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PRELIMINARY REPORT ON THE BEDROCK GEOLOGY AND COPPER DEPOSITS OF THE MATCHWOOD QUADRANGLE, ONTONAGON COUNTY, MICHIGAN

By

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Contents

	Page
Introduction	1
Rock units	3
Extrusive and sedimentary rocks	3
Portage Lake Lava Series	3
Unnamed formation	5
Copper Harbor Conglomerate	9
Nonesuch Shale	13
Freda Sandstone	16
Jacobsville Sandstone	16
Intrusive rocks	17
Structure	18
Folds	19
Faults	20
Economic geology	23
References cited	27

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INTRODUCTION

The Matchwood quadrangle is in central Ontonagon County, just west of the Ontonagon River and its Middle Branch. The Portage Lake Lava Series, of middle Keweenawan (late Precambrian) age, underlies a low range of hills that crosses the northern half of the quadrangle with east-northeasterly trend. To the north of and overlying the Portage Lake Lava Series is a succession of formations; from oldest to youngest, these include an unnamed formation consisting of mafic and felsic lava flows, the Copper Harbor Conglomerate, the Nonesuch Shale, and the Freda Sandstone. All these formations dip north-northwest. The volcanic formations are intruded by sill-like bodies of gabbro-granophyre and possibly dacitic quartz porphyry. The southeastern boundary of the outcrop area of the Portage Lake Lava Series is probably a fault--the Keweenaw fault. The southern half of the quadrangle is underlain by flat to very gently dipping Jacobsville Sandstone, which, though probably also Precambrian in age, is believed to be the youngest formation of the area.

Bedrock is heavily mantled by glacial drift, lake sediments, and recent alluvium, particularly in the southern half of the quadrangle. The map shows all the outcrops found by following the streams and larger gullies and by traverses at 1,000-foot intervals that crossed the general strike of the rocks. These outcrops are believed to represent a majority of those that might be found by a far more exhaustive search. Most of what is known about the Nonesuch Shale and Freda Sandstone in the quadrangle is based on study of drill core of the White Pine Copper Co. We have made extensive use of an aeromagnetic map of the quadrangle (Balsley, Meuschke, and Kirby, 1964) in drawing boundaries.

Most of the quadrangle was mapped by Johnson as part of a cooperative program being carried out in Ontonagon and Gogebic Counties by the Geological Survey Division of the Michigan Department of Conservation and the U.S. Geological Survey. The upper part of the Copper Harbor Conglomerate and higher formations in the northern part of the quadrangle were studied on the surface and in drill core by White and James C. Wright as part of a regional investigation of the copper-bearing Nonesuch Shale.

Members of the geological staff of the White Pine Copper Co. have been most helpful in discussing their own field work in the area with Johnson. White is indebted to officials of that company and of the Bear Creek Mining Co. for permission to examine drill core and drilling records for this and adjacent areas. Mr. Milo Steffans, District Ranger, U.S. Forest Service, Bergland, directed Johnson to several old exploratory workings in the central part of the quadrangle.

ROCK UNITS

EXTRUSIVE AND SEDIMENTARY ROCKS

Portage Lake Lava Series

The Portage Lake Lava Series, named for exposures in the vicinity of Portage Lake in Houghton County (White, Cornwall, and Swanson, 1953), underlies a belt that can be traced without interruption from the type locality to the Matchwood quadrangle and beyond. It is a series of flood basalts or basaltic andesites, with which are interbedded a few thin conglomerate or sandstone beds. The base of the formation is not exposed because the southern boundary of the lava series is the Keweenaw fault. As the map shows, this fault, drawn at the southern edge of the southernmost aeromagnetic high, lies close to the southernmost outcrops of lava at the eastern edge of the quadrangle, and 8,000 feet from the nearest exposures of lava at the western edge. The belt containing all the exposures represents a thickness of 8,500-9,000 feet of lava flows in both eastern and western parts of the quadrangle. The 8,000-foot-wide interval without exposures at the western edge of the quadrangle could represent an additional 6,000 feet of lava flows.

