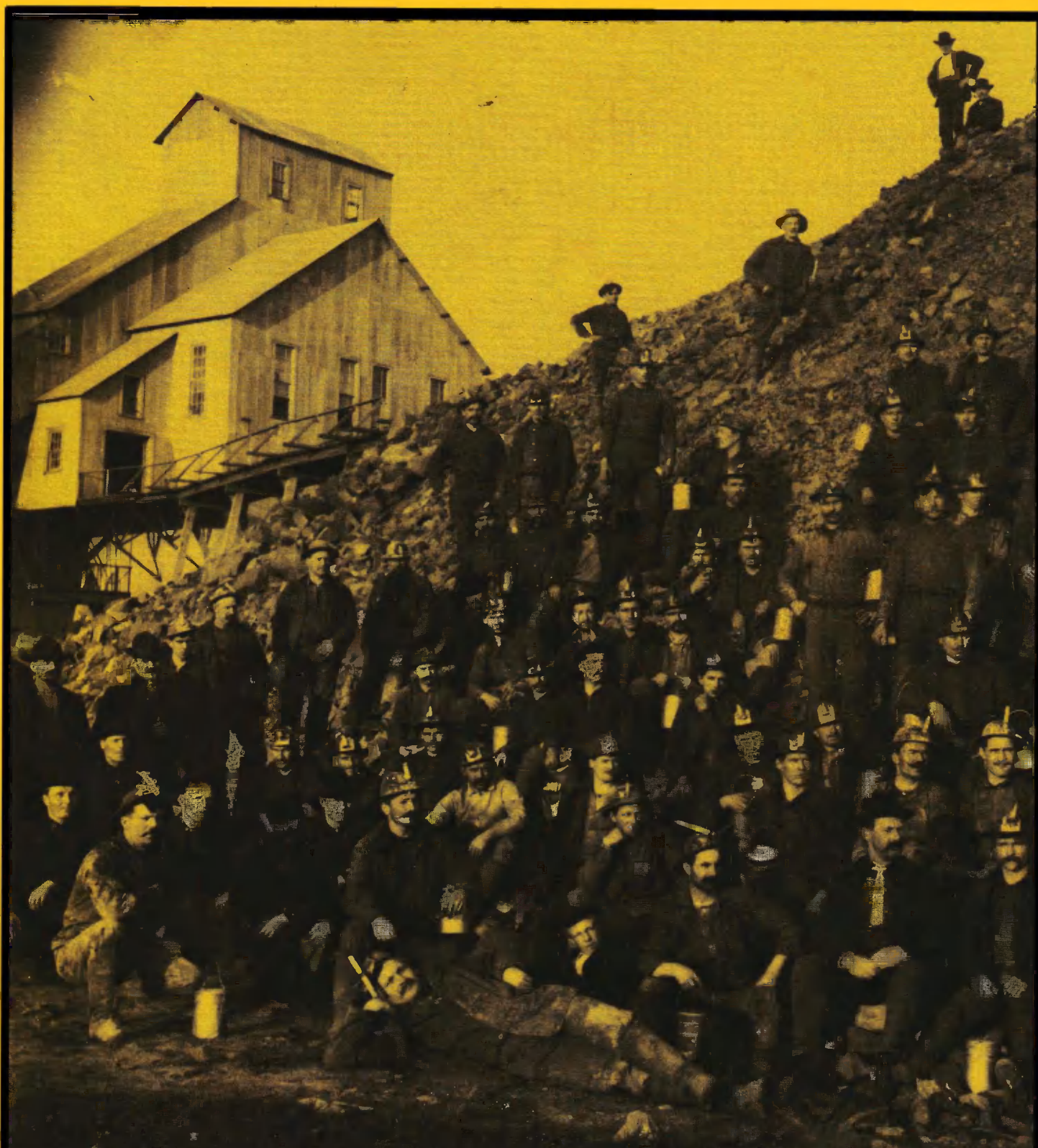
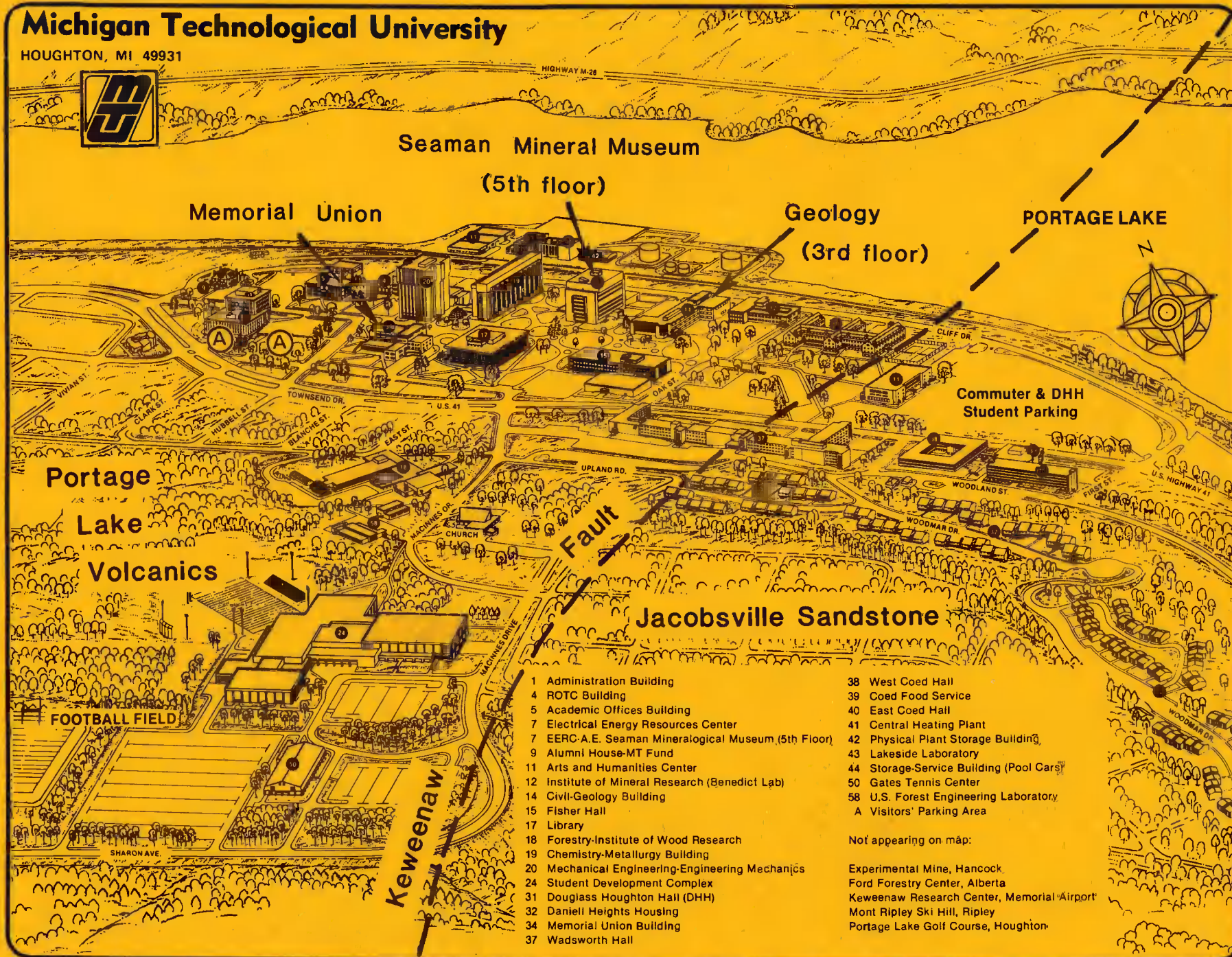




Field Guide to the Geology of the Keweenaw Peninsula, Michigan

Michigan Technological University

HOUGHTON, MI 49931



Seaman Mineral Museum

(5th floor)

Memorial Union

Geology

(3rd floor)

PORTAGE LAKE

Commuter & DHH
Student Parking

Portage

Lake

Volcanics

Jacobsville Sandstone

FOOTBALL FIELD

- 1 Administration Building
- 4 ROTC Building
- 5 Academic Offices Building
- 7 Electrical Energy Resources Center
- 7 EERC-A.E. Seaman Mineralogical Museum (5th Floor)
- 9 Alumni House-MT Fund
- 11 Arts and Humanities Center
- 12 Institute of Mineral Research (Benedict Lab)
- 14 Civil-Geology Building
- 15 Fisher Hall
- 17 Library
- 18 Forestry-Institute of Wood Research
- 19 Chemistry-Metallurgy Building
- 20 Mechanical Engineering-Engineering Mechanics
- 24 Student Development Complex
- 31 Douglass Houghton Hall (DHH)
- 32 Daniell Heights Housing
- 34 Memorial Union Building
- 37 Wadsworth Hall

- 38 West Coed Hall
- 39 Coed Food Service
- 40 East Coed Hall
- 41 Central Heating Plant
- 42 Physical Plant Storage Building
- 43 Lakeside Laboratory
- 44 Storage-Service Building (Pool Cars)
- 50 Gates Tennis Center
- 58 U.S. Forest Engineering Laboratory
- A Visitors' Parking Area

Not appearing on map:

Experimental Mine, Hancock
Ford Forestry Center, Alberta
Keweenaw Research Center, Memorial Airport
Mont Ripley Ski Hill, Ripley
Portage Lake Golf Course, Houghton

FIELD GUIDE TO THE GEOLOGY OF THE
KEWEENAW PENINSULA, MICHIGAN

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COVER PHOTO: Miners at the
Baltic Mine(?) circa 1910.
Michigan Technological Uni-
versity Archives and Copper
Country Historical Collections.

PREFACE

It is presumptuous for us to put together a book which is based mainly on the work of others. We have done so because hundreds of people come to the Keweenaw each year to look at geological features and many of them ask us for advice. So we've tried to communicate with people who are doing serious geological field trips.

This is a first draft of an evolving document, which we expect to continually revise. Please help us make it better by suggesting changes, finding mistakes and telling us what we've left out.

Starting with Douglass Houghton almost 150 years ago, dozens of geologists have contributed a mountain of geological information on the Keweenaw which makes it a real challenge to compile this book. The greatest contribution by far has come from Walter S. White, who devoted much of his professional career to Keweenawan geology and whose impact can be traced to virtually every page of this book. We hope that we have faithfully transmitted his ideas with a fraction of his ingenuity and enthusiasm.

Houghton
30 March 1983

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HOW TO USE THIS GUIDE

To make all the stops listed in this guide would take three days. If you wish to emphasize certain types of stops, we recommend the following subsets:

Suggested Stops

Sediments	5, 6, 8, 9, 10, 13, 16, 17, 19, 20, 24
Volcanic Rocks	1, 3, 11, 12, 13, 14, 15, 16, 17, 18, 21
Mineral Deposits	2, 3, 4, 7, 11, 13, 17, 22, 23
Broad Coverage	3, 6, 10, 11, 13, 16, 18, 19, 20, 24

Be imaginative and make up your own subset of stops.

Many stops are on or near private land. Please respect private property. The present problems of access are minimal, but obviously we could ruin things if we don't use low profile outdoor principles. A few stops are located on old mine dumps. These can be hazardous, especially where bad ground occurs. Use common sense.

All maps have north to the top and are 1:24,000 (4 cm to 1 km). Dots follow the road log route on the maps, while stars mark the stops.

Mineral collectors have long flocked to the Keweenaw to collect its unusual minerals. One of the best mineral museums in the world is located at the starting point of this field trip. The Seaman Mineralogical Museum, open from 9:00-4:30 weekdays, is housed in the EERC Building, Fifth Floor, on the Michigan Tech Campus. The mineralogical collection includes samples from all over the Keweenaw and is a must for all rockhounds.

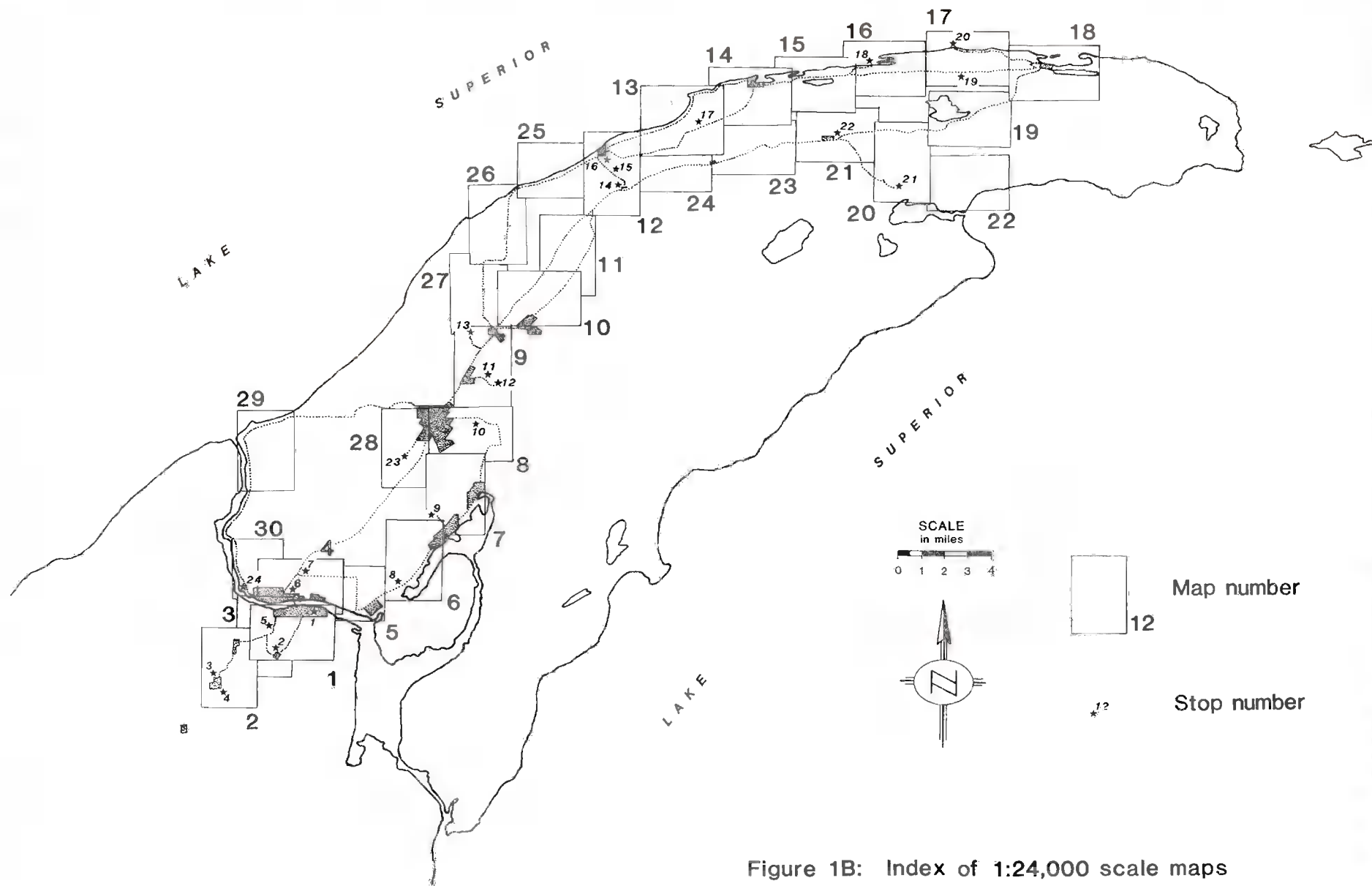
LIST OF STOPS

The following list of stops can be used to help you design your own field trip to see the geology of the Keweenaw Peninsula. The location of stops are shown in Figure 1a. The appropriate maps for each stop and trip route are located in Figure 1b.

STOP	(APPROPRIATE MAP)	STOP DESCRIPTION
1	(1)	Ophitic Scales Creek basalt flow and Keweenaw Waterway view, 7th St., Houghton.
2	(1)	Secondary minerals in amygdaloid at dump of Isle Royale Mine, Dodgeville.
✓ 3	(2)	Section through a lava flow at South Range quarry.
✓ 4	(2)	Secondary minerals in amygdaloid at dump of Baltic Mine.
5	(3)	Glacial deposits on M-26 south of Houghton.
✓ 6	(4)	Overlook of Keweenaw Waterway, Houghton and the Range towns; Quincy Hill, Hancock.
7	(4)	Secondary minerals of amygdaloid at dump of Quincy Mine.
8	(6)	Flat-lying Jacobsville Sandstone along M-26, near Dollar Bay.
9	(7)	Keweenaw Fault at Hungarian Falls, near Hubbell.
✓ 10	(8)	Keweenaw Fault at Natural Wall Ravine, near Laurium.
✓ 11	(9)	Secondary minerals in amygdaloid at dump of Wolverine Mine.
12	(9)	Ophitic Scales Creek basalt flow, at Scales Creek near Copper City.
✓ 13	(9)	Lava flows of Portage Lake Volcanics and mineralized conglomerate with an excellent view of the central part of the Keweenaw Peninsula, Bumble-town Hill.
✓ 14	(12)	Ophitic Greenstone flow and vein mineralogy at dump of Phoenix Mine.
15	(12)	Section through the upper part of the Portage Lake Volcanics along Eagle River.
✓ 16	(12)	Contact between Portage Lake Volcanics and Copper Harbor Conglomerate at Eagle River Falls.

LIST OF STOPS (Cont'd.)

STOP	(APPROPRIATE MAP)	STOP DESCRIPTION
17	(13)	Section through the upper part of the Portage Lake Volcanics along Owl Creek and amygdaloid/vein mineralogy at dump of Copper Falls Mine.
✓18	(16)	Lava flows of the Lake Shore Traps at Esrey Park.
✓19	(17)	Overlook of Lake Superior and the eastern end of the Keweenaw Peninsula and outcrops of Copper Harbor Conglomerate at Brockway Mountain.
✓20	(17)	Copper Harbor Conglomerate at Dan's Point.
21	(20)	Diorite and granophyre stock at Mt. Bohemia.
22	(21)	Secondary mineralogy of veins and conglomerate at Delaware Mine. The Delaware Mine is open to tourists for a fee.
23	(28)	Amygdaloid mineralogy of dumps at Osceola Mine.
24	(30)	Nonesuch Shale at Hancock campground quarry.



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INTRODUCTORY NOTES ON THE GEOLOGY OF THE KEWEENAW PENINSULA

General Background

The Mid-Continent Rift System extends northeasterly from Kansas to Lake Superior and then southeasterly through lower Michigan (Fig. 2). It was formed about 1.1 to 1.2 b.y. ago (Keweenaw age) by extensional thinning of the rigid Precambrian Superior crustal block (Klasner and others, 1982). Present day crustal thickness in the Lake Superior region, however, is between 40 and 50 Km, which is thicker than adjacent areas (Halls, 1982).

The present Keweenaw Peninsula is located on the margin of the Lake Superior Basin, one of the basins within the Mid-Continent Rift System (Fig. 3). The volcanic and sedimentary rocks on the northwest side of the Keweenaw Peninsula generally dip moderately toward Lake Superior and include the Portage Lake Volcanics, Copper Harbor Conglomerate, Nonesuch Shale and the Freda Sandstone. The Jacobsville Sandstone occupies the southeast side of much of the Keweenaw Peninsula and is in fault contact with the Portage Lake Volcanics along the Keweenaw Fault. The Jacobsville Sandstone is probably slightly younger than the Freda Sandstone, however, it is still most likely upper Keweenaw in age (Kalliokoski, 1982).

At some time after the deposition of basin filling sediments, the Lake Superior region was subjected to compression roughly normal to the basin axis. These stresses resulted in the Keweenaw and Isle Royale Faults, both high angle reverse faults near the margins of the Lake Superior Basin (Fig. 3). This faulting steepened the dips of strata exposed on both the Peninsula and on Isle Royale. Definite age relationships between reverse faulting and deposition of the Jacobsville Sandstone are unclear: faulting may be partially syn- or wholly post-depositional.

The Lake Superior Syncline was affected by a regional burial metamorphic and/or hydrothermal event. Remobilization of many elements, particularly within the Portage Lake Volcanics, caused strong alteration of lava flow tops and interbedded conglomeratic units. Native copper deposits of the Keweenaw Peninsula are believed to have formed wholly or in part after the deposition of much or all of the Freda Sandstone (White, 1968).

Paleozoic geologic processes were largely atectonic. Sediments associated with the Michigan basin probably once covered the Keweenaw Peninsula, as evidenced by the isolated occurrence of Ordovician limestone at Limestone Mountain and Sherman Hill, about 20 miles south of Houghton. The present day landscape of the Keweenaw Peninsula is strongly influenced by Pleistocene glaciation.

Stratigraphy

The bedrock geology of the Keweenaw Peninsula consists of five major stratigraphic units. Portage Lake Volcanics, Copper Harbor Conglomerate, Nonesuch Shale, Freda Sandstone and Jacobsville Sandstone (Figs. 3 and 4). The accumulated maximum thickness of these units is over 14,000 m. The bedrock in the Keweenaw Peninsula is unconformably capped by a variety of glacial deposits.

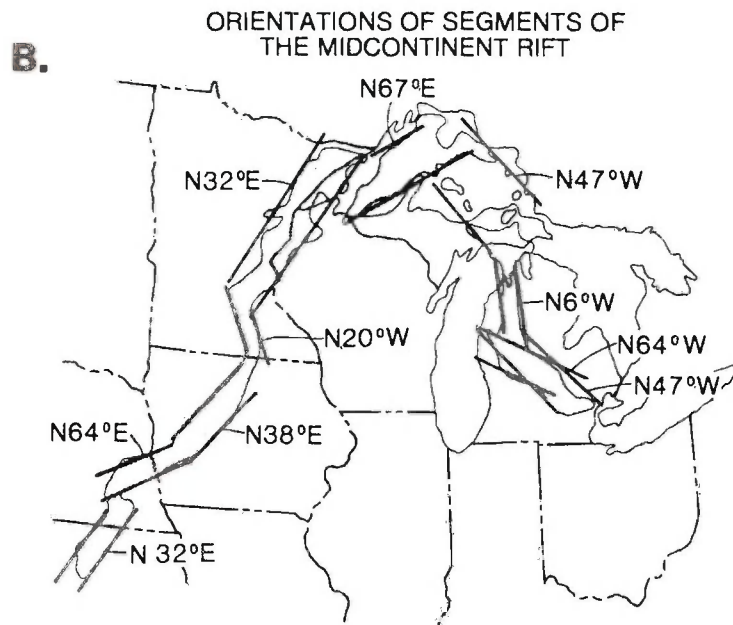
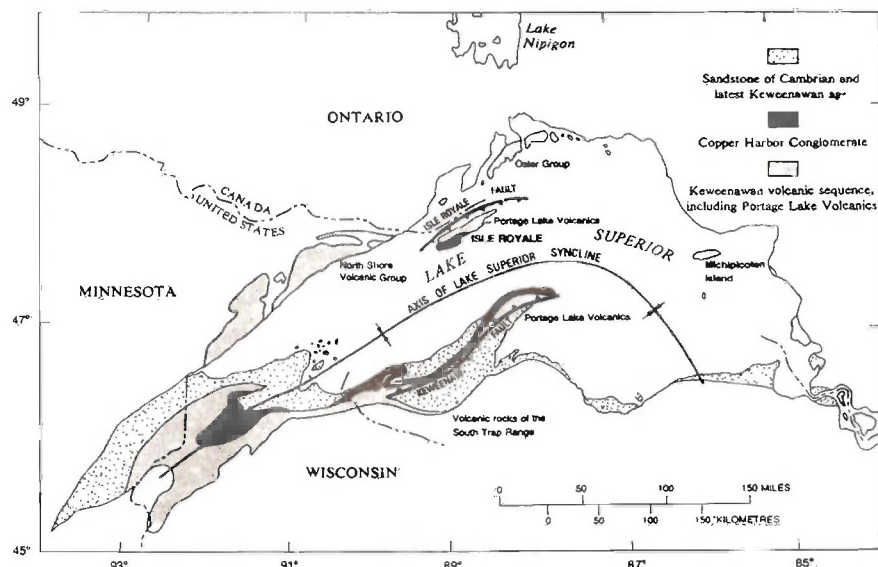
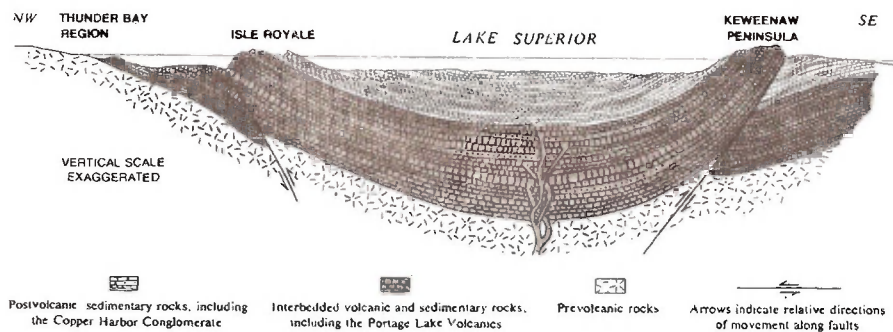


Figure 2: Location of the Mid-Continent Rift System. A. Major Proterozoic and Paleozoic rifts of North America (from Burke, 1980). B. Orientation of individual segments of the Mid-Continent Rift System (from Klasner and others, 1982).



LAKE SUPERIOR REGION—distribution of selected rock units.



LAKE SUPERIOR BASIN—cross section.

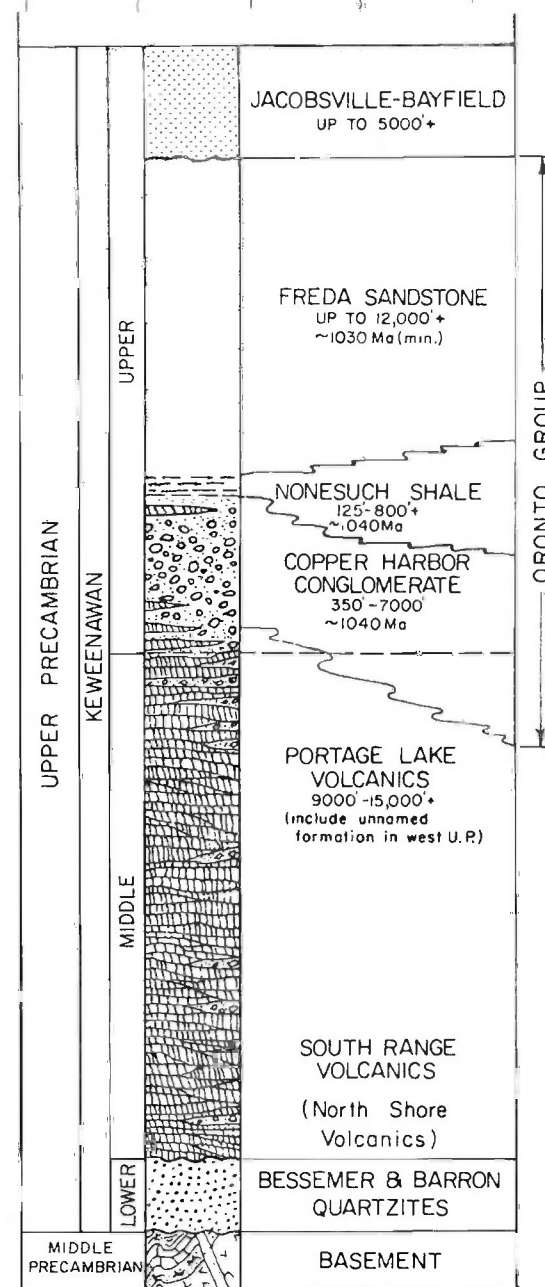


Figure 3: Simplified geologic map, cross-section, and stratigraphic column of upper Precambrian rocks in the western Lake Superior region (map and cross-section from Huber, 1975; stratigraphic column from Daniels, 1982).

