-area projection, lower hemisphere, northwest quadrant.

PALEOMAGNETIC DATA

DuBois (1962) obtained paleomagnetic pole positions for the formations of concern to us here, and his results led him to conclude that the Copper Harbor Conglomerate is more closely related to the Portage Lake Lava Series than to the Nonesuch Shale and Freda Sandstone (fig. 2); his argument may be summarized by the observation that points B and C of figure 4 lie close to point A and relatively distant from point D.

More recently, Vincenz and Yaskawa (1968) have found that both thermal and alternating-field demagnetization materially flatten the direction of remanent magnetism in samples of lava from the Copper Harbor Conglomerate but cause very little change in samples of Portage Lake lavas or the younger sedimentary rocks. When the soft components of the magnetism are removed, the remanent direction that they obtained for lavas from the

Copper Harbor Conglomerate (point F, fig. 4) lies closer to the directions for the Freda and Nonesuch (points G and D) than to those for the Portage Lake Lava Series (points E and A). They conclude from this relationship that, contrary to the view of DuBois, the Copper Harbor Conglomerate is closer paleomagnetically to the younger sedimentary rocks than to the Portage Lake Lava Series.

Kenneth Books has kindly provided data on paleomagnetic directions that he has determined for a few samples of lava from the Copper Harbor Conglomerate. The three sites represented by the data of figure 4 (points H, J, and K) are in the same general area as those sampled by DuBois (1962) and by Vincenz and Yaskawa (1968). The samples represented by H in figure 4 represent the lower lava member of figures 1 and 2 and are from the same locality as DuBois' samples KH1-KH6 and Vincenz and Yaskawa's C1-C6. The samples represented by J and K in figure 4 are from the SE¼NW¼ sec. 26, T. 57 N., R. 33 W.; they represent the same group of flows (upper lava member of fig. 2) as DuBois' samples KP2-KP10 and Vincenz and Yaskawa's sites C9-C12, both of which suites were collected about a mile farther to the southwest along the strike.

Samples by K. G. Books (unpub. data, 1971) were magnetically "washed" in alternating fields in steps up to 200 oersteds, which is roughly the intensity at which Vincenz and Yaskawa found little further change of direction. Books' direction for samples represented by point H is very close to Vincenz and Yaskawa's mean for lavas of the Copper Harbor Conglomerate (point F), but point K is very close to the mean direction for the Portage Lake Lava Series. The third of Books' site means (J, fig. 4) is unlike any others. These data are presented primarily to illustrate the scatter remaining in data from these particular lavas after magnetic "washing"—scatter that will make conclusions about stratigraphic affinities risky until far more measurements have been made.

Paleomagnetic data, therefore, are still too few and equivocal to provide much basis for saying which geologic boundary, the top or the bottom of the Copper Harbor Conglomerate, marks the greater stratigraphic break, even if there were some basis for assuming that the magnetic pole wandered at a constant rate. A secular flattening of the paleomagnetic direction between Portage Lake and Freda time seems fairly well established, however, and this may ultimately prove very useful in stratigraphic correlations beyond the area treated here, wherever the base of the upper Keweenawan is placed.

SEISMIC DATA

It may also prove possible to locate the boundary, as defined, over large areas in the subsurface by explosion seismology. Table 1 presents some of the results of recent work in this field that has been designed specifically to get the kind of information needed. The table does not summarize the results of that work but is an extract of the particular data that appear most reliable; that is, from the numerous velocity determinations in each study, I have selected only those few that appear to me to be most trustworthy and to represent the cited formation beyond any reasonable doubt, and have excluded many determinations where the units cannot be correlated unequivocally with formations of the type areas.

TABLE 1.—*Compressional wave velocities (km/sec) for selected Keweenawan stratigraphic units, Lake Superior region*

	Halls (1969), experimental	Halls and West (1971), reversed refraction profiles [1]	Mooney and others (1970b), unreversed profiles
Bayfield Group	3.9–4.7	------	2.8–3.4
Freda Sandstone:			
Sandstone	5.1–5.5	------	------
Siltstone	3.7–4.6	------	------
Formation velocity	[2] 4–5	------	[3] 4.2
Copper Harbor Conglomerate:			
Sandstone	[4] 5.7–6.0	------	------
Formation velocity	------	5.1–5.4	[5] 5.2–5.5
Portage Lake Lava Series			
Conglomerate beds	5.7–5.9	------	------
Formation velocity	5.9–6.1	5.8–6.1	[6] 5.3–5.8