The lithologic character of the Portage Lake Lava Series is essentially the same in the Matchwood quadrangle as in the main part of the Michigan copper district to the northeast, where it has been described at length (Lane, 1911, p. 51-66, 120-141; Butler and Burbank, 1929, p. 18-33; Cornwall, 1951; White, Cornwall, and Swanson, 1953; White, 1960). The thickness and textural characteristics of the individual flows and interbedded sedimentary rocks in the upper 8,500 feet of the lava series, as determined from drill holes and mine openings, are given in detail by Butler and Burbank (1929, pls. 15, 31, and 32, Victoria, Cass, and Onondaga sections; the Victoria section is just east of the Matchwood quadrangle; the Cass section is in secs. 6 and 7, T. 49 N., R. 40 W., in the central part of the Matchwood quadrangle; and the Onondaga section is just west of the Matchwood quadrangle). The Portage Lake Lava Series is distinguished from the overlying unnamed formation primarily by the presence of flows with pronounced ophitic texture and the scarcity or absence of felsic flows in the Portage Lake. Flows with prominent ophitic texture make up 41 percent of the total volume of the Portage Lake Lava Series, both in the Matchwood quadrangle and for 95 miles to the northeast (W. S. White, unpub. data). Conglomerate and sandstone beds between some of the flows have predominantly rhyolitic clasts, here, as to the northeast. Sedimentary units make up about 11 percent of the total thickness of the Portage Lake Lava Series in Ontonagon County, compared to 1-3 percent on the Keweenaw Peninsula, 40-90 miles northeast of the Matchwood quadrangle.

Certain horizons within the Portage Lake Lava Series can be reliably correlated with the standard section in the main copper district, in the Portage Lake area (Butler and Burbank, 1929, pl. 15). Two such horizons are shown on the geologic map of the Matchwood quadrangle. The Forest Conglomerate, well exposed at a number of outcrops in the eastern half of the quadrangle, is apparently the same as the Bohemia Conglomerate (No. 8) of the main copper district. The Allouez Conglomerate (No. 15) of the copper district has been reliably identified in both the Victoria and Onondaga sections (Butler and Burbank, 1929, pl. 15), but was not observed in outcrop. On the geologic map, its trace is drawn parallel to a linear magnetic anomaly and between the points where it projects to the surface in the Victoria and Onondaga sections.

Unnamed formation

North of the line shown as the top of the Portage Lake Lava Series on the geologic map is a series of mafic to felsic lava flows that appears to form a distinctive unit, not equivalent in lithology or age to the rocks mapped as Portage Lake Lava Series in the vicinity of Portage Lake. This formation increases in thickness from about 4,000 feet at the eastern edge of the quadrangle to 6,500 or 7,000 feet at the western.

The flows are predominantly andesitic. Most are reddish-brown to maroon, and fine-grained to aphanitic; many contain scattered small plagioclase (An_{25} to An_{45}) phenocrysts. Texturally most of the flows are of the types called "melaphyre" and "feldspathic melaphyre" in reports on the Michigan copper district (see Cornwall, 1951, p. 161). Both fragmental and cellular (pahoehoe) types of flow top are represented. The best exposure of the formation lies along a strand line of ancient Lake Duluth at an altitude of approximately 1,160 feet near the western edge of sec. 24, T. 50 N., R. 41 W. Basaltic flows with prominent ophitic texture have not been noted either in outcrops or in the only drill holes that cut this formation (holes nos. 6-9 of the Onondaga section, Butler and Burbank, 1929, pl. 32), although sparse ophitic to subophitic grains of augite can be seen in thin sections of some flows.