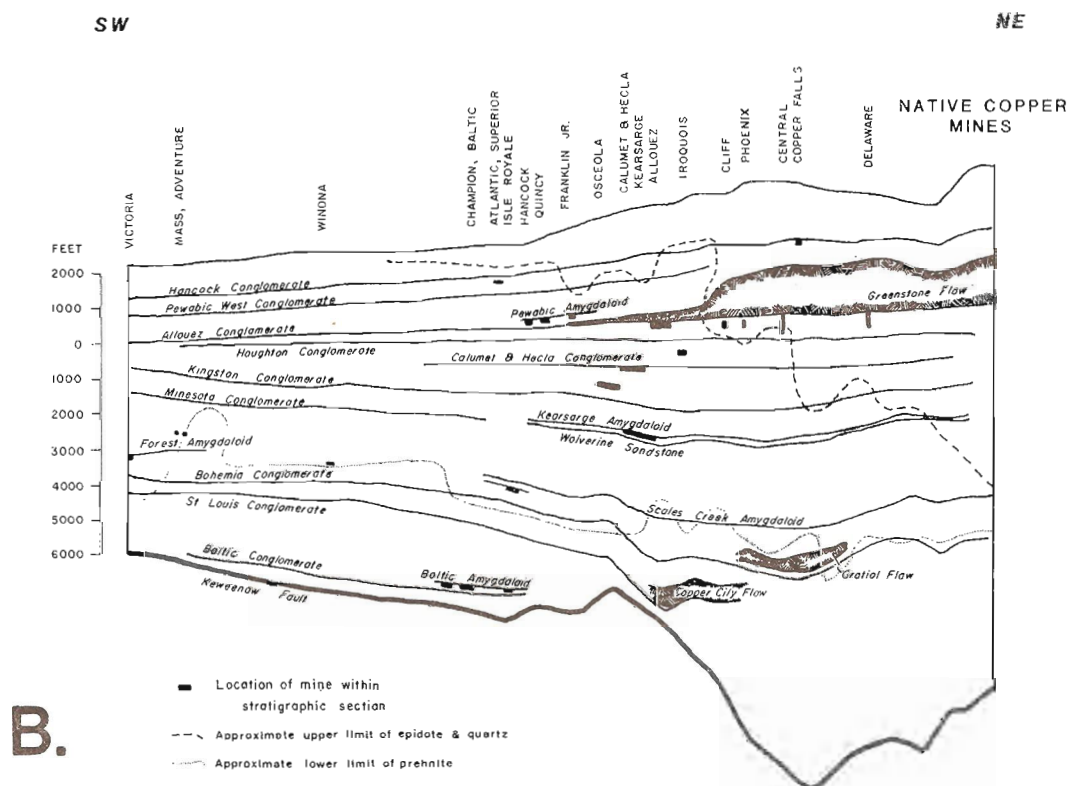
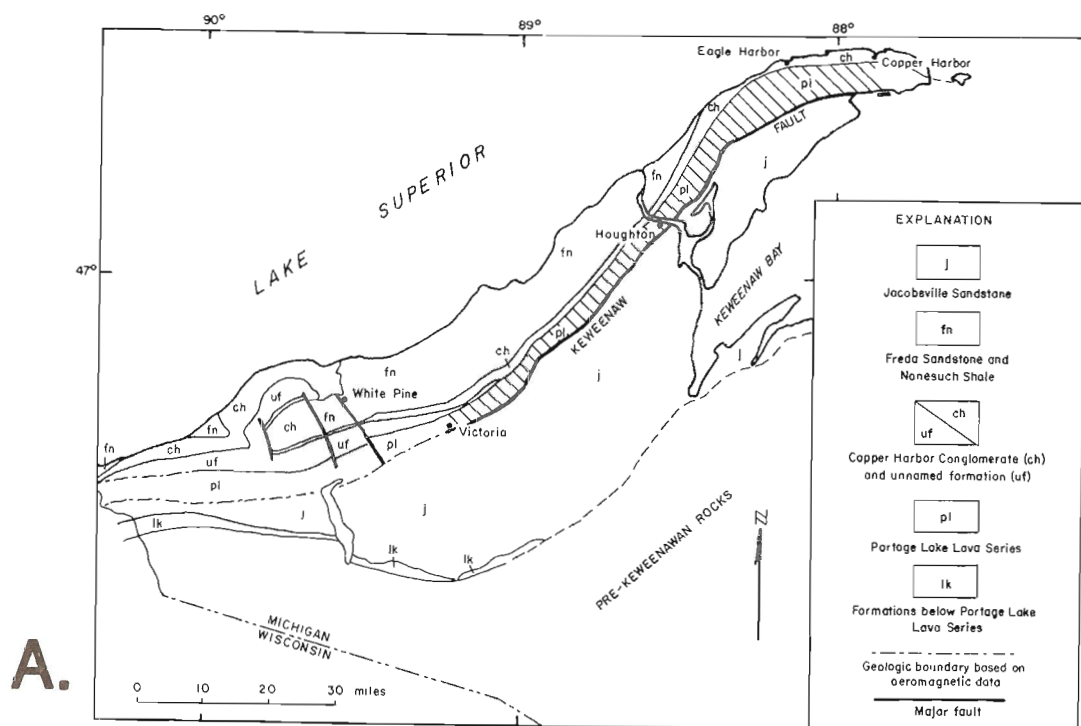


Figure 4: A. Generalized geologic map of upper Precambrian rocks of western Upper Peninsula, Michigan. Hatched area is represented in cross-section in B. B. Generalized stratigraphic section of the Portage Lake Volcanics from Victoria to Copper Harbor (modified from Stoiber and Davidson, 1959). The major marker horizons and mines are shown. The dashed and dotted lines represent the approximate stratigraphic limits of secondary epidote and quartz and prehnite respectively.

Portage Lake Volcanics

The Portage Lake Volcanics is a succession of more than 200 individual basaltic lava flows with a total thickness of 2500 m to 5200 m (Butler and Burbank, 1929; Huber, 1973; White, 1968) (Fig. 4). White (1960) recognized these volcanics as a thick pile of subaerial tholeiitic flood basalts. They are the product of rift zone magmatism and are comparable to the rift zones of East Africa and Iceland (Basaltic Volcanism Study Project, 1981; Chase and Gilmer, 1973; Green, 1977 and 1982; White 1960 and 1972). Volcanism was apparently controlled mainly by eruptions from fissures located under Lake Superior. The Portage Lake Volcanics are about 1,100 m.y. old (Van Schmus and others, 1982).

Most of the lava flows are difficult to follow laterally with confidence. The Scales Creek, Kearsarge and Greenstone flows are the best documented laterally continuous flows. The Greenstone flow can be correlated to Isle Royale (Huber, 1975; Longo, 1982). There are thin conglomerate and sandstone beds throughout the section and these are excellent marker horizons (Fig. 4). The sediment interbeds in all but the uppermost part of the Portage Lake Volcanics have been given names and are shown on the maps included in this field guide (Fig. 5). The interbedded sediments make up approximately 3 to 8% of the formation (White, 1971a). The conglomerates of the Calumet area the host rocks for large native copper deposits. The lithology of the conglomerates is dominated by clasts of rhyolitic volcanic rocks (Merk and Jirsa, 1982). The frequency of interbedded sediments increases in the upper part of the formation. Eventually volcanism waned and sediment deposition became dominant, the overlying Copper Harbor Conglomerate.

The dominant composition of the lava flows of the Portage Lake Volcanics is tholeiitic basalt. Dikes of mafic and intermediate composition cut the volcanic pile but are as a whole uncommon. Silicic volcanic and subvolcanic rocks comprise less than 1% by volume of the exposed Portage Lake Volcanics (Bornhorst, 1975; Grimes, 1977; Robertson, 1974; Robertson and others, 1979). They tend to be in the lower part of the stratigraphic section in the Keweenaw Peninsula (Fig. 6).

The composition of volcanic rocks of the Portage Lake Volcanics was affected by both igneous and metamorphic processes. Primary magmatic differentiation has long been recognized both within and between tholeiitic flows (Broderick, 1935; Broderick and Hohl, 1935; Cornwall, 1951a and b). For example, the Greenstone flow, the thickest individual flow in the formation (Figs. 4 and 5), is chemically stratified due to internal differentiation (Cornwall, 1951b; Longo, 1983). Copper may have concentrated in the pegmatitic differentiation and more importantly in the flow tops. Work by Scofield (1976) demonstrated that copper can also be concentrated in the base of individual flows by gravitational setting of magnetite. Rose and Grimes (1979) showed the existence of three magmatic cycles within the Portage Lake Volcanics which initiate with basalts that have high incompatible element abundances. The degassing of volatiles during and after eruption in an oxidizing subaerial environment was also important in that it allowed degassing of SO_2 (Cornwall, 1951c). This created a sulfur deficient environment which favored the later deposition of native copper. A third pre-metamorphic process was deuteric or diagenic alteration of olivine and glass to hydrous minerals, the most important of which is chlorite. Livnat and others (1976) used δD and $\delta^{18}\text{O}$ to show that the basalts have undergone extensive isotopic exchange with low-temperature meteoric waters prior to metamorphism/hydrothermal mineralization. After emplacement the volcanic pile was subjected to extensive low-temperature, low-pressure hydrothermal/metamorphic alteration. The Portage Lake Volcanics on the Keweenaw Peninsula are in fact a classic

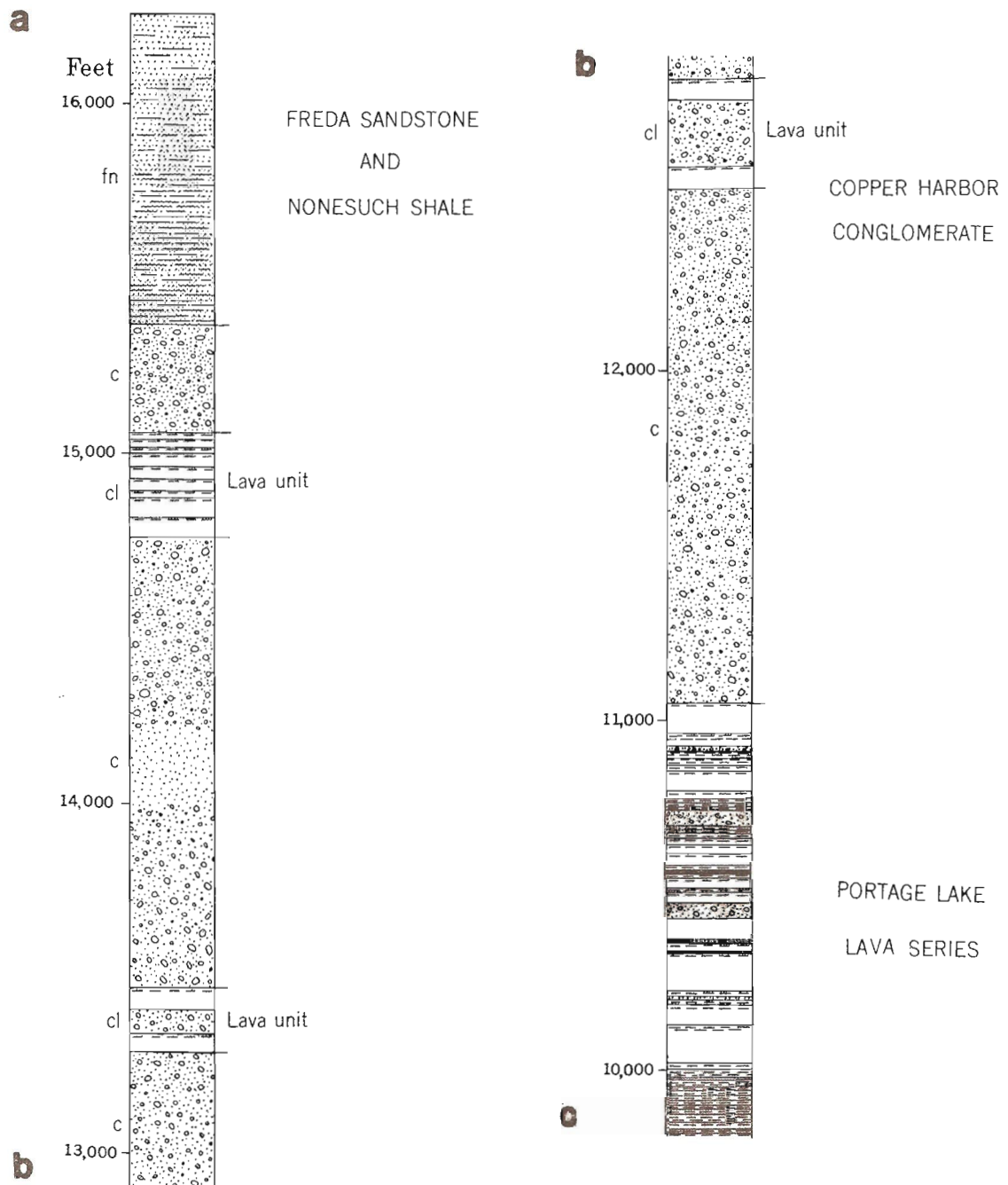


Figure 5: Columnar stratigraphic section of rocks northwest of the Keweenaw Fault in the Calumet-Ahmeek area (from White and others, 1953). The labels for units within the Portage Lake Volcanics are consistent with those used on the maps in the field guide.

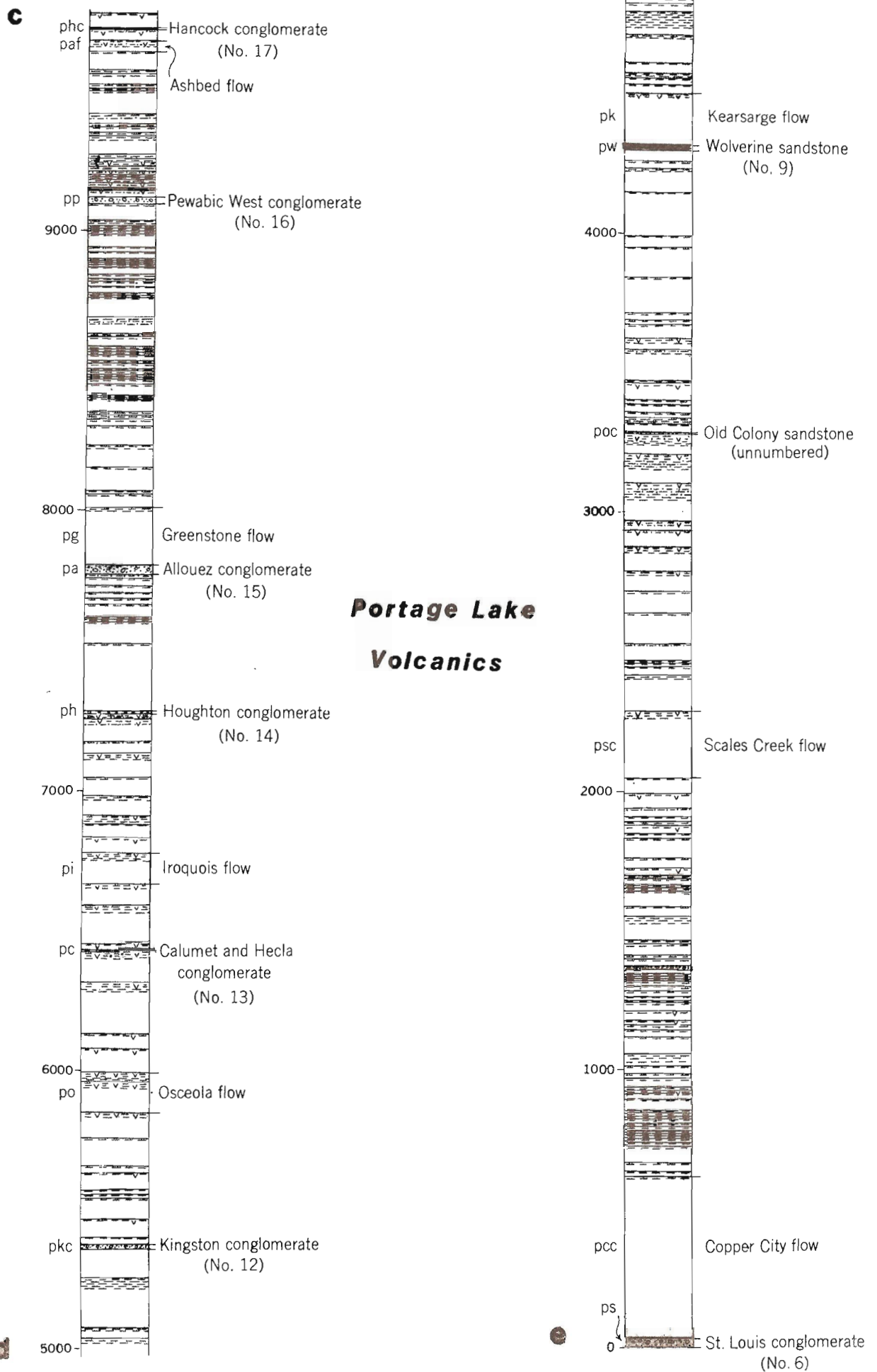


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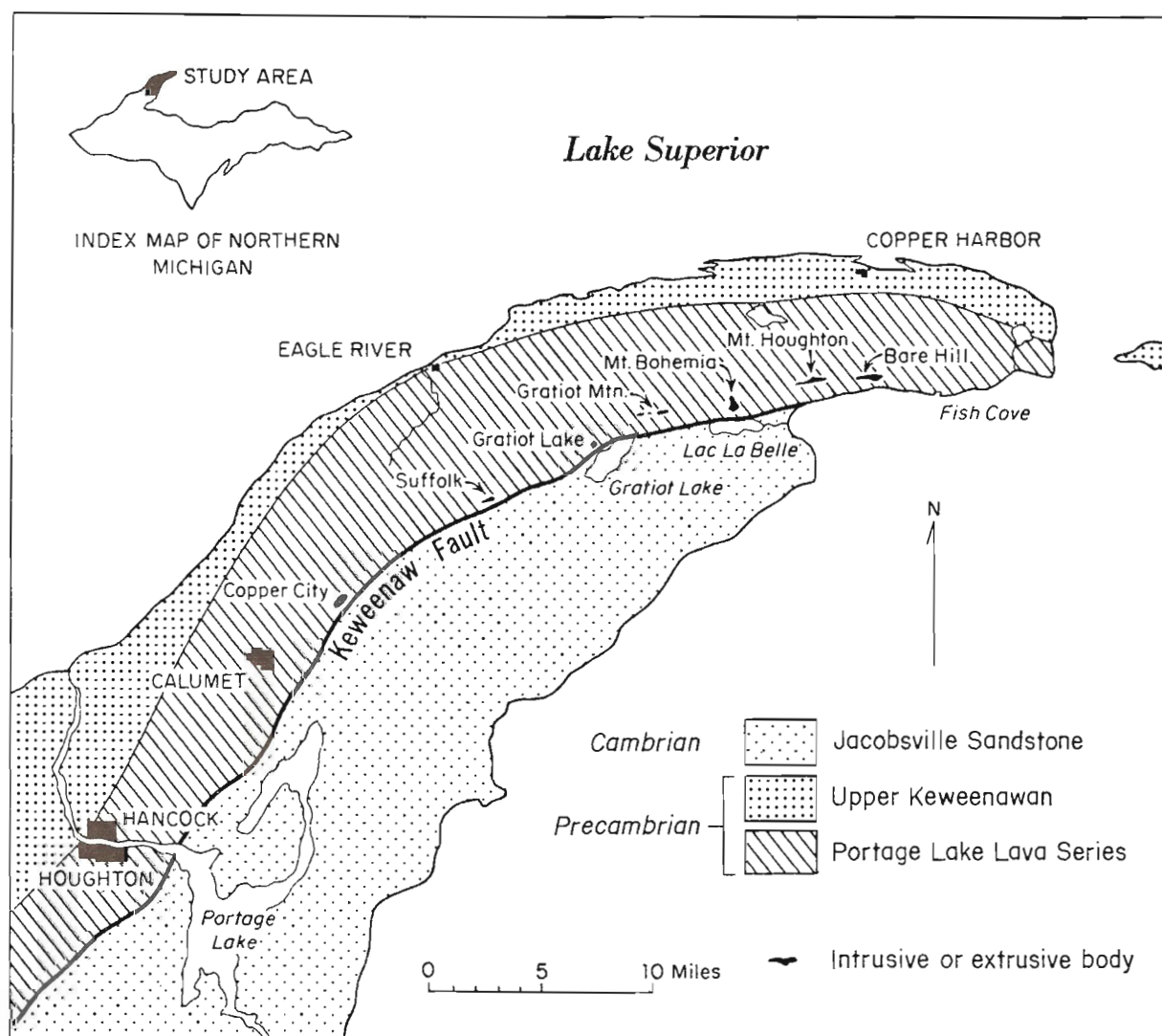


Figure 6: Bedrock geology of the Keweenaw Peninsula showing the location of silicic to intermediate volcanic and subvolcanic rocks (from Robertson, 1975).

locality of abundant and widespread low temperature alteration minerals (Table 1). Penetrative deformation did not accompany the metamorphic episode and primary textures are preserved even in the most intensely recrystallized areas.

Copper Harbor Conglomerate

The Copper Harbor Conglomerate conformably overlies and locally interfingers with the Portage Lake Volcanics (Fig. 3). It varies in thickness from about 100 m to 1800 m. The Copper Harbor Conglomerate is a red-brown basinward-thickening wedge of volcanogenic clastic sediments. These clastic sediments fine distally and up-section. Sandstones are lithic graywackes and conglomerates are composed of volcanic clasts with a ratio of mafic to intermediate + silicic composition of about 2:1 (Daniels, 1982). Daniels (1982) has interpreted the Copper Harbor Conglomerate as a prograding alluvial fan complex (Fig. 7). Mafic to intermediate lava flows are interbedded in the exposed Copper Harbor Conglomerate (Fig. 5). These lava flows are termed the Lake Shore Traps and occur predominantly within the middle section of the formation.

Nonesuch Shale

The Nonesuch Shale is a succession of gray-black siltstone, shale and sandstone which overlies and interfingers with the Copper Harbor Conglomerate (Fig. 3). The Nonesuch has a thickness of between 40 m and 215 m. The Nonesuch was deposited in a reducing, rift-flanking lacustrine environment initiated through disruption of drainages (Fig. 7) (Daniels, 1982). This differs from the over and underlying redbeds that formed in an oxidizing environment.

Freda Sandstone

The Freda Sandstone is a cyclic succession of red-brown, ferruginous, sandstone and mudstone overlying and gradational with the Nonesuch Shale (Fig. 3). The Freda has a maximum thickness of over 3700 m. It is dominantly fluvial in origin with greater compositional maturity than the Copper Harbor Conglomerate. The top of this formation is not exposed.

Jacobsville Sandstone

The Jacobsville Sandstone is a red to bleached white succession of coarse-to-fine-grained feldspathic and quartzose sandstone with varying amounts of siltstone, shale and conglomerate which rests in fault contact with the Portage Lake Volcanics in the Keweenaw Peninsula. Elsewhere it can be found overlying Middle Precambrian basement. Jacobsville is probably slightly younger than Freda Sandstone. Jacobsville has a maximum thickness of over 3,000 m. Sandstones are fluvial in origin whereas conglomerates are believed to be alluvial fan deposits (Kalliokoski, 1982).

Structure

Structure of the Keweenaw Peninsula is dominated by the Keweenaw Fault (Fig. 4), a high angle reverse fault where older Portage Lake Volcanics are thrust to the northeast over younger Jacobsville Sandstone. Both units are affected by this major tectonic feature: the normally flat-lying Jacobsville Sandstone is often strongly deformed by drag folding near the fault contact and the Portage Lake Lavas are often highly fractured. The Keweenaw Fault cuts off the base of the Portage Lake Volcanic Series along its entire strike length so that the total stratigraphic thickness

POSSIBLE "LAVA-DAMMED LAKE" MODEL FOR NONESUCH SHALE DEPOSITION

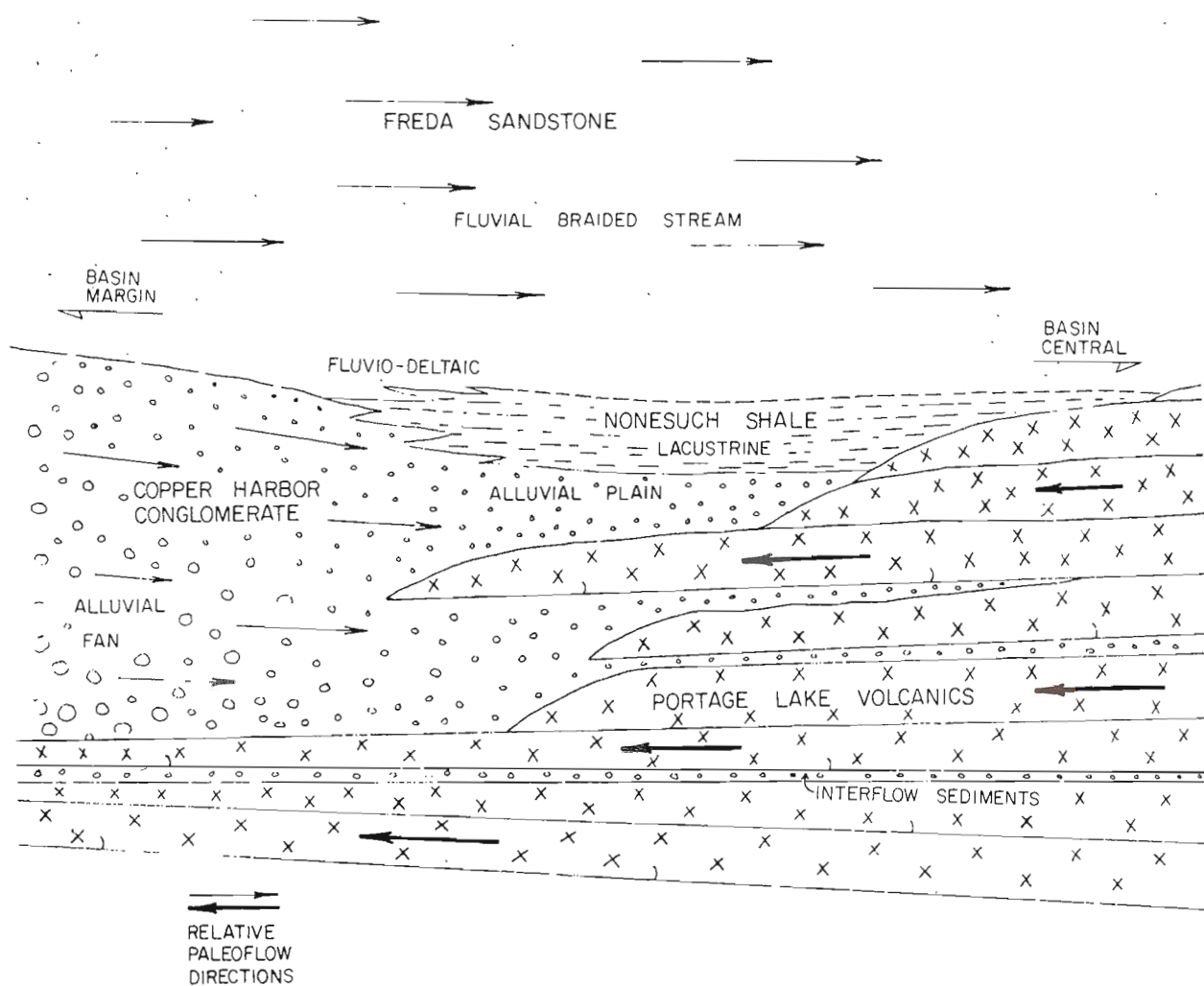


Figure 7: Schematic diagram showing the interrelationships between major stratigraphic units found northwest of the Keweenaw Fault in the Keweenaw Peninsula (from Daniels, 1982).

Table 1: Secondary minerals found within the Portage Lake Volcanics, Keweenaw Peninsula, Michigan (from Butler and Burbank, 1929; Stoiber and Davidson, 1959; Jolly and Smith, 1972).

<u>Widespread Minerals</u>	<u>Locally Important Minerals</u>	<u>Rare Minerals</u>
Laumontite	Analcime	Apophyllite
Prehnite	Sericite	Atacamite
Pumpellyite	Orthoclase/Microcline	Bowlingite
Quartz	Chalcedony	Brucite
Epidote	Thompsonite	Chlorastrolite
Albite	Natrolite	Chrysocolla
Chlorite	Chabazite	Cuprite
Hematite	Native Silver	Faujasite
Sphene	Sulfides	Fluorite
Calcite	Arsenides	Powellite
Native Copper	Datolite	Serpentine
	Heulandite	Stilbite
	Ankerite	Tenorite
	Sulfates	Tourmaline
	Clay Minerals	Whitneyite
		Wairakiite

as well as the total displacement along the fault is unknown. The regional tectonic context of the compressional stresses which caused development of major reverse faults is unknown at the present time, although it is probably unrelated to processes which formed the Mid-Continent rift.