[1] Profiles 7-11, off Isle Royale, and 14, off Keweenaw Peninsula.
[2] Very general average, assuming similar proportions of siltstone and sandstone; actual ratio varies considerably, silt:sand increasing toward axis of the Lake Superior basin.
[3] Refractor 2,200 to 6,000 feet below surface, line 17, Bayfield County, Wis. Base of Nonesuch Shale should be close to 6,000 feet, by geologic projection. Main refractor in profile 16, velocity 3.8, may also be Freda Sandstone.
[4] Specimens all from Houghton Point, Isle Royale; may not be representative.
[5] Main refractor line 18, and lowest refractor, line 17, Douglas and Bayfield Counties, Wis. Line 18 is near the axis of the Ashland syncline, and the bedrock can only be Copper Harbor Conglomerate. In profiles 34 and 95, lowest refractor, representing clastic filling, Twin Cities basin, Minnesota, has velocities of 4.7-5.1 km/sec.
[6] Lowest refractor or only bedrock refractor, lines 6, 21, 23, 24, 25, 26, 33, 45, "St. Croix horst." It is not known that any of these rocks correlate specifically with the Portage Lake Lava Series; they are included simply to represent mafic lava flows.

It is to be expected that experimental velocities would commonly exceed seismically determined velocities, particularly for the less well indurated sedimentary formations; there is some bias in sampling outcrops, which generally represent the more resistant elements of a formation, and, in addition, a small specimen does not represent the fractures and pores that reduce velocities in rock in place. When allowance is made for this bias, the experimental results fit the field determinations closely enough to confirm the existence of a marked difference in velocity between the Copper Harbor and the Freda; it is comparable, in fact, to the difference between the Copper Harbor and the Portage Lake Lava Series.

SUMMARY AND RECOMMENDATION

The base of the upper Keweenawan (and of the Oronto Group) could be placed at the top, within, or at the bottom of the Copper Harbor Conglomerate; any decision would be arbitrary. A boundary at the top of the highest lava flow, within the Copper Harbor

Conglomerate, has the advantage of following the original definition precisely, but this advantage is more apparent than real if one attempts to trace the boundary away from Irving's type area on Keweenaw Point. This choice has the serious disadvantage of placing a major stratigraphic boundary within a stratigraphic unit that regionally, at least, cannot be subdivided on any consistent basis.

A boundary at the base of the Copper Harbor Conglomerate is generally satisfactory from the standpoint of regional correlations and geologic mapping and has been widely used in Michigan and Wisconsin. Its main advantage is that it separates a dominantly sedimentary group of rocks from one that is dominantly volcanic and is, therefore, readily located if exposures are good; under favorable circumstances, it may also be located magnetically or seismically. Its main disadvantages are as follows: (1) It does not even approximately mark the close of volcanism in the Lake Superior region. (2) In the area between long. 89° and 90°20' W. (fig. 3), one of the two virtues it has elsewhere must be sacrificed to preserve the other: if it is regarded as an approximate time horizon, it should probably be carried beneath the unnamed formation, losing its distinctiveness as a lithologic break; if it is carried over the unnamed formation, it may separate lavas on one side from more or less contemporaneous sedimentary rocks on the other, losing its meaning as a time break. (3) The location of the base of the Copper Harbor Conglomerate is not known with anything like the same precision as the location of the top at most places.

The top of the Copper Harbor Conglomerate seems to make the best boundary between the middle and upper Keweenawan for the following reasons: (1) It comes closest of any of the possible alternatives to marking the close of volcanism as a point in time; it is unaffected by such local factors as the pinching out of an individual lava flow that happens to be the highest one at a given locality. (2) It does not appear to be sufficiently transgressive to lose its value as a time break over a very large area. (3) Thanks to economic interest in the copper found in rocks adjoining this boundary, the position of this boundary is better known for a higher proportion of its total strike length than the position of any other boundary in the Keweenawan province.

If, then, the top of the Copper Harbor Conglomerate (base of the Nonesuch Shale) were adopted as the base of the upper Keweenawan in the region between Keweenaw Point and the vicinity of Ashland, Wis., what would be the effect on existing literature and usage, both within and beyond the limits of this region?

Rocks described and mapped as Copper Harbor Conglomerate would be classed as middle rather than upper Keweenawan. The boundaries on existing large-scale maps, showing individual formation boundaries, would be unaffected—the only difference would be in their classification as defined by the map explanation. New small-scale maps, however, might differ significantly from existing maps where formations are lumped into large units like "upper Keweenawan" and Oronto Group. Locating the base of the upper Keweenawan (base of Oronto Group) for purposes of a new map would pose no problem in Michigan and Wisconsin, because the position of the Nonesuch Shale is well established throughout the region. The actual differences between new and old regional maps would be significant, however, because, except in the Keweenaw Peninsula and Porcupine Mountain region, so many existing regional maps, going back to Van Hise and Leith (1911, pl. 1), include the whole Copper Harbor Conglomerate in the upper Keweenawan over wide areas, rather than just the uppermost few hundred feet correlative with the true "Outer Conglomerate." For this reason, some of the areas affected are large, such as that underlain by the Copper Harbor Conglomerate on Isle Royale, and in the syncline southwest of Ashland, Wis., particularly west of long. 91°45' W.