The flows are significantly thinner than those of the Portage Lake Lava Series. In Onondaga drill holes 7 to 9, 115 mafic flows or flow units have an average thickness of 28 feet, compared with an average of 43 feet for the Portage Lake Lava Series. Half of the total thickness of lava intersected by these three drill holes is in flows greater than 38 feet thick; the comparable figure for the Portage Lake Lava Series as a whole is 74 feet (W. S. White, unpub. data), or about 55 feet even if ophitic flows are left out of consideration.

Felsite flows (rhyolite and trachyte) are prominent, particularly in the uppermost 500-1,000 feet of the formation. One rhyolite flow, at least 200 feet thick, is well exposed in cliffs and a quarry on the hill in sec. 21, T. 50 N., R. 41 W.; it contains numerous flattened and streaked-out pumice fragments, and represents a welded tuff. Most of the felsite flows, however, are massive to flow banded, commonly with amygdular tops, and appear to have been more like obsidian flows originally. The glass is now wholly crystallized to an intimate intergrowth of quartz and potash feldspar (intermediate microcline) with minor low albite. Albite is far more abundant than potash feldspar, on the other hand, in felsic rocks with prominent trachytic texture.

Scattered outcrops of red porphyritic felsite lie along the boundary between the Portage Lake Lava Series and the unnamed formation, from the western border of the quadrangle to sec. 29, T. 50 N., R. 40 W. Though these outcrops could belong to at least two separate bodies, they have been connected to form a single continuous belt. The boundaries have been drawn to make the outcrop belt coincide with a linear magnetic low. The outcrops at the western border are at the eastern end of a large mass of quartz porphyry exposed in the Bergland quadrangle (Brooks and Garbutt, 1969). The outcrops in secs. 25 and 26, T. 50 N., R. 41 W., and 29 and 30, T. 50 N., R. 40 W., closely resemble quartz-free phases of this mass in the Bergland quadrangle, and contain only phenocrysts of oligoclase and potash feldspar. The felsite body is at least 1,400 feet thick in sec. 26, T. 50 N., R. 41 W., and may be as much as 5,000 feet thick in the Bergland quadrangle, if it is assumed to be concordant.

It is not clear how much, if any, of this porphyritic felsite is hypabyssal and how much extrusive. Where the felsite pinches out in sec. 29, T. 50 N., R. 40 W., the margin is fragmental and the felsite is mixed with fragments of an underlying conglomerate, suggesting the end of a flow (see Cornwall, 1954, description of rhyolite dome at Mt. Houghton, Keweenaw County). Brooks and Garbutt (1969) present even more convincing evidence that the upper contact is an erosional surface in the Bergland quadrangle. A second argument for an extrusive origin is based on the thickness of the unnamed formation: if the porphyritic felsite is assumed to be extrusive and to form the basal unit of the formation, the thickness of the formation increases regularly from about 4,000 feet at the Victoria section to about 8,000 feet at the Onondaga section; if the felsite is intrusive, on the other hand, the thickness of the unnamed formation increases from 4,000 to 6,000 feet and then decreases to 3,000 feet in this same distance. The best evidence for an intrusive origin is the Rb-Sr whole-rock age of 978±40 m.y. obtained by Chaudhuri and Faure (1967) on samples of the quartz porphyry in the Bergland quadrangle. This is much younger than the age of 1,100±25 m.y. that they obtained by the same method for extrusive rhyolites from near the top of the unnamed formation.

Sedimentary rocks are not conspicuous in the unnamed formation. Butler and Burbank (1929, pl. 32) show less than 2 percent of sedimentary rock in the Onondaga drill holes. Reddish siltstone crops out west of B.M. 1,287 in sec. 31, T. 50 N., R. 41 W., and a small isolated exposure of dark-reddish sandstone, composed largely of mafic grains, was found in a gully about half a mile to the south. This sandstone may correlate with felsic conglomerate underlying the porphyritic felsite body farther east.