The Keweenaw strata dip moderately northwesterly toward the center of the Lake Superior Basin and their dip angles increase toward the base of the section. This is in part due to modification attributed to the Keweenaw Fault, but White (1960) has demonstrated syn-depositional downwarping of the basin. Thus, lava flows and sediments formed wedge-shaped beds thickening basinward such that a relatively constant horizontal datum level was maintained throughout the life of the basin. Smaller scale, post-depositional folds are also present as broad synclines and anticlines (wavelengths from 5 to 10 miles) (Fig. 8). The regional context of these folds is not clearly understood, however, they appear to predate major reverse faulting. Late high angle faulting occurred throughout the area and produced several major offsets of the Keweenaw Fault. This type of fracturing and faulting is particularly abundant in the upper portion of the section northeast of Mohawk. Significant deposits of massive native copper later filled many of these cross-cutting channelways (summarized from White, 1968).

Mineralization and Alteration

The Keweenaw Peninsula is the location of a dormant billion-dollar copper mining district. From 1845 to 1968 the mines of the Keweenaw native copper district produced about 11 billion lbs. of refined copper (Weege and Pollack, 1971). The major ore producing horizons are geographically restricted to a 45Km long belt within the Portage Lake Volcanics in the Keweenaw Peninsula (Fig. 8a). There is a close relationship in both time and space between native copper mineralization and alteration in the Portage Lake Volcanics (Fig. 9). Native copper, the principal ore mineral in the Keweenaw Peninsula, occurs in amygdaloidal and brecciated flow tops, interflow conglomerate units, and fracture systems (Butler and Burbank, 1929; White, 1968 and 1971a).

The predominant native copper deposits are lenticular blanket-like ore bodies that are found along certain stratigraphic horizons such as the tops of lava flows and conglomerate beds. Weege and Pollack (1971) estimated that 58.5 percent of the district copper production came from flow top ore bodies and 39.5 percent came from conglomerate ore bodies. The remaining 2 percent of copper production was from fissure (or vein) ore bodies.

There are three main varieties of lava flow top recognized in the Keweenaw native copper district: 1) fragmental or flow top breccia; 2) nonfragmental / cellular or vesicular basalt; 3) "scoriaceous" or flow top breccia with a sandy or silty matrix. White (1968) estimated that 21 percent of the lava flow tops in the Portage Lake Volcanics are brecciated (fragmental). These flow tops consist of a rubble of vesicular and massive lava. The interstices between fragments and the vesicles are commonly filled with secondary minerals. Most of the major flow top (amygdaloid) copper ore bodies are of the fragmental type. White (1968) has estimated that uppermost 5 to 20 percent of most individual lava flows is vesicular and contains between 5 and 50 percent vesicles which are commonly filled with secondary minerals. The abundance of amygdules decreases downward and the middle and lower parts of flows are amygdule-free massive basalt. The tops of these flows are locally termed cellular and often have smooth tops. Cellular amygdaloid may have traces of native copper but

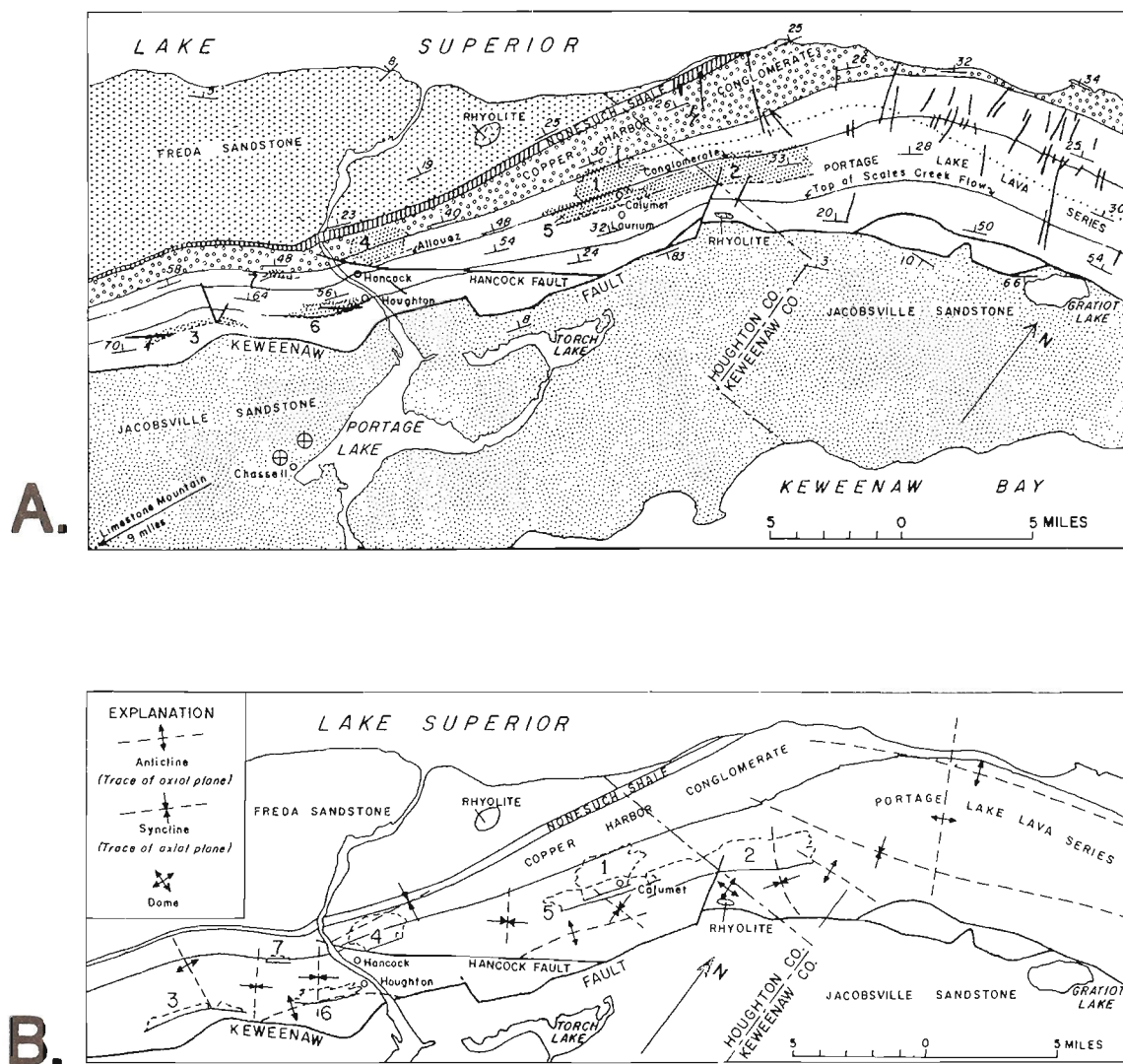


Figure 8: A. Geologic map of the Keweenaw native copper district (from White, 1968). Major deposits are identified by the bold number, in order of production: 1) Calumet and Hecla conglomerate; 2) Kearsarge amygdaloid; 3) Baltic amygdaloid; 4) Pewabic amygdaloid; 5) Osceola amygdaloid; 6) Isle Royale amygdaloid; and 7) Atlantic (ashbed) amygdaloid. The dotted line is the approximate northwest limit of quartz in amygdaloids. B. Folds of the Keweenaw native copper district (from White, 1968).

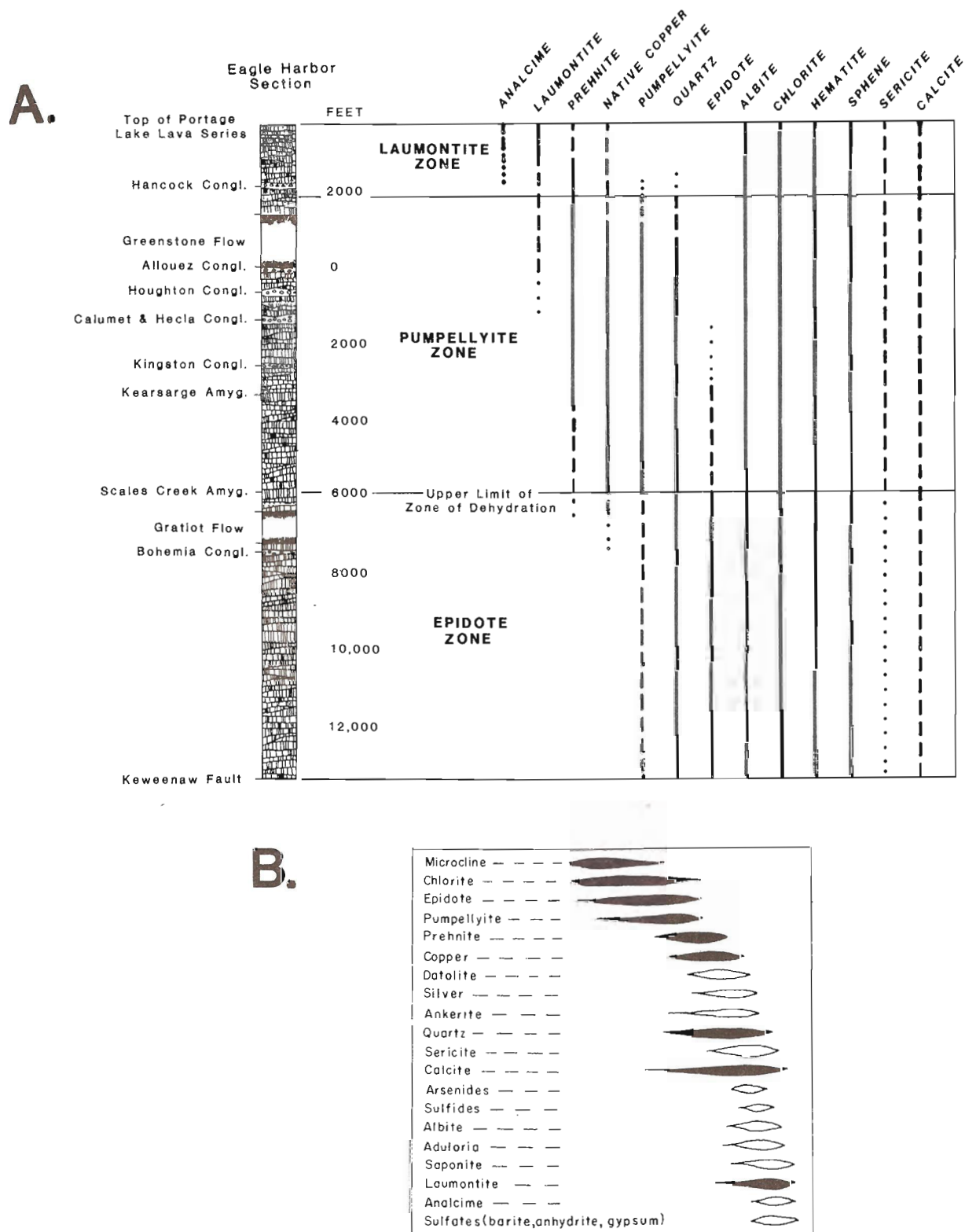


Figure 9: A. Distribution of secondary minerals in the Eagle Harbor section of the Portage Lake Volcanics (compiled from Butler and Burbank, 1929; Jolly, 1974; Jolly and Smith, 1972; Stoiber and Davidson, 1959; White, 1968). Location of section is between Copper Falls and Delaware Mines shown in Figure 4. B. Paragenesis of secondary minerals in the flow tops and veins (from White, 1968). Solid black symbols are the more abundant minerals. Secondary minerals shown here are nonmagmatic and not of supergene origin.

no ore deposits are only of this type. A few smooth topped flows show a tendency for the amygdules to be laterally interconnected in bands, forming what are locally termed "coalescing cellular amygdaloid". This is an important host rock for ore at the Quincy Mine. "Scoriaceous" amygdaloid is used locally for flow top breccia in which interstices between vesicular fragments are filled with sandy or silty detritus. The Ashbed amygdaloid is the only significantly mineralized example of this type.

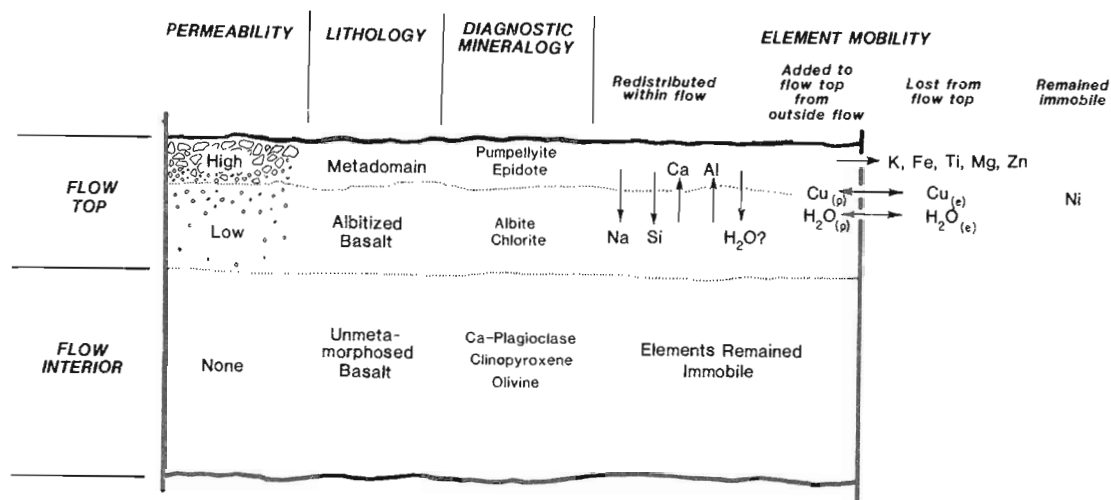
Conglomerates interbedded with lava flows are host for major native copper deposits, particularly in the vicinity of Calumet. The fundamental control of copper distribution is the permeability of the host conglomerate. Permeability is decreased by abundant fine detrital material. Localization of ore depends greatly on sedimentological and environmental factors, such as the bedrock topography which might influence location of a stream channel resulting in differing thickness of conglomerate.

Fissure deposits are tabular and commonly crosscut the bedding at nearly right angles to strike. Large masses of native copper weighing many tons were first discovered in the fissure deposits. These deposits are economically much less important than the other types.

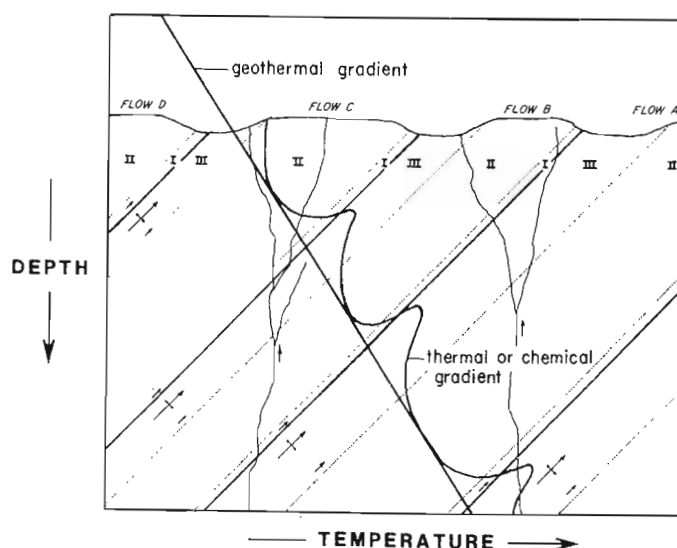
Copper sulfides are a minor constituent of the system, and are found as small veins cutting the flow top native copper deposits, joint-coatings in the conglomerate units, and in association with Mt. Bohemia intrusive (Butler and Burbank, 1929; Broderick, 1931; Robertson, 1975). Copper sulfides and arsenides are paragenetically late in flow tops and conglomerates (Fig. 9b). Significant copper sulfides with minor native copper also occur at the base of the stratigraphically higher Nonesuch Shale and top of the Copper Harbor Conglomerate (Brown, 1971) at White Pine, approximately 70 Km southwest of most of the discovered mineralization in the Keweenaw Peninsula. The solutions that formed the White Pine deposit may have been related to those which formed the deposits in the Keweenaw Peninsula (Ensign and others, 1968).

Vesicular and fragmented flow tops of the Portage Lake Volcanics were pervasively altered by hydrothermal fluids, producing low temperature metamorphic mineral associations occurring as amygdule and vein fillings as well as whole rock replacements in the most permeable horizons. The systematic metamorphic zoning varies vertically within the volcanic pile and is equivalent to zeolite, prehnite-pumpellyite facies (Jolly and Smith, 1972; Stoiber and Davidson, 1959), and possibly lower greenschist facies (Fig. 9a). The copper deposits lie stratigraphically within the pumpellyite zone. The copper, in the deposits, may have been leached from dehydrated lava flows (epidote zone) in the deep parts of the pile and migrated up dip and precipitated in the zone of hydration where conditions were sufficiently reducing (Jolly, 1974; Scofield, 1976; White, 1968). These workers and Cornwall and Rose (1957) suggest that most of the copper was probably initially tied up in Fe-Ti oxides and their oxidation released the copper. The oxidation reactions of magnetite to hematite and pumpellyite to epidote may occur along with native copper deposition (Jolly, 1974).

The intensity and degree of alteration varies as a function of position within individual flows, position in the volcanic pile, and proximity to cross-cutting fractures (Jolly and Smith, 1972). Local controls, such as pre-alteration composition, appear to govern the assemblages of final alteration products and their major-element compositions. Figure 10 shows a summary of known elemental mobilities and a schematic picture of alteration conditions.



A.



B.

Figure 10: A. Possible elemental mobility pattern in an idealized lava flow in the pumpellyite and epidote zones within the Portage Lake Volcanics (based on chemical data of Jolly and Smith, 1972; Jolly, 1974; Scofield, 1976; Stoiber and Davidson, 1959). According to Jolly (1974) Cu and H₂O were derived from the epidote (dehydration) zone and deposited in the pumpellyite (hydration) zone. B. Diagrammatic regional model for the Portage Lake Volcanics showing local thermal/chemical gradients superpositioned on the regional geothermal gradient and showing the movement of fluids along flow tops and bottoms and through fractures (modified from Jolly and Smith, 1972; Scofield, 1976).

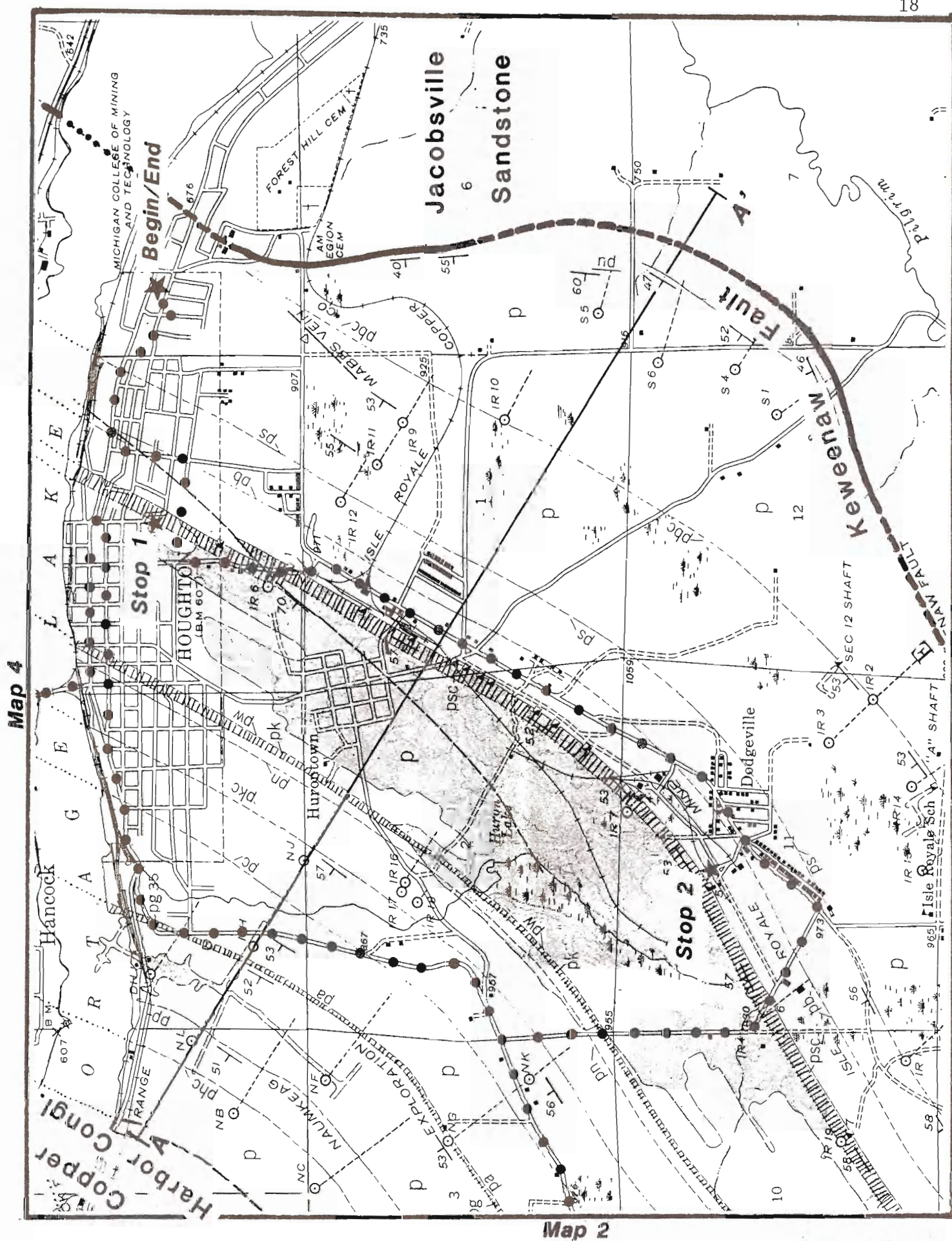
Mileage

MAP 1

- 0.0 Assemble at the Memorial Union on the campus of Michigan Technological University. Begin the field trip from the circular drive located on the northeast side of the Union. The Michigan Tech campus is located on a kame terrace to the south of the Portage Lake.
- 0.1 Right turn.
- 0.2 Left turn. Immediately after there is a right turn on to Townsend Drive. The Quincy Mine can be seen on the ridge on the skyline.
- 0.55 Left turn on Agate Street, where we go up the steep hill on the south side of the Portage. We are climbing off of the kame terrace.
- 0.8 Right turn on Seventh Street.
- 1.0 STOP 1. Scales Creek flow on Seventh Street, City of Houghton.

This stop is marked by a prominent ridge of ophitic basalt, which is an outcrop of the Scales Creek flow, one of the great Keweenaw flows, which can be traced continuously for a strike length of more than 160 Km along the Peninsula. It is about 70 m thick, with an amygdaloidal top which is typically not resistant and a prominent, ridge-forming, ophitic core. The ridge at this site can be followed down hill all the way to Sheldon Avenue, where it is covered by glacial deposits. It can be traced across the valley, where it passes through the Ripley School, a prominent brick building across the Keweenaw Waterway. This bearing, about N30E, is the regional strike of the Portage Lake Volcanics which dip about 50° to the NW. Another clue to the attitude of the rocks is given by the Quincy #2 shaft house on the horizon which heads up an inclined shaft down dip along the amygdaloidal ore bodies of lava flows just over 2000 m higher in the Portage Lake section. Throughout the Portage Lake section between Baltic and Mohawk, most amygdaloidal and conglomerate zones show well developed zeolite and prehnite-pumpellyite facies metamorphism and native Cu mineralization. At this site the amygdaloids just below the Scales Creek flow are strongly mineralized. One mine, the Sheldon Columbian, operated just a few hundred m to the east in the early 1900's. This same horizon is exploited by a series of shafts called Isle Royale Mines, for several km to the SW. Stop 2 is at one of these mine dumps.

The most obvious geomorphological feature here is the Keweenaw Waterway, whose origin was thoroughly investigated by Warren (1981). The waterway formed in a fault zone like many which crosscut the Portage Lake stratigraphy. A bedrock valley, more than 200 m deep formed along the fault as a result of stream superposition through a cover of flat-lying sediments. This valley, like others on the Keweenaw, was deepened and widened by glacial erosion, in a fashion similar to the finger lake region of New York State. The complex glacial deposits, consisting of moraines, terraces, varved clays and gravels were the result of the pattern of ice retreat from the region, which had profound and complex effects on the drainage patterns.



- 1.1 Left turn on Portage Street.
- 1.25 Grand Portage Mine dump on left.
- 1.45 Near the Houghton water tower. At this spot the Scales Creek ridge is exposed higher on the south slope of the Keweenaw Waterway. There are many bald knobs with more or less east-west trending deep glacial grooves on them. To the east of the prominent ridge, there are many mine openings from the series of Isle Royale shafts. The Adams Township takes its water supply from these Isle Royale mines which are now filled with water, and this is the source of water for Hancock and several other towns.
- 1.55 Cross Sharon Avenue and continue on Portage Street east of the City of Houghton fire station.
- 2.15 Right turn immediately followed by a left turn so we are now on Bridge Street heading south.
- 3.0 Entering Dodgeville. On the right hand side of the road is one of the prominent Isle Royale mine dumps.
- 3.2 Center of Dodgeville. If you turn on the road to the right through the Trailer Park, there is access to the Isle Royale mine dumps from Shaft No. 4 and 5. The Isle Royale Mine is described at Stop 2, continue ahead.
- 3.6 Junction to the Green Acres Road and make a right turn.
- 3.7 STOP 2. Isle Royale Shaft No. 6 mine dump on the Green Acres Road.

The Isle Royale mine worked the top of the Isle Royale flow. Production from the Isle Royale amygdaloid began in 1855, the mine closed in 1948. A total of about 350 million lbs. of refined copper was removed from this mine (Weege and Pollack, 1971). The Arcadian Mine (see Map 4) may also work the Isle Royale amygdaloid.

The Isle Royale flow varies in thickness but is about 70 to 150 ft. thick and lies just below the Scales Creek flow discussed in Stop 1. It dips about 50 to 60° to the northwest (Fig. 11). A gentle fold accounts for the curvature of the flow (see Map 1), Isle Royale syncline. The flow from the top down is characterized by fragmental zone, banded amygdaloid, foot inclusion zone, and massive main trap. The fragmental zone consists of irregular fragments of amygdaloid and fine-grained basalt ranging from small grains to tabular blocks several feet in long direction. The vesicles and spaces between the fragments are filled with secondary minerals. The banded amygdaloid is an unbroken rock body over considerable area. Amygdules are commonly abundant at certain horizons giving this zone a banded appearance. Below the fragmental zone or banded amygdaloid is the foot inclusion zone which is indefinite patches or inclusions of amygdaloid basalt. The foot inclusion zones grades into massive basalt practically devoid of amygdules (summarized from Butler and Burbank, 1929).