Outside the region that is the main concern of this paper, the effect is more difficult to assess. Certain red sandstone and conglomerate formations of Minnesota, particularly in the subsurface within basins along the crest of the midcontinent gravity high, may be, in part, correlative with the Copper Harbor Conglomerate. If the Nonesuch Shale does not extend that far west, as it probably does not, it may prove difficult to locate the base of the upper Keweenawan according to the definitions suggested here. It may ultimately be possible to make a good separation, however, by a combination of lithologic and paleomagnetic data from drill holes and seismic data.

Data presently available strongly suggest that the paleomagnetic directions in the Freda Sandstone and Nonesuch Shale are much flatter than those in the Portage Lake Lava Series. These data offer hope that when more measurements have been made, the direction for rocks close to the top of the Copper Harbor Conglomerate will have an identifiable position on a curve for secular wandering of the virtual geomagnetic pole.

The work of Mooney and others (1970a, b) indicates that velocity differences comparable with those listed in table 1 persist in the buried parts of the midcontinent gravity high in Minnesota. By means of such seismic investigations, it may ultimately be possible to trace the base of the upper Keweenawan, defined as suggested here, over large areas in the subsurface if it can be located at a relatively few places by lithologic or paleomagnetic criteria.

In the areas where the Copper Harbor Conglomerate is known to be present, it appears to have the form of clastic wedges that need not have extended far outside the elongate bowl of Portage Lake Lava Series that now contains them. There is no positive geologic evidence, therefore, that sedimentary formations correlative with the Copper Harbor Conglomerate even exist in the areas that Mooney and others (1970a, b) call the eastern and western basins. If there are none, the definition proposed here may only create a problem in areas like the Twin Cities basin that are within the midcontinent gravity high.

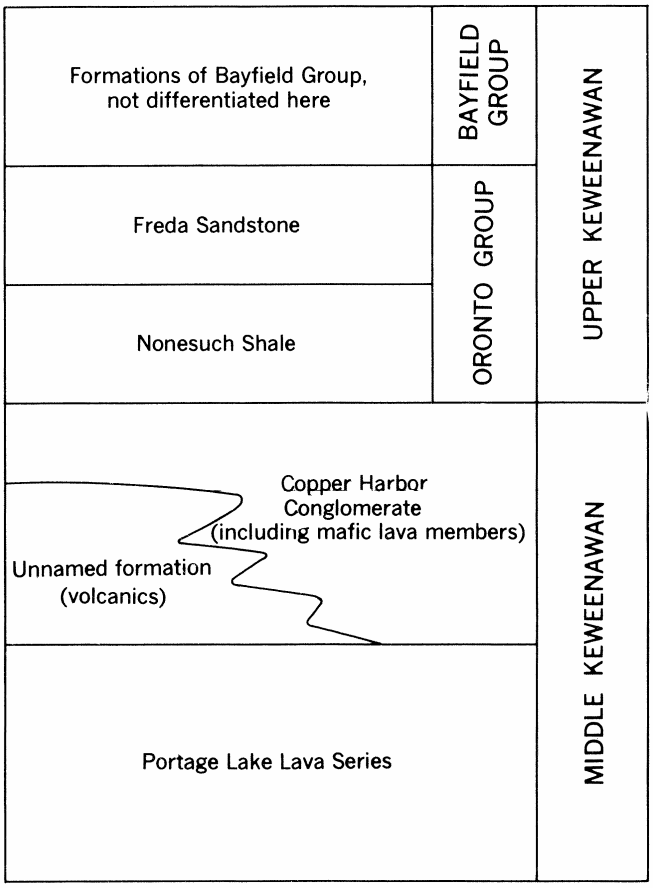

FIGURE 5.—Proposed nomenclature for middle and upper Keweenawan rocks of northern Michigan and adjacent parts of Wisconsin.