Copper Harbor Conglomerate

The Copper Harbor Conglomerate, of late Keweenawan age, consists of red to brown arkosic sandstone and conglomerate. The formation is named from exposures in the vicinity of Copper Harbor, Keweenaw County (Lane and Seaman, 1907; Lane, 1911, p. 37-39; White, Cornwall, and Swanson, 1953), and its outcrop belt extends without interruption from the type locality to the Matchwood quadrangle. The thickness of the Copper Harbor Conglomerate decreases from about 1,600 feet at the eastern boundary of the quadrangle to 350 feet at the western. It should be noted that this decrease complements, to some extent, an increase in the thickness of the underlying unnamed formation. White and Wright (1960, 1966) have concluded from this relationship that the unnamed formation represents a volcanic pile that was blanketed by the Copper Harbor Conglomerate[1/].

[1/] This volcanic pile coincides with a doughnut-shaped magnetic anomaly, the northern and western parts of which follow the trend of the Porcupine Mountain anticline (see White and Wright, 1966, fig. 1). The magnetic anomaly suggests that an ancient caldera may be present here, but if it is, the walls of the southeastern part are not well expressed by the geologic map of the westernmost Matchwood quadrangle.

The mapped outcrops provide tenuous evidence that the base of the Copper Harbor Conglomerate is in contact with successively lower horizons of the unnamed formation toward the east, but the outcrop information is not good enough to establish whether this indicates an angular unconformity or interfingering. Interfingering would suggest that the unnamed formation is more or less contemporaneous with the Copper Harbor Conglomerate, whereas an angular unconformity would be consistent, at least, with a significant difference in age; the point is of interest, in part, because it bears on the question of whether the unnamed formation should be called middle or upper Keweenawan.

To the accuracy with which it can be measured, the upper boundary is parallel to the transition from conglomerate up to sandstone in the uppermost hundred feet of the Copper Harbor Conglomerate. The upper boundary is exactly concordant with bedding in the overlying Nonesuch Shale..

The lithologic characteristics of the Copper Harbor Conglomerate have been summarized by White and Wright (1960) for the northern Michigan area as a whole, and only the salient features of the formation in the Matchwood quadrangle are treated here. The uppermost 400 feet consist primarily of thick-bedded, well-sorted conglomerate in which felsic debris predominates; the most abundant type has a modal pebble size in the vicinity of 2-4 inches, but conglomerate beds with modal diameters of 8 inches and maximum diameters in the range 15-18 inches are fairly common. Sandstone beds become increasingly abundant toward the top of this unit, and the uppermost 100 feet of the formation is predominantly coarse, grayish-red arkosic sandstone with few pebbly layers. These rocks are believed to represent alluvial-fan deposits (White and Wright, 1960).

In the central part of the quadrangle, at least, the interval from 400 to 800 feet below the top is characterized by uniformly fine grained reddish-brown, platy to slabby sandstone. It is well exposed in Cunningham Creek in the southwest part of sec. 18, T. 50 N., R. 40 W. These rocks belong to the "red facies" described by White and Wright (1960); foreset bedding in this unit suggests a northerly source, in contrast to the southerly source indicated by foreset bedding and imbricate pebbles in the more typical rocks of the Copper Harbor Conglomerate. This unit of "red facies" must thin greatly or even pinch out entirely near the western border of the Matchwood quadrangle. Whether the unit thickens or thins eastward is not known. It may be the unit that underlies a gap between extensive conglomerate exposures 1,000-1,500 feet south of the north line of sec. 8, T. 50 N., R. 39 W., in the next quadrangle to the east (see Lane, 1911, pl. 14); the rocks underlying this gap occupy a stratigraphic interval 300-700 feet below the top of the formation.

The base of the Copper Harbor Conglomerate near the western border of the quadrangle is marked by at least 50 feet of cobble conglomerate in which mafic pebbles predominate. The best exposures are on Duck Creek in the northeast corner of sec. 25, T. 50 N., R. 42 W.