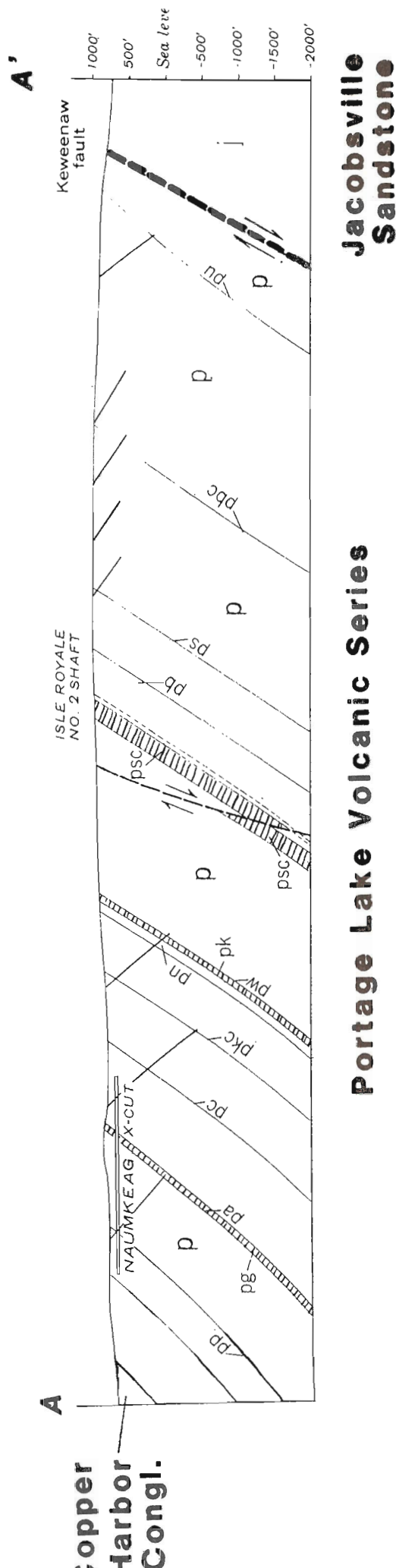


Figure 11: Cross section A-A' on Map 1 (from White, 1956). Labels are as follows for the Portage Lake Volcanic Series (P) and its subunits: Pewabic West conglomerate (pp), Greenstone flow (pg), Allouez conglomerate (pa), Calumet and Hecla conglomerate (pc), Kingston conglomerate (pkc), National sandstone (pn), Kearsarge flow (pk), Wolverine sandstone (pw), Scales Creek flow (psc), Bohemia conglomerate (pb), St. Louis conglomerate (ps), Baltic conglomerate (pbc), and Unnamed conglomerate (pu).

Butler and Burbank (1929) recognized two distinct periods of alteration. The earliest alteration was oxidation which caused the development of hematite, which produced reddened basalt. This oxidation could essentially represent deuteric alteration shortly after eruption. The second period of alteration was probably after the flows had been tilted. This period was complex and resulted in deposition of native copper. This stage is divisible into three substages: 1) An early stage of deposition of epidote, pumpellyite quartz, calcite, most of the native copper and minor prehnite, alkali feldspar, and laumontite; 2) an intermediate stage characterized by the development of sericite with quartz, calcite, anhydrite, gypsum and minor barite; 3) a final stage of copper sulfides and arsenical copper accompanied by calcite, sericite, quartz, chlorite, and specular hematite occurring in numerous veinlets. Stoiber (unpublished data) made the following estimate of the percentage of alteration minerals on dumps from four shafts of the Isle Royale Mine: quartz, 26-59; calcite, 5-39; prehnite, 6-32; pumpellyite, 1-17; epidote, 1-10; sericite, 0-12; chlorite, 0-3; K-feldspar, 0-trace. This dump and the ones near Dodgeville are freshly reworked and good specimens of native copper and alteration minerals can be found.

- 3.9 Junction M-26 at the Copper Country Mall and you are going to make a left turn.

MAP 2

- 5.6 Entering Atlantic Mine.

- 6.9 Right turn at the sign that says South Range Village Limit and drive about 150 yards into the road and walk to the right through a notch up the hill another 60 meters to Stop 3, the South Range Quarry.

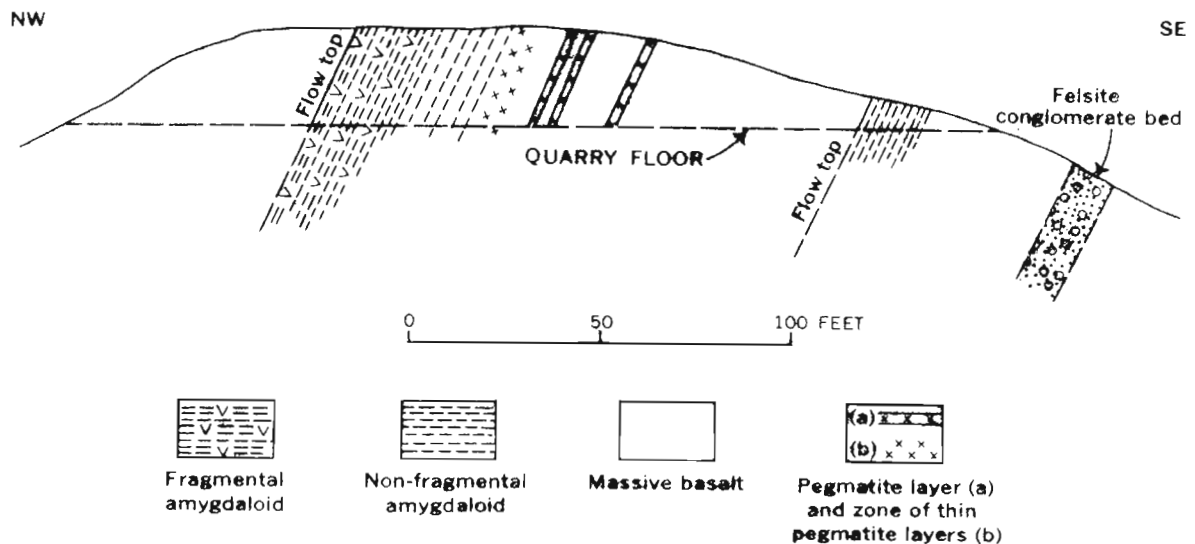
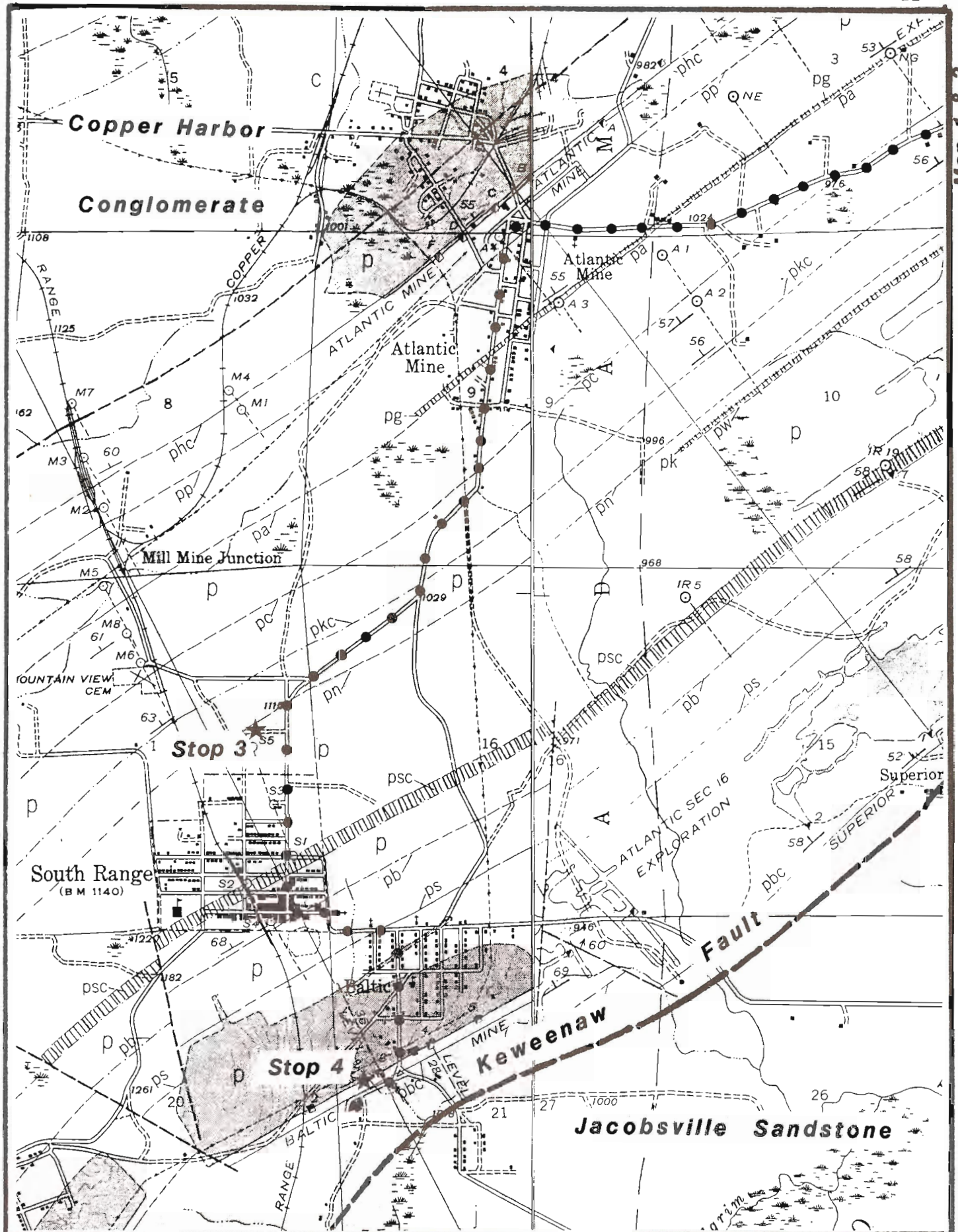


Figure 12: Geologic profile of the South Range quarry along the north-east wall (from Cornwall, 1951; White, 1971b). Location of the quarry is shown in Map 2, Sec. 17, T54N, R34W.



MAP 2

STOP 3. South Range Quarry.

South Range quarry provides an excellent cross sectional view of a massive to amygdaloid lava flow (Fig. 12) of the Portage Lake Volcanic Series. The base of the section is a conglomerate bed, about 4 m thick; it is exposed on the main path to the quarry. This is overlain by an 18 m thick fine-grained basalt flow, followed by a 42 m thick ophitic basalt flow and finally the lower 17 m of another ophitic basalt flow.

The conglomerate is well indurated and consists mostly of pebbles and cobbles of rhyolite with subordinate clasts of basaltic lava set in a sandy matrix of similar composition. The clasts are subangular to sub-rounded. The overall character is similar to the Copper Harbor Conglomerate which will be seen later in the field trip. This conglomerate is one of a number of sedimentary beds which are interbedded with the Portage Lake lava flows. This particular bed is correlatable with the National Sandstone, a marker bed in the Mass-Rockland area.

The basalt flow that occupies most the quarry face has features which characterize the thicker flows of the Portage Lake Volcanics. The lower half of the flow is massive basalt, overlain by a zone with progressively smaller pegmatitic layers, topped with cellular amygdaloidal basalt, and at the top a discontinuous layer of flow top breccia (called fragmental amygdaloid). A typical pegmatitic layer, consists of 4 cm to 1.3 m core of green amygdaloidal lava surrounded by a 4-9 cm border zone at the top and bottom. The border zone is composed of a medium to coarse grained aggregate of albite/oligoclase, augite, ilmenite, and magnetite. Pegmatitic layers toward the top of the zone are more amygdaloid. Quartz, prehnite, and a green or red cherty substance occurs in flattened vesicles at the top of the layer. The pegmatitic layers are products of cooling and differentiation as it cooled (description of pegmatitic layers from Cornwall, 1951). Amygdules and interfragmental spaces are filled with quartz and prehnite containing traces of copper. Locally the basalt is intensely epidotized or prehnitized.

Outside of the Quarry and to the north are a series of glacially grooved outcrops in which the exposures of the pegmatitic zones are spectacular.

- 7.9 Return from Stop 3. Take a right turn on M-26, going into the town of South Range.
- 8.4 At stop sign in South Range, take a left turn.
- 8.6 Right turn at the church and immediately followed by a left turn as the whole road jogs to the left.
- 8.7 Entering the town of Baltic.
- 8.8 Right turn.
- 9.2 The main road turns to the left, we go to the right on a small paved road driving past a concrete building towards some very large mine dumps.

*amyg. basal
Chalcocite w/ iron-stain calcite
Native Copper in*

9.4 STOP 4. Baltic Shaft No. 3 Mine Dump.

The Baltic, Champion, and Trimountain mines worked the Baltic amygdaloid. The Baltic Mine opened about 1898, the others opened in 1902. Total production from the Baltic amygdaloid was about 1.85 billion lbs. of refined copper which was the third largest producer in the Keweenaw native copper district (Weege and Pollack, 1971). The amygdaloid was developed for about 7 Km along strike and to the 38th level in the Baltic Mine.

The Baltic flow is an ophite that varies considerably in thickness but is around 50-70 m thick. The Baltic amygdaloid in many places is 17 m or more in thickness and is composed of fragmental amygdaloid, the average stoping width is about 5-8 m. However, like all fragmental amygdaloids of the district, there are significant variations, e.g. the lode can thin to only a few feet thick composed of trappy or cellular amygdaloid. The lode dips at about 70°NW (summarized from Butler and Burbank, 1929).

The abundant minerals associated with copper in the Baltic amygdaloid are quartz, pumpellyite, epidote and carbonate. Copper sulfides are unusually abundant. The sulfides characteristically occur in fissures that dip 75 to 90° and strike nearly parallel with the lode. Most of the copper sulfide in the lode is chalcocite associated with iron-bearing carbonate, there is some bornite and rare chalcopyrite. Native copper is irregularly distributed through the amygdaloid ranging from minute specks to masses weighing several tons. Native copper occurs at the margins of sulfide veins and it may occur with quartz in the center of veins. Sulfides are in general paragenetically late (Fig. 9b Introduction) (summarized from Butler and Burbank, 1929).

The majority of the dump at this stop is amygdaloid basalt. R. E. Stoiber (unpublished) made the following estimate of the percentages of the secondary minerals in the dump as a whole: calcite, 91; quartz, 5; epidote, 3; chlorite, 1. Paragenetically epidote and chlorite were early minerals; calcite, quartz and native copper were intermediate; and copper sulfides and iron-bearing carbonate were later. Excellent specimens of chalcocite can be found on this dump as well as native copper.

- 9.4 Retrace route in Baltic.
- 9.9 Stop sign in Baltic, make a left turn to go back in the direction of South Range.
- 10.1 Right turn, immediately followed at the church by a left turn.
- 10.3 In the center of South Range, right hand turn off M-26.
- 10.8 Passing the South Range Quarry, Stop 3.
- 12.5 M-26 jogs to the right at the center of Atlantic Mine

MAP 3

14.7 STOP 5. Glacial Deposit Near Pamida

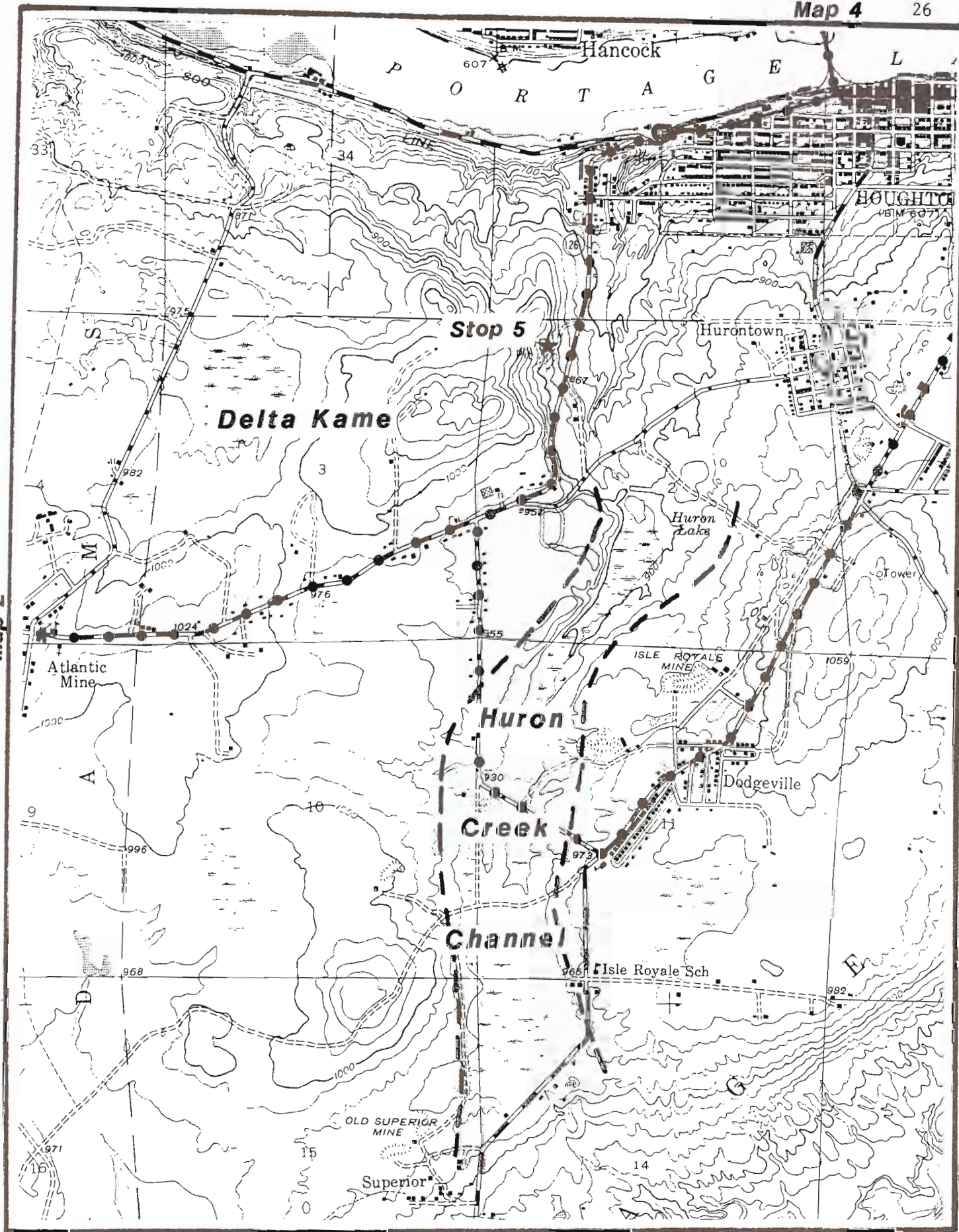
The Keweenaw Peninsula has probably been modified by all of the major glacial episodes of the Pleistocene. During maximum glaciation the entire Keweenaw Peninsula is believed to have been overridden by around 3000 m of ice. The present form of Portage and Torch Lakes is related to the final retreat of the Laurentide ice sheet in the Lake Superior basin (shown in Figs. 13 and 15). The final glacial advance and still-stand over the Keweenaw Peninsula was made by the Keweenaw Bay Lobe, marked by an end moraine of Wisconsin stage (Fig. 14) (summarized from Warren, 1981).

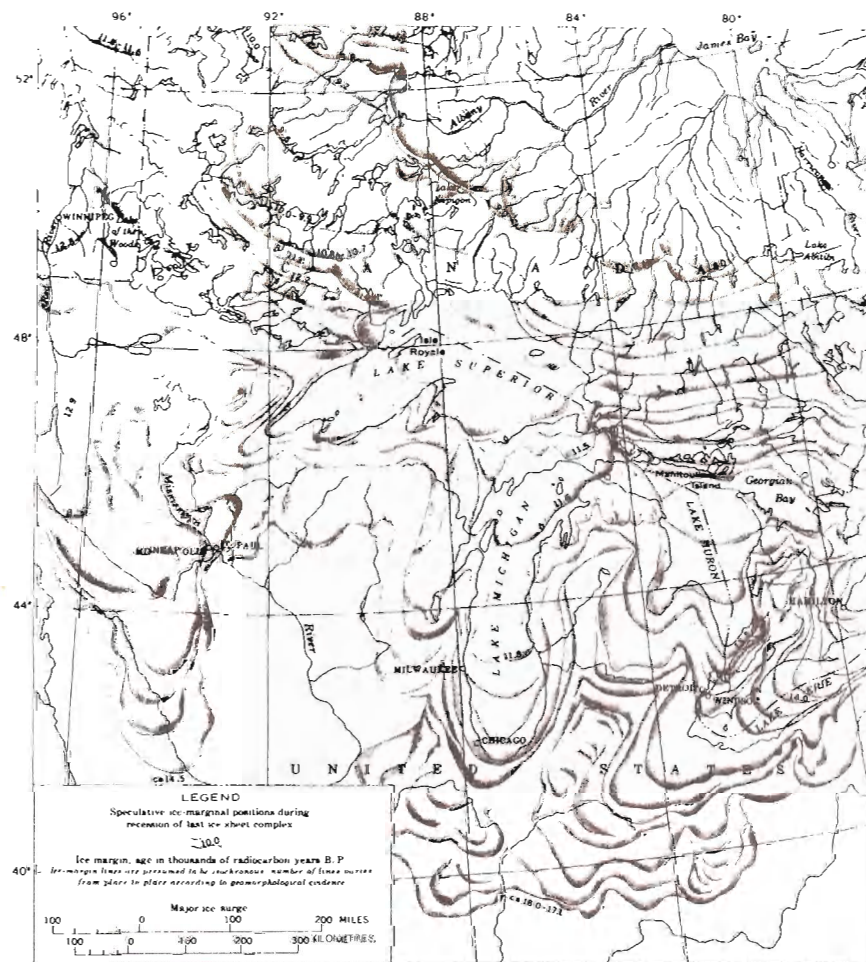
The earliest recognized channel cut by drainage through the Portage Gap area is the Huron Creek channel (Map 3). The channel is waterworn bed-rock due to southward flow. Since there is no delta at the southern end of this channel perhaps the source of water was a large lake where glacial sediments had time to settle before the water was removed. The drainage pattern through the Portage Gap is shown in Fig. 16 (summarized from Warren, 1981).

A delta kame is just west of the Huron Creek channel and is the location of Stop 5 (Map 3). The sediments, in this dissected knob, show strong evidence of being deposited by a braided stream closely associated with a glacier. Extreme variations in grain size and sorting occur within a distance of a few meters. This suggests differing flow regimes during deposition. Poorly to well-worked unconsolidated sands predominate but poorly sorted pebble conglomerates are also present. Numerous cut-and-fill structures are present. Large striated boulders of basalt within the gravel and sand must have originated from a nearby glacier. This large exposure is capped by a thin (less than one meter) poorly sorted clay till which thickens rapidly to the south; it is about 7 meters thick at the top of the nearby hill. The later unit may be a flow till(?) which slumped off the nearby glacier (description by S. Beske-Diehl and S. Nordeng, Dept. of Geol. & Geol. Engrg., MTU).

- 15.75 Between Junction of M-26 and US-41, so turn right on US-41 past the Mobil and Erickson gas stations.
- 16.2 Excellent outcrop of basalt with exposed amygdaloid on both sides of the road.
- 16.35 Make a left U-turn back onto US-41 going one way back through the City of Houghton.
- 16.45 Amygdaloidal basalt with pegmatitic zones at Burger King Restaurant, Sheldon Avenue, Houghton.

This stop is an alternate to the South Range Quarry Stop. Excellent exposures of the cellular amygdaloid and pegmatitic interior of a thin Portage Lake lava flow are found to the west of the restaurant and along Montezuma Avenue, just a few steps to the north. The flow top is strongly metamorphosed with a variety of amygdale minerals of the prehnite-pumpellyite facies. The green color of the basalt is due to the abundance of epidote. Below the amygdaloid the basalt is virtually unmetamorphosed except where thin pegmatite zones cross it.





WISCONSIN ICE RETREAT from central North America. Note major ice surge, or readvance, in the Lake Superior basin (from V. K. Prest, 1969, Geological Survey of Canada Map 1257A). (Fig. 46)

Figure 13: Speculative ice-marginal positions during the Wisconsin ice retreat from central North America (from Huber, 1975; Prest, 1969).

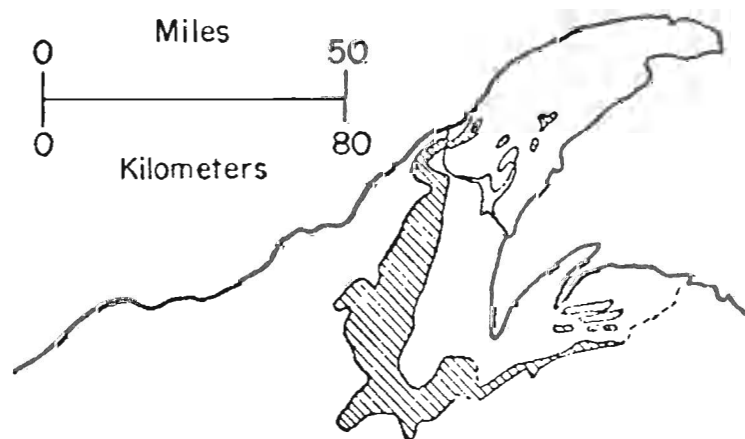


Figure 14: End moraine of the Keweenaw Bay Lobe glacier (from Kalliokoski, 1976; Warren, 1981).

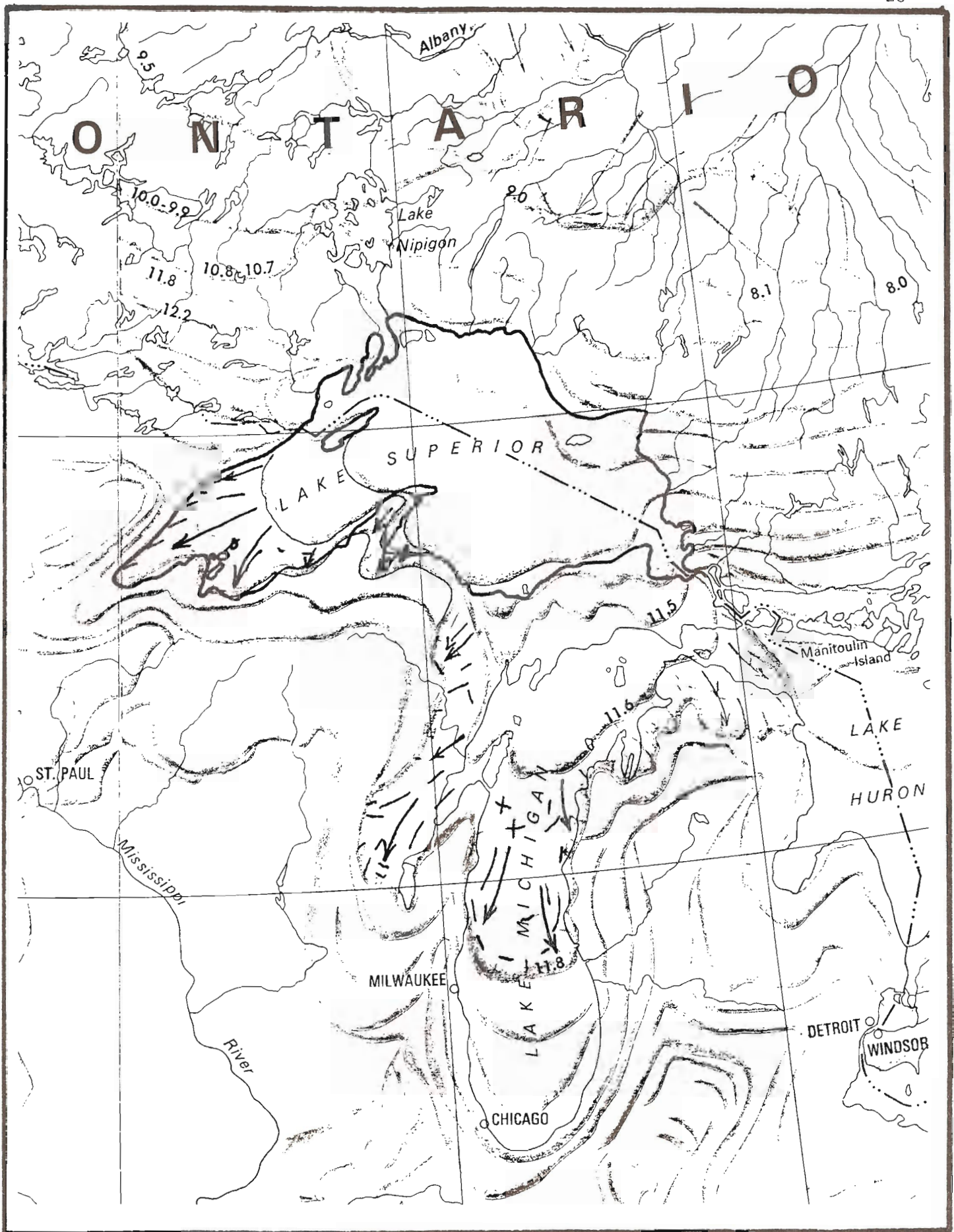


Figure 15: Enlarged view of ice-marginal positions during Wisconsin ice retreat (from Prest, 1969). Note the major ice readvance in the Lake Superior Basin and

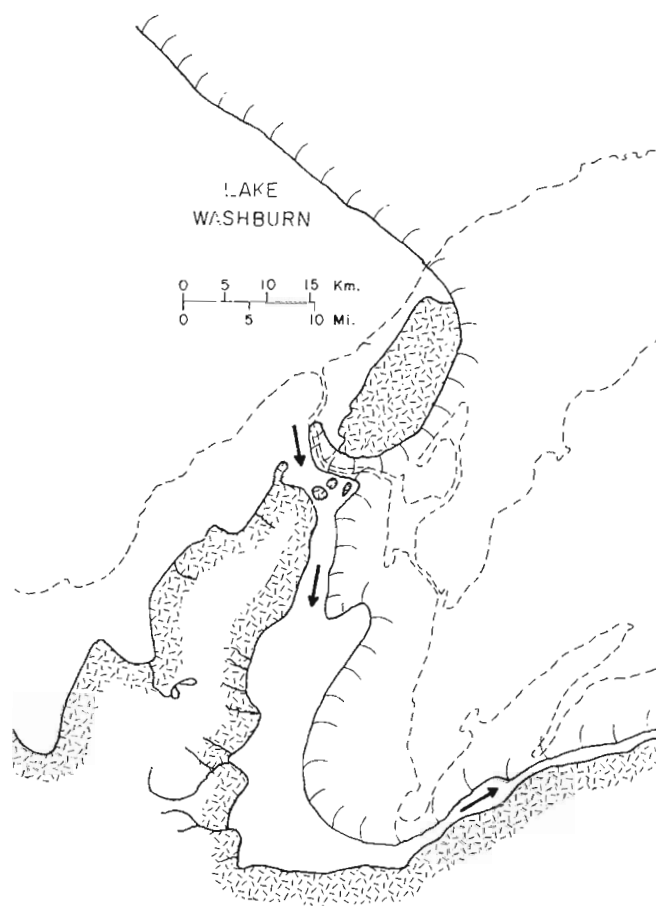


Figure 16: High level drainage through the Portage Gap during the Washburn Stage (from Warren, 1981).