For geophysical work in parts of the region covered by Lake Superior, it might at first appear desirable to place the boundary at the top of the main body of lavas rather than higher up, within a predominantly sedimentary group of rocks. This would, indeed, be true if there were any reason to believe that the Copper Harbor Conglomerate remains a predominantly sedimentary formation in the central parts of the Lake Superior Basin. Groups of flows within the Copper Harbor Conglomerate ("Lake Shore traps"), however, pinch out away from the basin axis and become thicker and more numerous toward it. This fact suggests that the top of the lavas determined seismically is likely to be nearer the top than the bottom of the Copper Harbor Conglomerate.

In conclusion, the top of the Copper Harbor Conglomerate (base of Nonesuch Shale) appears to be the best stratigraphic location for the base of the upper Keweenawan and the Oronto Group from both a theoretical and practical standpoint, and a purpose of this paper is to propose its adoption (fig. 5). This represents a far smaller departure from Irving's original concept than do most of the maps and classifications that have attempted to follow him more faithfully. Any change in usage such as that proposed here is bound to cause some confusion for a while, but substituting a contact that can be rigorously and simply defined and located over a very large area for one that cannot should, in the long run, be a gain.

REFERENCES

Aldrich, H. R., 1929, The geology of the Gogebic Iron Range of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 71, 279 p.

Books, K. G., 1968, Magnetization of the lowermost Keweenawan lava flows *in* the Lake Superior area in Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600-D, p. D248-D254.

Butler, B. S., Burbank, W. S., and others, 1929, The copper deposits of Michigan: U.S. Geol. Survey Prof. Paper 144, 238 p.

Cornwall, H. R., 1954a, Bedrock geology of the Phoenix quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-34.

---------- 1954b, Bedrock geology of the Delaware quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-51.

---------- 1954c, Bedrock geology of the Lake Medora quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-52.

---------- 1955, Bedrock geology of the Fort Wilkins quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-74.

Cornwall, H. R., and White, W. S., 1955, Bedrock geology of the Manitou Island quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-73.

Cornwall, H. R., and Wright, J. C., 1954, Bedrock geology of the Eagle Harbor quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-36.

---------- 1956a, Geologic map of the Hancock quadrangle, Michigan: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-46.

---------- 1956b, Geologic map of the Laurium quadrangle, Michigan: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-47.

Davidson, E. S., Espenshade, G. H., White, W. S., and Wright, J. C., 1955, Bedrock geology of the Mohawk quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-54.

DuBois, P. M., 1962, Paleomagnetization and correlation of Keweenawan rocks: Canada Geol. Survey Bull. 71, 75 p.

Gordon, W. C. (assisted by Lane, A. C.), 1907, A geological section from Bessemer down Black River: Michigan Geol. Survey Rept. for 1906, p. 397-507.

Halls, H. C., 1966, A review of the Keweenawan geology of the Lake Superior region, *in* Steinhart, J. S., and Smith, T. J., eds., The earth beneath the continents: Am. Geophys. Union Geophys. Mon. 10 (Natl. Acad. Sci.-Natl. Research Council Pub. 1467), p. 3-27.

---------- 1969, Compressional wave velocities of Keweenawan rock specimens from the Lake Superior region: Canadian Jour. Earth Sci., v. 6, no. 4, pt. 1, p. 555-568.

Halls, H. C., and West, G. F., 1971, A seismic refraction survey in Lake Superior: Canadian Jour. Earth Sci., v. 8, p. 610-630.

Hamblin, W. K., 1961, Paleogeographic evolution of the Lake Superior region from Late Keweenawan to Late Cambrian time: Geol. Soc. America Bull., v. 72, no. 1, p. 1-18.

Hamblin, W. K., and Horner, W. J., 1961, Sources of the Keweenawan conglomerates of northern Michigan: Jour. Geology, v. 69, no. 2, p. 204-211.

Hite, D. M., 1968, Sedimentology of the upper Keweenawan sequence of northern Wisconsin and adjacent Michigan: Madison, Wis., Univ. Wisconsin, unpub. Ph.D. thesis, 202 p.

Hubbard, H. A., 1968, Stratigraphic relationships of some Keweenawan rocks of Michigan and Wisconsin [abs.]: *in* Inst. Lake Superior Geology, 14th Ann., 1968, Tech. Sess. Abs.: Superior, Wis., Wisconsin State Univ., p. 35-37.

Huber, N. K., 1971, The Keweenawan geology of Isle Royale, Michigan: U.S. Geol. Survey open-file report, 9 p.

Irving, R. D., 1883, The copper-bearing rocks of Lake Superior: U.S. Geol. Survey Mon. 5, 464 p.

Kelley, R. W., comp., 1968, Bedrock of Michigan: Michigan Geol. Survey Small Scale Map 2, 1 sheet.

Lane, A. C., 1898, Geological report on Isle Royale, Michigan: Michigan Geol. Survey, v. 6, pt. 1, 281 p.