Nonesuch Shale

The Nonesuch Shale, best known for the widespread occurrence of copper in its basal beds, is named for the Nonesuch mine (Irving, 1883, p. 221-224), 5.5 miles west of the northwest corner of the Matchwood quadrangle. It consists primarily of gray siltstone with subordinate dark-gray shale and light-gray sandstone. The formation crops out only as a narrow belt near the northern border of the quadrangle, but its character down-dip is known throughout a very large area to the north and west because of the hundreds of exploratory holes that have been drilled to its base through the overlying formation. The thickness of the Nonesuch Shale decreases from about 575 feet near the western edge of the quadrangle to about 540 near the eastern; the formation thickens northward at a rate of about 25 feet per mile.

The lithologic characteristics of the Nonesuch Shale and the immediately underlying sandstone have been summarized by White and Wright (1954), Ensign and others (1968), and Hamilton (1967) for the White Pine area, north and west of the Matchwood quadrangle, and only features of the formation within the Matchwood quadrangle are described here. The formation is not well exposed, and almost all the information comes from drill holes. Rocks at or near the base of the formation can be seen in the beds of the Cranberry River (sec. 14, T. 50 N., R. 41 W.), Cunningham Creek (sec. 18, T. 50 N., R. 40 W.), and Gates and Forsling Creeks (secs. 14 and 11, T. 50 N., R. 40 W.; columnar section K, White and Wright, 1954, fig. 6). Outcrops of the middle and upper part of the formation in the Cranberry River help locate the formation on the map, but the ledges are small, mostly under water, and commonly of brecciated rock; they are not abundant enough to give a representative or useful section of the formation.

The generalized description of the formation as a whole given by White and Wright (1954, p. 680 and fig. 2) is valid for the Matchwood quadrangle, and there are no noteworthy changes in lithology across the width of the quadrangle. Shaly layers are more prominent near the base than higher up. In the western half of the quadrangle, at least, massive beds of very fine grained sandstone to coarse siltstone are more abundant in the lower half than in all but the uppermost hundred feet or so of the upper half, but drill hole M5 (sec. 11, T. 50 N., R. 40 W.) seems to have more of these beds in the upper half of the formation. Rippled siltstone with thin reddish-gray shaly partings is the commonest rock type in the central part of the formation.

The principal subdivisions of the basal part of the formation recognized at White Pine (White and Wright, 1954, p. 680-685; Ensign and others, 1968, p. 470-477) persist eastward across the Matchwood quadrangle. The thickness of rocks between the base of the so-called "striped bed" and the base of the Nonesuch Shale increases from about 45 feet near the western border to 52 feet near the eastern.

The parting shale, within a mile or so of its outcrop, does not have the stratigraphy and appearance that is typical for the White Pine mine area (see White and Wright, 1954, figs. 3 and 5; Ensign and others, 1968, fig. 5) except in drill hole M5 (sec. 11, T. 50 N., R. 40 W.). In most of the drill holes, it is thinner than normal (3-4 feet), or, if thicker, contains sandstone (sec. 13, T. 50 N., R. 40 W.); red siltstone is abundant, and individual subunits of the parting shale are difficult to identify with assurance. In drill hole M5, on the other hand, the parting shale is 7 feet thick, and has essentially the same stratigraphy that it has in the mine area. The occurrences in the western part of the quadrangle are believed to represent a facies of the parting shale formed closer to shore than the facies exposed in drill hole M5, which is typical of the mine area.

The upper sandstone, composed of fine- to coarse-grained sandstone, thickens from about 4 feet in the western part of the quadrangle to 12 feet in drill hole M5. The base of the unit is pebbly in the western part of the quadrangle.

The rocks for 10 to 18 feet below the striped bed are notably sandy over the entire width of the quadrangle.

Freda Sandstone

The Freda Sandstone consists largely of reddish-brown siltstone to very fine grained sandstone, with subordinate amounts of red shale. It is named for exposures near Freda, Houghton County, 34 miles northeast of the Matchwood quadrangle. The Freda is the only formation overlying the Nonesuch Shale throughout the outcrop area in Michigan, and may attain a thickness of 12,000 feet at the Wisconsin State line. Only the lowermost 2,000 feet or so are represented in the Matchwood quadrangle.