- 16.9 Right turn on US-41/M-26 and crossing the Portage Lake Lift Bridge into Hancock.

The bridge was built in 1957, and is designed to accommodate Great Lakes ore boats, who prefer the Keweenaw Waterway route to rounding Keweenaw point in stormy weather. The present bridge abuts the Hancock side of the canal at approximately the site of the old Quincy Mill where the tramway descended Quincy Hill from the mines.

MAP 4

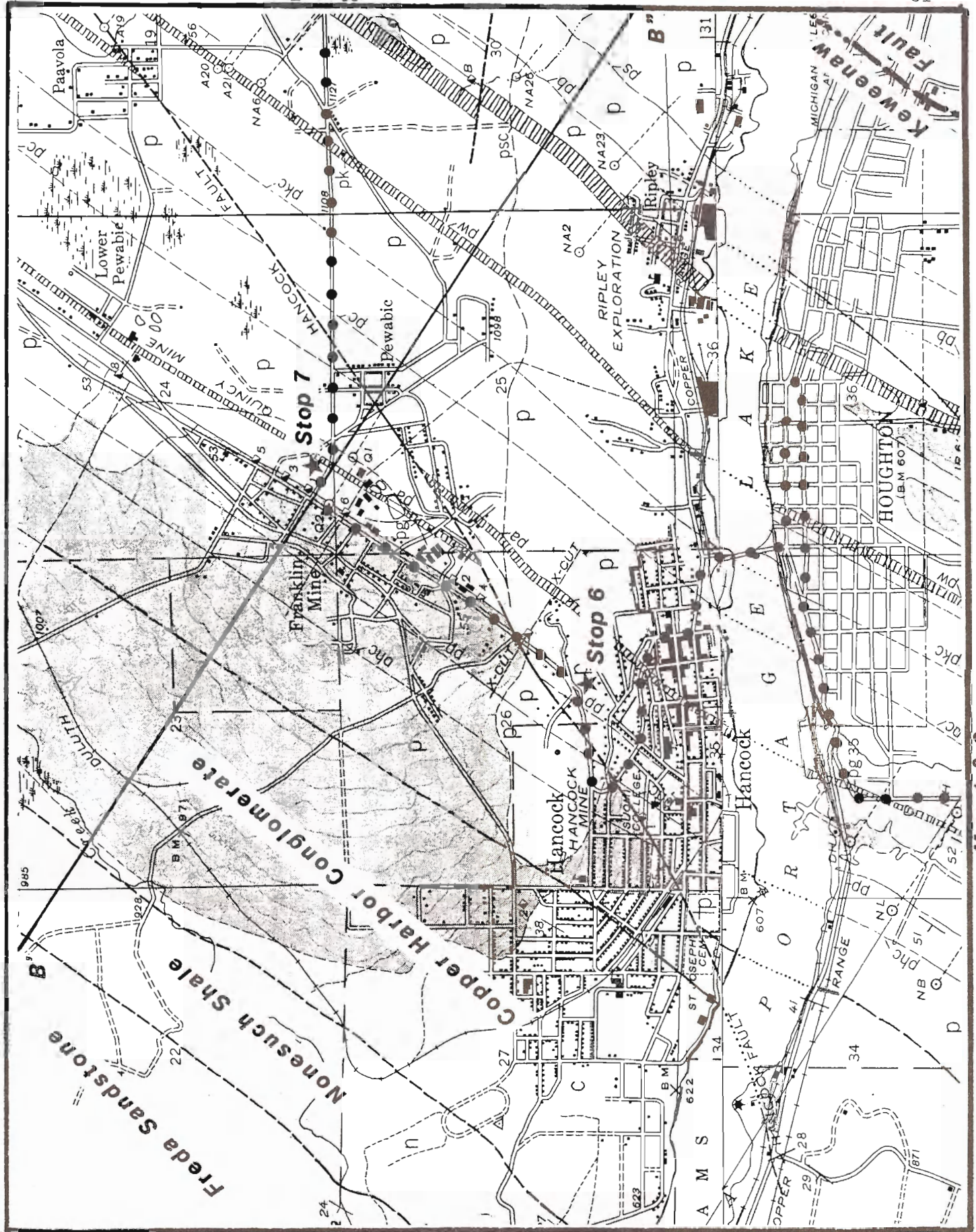
- 17.15 Left turn on US-41 into Hancock.
- 17.35 Right turn and immediately followed by US-41 going to the left but we go straight at 17.4.
- 17.5 Bear to the left on White Street.
- 18.0 Junction between White Street and Lincoln Drive which is US-41, we take a right turn.

The fenced ground near this locality surrounds an area of recently caved ground, which is thought to be related to shallow stopes of the Hancock Mine. The detection and distribution of such openings is a problem of considerable concern to local authorities, since many mines had shallow workings, since towns grew up adjacent to mines and since maps of the underground workings are incomplete and/or inaccurate.

- 18.3 Turn off US-41 to the right to the overlook of the Keweenaw Waterway or Portage Lake which is Stop 6.

STOP 6. Keweenaw overlook near Quincy Mine.

This overlook, near the crest of Quincy Hill, allows a broad overview of all the previous stops and also the best general view of the Keweenaw Waterway (Fig. 17). The features which can be seen are, from east to west (left to right): 1) On the skyline, the knobby terrane of the Huron Mountains, which lie across Keweenaw Bay. The mountains are underlain by the Archean gneisses and granites of the Northern Complex, and are the main source area for the extensive deposits of Jacobsville Sandstone. 2) In the foreground, underlying the flat topography of Jacobsville Sandstone is clearly visible. The Jacobsville extends from the Keweenaw fault, which crosses the Waterway just east of the Michigan Tech campus, across the Keweenaw Bay and under the Huron Peninsula (Pointe Abbaye). The formation is generally flat-lying, while all of the other rocks of the Peninsula dip northwestward toward Lake Superior. 3) Within the town of Houghton several ridges of basalt can be traced downhill, the most prominent being the Scales Creek flow horizon, where Stop 1 was made. The attitude of the Portage Lake flows and the alternation of resistant flow interiors and interflow conglomerates with less resistant flow tops makes site investigation work critical for construction projects, to accurately determine depths to bedrock and to make hydrologic interpretations. For example, site investigations of the extensive area south of the main campus, where the Michigan Tech Student Development Complex (visible from the overlook) is now located, provided the focus of several Master's theses for students in Geological Engineering (Stevens, 1971; Hase, 1973). A



MAP 4

Map 1 & 3

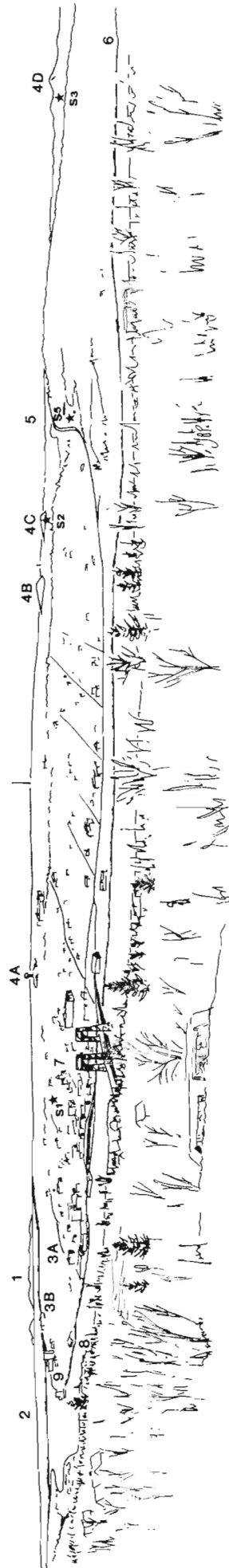


Figure 17: View from Portage overlook facing south. Notable features include: 1) Huron Mountains, 2) Flat-lying Jacobsville terrain, 3A) Scales Creek flow ridge, 3B) Student Development Complex, 4A) Houghton water tower at Isle Royale Shaft #1, 4B) Isle Royale dump #4, 4C) Isle Royale dump #5, 4D) Wheelkate Bluff (Trimountain, 5) Highway M-26, 6) Contact between the Portage Lake Volcanics and the Copper Harbor Conglomerate, 7) Houghton County Courthouse, 8) Quincy Smelter, 9) Michigan Technological University Main Campus. Previous stops are located with stars and stop numbers are prefixed with an S.

general map, showing the detailed bedrock geology of the City of Houghton (Holcomb, 1975) is used routinely by developers in the area. 4) On the skyline on the opposite side of the Waterway, beginning at the Houghton water tower a series of mine dumps representing the Isle Royale lodes can be seen extending into the distance. This marks the approximate route of the road between Stops 1 and 2, and shows the strike of the Portage Lake Lavas. The knob on the skyline is Wheel-kate Bluff near South Range which is one of several residual bedrock highs and is located just south of Stop 3. 5) The divided M-26 highway is visible, traversing the glacial deposits described at Stop 5. 6) To the right, the Waterway traverses the upper contact of the Portage Lake Volcanics and the Copper Harbor conglomerate, Nonesuch Shale and Freda Sandstone.

The Stop is the best single locality to observe the Keweenaw Waterway. The Waterway and the peninsula are named for an Indian word for Portage route, but to make the Waterway accessible to Lake Superior shipping, canal work was necessary at both the northern and southern shores. This was completed in 1873. The geological history of the Waterway was investigated in detail by Warren (1981). This and other major bedrock valleys were formed by stream superposition as ancient rivers eroded through flat-lying Paleozoic rocks into the tilted Keweenaw strata. But the valleys were greatly deepened by glacial erosion during the Pleistocene. Then as the Keweenaw Bay sub-lobe retreated at the end of the Wisconsin glaciation, the Waterway allowed eastward drainage across the Peninsula to lower lake levels to the east. First, drainage occurred in the Portage Gap (between Houghton and Hancock) while a tongue of ice remained in what is now western Portage Lake. As the ice retreated further, the valley now occupied by Portage Lake was formed by eastward drainage of successively lower proglacial lakes in western Lake Superior. Torch Lake was formed by a trapped block of ice which later melted in place to form the lake basin. Warren's study includes a complete bedrock topographic map of the Keweenaw and a series of maps showing the pattern of ice retreat, based on the distribution of glacial deposits.

Houghton was named for Douglass Houghton, the geologist who sparked the Michigan copper mining boom by publishing his Michigan State Geologist Report in 1841. Houghton was settled in 1852 and is the site of several historic buildings, the most important of which is the Houghton County Courthouse (1887), a prominent yellow brick building with Jacobsville Sandstone facing and copper roof and a flag pole, on the hill above the main part of town. Hancock was settled in 1859. Across the road and just slightly up hill is Quincy Hill House (1871), the mine manager's house for the Quincy Mine. The Quincy No. 6 mine shaft house dominates the skyline behind the viewpoint. A map of the Quincy operations in its heyday are given in Figure 18. The inclined No. 2 shaft descends at about a 45° angle more than 3 Km (1.7 Km below the surface) making this one of North America's deepest mines. The surface projection of the area mined is shaded on Map 4.

- 18.35 Right turn back on US-41 going up the hill.
- 18.75 Prominent outcrop of basalt with glacial grooves.

- 18.85 Right hand turn would lead to the Quincy Steam Hoist, we're in the center now of the Quincy Mine area (Fig. 18). The Quincy Steam Hoist can be visited during the summer months for a small admission charge. Inside is the largest steam mine hoist in the world. This great machine, invented by Bruno Nordberg and installed in 1920, could lift a 10 ton ore load at a rate of more than 1000 m per minute. The hoist is still in pristine condition and a full museum of the Quincy Mine is maintained inside as well.

MAP 4 or 5

- 19.3 Turn right on Arcadian Road. On the left hand side, immediately after the turn are some of the Quincy mine dumps, nearest Shaft No. 1. This will be Stop 7. Please respect private property signs and stay within the public right-of-way.

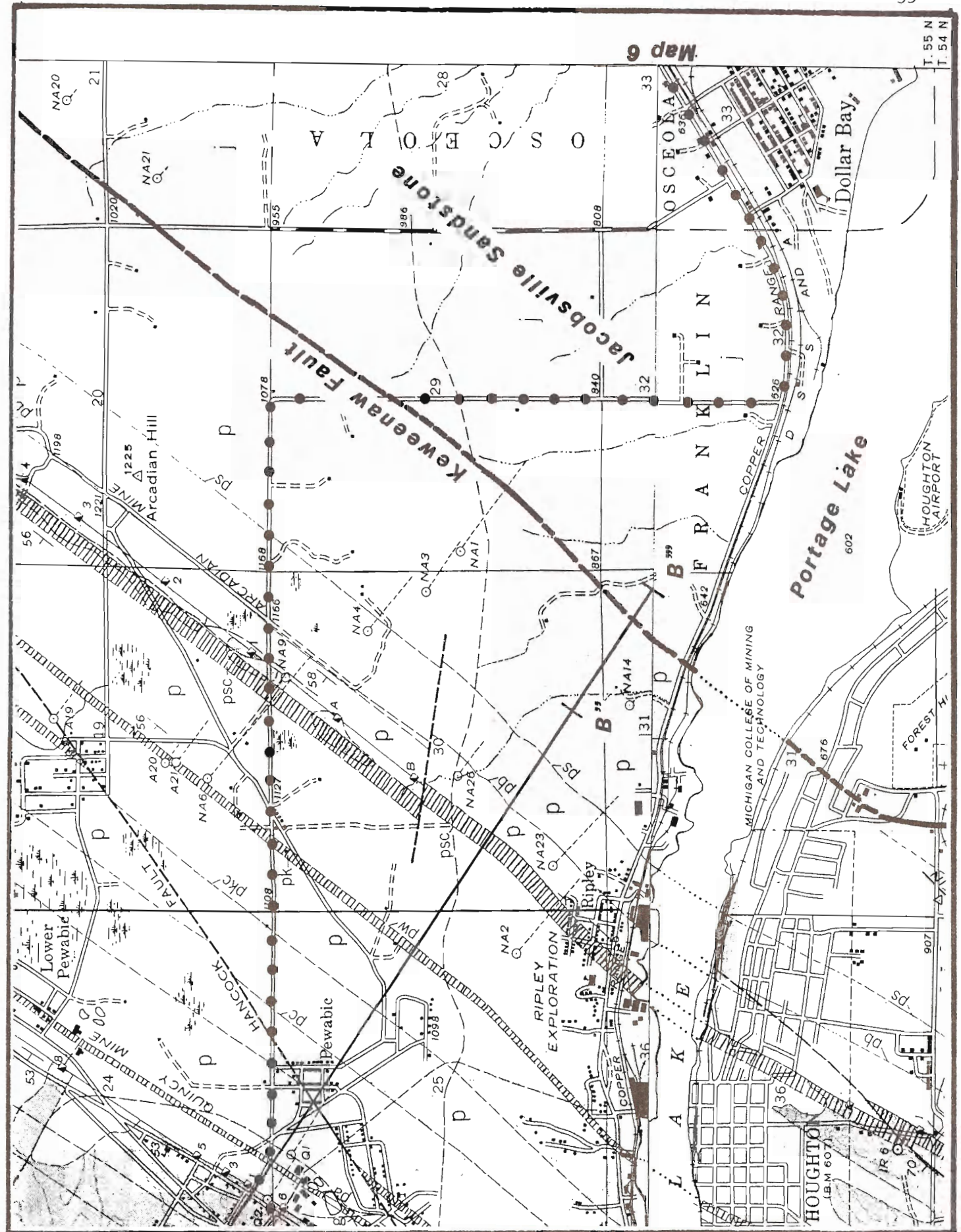
STOP 7. Quincy Mine Dumps.

The Quincy Mine worked the Pewabic amygdaloid. Production from the Quincy Mine began in 1856 and ended in 1967. Total production from the Pewabic amygdaloid was about 1 billion lbs. of refined copper, ranking fourth in the district (Weege and Pollack, 1971). Lankton and Hyde (1982) give an outstanding illustrated historical account of the history of the Quincy Mining Company which earned the name "Old Reliable" because it paid dividends so regularly.

The Pewabic amygdaloid deposit consists of a group of relatively thin flows. A geologic cross section is shown in Figure 19. These basaltic flows are texturally distinctly porphyritic with large feldspar phenocrysts. Some of the thicker flows have an ophitic texture. The tops of flows in some places are cellular whereas thick flows may be either cellular or fragmental. The amygdaloids of Pewabic flows are characteristically of a type termed locally as coalescing. Flows of this type typically have smooth tops in which individual vesicles are larger than average, reaching an inch or more in diameter. Vesicles in the same layer may coalesce to form a thin, jagged gash with a lateral extent of up to 12 feet or more. A series of such openings provided an almost continuous path for the flow of mineralizing hydrothermal solutions. Several such layers may occur in the same flow top. Where coalescing is well developed in the Pewabic amygdaloid there may be 2 to 10 layers from 3 to 5 feet thick. There is every gradation from coalesced layers of vesicles to those that show only a moderate tendency to collect in layers (summarized from Butler and Burbank, 1929).

In the Pewabic lode, quartz is the most abundant secondary mineral associated with native copper. Calcite is also abundant. Pumpellyite, epidote and chlorite are common but not abundant and prehnite is present. Laumontite and datolite are common in upper levels but not lower levels (summarized from Butler and Burbank, 1929).

The majority of the dump at this stop is amygdaloidal to massive basalt. Secondary minerals in this dump are mostly quartz and calcite with lesser amounts of pumpellyite followed by epidote. Paragenetically epidote and pumpellyite seem to be early whereas quartz, calcite and native copper formed later.



QUINCY MINE LOCATION HOUSING AND COMMUNITY STRUCTURES

c. 1920

- | | |
|-----------------------------|--|
| 1. Doctor's Residence | 10. Clubhouse (Bathhouse). |
| 2. Dispensary | 11. Methodist Church |
| 3. Agent's Residence | 12. Catholic Church and Priest's Residence |
| 4. Clerk's Residence | 13. James H. Seagar and Company Franklin Store |
| 5. Mine Office | 14. Franklin School |
| 6. George North's Residence | 15. Old Franklin School, Franklin Boarding House |
| 7. Captain's Residence | 16. Pewabic School |
| 8. North's Store | |
| 9. Quincy School | |

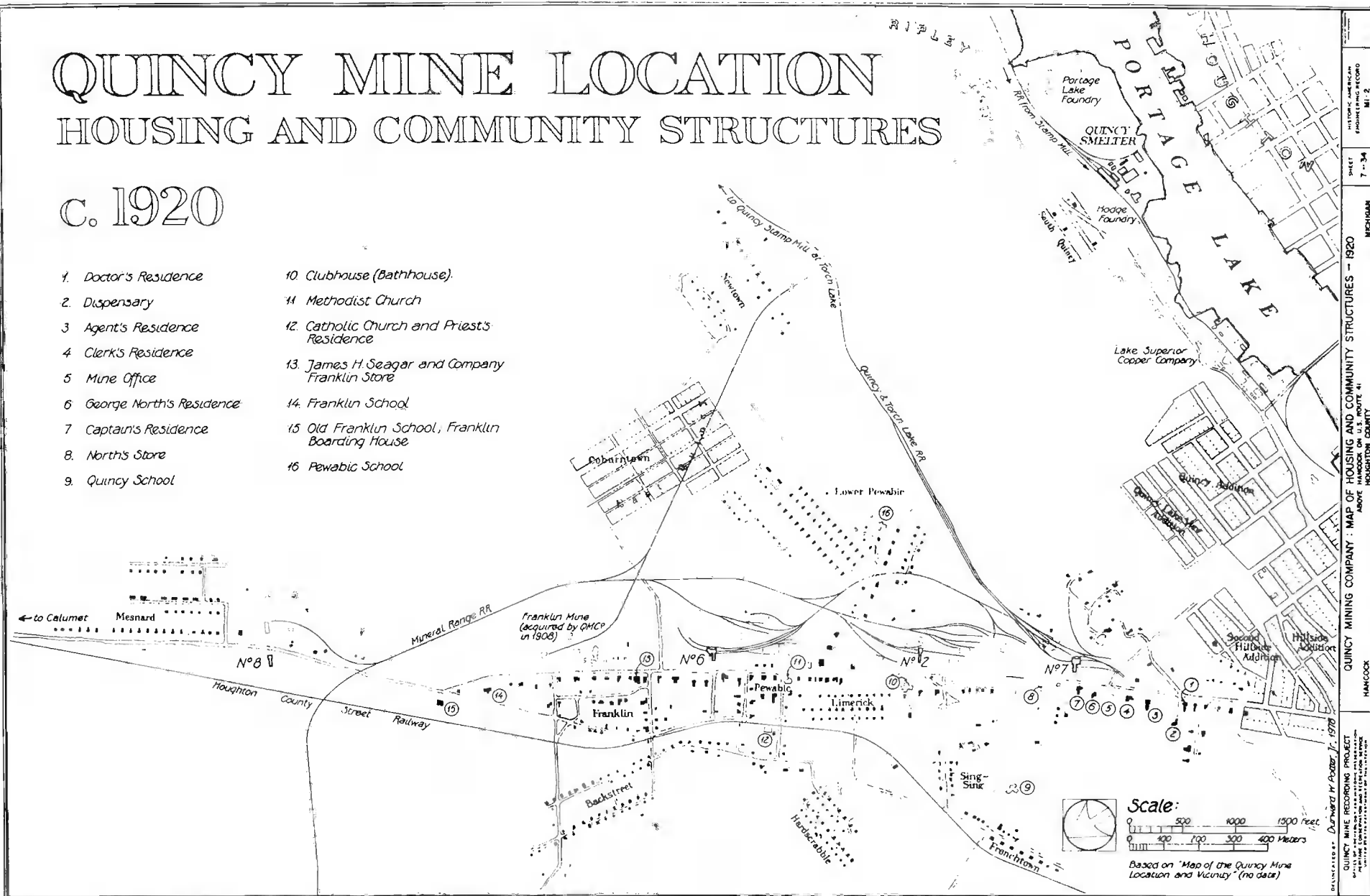


Figure 18: Structures of the Quincy Mine location (from Lankton and Hyde, 1982).

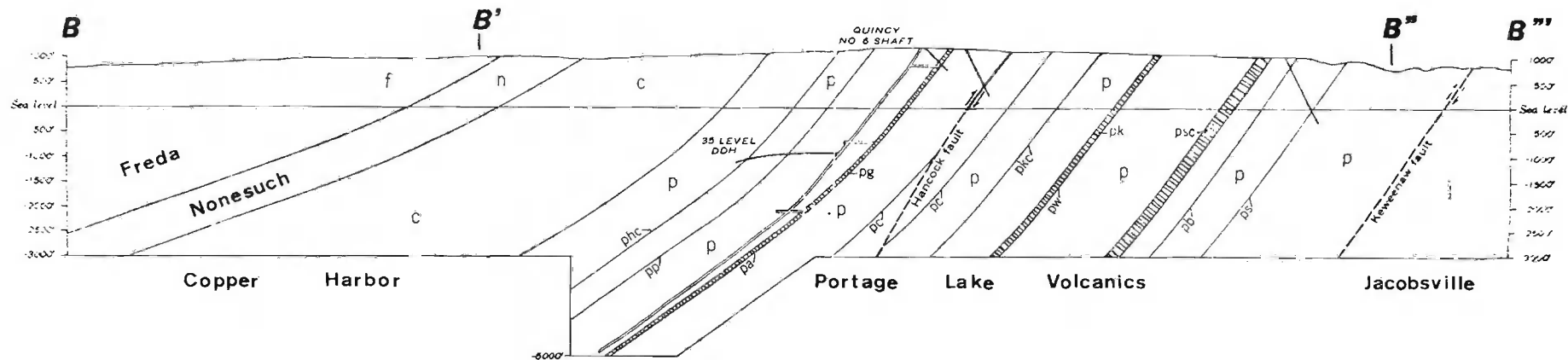


Figure 19: Geological cross section from B to B' on Map 30, B' to B'' on Map 4, B'' to B''' on Map 5. This cross section illustrates the general geologic relationships of the Keweenaw Peninsula. The Portage Lake Volcanics are overlain successively by the Copper Harbor Conglomerate, the Nonesuch Shale and the Freda Sandstone. The Portage Lake Volcanics are in fault (reverse) contact with the younger Jacobsville Sandstone (see Fig. Introduction). Labels for the Portage Lake Volcanics (P) are as follows: Hancock conglomerate (phc), Pewabic West conglomerate (pp), Greenstone flow (pg), Allouez conglomerate (pa), Calumet and Hecla conglomerate (pc), Kingston conglomerate (pkc), Kearsarge flow (pk), Scales Creek flow (psc), Bohemia conglomerate (pb), St. Louis conglomerate (ps).

MAP 5

- 19.5 Entering Coburntown. This is another one of the communities that sprung up around the Quincy operations, most of the houses built and owned by the company. Several ethnically distinct neighborhoods existed "on the hill" in the early 1900's. In all more than 6,000 people lived on the hill in 1905.
- 20.45 There is a Y in the road, we take the right hand branch which is essentially a straight road with a sign saying Arcadian Scenic View.
- 20.7 Passing a radio tower on the right. We are now crossing the Scales Creek flow at the top of the small ridge (see Map 5). The Arcadian Mine worked an amygdaloid just below the Scales Creek flow. The amygdaloid may correlate with the Isle Royale amygdaloid discussed at Stop 2. North of the road is Shaft No. 1 of the Arcadian Mine. Stoiber (unpublished date) estimated the percentages of non-metallic secondary minerals in the dump from Shaft No. 1 as: calcite, 43; prehnite, 25; quartz, 16; K-feldspar, 8; epidote, 6; pumpellyite, 1; chlorite 1; and laumontite, trace.
- 21.4 Down to the right of the road you can see the largest part of Portage Lake, Keweenaw Bay and the Huron Mountains. Much of the field of view is basically flat-lying Jacobsville terrane.
- 21.6 Road turns to the right and changes to gravel.
- 21.8 We're descending off the Portage Lake Volcanic Series across the Keweenaw Fault onto Jacobsville Sandstone.
- 23.0 We are descending the hill and we have a view of the Isle Royale sands across Portage Lake in Houghton. These are tailings from the Isle Royale dumps (Stop 2) which were brought out and into Portage Lake.
- 23.15 Junction with M-26 and take a left turn at the Portage Lake Coal Dock.
- 23.6 Entering Dollar Bay on M-26.