---------- 1911, The Keweenaw series of Michigan: Michigan Geol. and Biol. Survey Pub. 6 (Geol. ser. 4), 2 v.: 983 p.

Lane, A. C., and Seaman, A. E., 1907, Notes on the geological section of Michigan; Part 1, The pre-Ordovician: Jour. Geology, v. 15, p. 680-695.

Leith, C. K., Lund, R. J., and Leith, Andrew, 1935, Pre-Cambrian rocks of the Lake Superior region: U.S. Geol. Survey Prof. Paper 184, 34 p.

Moerlein, G. A., 1963, Structure and stratigraphy of the upper Keweenawan rocks in northwestern Wisconsin [abs.]; *in* Inst. Lake Superior Geology, 9th Ann., 1963: Duluth, Minn., Univ. Minnesota, Dept. Geology, p. 8.

Mooney, H. M., Craddock, Campbell, Farnham, P. R., Johnson, S. H., and Volz, Gary, 1970a, Refraction seismic investigations of the northern midcontinent gravity high: Jour. Geophys. Research, v. 75, no. 26, p. 5056-5086.

Mooney, H. M., Farnham, P. R., Johnson, S. H., Volz, Gary, and Craddock, Campbell, 1970b, Seismic studies over the midcontinent gravity high in Minnesota and northwestern Wisconsin: Minnesota Geol. Survey Rept. Inv. 11, 191 p.

Ostrom, M. E., 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. 8, 1 sheet.

Thwaites, F. T., 1912, Sandstones of the Wisconsin coast of Lake Superior: Wisconsin Geol. and Nat. History Survey Bull. 25 (Sci. Ser. 8), 117 p.

Tyler, S. A., Marsden, R. W., Grout, F. F., and Thiel, G. A., 1940, Studies of the Lake Superior pre-Cambrian by accessory-mineral methods: Geol. Soc. America Bull., v. 51, no. 10, p. 1429-1537.

Van Hise, C. R., and Leith, C. K., 1911, The geology of the Lake Superior region: U.S. Geol. Survey Mon. 52, 641 p. [See particularly chap. 15, The Keweenawan Series, p. 366-426.]

Vincenz, S. A., and Yaskawa, K., 1968, Phenomenon of partial self-reversal in Keweenawan rocks. [Pt.] 2. Magnetization of upper Keweenawan lavas and sediments and of lower Keweenawan dikes: Jour. Geophys. Research, v. 73, no. 8, p. 2753-2767.

White, W. S., 1952, Imbrication and initial dip in a Keweenawan conglomerate bed [Michigan]: Jour. Sed. Petrology, v. 22, no. 4, p.. 189-199.

---------- 1956, Geologic map of the Chassell quadrangle, Michigan: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-43.

---------- 1966, Tectonics of the Keweenawan basin, western Lake Superior region: U.S. Geol. Survey Prof. Paper 524-E, 23 p.

---------- 1968, The native-copper deposits of northern Michigan, in J. D. Ridge, ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume): New York, Am. Inst. Mining, Metall., and Petroleum Eng., v. 1, p. 303-325.

White, W. S., Brooks, E. R., Hubbard, H. A., Johnson, R. F., Wilband, J. T., 1971, Keweenawan stratigraphy of westernmost Michigan [abs.], *in* Inst, on Lake Superior Geology, 17th Ann., 1971, Abs. and Field Guides: Duluth, Minn., p. 71-72.

White, W. S., Cornwall, H. R., and Swanson, R. W., 1953, Bedrock geology of the Ahmeek quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-27.

White, W. S., and Wright, J. C, 1956, Geologic map of the South Range quadrangle, Michigan: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-48.

---------- 1960, Lithofacies of the Copper Harbor Conglomerate, northern Michigan: U.S. Geol. Survey Prof. Paper 400-B, p. B5-B8.

---------- 1966, Sulfide-mineral zoning in the basal Nonesuch Shale, northern Michigan: Econ. Geology, v. 61, no. 7, p. 1171-1190.

Wright, F. E., and Lane, A. C., 1909, Preliminary geological map of the Porcupine Mountains and vicinity: Michigan Geol. Survey Ann. Rept. for 1908, pl. 1 (facing p. 8).

Wright, J. C, and Cornwall, H. R., 1954, Bedrock geology of the Bruneau Creek quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ-35.

Zietz, Isidore, and Kirby, J. R., 1971, Aeromagnetic map of the western part of the northern peninsula, Michigan, and part of northern Wisconsin: U.S. Geol.. Survey Geophys. Inv. Map GP-750.

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