This formation has been described at length elsewhere (Hamblin, 1961a, 1961b). No study was made of the few scattered outcrops or of drill core from the Matchwood quadrangle, and the formation will not be discussed further here.

Jacobsville Sandstone

The Jacobsville Sandstone, which blankets all of the quadrangle south of the Keweenaw fault, is a reddish-brown sandstone with subordinate shale; the sandstone is more mature, with a higher proportion of quartz (of the order of 75 percent) and better rounded grains than that of the Keweenawan formations treated above. The Jacobsville is named from a village, 43 miles east-northeast of the Matchwood quadrangle, where the formation was once quarried for building stone. It is older than Upper Cambrian, and is generally considered to be the youngest of the Keweenawan formations in Michigan. The only exposures seen are in cliffs on the West Branch of the Ontonagon River in sec. 2, T. 49 N., R. 40 W. The most complete section of the formation is in a drill hole at the west quarter-corner of sec. 36, T. 48 N., R. 40 W., where, at a depth of 2,288 feet below the surface, it lies unconformably above mafic lava. The bulk of the section exposed in the drill hole is essentially the same as the sandstones exposed near the type locality, except that coarse-grained to gritty sandstone is somewhat more abundant. About 1.5 percent of the rock is red shale, and about 3 percent is conglomerate, not counting 98 feet of pebble conglomerate at the base of the section.

The formation and its regional relationships and paleogeography have been described in considerable detail by Hamblin (1958, 1961b), and are not further discussed here.

The mafic lava overlain by the Jacobsville Sandstone in the drill hole mentioned above causes a magnetic high that can be traced 30 miles westward, without interruption, to the exposures of basal Keweenawan rocks just north of Wakefield, Gogebic County, and 28 miles east-northeastward to the exposure on Silver Mountain, Houghton County (Bacon, 1966). These exposures appear to represent a group of lava flows, also dipping northward, that antedates and probably should be considered as separate from the Portage Lake Lava Series (H. A. Hubbard, informal commun., 1967).

INTRUSIVE ROCKS

The Portage Lake Lava Series and the unnamed formation have been intruded by mafic and felsic dikes, and a differential sill-like diabase-granophyre intrusion lies on or close to their common boundary. Small felsic dikes locally cut the Copper Harbor Conglomerate. The possible intrusive origin of the porphyritic felsite at the base of the unnamed formation is discussed as part of the description of that formation.

The diabase-granophyre intrusion crops out in a line of cliffs in secs. 5 and 6, T. 49 N., R. 41 W. The base appears to be conformable with the underlying basalt; the top is not exposed, and relations there are ill-defined. The intrusion is about 600 feet thick near Bush Creek and probably thicker a mile or so to the east. The apparent absence of the intrusion west of the White Pine fault can be explained by the upward and right-lateral displacement of the rocks northeast of the fault, if one adopts the reasonable assumption that the intrusion pinches out up dip. The lower part of the intrusion is olivine diabase, at least 150 feet thick where the intrusion is thick. This diabase grades upward fairly abruptly into typical granophyre by an increase in the amount of interstitial micrographic quartz-potash feldspar intergrowths.

The mafic and felsic dike rocks are poorly exposed, for the most part, and have not been studied. The stratigraphically highest rocks known to be cut by dikes are sandstones within 100 feet or so of the top of the Copper Harbor Conglomerate (NW1/4SE1/4 sec. 16, T. 50 N., R. 41 W.). Two dikes, both felsic, were found here, one up to 22 inches and the other up to 9 inches in width, striking north to north-northeast and dipping 70°-90° east.

STRUCTURE

The major structural elements of the area are the Keweenaw fault, the homoclinal northwesterly dip of the layered rocks north of the fault, the anticlinal and synclinal bends in the layered rocks, and the north to northwesterly striking transverse faults located in the axial area of the bands.