MAP 6

- 25.2 Exposure of flat-lying cross-bedded redbeds of the Jacobsville Sandstone on the left hand side of the road (northwest side).

STOP 8. Jacobsville Sandstone.

The Jacobsville Sandstone is a fluvial succession of feldspathic and quartzose sandstones, conglomerates, siltstones, and shales up to 1,000 m thick (Fig. 20a). There are no interbedded lava flows or cross-cutting dikes. The Jacobsville Sandstone is separated from the Portage Lake Volcanics by the Keweenaw Fault, a reverse fault. The Jacobsville Sandstone is probably upper Keweenawan in age and may be slightly younger than the Freda Sandstone. Current directions in the Keweenaw Peninsula are to the northeast and east which suggests transport to deeper parts of a basin located northeast of Keweenaw Bay (Fig. 20b). West of Lake Gogebic thickness and current directions suggest another deep part to the basin. East of Calumet, near the Keweenaw Fault (Stop 10) the Jacobsville Sandstone contains boulders of basalt which suggests a topographic high in the Portage Lake Volcanics north of the fault during this period of Jacobsville sedimentation. Metamorphosed



MAP 6

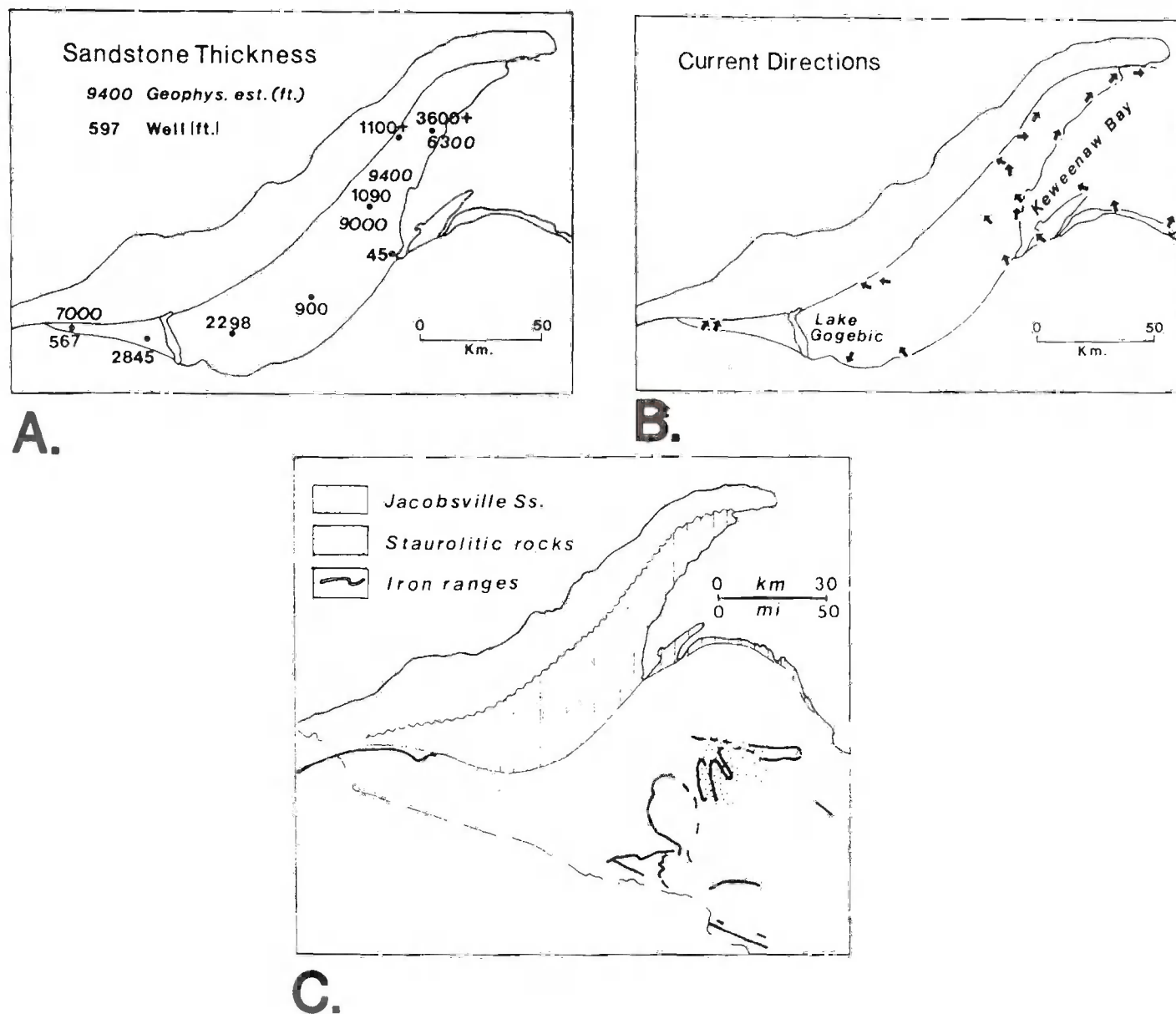


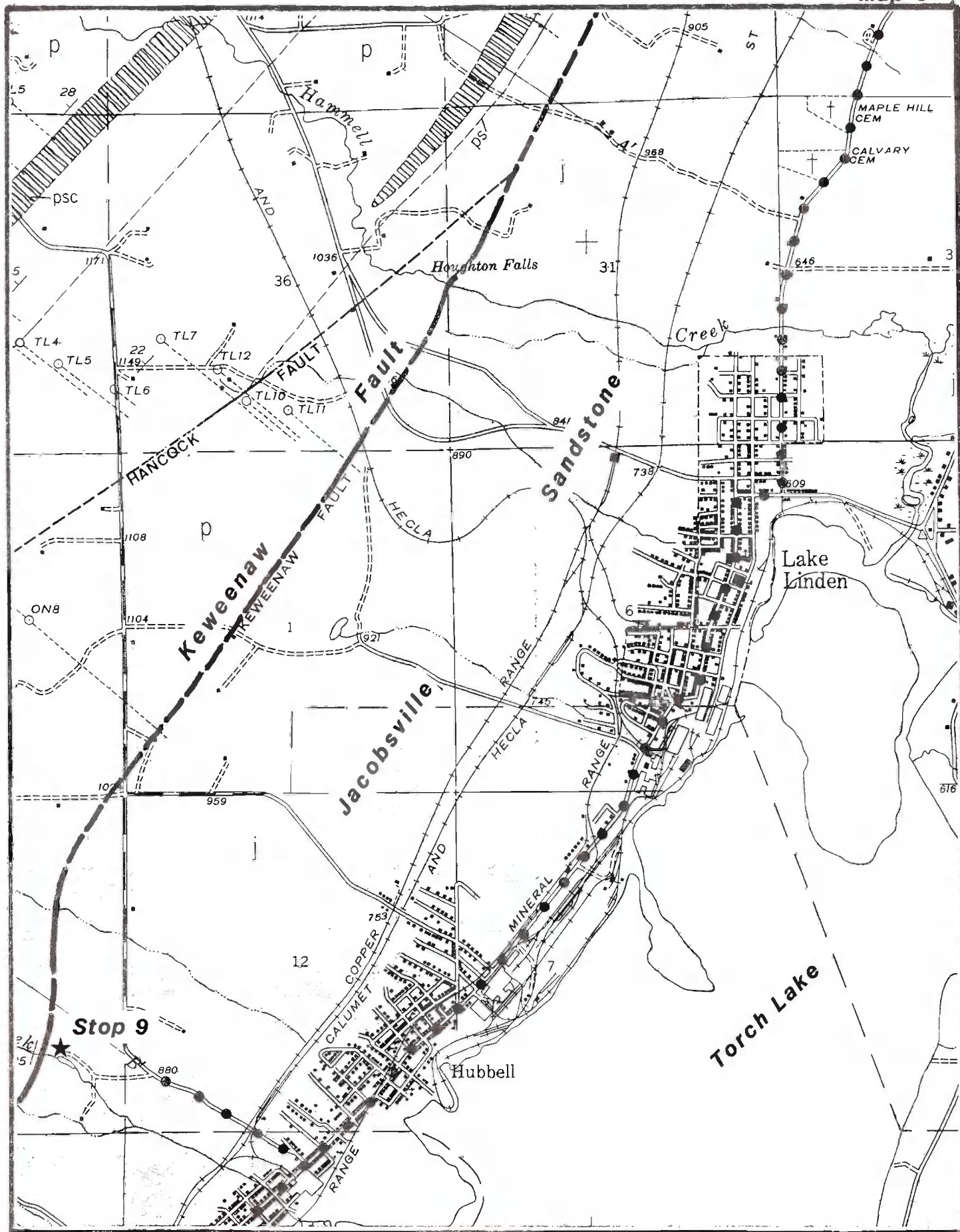
Figure 20: Relationships of Jacobsville Sandstone (from Kalliokoski, 1982).
 A. Thickness of Jacobsville Sandstone with minimum thickness denoted by '+'. B. Current directions in the Jacobsville Sandstone. C. Location of possible source areas of iron formation and of staurolitic metasedimentary rocks.

iron-formation and quartz-staurolite pebbles suggest a source from the southeast (Fig. 20c). Jacobsville sedimentation was preceded by a long period of cratonic stability with little or no volcanic activity. Erosion was apparently initiated by late Keweenawan warping along the mid-continent rift system. The major movements on reverse faults were after Jacobsville deposition (summarized from Kalliokoski, 1982).

Lithology of sandstones varies from subarkose to quartz sublithic arenite. There are some beds of arkose and quartz arenite. Grain size varies from fine to coarse. Quartz grains show evidence of volcanic and metamorphic origin. Microcline is relatively unaltered and plagioclase is unaltered to highly altered. Other clasts include: volcanic rocks, schist, shale and the minerals epidote, biotite, muscovite and chlorite. Sandstone varies in color from red to a cream-white or purplish-red color. The color depends on the alteration of ferromagnesian minerals and the amount of iron oxide deposited as rims on feldspar grains. Ripple marked bedding surfaces and cross-bedding are common in some localities. Sandstones are fluvial and conglomerates probably represent alluvial fan deposits (summarized from Kalliokoski, 1982).

At this stop the character of the Jacobsville Sandstone can be seen in the exposures on the left side of the road. The exposures here can be compared and contrasted to Jacobsville that will be seen at Stop 9 and Stop 10.

- 25.9 Entering the small town of Mason. Mason was the site of company housing for the Quincy mill operations from 1890.
- 26.5 On the right hand side of the road is an old dredge which is stuck in tailings in Torch Lake. This is the C&H dredge #1, built in 1913, bought by Quincy in 1955 and used until 1967.
- 26.7 Now we pass the remains of the main buildings of the Quincy Mill, built in 1890 to accommodate steam stamps, required when the Quincy operation expanded to the Pewabic Lode.
- 27.0 Along the road on the left there are more outcrops of flat-lying Jacobsville Sandstone.
- 27.3 On the right, Torch Lake.
- 27.7 On the right hand side of the road are tailings which have been revegetated. These tailings now as we are entering Tamarack City are part of the mill operation of the Calumet & Hecla company mines and the Calumet region which have major mills located at Tamarack and Hubbell.
- 28.15 On the left hand side of the road are the footings from one of the Tamarack Mills.
- MAP 7
- 28.6 On the right hand side of the road are the remains of a steam stamp mill.
- 28.7 Left turn, going up the hill toward Stop 9. Follow the paved road which jogs a little to the left and goes up the hill.



Map 6

MAP 7

- 28.85 Cross the old Copper Range railroad grade.
- 29.0 Sign indicating Hungarian Falls. This is the lower part of the falls. Continue going up the hill, straight ahead.
- 29.25 Junction of a four-wheel drive road to the left. Stop here and walk towards Tamarack reservoir/Hungarian Falls upper part where excellent exposures of Jacobsville Sandstone are found near the Keweenaw Fault.

STOP 9. Hungarian Falls.

Hungarian Falls is located near the Keweenaw Fault (Fig. 21). The Keweenaw Fault is a reverse fault that juxtaposes older Portage Lake Volcanics and the younger Jacobsville Sandstone. In this locality, the Keweenaw Fault presumably dips at a high angle to the west similar to that illustrated in Figure 19, Stop 7. The Keweenaw Fault at the surface varies from a single fault plane to a more complex fault zone, such as described near Lac La Belle. Structural relationship of beds near the fault also varies from steepened dips to folds. In general the dip of the Portage Lake Volcanics and Jacobsville Sandstone steepen appropriately as one approaches the fault.

At Hungarian Falls the fault contact causes very little deformation of the Jacobsville Sandstone, which is only tilted slightly. To the west of the fault at this site the Portage Lake Volcanics are unusually shallow dipping. If not viewed in the context of many other localities, the fault might not be recognized as such a profound feature, and could appear as a conformable contact. The contrast between the fault exposure here and that at the next stop (Stop 10) at Hungarian Falls is striking and illustrates the structural variability of rocks along this major feature.

The Portage Lake Volcanics near the Keweenaw Fault at Hungarian Falls consists of basaltic lava flows with interbedded conglomerate. Interbedded sediments make up a small part of the stratigraphic section of the Portage Lake Volcanics and are found as relatively thin widely separated beds. However, here and at some other localities in the Keweenaw Peninsula conglomerates within the Portage Lake Volcanics are either near or at the fault contact.

Walking downstream along the stream to the upper and lower falls allows examination of good exposures of Jacobsville Sandstone with cross bedding, interbedded shaly and conglomeritic horizons and many typical arkosic red-bed sedimentary features.

- 29.25 Turn around and go back down the hill to Tamarack City.
- 29.8 Stop sign. Stamp mill remains are straight ahead. Turn left on M-26.
- 29.9 Entering Hubbell
- 30.5 On the right are Calumet & Hecla mill buildings which have recently been taken over by Michigan Tech Ventures as a pilot plant location for small industries. Torch Lake is still on the right with many of the tailings out in the lake.

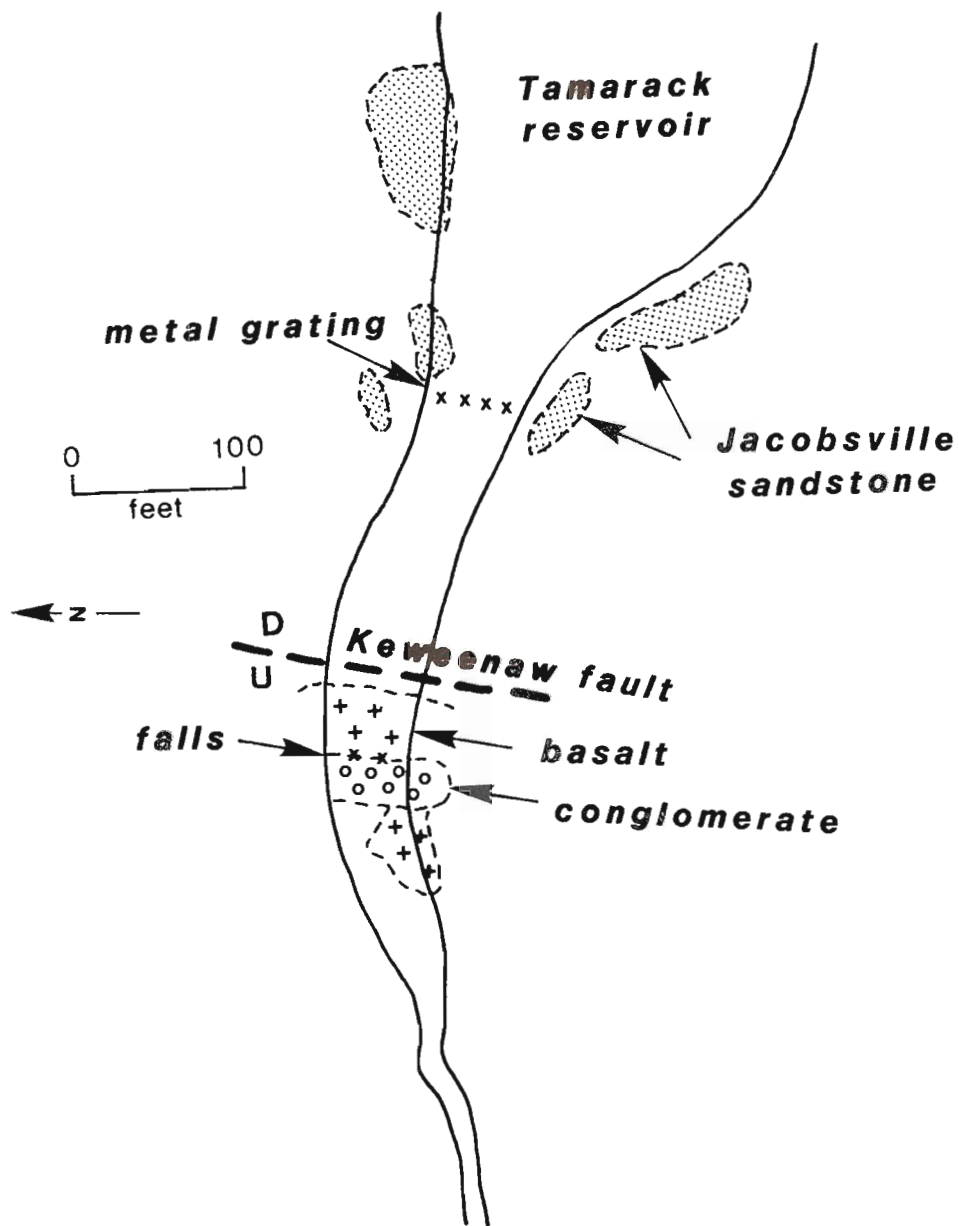


Figure 21: Geologic sketch map of the Hungarian Falls area (by J.M. Robertson, 1973). Basalt and conglomerate are part of the Portage Lake Volcanics. Note that north is toward the left margin of the page.

31.4 Entering the town of Lake Linden. The Houghton County Historical Museum is on the right hand side of the road. The building (1917) was donated by the C&H Company to the Houghton County Historical Society in 1963. Among the best displays are scale models of underground mines and a rich photographic record of the boom copper days.

32.2 Right turn on Ninth Street (the so-called Bootjack Road) in Lake Linden.

32.35 Left hand turn at two blocks after 32.2. Follow the signs to the Lakes Drive-In Theatre. This is Gregory Street.

MAP 8

33.3 On the left hand side of the road is the Lake Linden cemetery. The road heads north along the Trap Rock River Valley. On the left hand side of the road at the top of the steep slope is the Keweenaw Fault. On the right hand side of the road is a flat-lying Jacobsville terrane. The Trap Rock River follows another of the glacially eroded, deep bedrock valleys described by Warren (1981).

34.5 Pavement ends.

34.6 The gravel road bears to the right.

34.9 Cross a bridge over the Trap Rock River.

35.0 Left turn at the Trap Rock Schoolhouse.

35.0 Cross the Trap Rock River again.

35.7 Left turn on to another dirt road that begins to go up hill.

36.1 Cross the railroad grade of the Copper Range railway. Access to the Natural Wall ravine for mapping purposes can be gained by walking a couple hundred yards to the left along this railroad grade and then walking along the stream valley up toward the fault line.

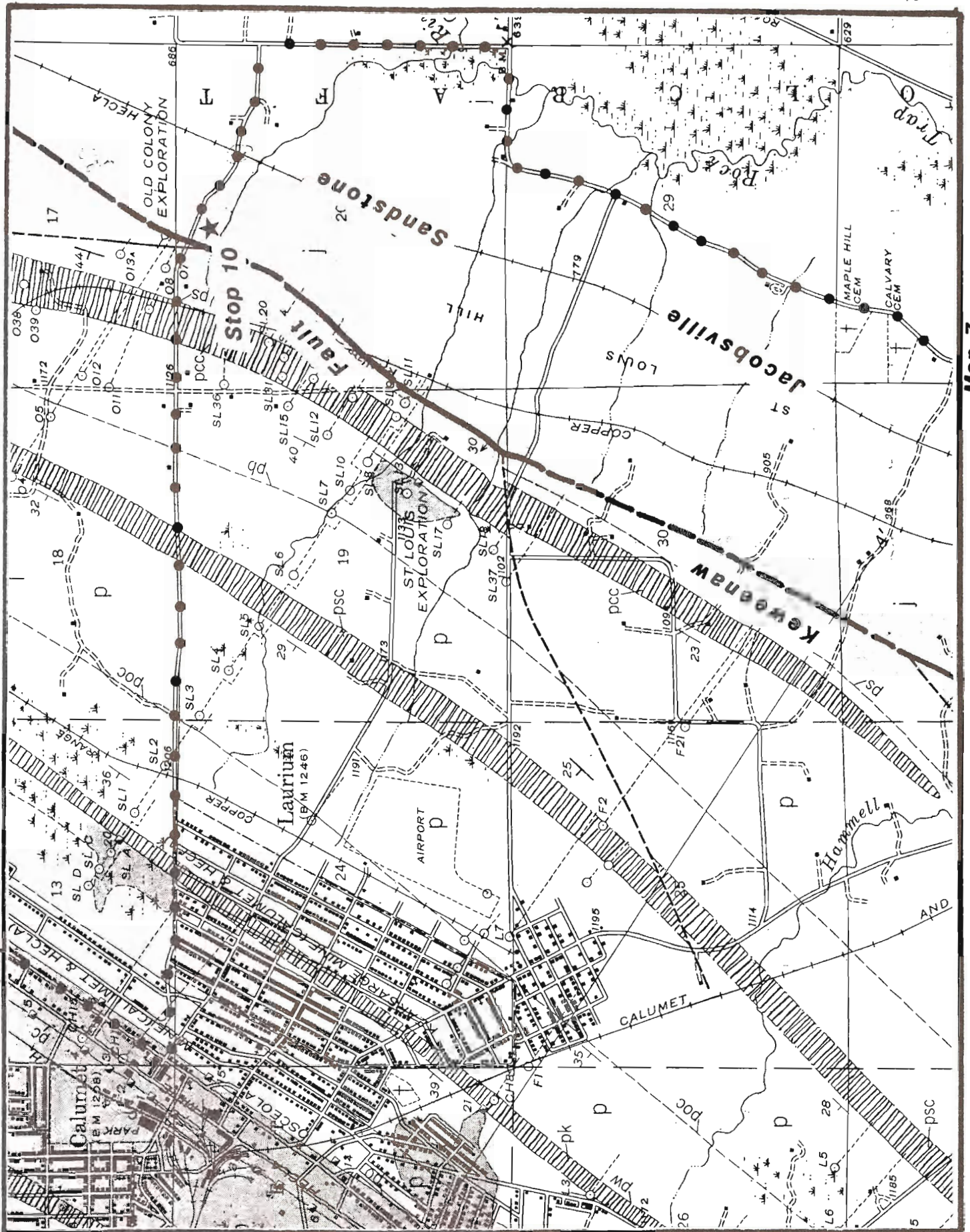
36.2° Poor exposures of flat-lying conglomerate beds within the Jacobsville Sandstone on the left hand side of the road.

36.4 Stop by an old wooden sign on the left hand side of the road. Walk about 200 meters to the left (south) to the Natural Wall ravine.

STOP 10. Keweenaw Fault at Natural Wall Ravine.

The Natural Wall is a bed of sandstone within the Jacobsville which has a near vertical attitude and because it is more resistant, it forms a wall which extends outward from the walls of the ravine. On the sides of the ravine the lithology of the Jacobsville here includes conglomeritic beds, sandstones and shaly horizons. The attitudes of beds in the creek bottom change from flat-lying to the east, to vertical and even locally overturned as the fault is approached. An anticline in the Jacobsville trends parallel to and 300 m east of the fault. West of the fault the Portage Lake Volcanics dip to the WNW at 35-40° (Fig. 22).

Map 9



MAP 8

Map 7

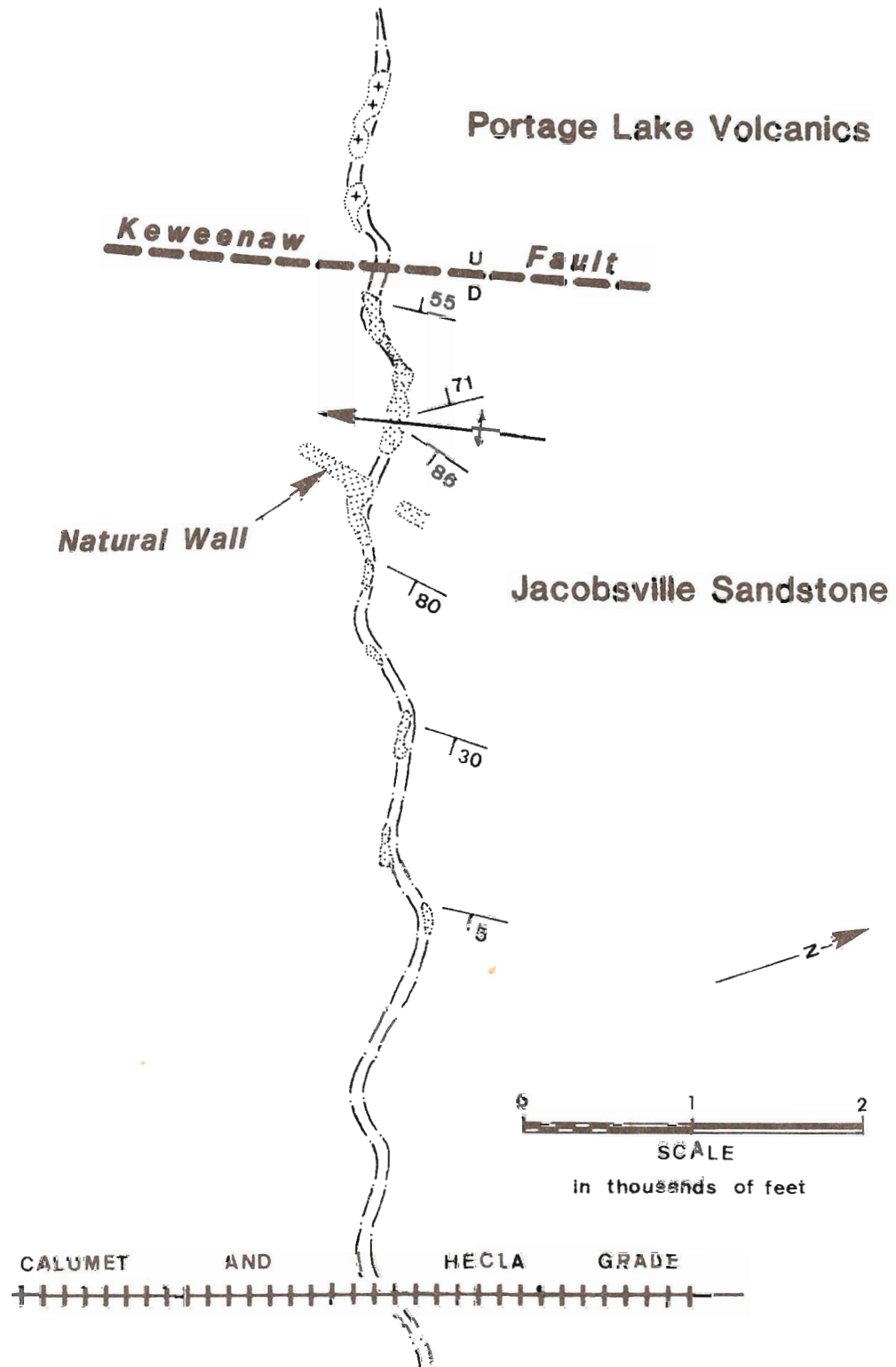


Figure 22: Geologic sketch map of the Natural Wall Ravine. Note that north is toward the right margin of the page.

- 37.95 The beginning of pavement, we are entering the town of Laurium.
- 38.7 Left turn which is followed immediately by a right hand turn at the next stop sign on School Street.
- 38.8 Junction of School Street and Calumet Avenue, which is US-41. Turn right. This is Calumet, Michigan, the center of the Michigan Copper District, and a site of the Calumet & Hecla headquarters. Here Edwin Hurlbut discovered the Calumet conglomerate lode in the early 1860's and this became the most important ore body in the whole district. Greater Calumet (including Red Jacket, Blue Jacket, Yellow Jacket, Laurium and Rambaultown) had a population of 33,000 in 1910. Among many historic buildings here are the Calumet Theatre (1900) and the C&H Community Library Building (1898).