FOLDS

All of the layered rocks north of the assumed position of the Keweenaw fault are on the south flank of the Lake Superior basin and dip toward the lake. Dips as steep as 55° are recorded from the southern edge of the lavas, but the beds flatten northward and dips become 15° or less near the north edge of the quadrangle. In addition to this regional dip, the beds have been warped into anticlinal and synclinal bends. The most prominent anticlinal bend is in the western half of the quadrangle. The flows strike about N. 50° E. near the western border and strike nearly east in the vicinity of the Norwich mine. Overlying sedimentary beds are bent still further and strike N. 75° W. near the Cranberry River in the northern part of the mapped area. A much weaker synclinal and anticlinal bend in the Portage Lake Lava Series farther east appears to die out in the overlying sedimentary beds.

FAULTS

The northeast-trending Keweenaw fault is thought to cross the central part of the quadrangle, as shown on the geologic map. On the Keweenaw Peninsula, this fault is a reverse fault that has thrust rocks of the Portage Lake Lava Series over the Jacobsville Sandstone. The reverse nature of the fault cannot be demonstrated in the Matchwood quadrangle, but the presence of nearly flat lying Jacobsville Sandstone near the base of steep slopes underlain by flows of the older Portage Lake Lava Series seems most easily explained by faulting whether it be reverse or normal. Aeromagnetic evidence for the fault in the mapped area (Balsley, Meuschke, and Kirby, 1964) is the nearly linear boundary between an area with numerous magnetic anomalies underlain by the lavas and an area of low magnetic variability thought to be over the Jacobsville Sandstone. Several thousand feet of the Portage Lake Lavas are cut out along this boundary; the No. 8(?) conglomerate is 9,000 feet stratigraphically above the boundary in the Norwich mine area, and only 1,500 feet above it 4 miles to the east, which lends support to the concept that the boundary marks a fault.

North- to northwesterly striking faults cut the volcanic rocks and overlying sandstones. The best known of these is the White Pine fault, which has a right-hand horizontal displacement of at least 3,000 feet at the White Pine mine, just northwest of the Matchwood quadrangle (Ensign and others, 1968, p. 470); the east side is also uplifted a few hundred feet at the White Pine mine. The projected position of the White Pine fault in the Matchwood quadrangle is along Bush Creek at the western edge of the map, and thence southeast along the valley of Cascade Creek. If the structural interpretation presented on the map is correct, the net slip on the White Pine fault is essentially parallel to bedding along Bush Creek. Several north-striking faults west and south of Cascade Creek may be splits from the White Pine fault.

Other transverse faults are indicated by linear gaps in the topography that roughly coincide with linear irregularities on the aeromagnetic map (Balsley and others, 1964). These include a topographic break along Clifton Creek extending north-northwest to sec. 17, T. 50 N., R. 41 W.; another west of the Norwich mine that extends north along Mason Creek and Cranberry River; and others along Whiskey Hollow Creek and Deer Creek.

The apparent displacement on these faults cannot be estimated from surface data but does not seem to be large. The trace of the No. 8(?) conglomerate as shown on the geologic map gives some idea of offsets on the eastern faults. The conglomerate does not appear to be offset in the broad gap at the head of Deer Creek, and there is only about 25 feet of left-hand separation along the fault in Gleason Creek. A right-hand offset of about 300 feet is possible in Whiskey Hollow Creek. The No. 8(?) conglomerate is cut off by the fault west of the Norwich mine, but the small outcrop in line with the conglomerate just west of the road resembles the flow beneath the conglomerate, suggesting a small right-hand offset for that fault as well.

The larger transverse faults are located near the axial areas of the bends in the layered rocks and Keweenaw fault or in the three western faults; they converge southward toward the axial area. This relationship suggests that the transverse faults are tensional features related to the bending.

Faults of economic importance strike nearly parallel to the lava flows but dip at a steeper angle (Irving, 1883, p. 422-423; Butler and Burbank, 1929, p. 117, 233). The slickensided fissures are filled with quartz and epidote and contain masses of native copper. Most of the production from the Norwich mine came from a fissure of this type and a parallel fissure about 800 feet to the north also yielded some copper.

ECONOMIC GEOLOGY

Native copper occurs in the mafic lava flows of the Portage Lake Lava Series, and chalcocite and native copper are mined from the base of the Nonesuch Shale and the top of the Copper Harbor Conglomerate. The Matchwood quadrangle appears to lie west of the most productive copper-bearing area in the lavas, which extends from Rockland, 5 miles east of the quadrangle boundary, northeastward along the Keweenaw Peninsula, but large reserves of copper ore have been developed by the Copper Range Corporation in the Nonesuch Shale in an area that includes the northwest corner of the Matchwood quadrangle (map in 1968 Annual Report of Copper Range Co., p. 7).

Copper mining in the lavas of the quadrangle began and ended early in the history of the Michigan copper district. The Norwich mine (sec.11, T. 50 N., R. 41 W.) began operations in 1850, and the last-recorded production was in 1869 with a total production of 494 tons of copper (Butler, Burbank, and others, 1929, p. 91). Other mines near the Norwich produced a few tons of copper prior to 1860. Jamison (undated pub.) lists all of the mining companies that have prospected in the Bergland-Matchwood area. Surface prospecting was intensive as shown by the numerous pits that are still visible. Interest in the early days was in fissure deposits, so many pits explored the intersection of northerly striking fractures with the tops of flows. Small amounts of native copper are visible in rocks in the dumps of these pits, but apparently not enough was found to be of interest. Butler, Burbank, and others (1929, p. 216) state that several lodes (flow tops) that were productive in the Rockland area have been prospected as far west as the Norwich mine but with poor results. The only drilling of which there is a record was done near the Norwich mine (Butler, Burbank, and others, 1929, pls. 14 and 32).

The main adits at the Norwich mine are near the base of a prominent lava bluff about 300 feet high. Stopes followed a slickensided fissure filled with quartz, epidote, and calcite, and containing native copper. The stopes come to the surface about 200 feet up the cliff. The fissure is essentially parallel to the strike of the enclosing basalt but dips at a steeper angle. The fissure contained large masses of copper, as well as milling-grade ore (Butler, Burbank, and others, 1929, p. 233). Small slabs of copper can still be found in the slickensided walls of the vein in pillars left in the stopes. A parallel fissure about 800 feet north of the Norwich vein was prospected and stoped over a length of about 2,000 feet and furnished ore for a small stamp mill, the tailings of which can be seen in a pond at the top of the cliff.

The White Pine mine of the Copper Range Co. is currently milling nearly 7,000,000 tons of ore per year from the base of the Nonesuch Shale. Most of the mine workings are west and northwest of the Matchwood quadrangle, but a shaft was completed in 1966 at the east edge of sec. 7, T. 50 N., R. 41 W., to provide access for southeastward expansion of the mine.

The nature of mineralization at the base of the Nonesuch Shale and in the uppermost Copper Harbor Conglomerate has been described in detail (White and Wright, 1954, 1966; Ensign and others, 1968). The top of the cupriferous zone described in these publications gradually descends stratigraphically from a high in or just above the No. 43 bed of local usage (see Ensign and others, 1968, fig. 5) near the western edge of the quadrangle to 2 or 3 feet above the base of the Nonesuch Shale in diamond-drill hole M5 (sec. 11, T. 50 N., R. 40 W.). The total amount of copper in the cupriferous zone, expressed as the product of the thickness of copper-bearing rock multiplied by average grade, decreases by a factor of 4 or 5 between the western and eastern borders of the quadrangle, but it should be noted that there is no drill-hole information for down-dip portions of the Nonesuch Shale along most of the northern boundary of the quadrangle.

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