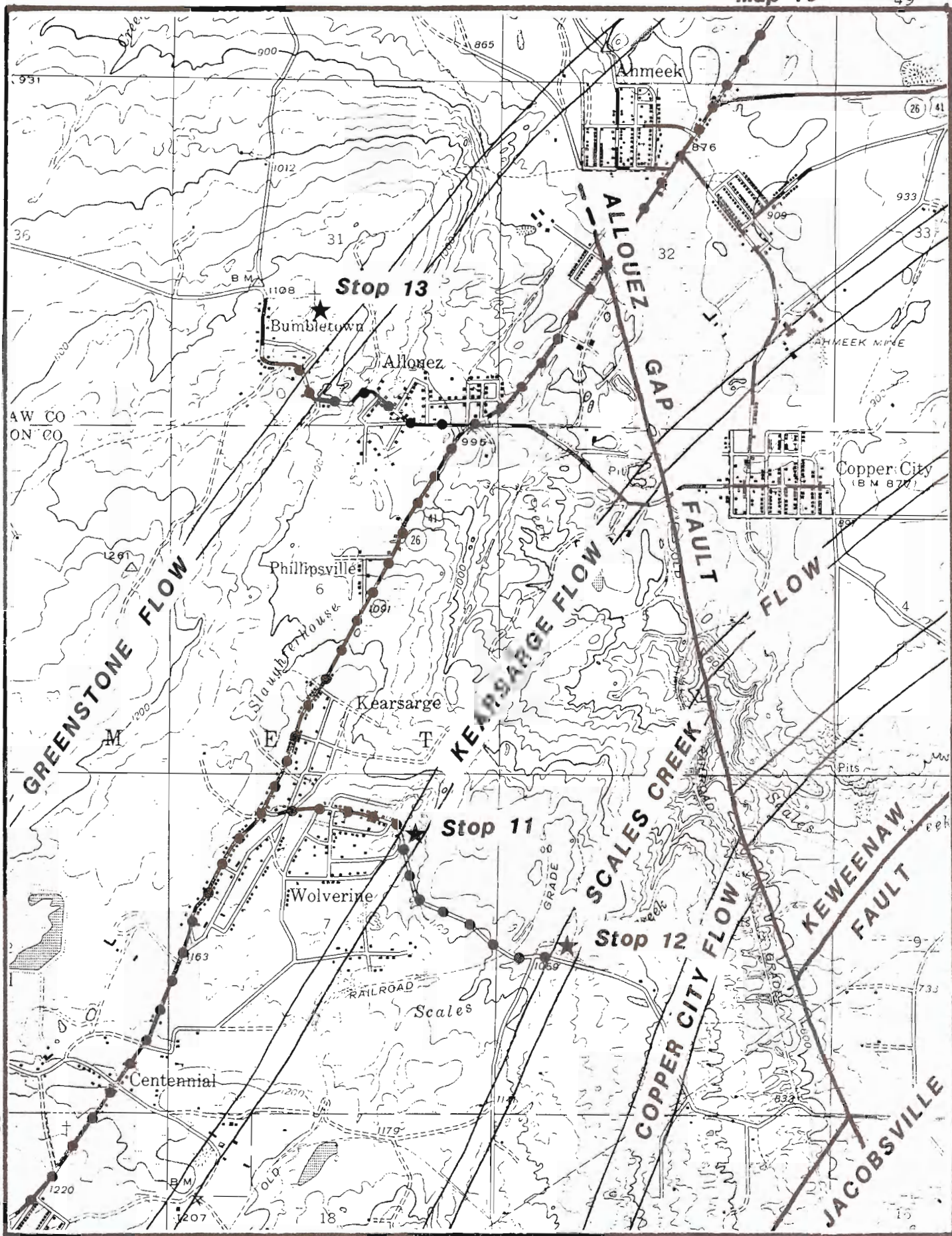
MAP 9

40.0 Entering Centennial

- 40.3 On the left hand side of the road you can see the Centennial Mine Shaft No. 6. After closing in 1968, this mine was dewatered in the mid-1970's by Homestake. This operation has since been abandoned.

The Centennial Mine Shaft Nos. 3 and 6 worked the Calumet and Hecla conglomerate. The ore body lies up dip and northeast from the main ore body in the C&H conglomerate mined by the Calumet and Hecla Mine in the Calumet area. The C&H conglomerate yielded about 4.2 billion lbs. of refined copper, the largest lode in the district and is over one-third of the total production from the Keweenaw native copper district (total district production of about 11 billion lbs.). The C&H lode had the highest average grade in the district of 57 lbs. of Cu per ton of rock treated (Weege and Pollack, 1971).

The Calumet and Hecla conglomerate can be followed along strike for more than 65 Km. Along most of this length it is less than about 1 m thick. In the Calumet area it averages over 3 m thick and tends to thicken with depth. The bed consists of north trending thicker and thinner zones representing channels. At the Centennial Mine Shaft Nos. 3 and 6 thickness is often less than 3 m and the C&H conglomerate was deposited in a tributary stream channel. The pebbles in conglomerate at Centennial are almost all quartz-feldspar phenocrystic rhyolite. The pebbles in the main channel conglomerate are a quite varied suite of rhyolite and granophyre with some quartz-feldspar phenocrystic rhyolite. Main and tributary channel conglomerates tend to be coarser and contain less fine material where thicker. Outside of the 5-foot thickness contours the bed is usually shaly or sandy. At Centennial, copper mineralization tends to occur in bands with the bed and the intensity is related to the type and amount of interstitial material and location of pinch-outs or barriers. Higher grade areas are related to conglomerate with coarse sand or small pebbles as interstitial material, especially when pebbles and sand grains are quartz-feldspar phenocrystic rhyolite. Evidence also strongly suggests that the mineralized areas follow the axis of stream channels and grade is highest adjacent to the 5-foot thickness contour where the conglomerate bed increases greatly in thickness down dip. These pinch-outs localized ore deposition from mineralizing solutions that were migrating up-dip. Sedimentological relationships are



MAP 9

important in exploring the conglomerate ore bodies (summarized from Weege and Pollack, 1971).

- 40.6 Entering Kearsarge, Michigan.
- 41.1 Stone boat on the right hand side of the road.
- 41.3 Right turn onto Water Street just before the Wolverine Market. Continue straight ahead on the main paved road.
- 41.5 STOP 11 is the Wolverine Mine dumps. There are dumps both on the right and left hand side of the road. The ones on the right hand side of the road (south), just on the other side of some old buildings, are somewhat dangerous because of bad ground. Mining in this area was very shallow (Shaft No. 3). The dumps on the left hand side of the road appear to be much safer (Shaft No. 2). Park along the road and walk about 100 m to the north.

The Wolverine Mine is one of seven different mines that worked the Kearsarge amygdaloid: Centennial, South Kearsarge, North Kearsarge, Ahmeek, Allouez, Mohawk, and Seneca. Production of copper from the Kearsarge amygdaloid began in 1887 and stopped in 1967. About 2.3 billion lbs. of refined copper were produced from the Kearsarge amygdaloid making it the second largest producer of the Keweenaw native copper district (Weege and Pollack, 1971). Underground workings are continuous for more than 12 km and extend down dip as much as 2500 m. The Kearsarge amygdaloid is one of the best documented ore bodies in the district.

The Kearsarge flow has been recognized for a distance of around 55 km along strike. It lies directly above the Wolverine sandstone. The flow dips between 35 and 40 degrees to the northwest (Fig. 23). The interior of the flow is a well developed ophite with a composition shown in Table 2. It has an amygdaloid top that ranges from near zero up to 10 m in thickness. Just below the amygdaloid there is a zone in which the flow is distinctly porphyritic with tabular plagioclase phenocrysts. Abundance and size of the plagioclase phenocrysts in this zone is variable but they can make up a large percentage of the rock and can be up to 2.5 cm in length. This zone is probably the result of plagioclase floating during in situ crystallization of the flow. The stratigraphic and textural relationships makes this flow more easily recognized than most. The near-surface thickness of the Kearsarge flow clearly shows that the most productive area is where it is thickest (Fig. 24). The flow top in the productive area is mostly a fragmental amygdaloid (flow top breccia). Individual fragments are generally less than 15 cm in greatest dimension and contain numerous small amygdules. The fragmental amygdaloid makes up the uppermost part of the flow grading downward into banded cellular amygdaloid with amygdules abundant at certain horizons. This grades downward into a zone with fewer and large amygdules with less tendency to be found in bands and still further downward into massive basalt. The amygdaloid top of the Kearsarge flow in the mined area has an average thickness of around 2 m (summarized from Butler and Burbank, 1929).

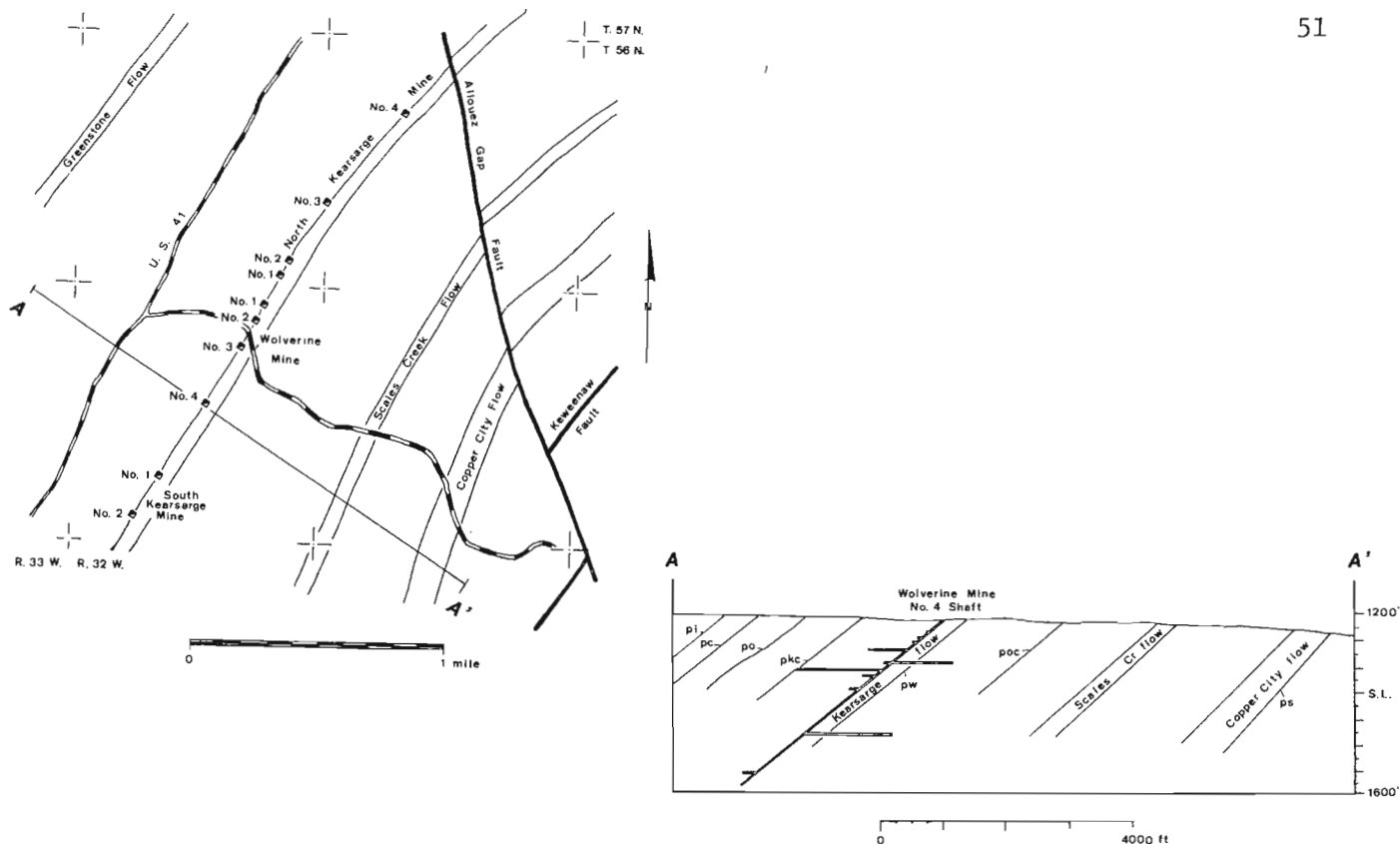


Figure 23: Geologic map and cross section showing the Kearsarge flow, Wolverine Mine and vicinity (modified from White and others, 1953). Stop 11 is the Wolverine Mine Shaft No. 2 dump (see Map 9). Labels are as follows: Iroquois flow, (pi); Calumet and Hecla conglomerate (pc); Osceola flow (po); Kingston conglomerate (pkc); Wolverine sandstone (pw); Old Colony sandstone (poc); St. Louis conglomerate (ps).

Table 2: Major-element composition of the Kearsarge flow (from Stoiber and Davidson, 1959). This is a weighted average exclusive of the top 12 feet and thus represents a close approximation to the original composition of the flow.

	Weight Percent
SiO ₂	48.55
Al ₂ O ₃	16.51
Fe ₂ O ₃ *	11.54
MgO	6.68
CaO	9.44
Na ₂ O	2.82
K ₂ O	0.58
TiO ₂	1.49
P ₂ O ₅	0.18
MnO	0.16
H ₂ O+	2.06
H ₂ O-	0.63
CO ₂	0.15
Total	100.79
ppm Cu	90

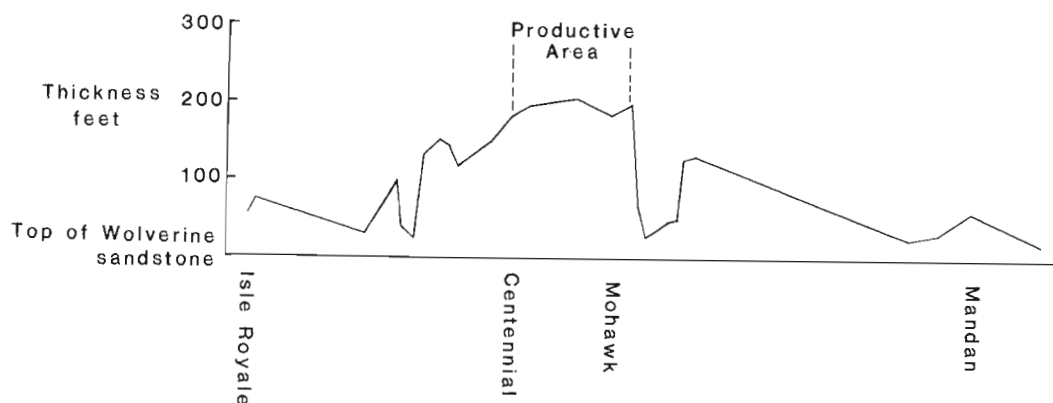


Figure 24: Thickness of the Kearsarge flow (modified from Butler and Burbank, 1929). This is the near surface thickness along a strike distance of around 35 miles from Isle Royale (Map) to Mandan (Map 20). The thickness is relative to the directly underlying Wolverine Sandstone which is arbitrarily shown as horizontal.

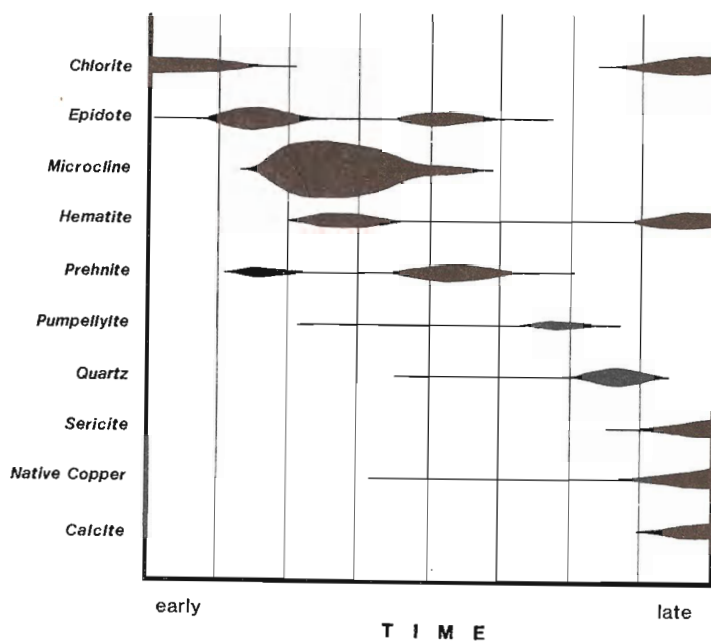


Figure 25: Paragenesis of secondary minerals in the Kearsarge amygdaloid at the Wolverine Mine Shaft No. 2 (Paces and Bornhorst, unpublished data). The relationships are based on a limited megascopic and thin section study of samples from the Shaft No. 2 dump and may be modified slightly as research proceeds. The exact timing of the later minerals are difficult to determine because they do not occur together.

The basalt in the Kearsarge amygdaloid is well oxidized. The flow top basalt has been affected by two types of alteration: albitization and pumpellyitization. Albitized basalt is about 60 percent euhedral albite laths set in a fine-grained to cryptocrystalline groundmass. Pumpellyitized basalt consists of fine-grained pumpellyite pseudomorphically replacing plagioclase. The amygdule and interfragmental space filling minerals in the Kearsarge amygdaloid as a whole, are (most to least abundant): calcite, epidote, K-feldspar, quartz and lesser amounts of chlorite, prehnite, pumpellyite, laumontite, and sericite. Native copper occurs associated with the secondary amygdule minerals (summarized from Stoiber and Davidson, 1959).

The secondary mineral assemblages vary both temporarily and spatially. Paragenetically chlorite, epidote, microcline and prehnite are early formed minerals and the latest formed minerals are quartz, native copper, calcite, and chlorite (Fig. 25). In the Ahmeek Mine Shaft No. 3 there is a banded arrangement of amygdule minerals from top to bottom of Kearsarge amygdaloid (Fig. 26 and Table 3). The bands are roughly parallel to bedding. There are five major mineral assemblages from the bottom to top of the amygdular layer: chlorite $\pm$ calcite $\pm$ microcline; quartz-epidote; calcite-epidote; calcite-microcline $\pm$ epidote; and chlorite-calcite $\pm$ microcline. The last assemblage is found in the base of the overlying flow (north hanging wall corner in Fig. 26). The banding may be explained by deposition of secondary minerals from a hydrothermal solution moving along a permeable channel. Chlorite and microcline would have been deposited first along the outer parts of the solution channel followed by quartz and epidote in the center of the channel and finally deposition of calcite in the remaining openings. This is consistent with the paragenetic relationships seen in individual samples (Fig. 25). There is no strict correlation between banding and the grade of native copper mineralization. However, the amygdule minerals and grade of native copper mineralization vary with depth (Fig. 27). Quartz is considerably less than 10 percent at shallower depths and as a whole averages about 15 percent within the quartz zone. There is an irregular increase in quartz content within the quartz zone with increasing depth. The amount of microcline decreases irregularly with depth until it is absent. The amount of native copper present is much more irregular than the mineral zones. The richest copper ore appears to straddle the quartz zone boundary. The limit of microcline may also mark the limit of significant copper mineralization. On a regional scale the Kearsarge amygdaloid lies within the quartz and prehnite zones. Thus, detailed data suggests that there are quartz and prehnite free islands within the regional zones (mostly summarized from Stoiber and Davidson, 1959 with addition of unpublished data of Paces and Bornhorst).

The temporal and spatial variation of amygdule minerals within the productive area of the Kearsarge amygdaloid is an excellent illustration of the complexity of amygdaloid ore bodies in the Keweenaw native copper district. At the Wolverine Mine Shaft No. 2 dump you will have the opportunity to see a variety of mineral assemblages and their paragenetic relationships. Excellent specimens with native copper can be found. For the Shaft Nos. 1 and 2 dumps as a whole, Stoiber (unpublished data) estimated the following percentage of minerals: calcite, 51; microcline, 38; epidote, 10; prehnite, 1; and quartz, trace. In the vicinity of the Shaft Nos. 2 and 3 dumps one can find outcrops of the Kearsarge flow interior.

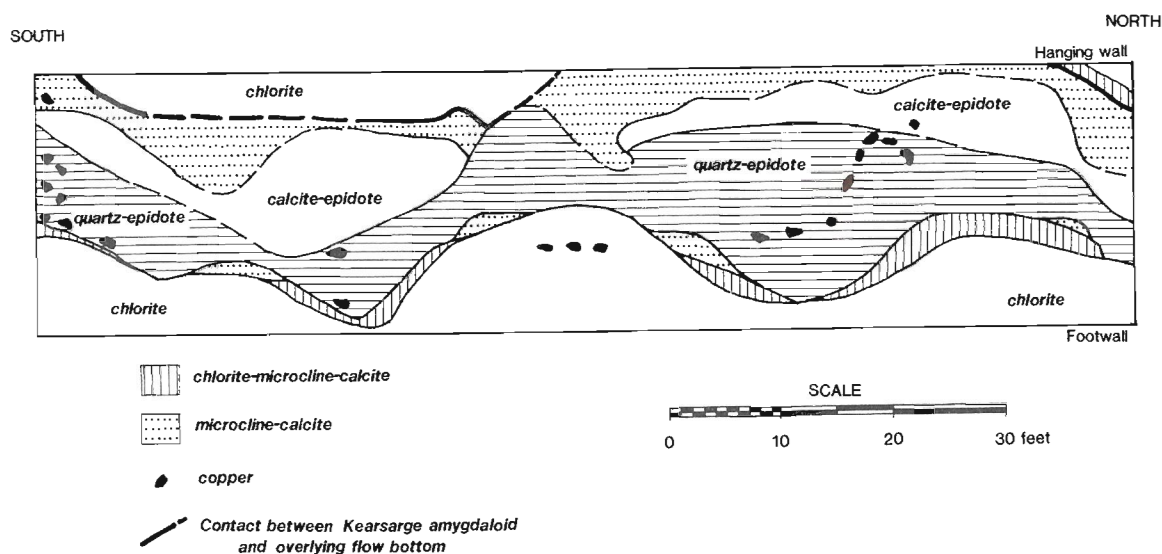


Figure 26: Cross section of the Kearsarge amygdaloid showing the banding of amygdule mineral assemblages, Ahmeek Mine, 35th level, 399 to 500 feet south of Shaft No. 3 (from Stoiber and Davidson, 1959). The footwall is the bottom of the Kearsarge flow. Data from the back and walls are projected to a horizontal plane. In one mapped locality Stoiber and Davidson (1959) found a laumontite-quartz-calcite zone. Amygdule mineralogy of the various zones are given in Table 3 below.

Table 3: Volume percent of amygdule minerals from mapped assemblages shown in Figure 26 (from Stoiber and Davidson, 1959).

Mineral Assemblage Band	Chlorite	Chlorite- Microcline- Calcite	Microcline- Calcite	Quartz- Epidote	Calcite- Epidote
Volume Percent Amydule Filling					
Chlorite	100	69-74	0-3	0	0
Microcline	0	15-25	45-82	0	0
Calcite	trace	0-5	0-47	0-1	87
Epidote	0	0-1	5-10	90-96	12
Pumpellyite	0	0-6	0-trace	0	trace
Quartz	0	0-5	0-8	4-9	1
	1	2	2	2	1

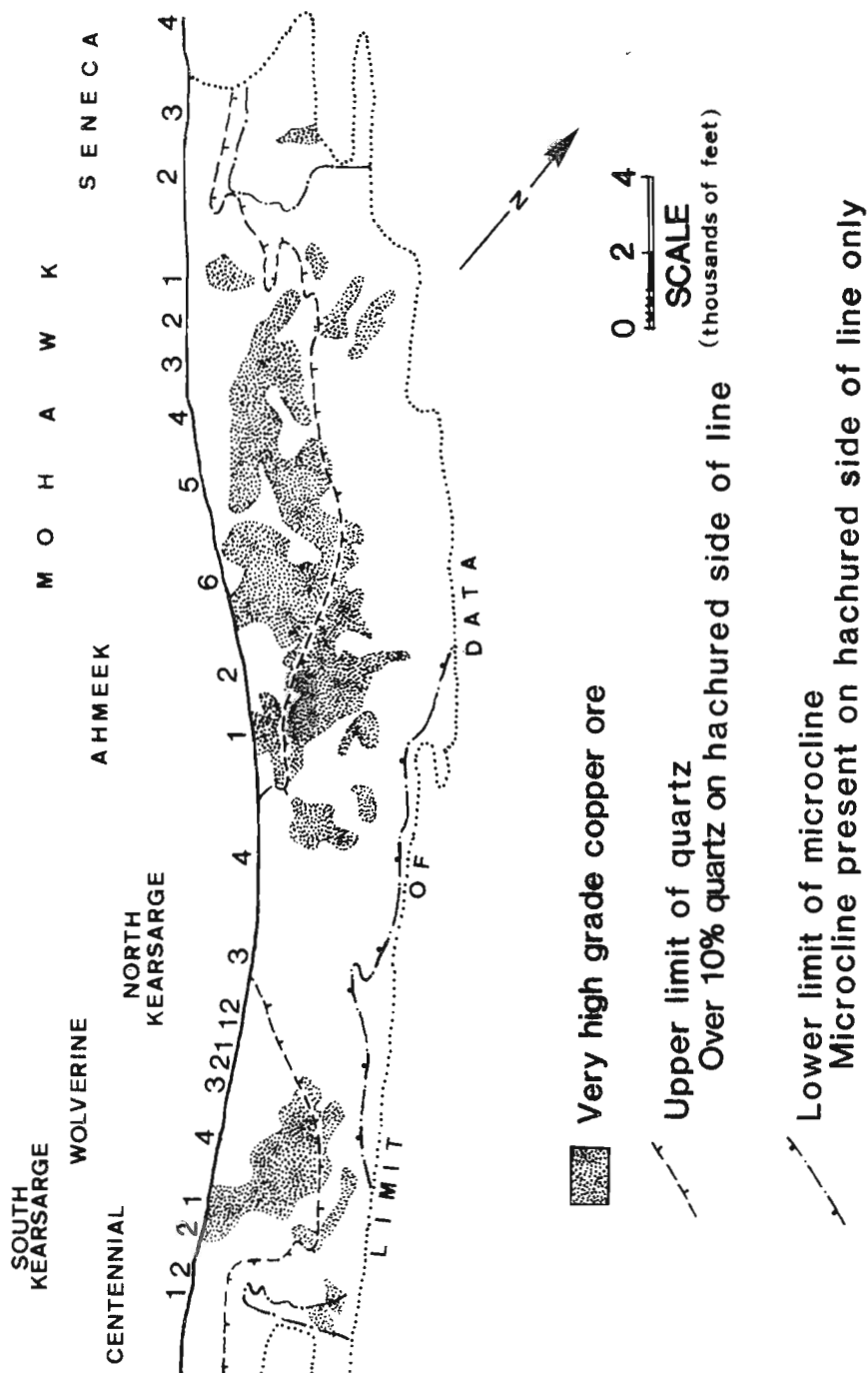


Figure 27: Distribution of quartz, microcline and high grade native copper ore in the Kearsarge amygdaloid (modified from Stoiber and Davidson, 1959). Calcite and epidote are present in all zones. The Kearsarge amygdaloid dips about 35 to 40 degrees to the northwest. Data from the incline are projected to a horizontal plane.

- 41.5 Continue on the same road and in the same direction as before (east), away from Kearsarge.
- 42.1 There is a dirt road junction to the right, stop here. We are now in the vicinity of Scales Creek, which is the type section of the Scales Creek flow. This is the same flow seen at Stop 1, about 14 miles to the south, in Houghton.

STOP 12. Scales Creek.

This stop gives one an opportunity to look at the Scales Creek flow, a regionally extensive basaltic flow. This is the same unit observed at Stop 1, and it has been traced for more than 150 Km along the Keweenaw. There are outcrops of the Scales Creek flow on both sides of the main road and along Scales Creek, just to the north and paralleling the road. The Scales Creek flow is characteristically ophitic. This flow was studied, from drill core northeast of here, by Scofield (1976). The Scales Creek flow has an amygdaloidal top and base and a massive interior. The massive interior of this flow is believed to be for the most part geochemically unaltered (Table 4). Mineralogically primary and secondary minerals are present. Modes estimated for the massive interior are plagioclase, 40 percent; pyroxene, 48 percent; olivine, 10 percent; and opaque oxides, 2 percent. Primary plagioclase, pyroxene, and opaque oxides can be found but olivine is pseudomorphically replaced by talc, serpentine, and/or chlorite. In the amygdaloidal flow top no primary minerals are present but all have been replaced by a suite of secondary alteration products. Plagioclase is now albite with some replacement by sericite, chlorite, and pumpellyite; clinopyroxene is replaced by chlorite; olivine is replaced by chlorite, epidote and pumpellyite, and opaque oxides are altered to hematite and sphene. Scofield (1976) has studied these changes in some detail.

- 42.1 Turn around and retrace route back to US-41.
- 42.7 Passing the Wolverine mine dumps, Stop 11.
- 42.9 Right turn on US-41 at Wolverine Market.
- 44.2 Entering the Village of Allouez. We have an excellent view of the southeast side of a prominent ridge. This ridge is held up by the Greenstone flow which is the thickest and volumetrically largest single flow within the Portage Lake Volcanics. It will be seen at Stop 14.
- 44.4 Left turn on a paved road called Bumbletown Road, just before a Standard gas station.
- 44.6 Stay on the paved road, bearing right.
- 44.75 STOP 13. Allouez Conglomerate and Bumbletown Hill (Fig. 28).

The description of this stop is modified only slightly from White (1971b).

The stop begins with a survey of the dumps of the Allouez conglomerate mine (1869-1892, 1300T Cu).

Table 4: Average composition of three samples from the massive part of the Scales Creek flow (from Scofield, 1976).

	Weight Percent
SiO_2	47.57
Al_2O_3	16.10
Fe_2O_3^*	12.54
MgO	7.67
CaO	10.00
Na_2O	2.24
K_2O	0.29
TiO_2	<u>1.43</u>
Total	97.84

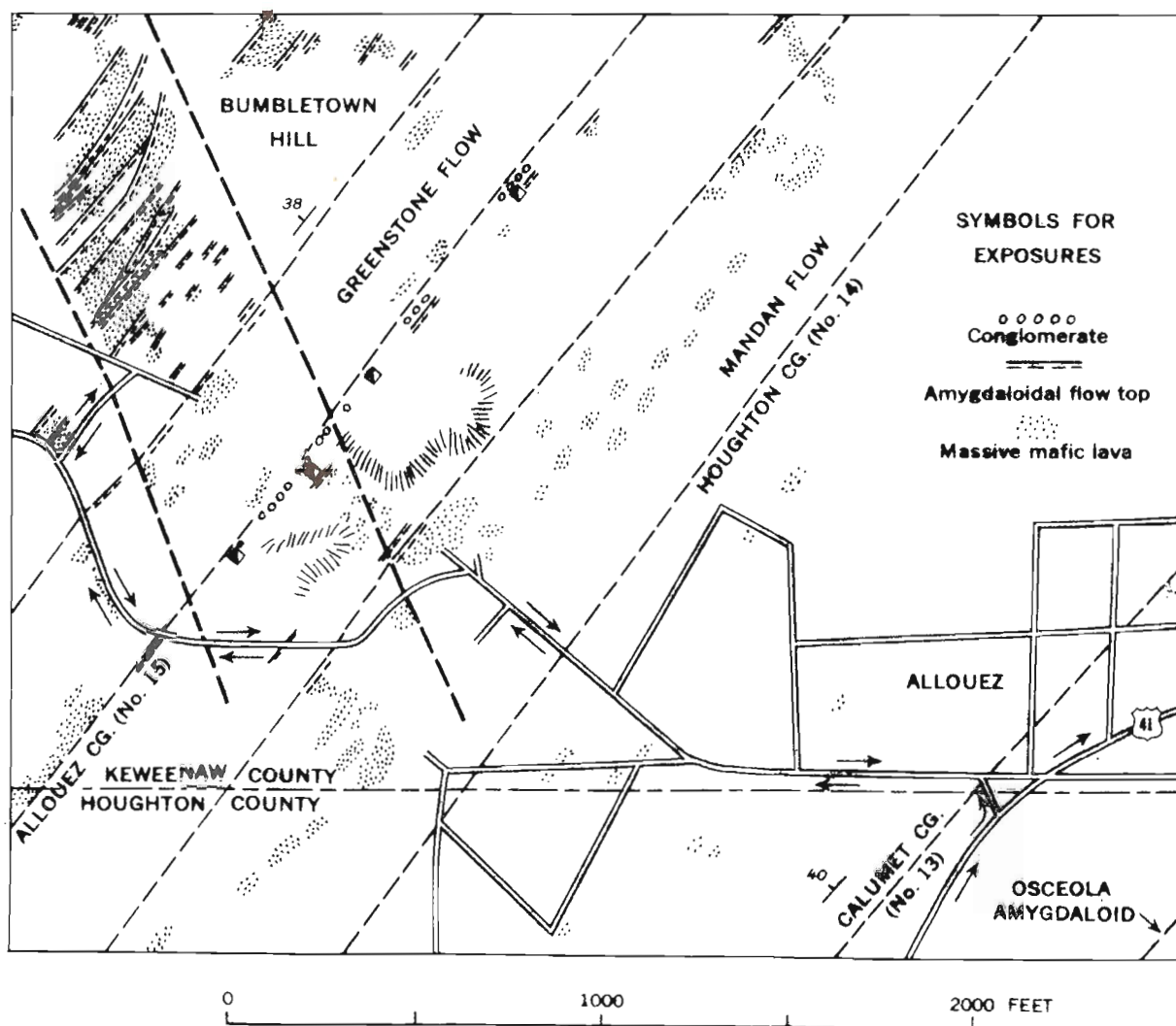


Figure 28: Outcrop map of the Allouez-Bumbltown Hill area (White, 1971b).

The lithology of the conglomerate is best studied in the dumps. The largest boulders in this conglomerate are about 2 feet in diameter, and the median size is about 3 inches. A pebble count of boulders more than 8 inches across gave the following results: mafic rock, mostly amygdaloidal, 16 percent; quartz porphyry, 36 percent; feldspar porphyry, 11 percent; granophyre, 37 percent. The greater heterogeneity of this assortment suggests a less restricted source terrane than the one that supplied the Kingston and Houghton Conglomerates in this area; the Kingston, in particular, is made up almost entirely of fragments of quartz porphyry. These dumps are well known to rockhounds as a chrysocolla locality. Thin black veinlets cutting the conglomerate are calcite full of chalcocite dust.

From the dump, it is a short walk to the top of the hill, which is an area of exceptionally good exposure and provides an opportunity to see several key units of the Portage Lake Lava Series. One has a unique view of both an area of intensive mining activity and of the general physiography of the Copper Range. From here, on a very clear day, one can see Isle Royale to the northwest. The Huron Mountains lie beyond Keweenaw Bay to the southeast.

Bumbletown Hill is on the southwest side of Allouez Gap, a saddle crossing the Copper Range, similar to, but much less pronounced than, the valley at Houghton-Hancock. At this gap, the strike of the lava flows swings, going northeast from about N35°E to N50°E. Fractures and minor faults associated with this bend are probably the reason for the gap.

To the northwest, the land slopes off very gradually toward Lake Superior, as it does through most of the length of the Copper Range. The southeast flank of the Copper Range has a steeper slope at the skyline, more or less along the line of the Keweenaw Fault. The low-lying plain between the fault and Keweenaw Bay to the southeast is underlain by flat-lying Jacobsville Sandstone.

Looking northeast along the strike of the Copper Range, one can see the cuesta form of the ridge upheld by the Greenstone Flow. At Bumbletown Hill, this flow is only 85 m thick; it thickens abruptly to more than 300 m at the near end of the cuesta ridge. To the right of the Greenstone ridge, the more distant hills are upheld by lavas much lower in the section; dips of bedding are steep, and cuesta forms are less pronounced.

The amygdaloidal top of the Kearsarge Flow has been the principal producer in this area. The line of shafts along its outcrop is a little more than a mile southeast of Bumbletown Hill, and the bottom levels are almost vertically below the surface trace of the Houghton Conglomerate (see outcrop map). This immediate area is unique in that five different and widely separated layers have been at least modest producers, suggesting a common plumbing system. Stratigraphically highest is the Allouez Conglomerate; dumps of the old Allouez mine (1869-1892, 13,000T copper) lie along the foot of the hill, 300 m southeast. A small headframe 1200 m N65°E of the hilltop is the Allouez No. 3 Shaft, which produced (1944-1964) about 17,000T of copper from the Houghton Conglomerate (No. 14) and 2000T copper from the Iroquois Amygdaloid, 170 m stratigraphically beneath; both were found by diamond drilling. The large headframe 6200 feet due

east of the hilltop serves the shaft of the Kingstone Mine; this deposit, discovered in 1962 also by diamond drilling, is in the Kingston Conglomerate (No. 12), 300 m stratigraphically above the Kearsarge Flow.

The outcrops on the top and upper slopes of Bumbletown Hill represent a series of andesite flows, some slightly porphyritic. The flows range up to 20 m in thickness. Unlike the basaltic flows found below the Houghton Conglomerate, these flows are not individually very extensive; the map shows two flows pinching out within this small area. As a group, the flows in the vicinity of the hilltop are stratigraphically equivalent and lithologically similar to those whose tops were mined at the Quincy Mine, just north of Hancock.

The Greenstone Flow is exposed in a series of outcrops 160-300 m south-east of the hilltop. Its thick amygdaloidal top is exposed at the end of a private roadway 200 m south-southeast of the hilltop. Columnar fine-grained basalt and ophitic basalt can be seen in exposures farther down the slope.

45.05 Retrace route back to US-41. Take a left turn on US-41 and cross into Keweenaw County from Houghton County.

45.9 Entering Ahmeek.

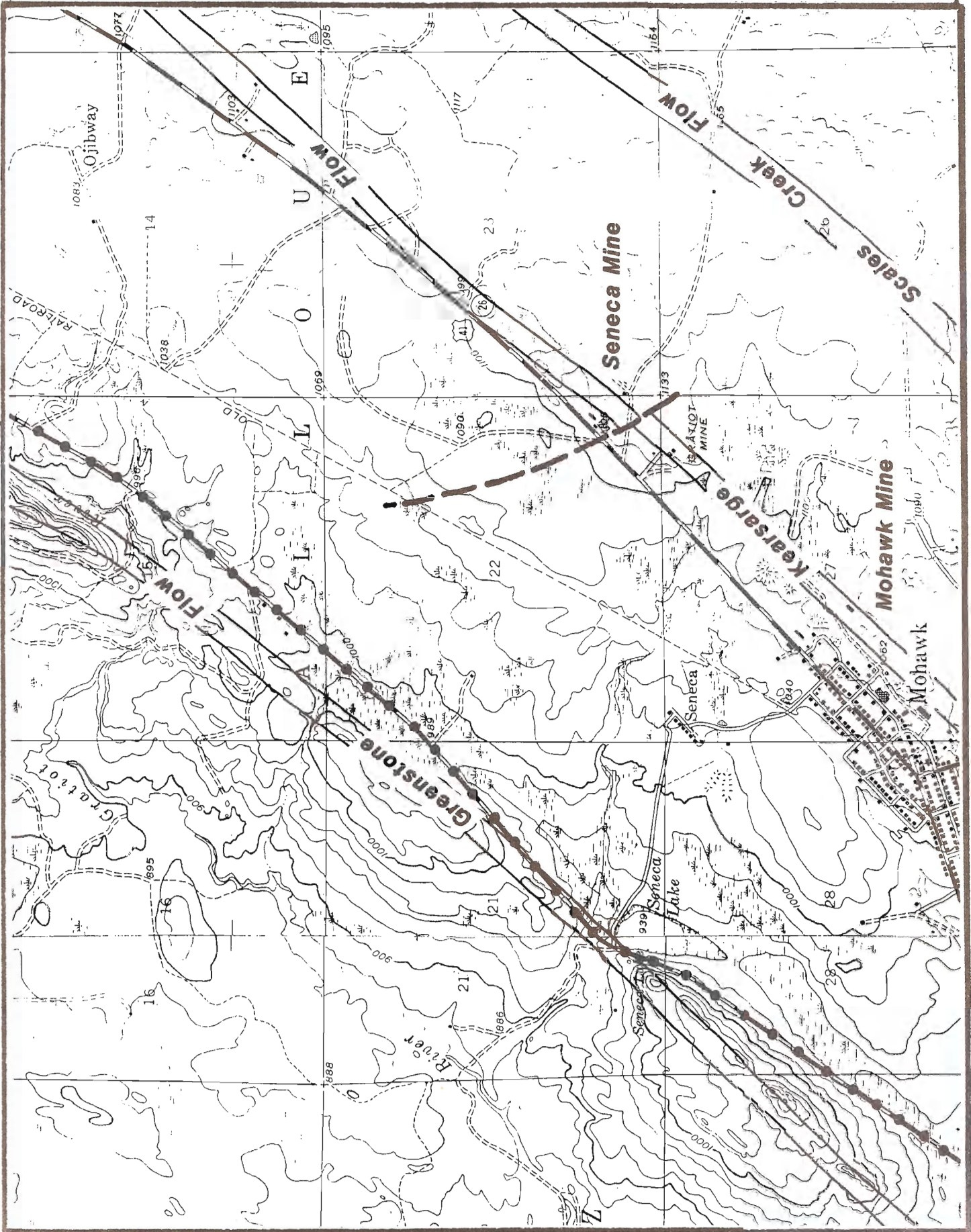
46.25 Junction to Cliff Drive. Turn left on Cliff Drive.

MAP 10

47.65 Passing Seneca Lake on the right hand side of the road. We are driving along strike, near the base of the Greenstone flow. Along the road are several small basalt outcrops mostly on the left side of the road.

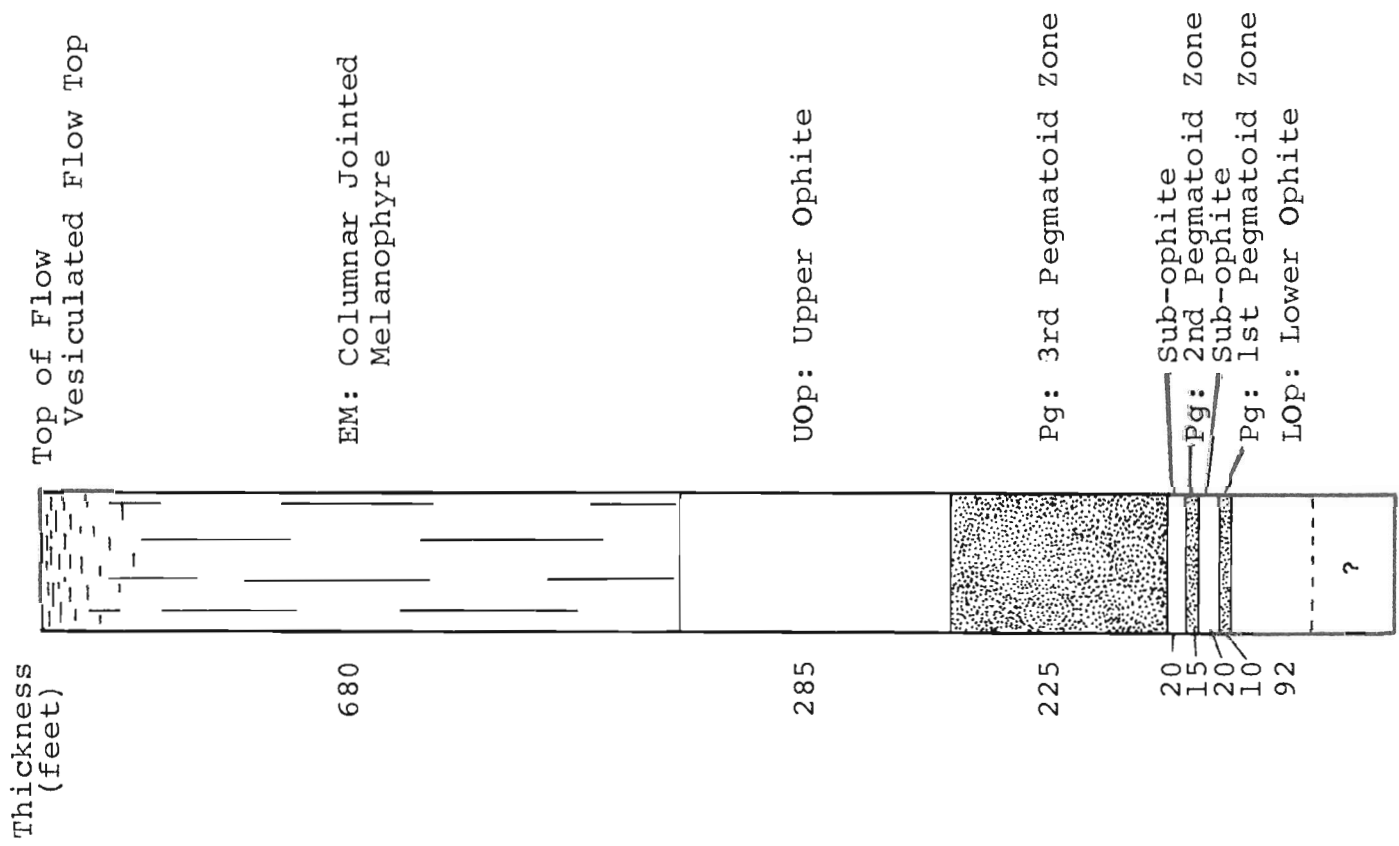
49.5 At this point the Greenstone Flow abruptly thickens to nearly 400 m. It dips northward at about 25° toward the Lake Superior Syncline. This lava flow can be traced along much of the Keweenaw and has been stratigraphically and geochemically correlated with a similar unit on Isle Royale, 90 Km away on the other side of the syncline (see Fig. 3a). Thus the areal extent of this great flow exceeds 5000 Km^2 and its volume is of the order of $800\text{--}1500 \text{ Km}^3$ according to White (1960) and Longo (1983). It rivals the composite Roza flow (Columbia R.) as the largest known lava flow on earth. The Greenstone typically shows spectacularly developed pegmatites, ophitic horizons and columnar jointed areas. A cross section of the Greenstone Flow at this locality and a map of the zone where the flow thickens rapidly are in Figure 29. The pegmatoid zone is unusually thick in the northern part of this map. The ophitic zones of the flow are relatively unaltered portions and Longo (1983) has shown that the composition of these zones are remarkably constant and demonstrated the great chemical similarity of the composition of the Isle Royale and Keweenaw ophitic exposures of the Greenstone Flow. The rapid thickening of the Greenstone here was suggested by White (pers. comm., 1982) to be caused by the separation of the upper part of the flow into multiple flow units, which appear to be separate flows. To the north the flow may be a continuous, single flow unit, while to the south it may have been made up of many flow units.

Map 11



Map 9

MAP 10



Vertical Scale: 1"=200'

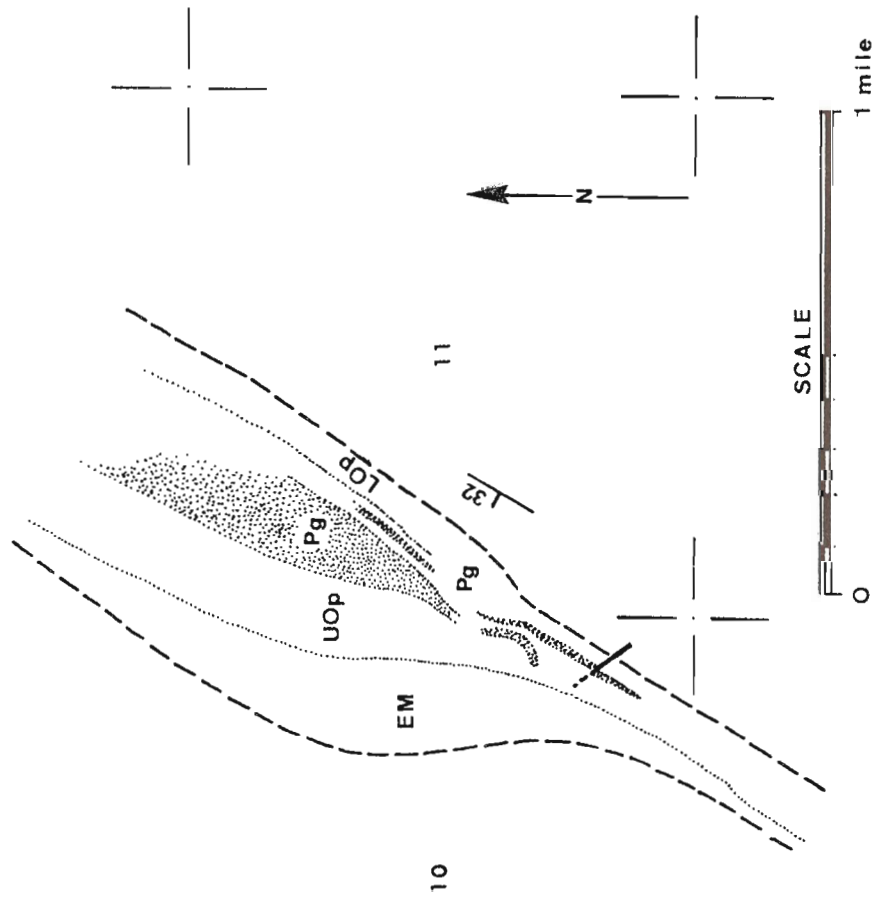


Figure 29: Map and cross section showing vertical zones within the Greenstone flow between Seneca and the Cliff Mine (from Longo, 1983).

MAP 10 and 11

50.0 Crossing the Gratiot River

MAP 11

50.6 We are now driving on the southeast side of a prominent ridge which is held up by the Greenstone Flow.

52.5 We are at the site of the Cliff Mine which was the first mine in the district. The dumps and old footings for the mine building are mainly on the left hand side of the road and the townsite, of which little remains, is on the right hand side of the road.

This is an optional stop where one can look at the Greenstone Flow and the Cliff Mine dumps. In this region the Greenstone Flow is mainly ophitic basalt and sometimes shows quite well developed coarse columnar jointing. The Cliff Mine worked the Cliff fissure. The mine operated discontinuously from 1845 to 1887. It produced a total of about 38 million lbs. of refined copper. The productive portion of the fissure lies under the Greenstone Flow. The Cliff fissure is nearly at right angles to the attitude of bedding and dips steeply to the east. Most of the mineralization was confined to the fissure although some amygdaloids were mineralized (Cliff Mine summarized from Butler and Burbank, 1929). Many large masses of native copper were mined from the Cliff Mine and larger masses weighed up to 100 tons. The large 100 ton mass had to be cut, by hand, into smaller pieces, it could not be blasted (Clarke, 1976). Among the fissures the Cliff was the most productive of silver. In addition to native copper and silver the following minerals are found at the Cliff Mine (not in order of abundance): calcite, epidote, chlorite, laumontite, prehnite, datolite, thomsonite, chlorastrolite, apophyllite, adularia, gypsum, sphalerite, galena, pyrite and surface oxidation minerals.

53.1 Junction of US-41/M-26, Turn left (north).

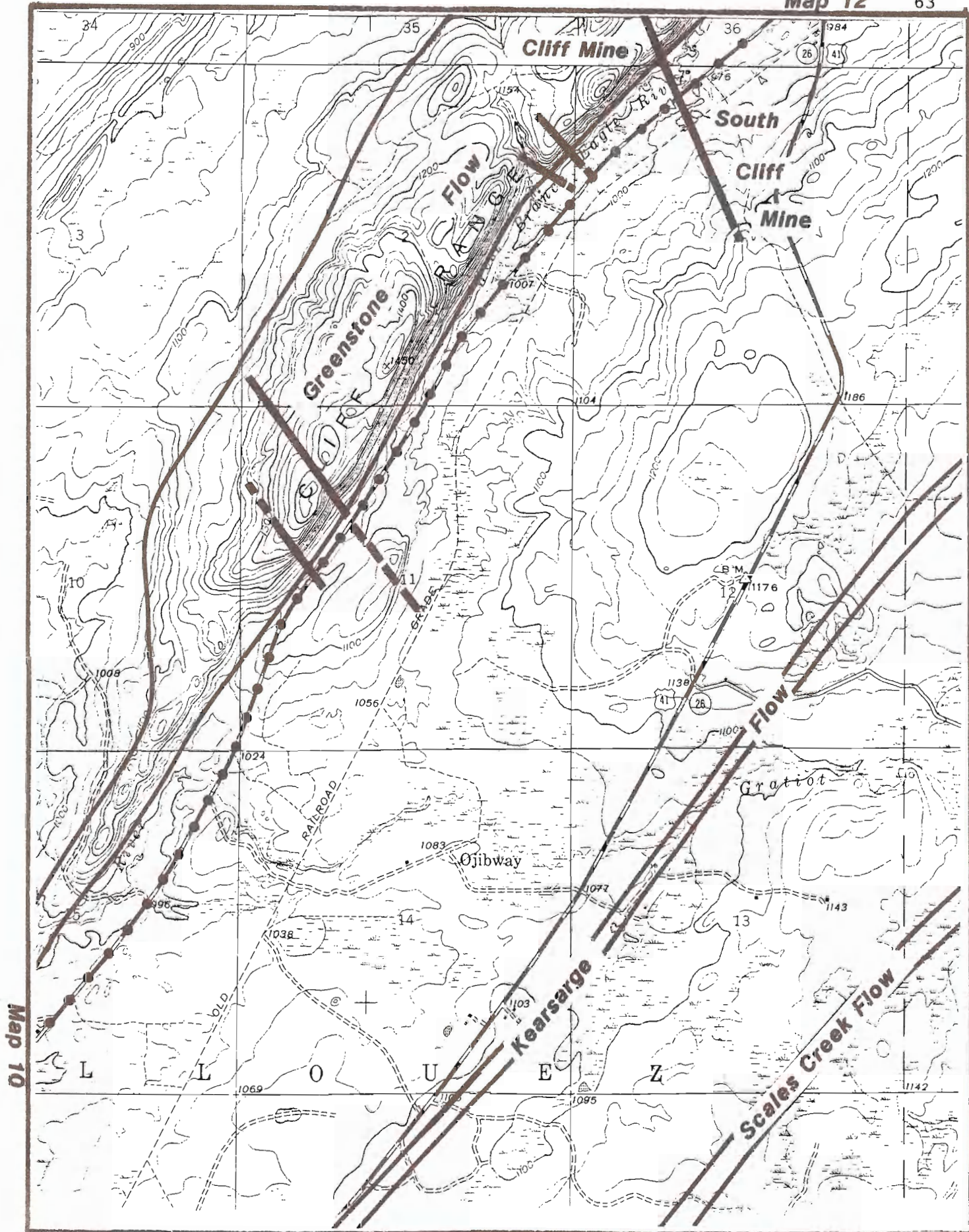
MAP 12

53.4 Entering Phoenix

54.5 Turn left on a dirt road just before (0.1 mile) the junction between US-41 and M-26. It is about 100 meters from the paved road to the base of the Phoenix Mine dump which is Stop 14.

STOP 14. Phoenix Mine and Greenstone Flow.

At this stop one can look at the Phoenix Mine dump and the lower ophite of the Greenstone Flow. The Phoenix Mine worked numerous veins below the Greenstone Flow. Like the Cliff Mine discussed at mileage 52.5, the Phoenix Mine was one of the earlier mines in the district and operated off and on from 1849 to 1917. It produced a total of about 17 million lbs. of refined copper (Butler and Burbank, 1929). The Phoenix Mine also worked the Ashbed amygdaloid where it is mineralized in the vicinity of vein copper occurrences. The Phoenix Mine dump is notable for halfbreeds (native copper plus native silver) and for spectacular secondary analcite. Other minerals reported in the Phoenix Mine area (Clarke, 1974a) include: pumpellyite, chlorite, natrolite, chlorastrolite, and apophyllite.



MAP 11

Lake Superior

Harbor

Conglomerate

DUNES

Stop 16

Copper

EAGLE RIVER

EAGLE RIVER CEM

Phoenix Ashbed

Stop 15

Workings

Phoenix Mine

Stop 14

Flow O

Ashbed

Greenstone

Phoenix

East

Branch

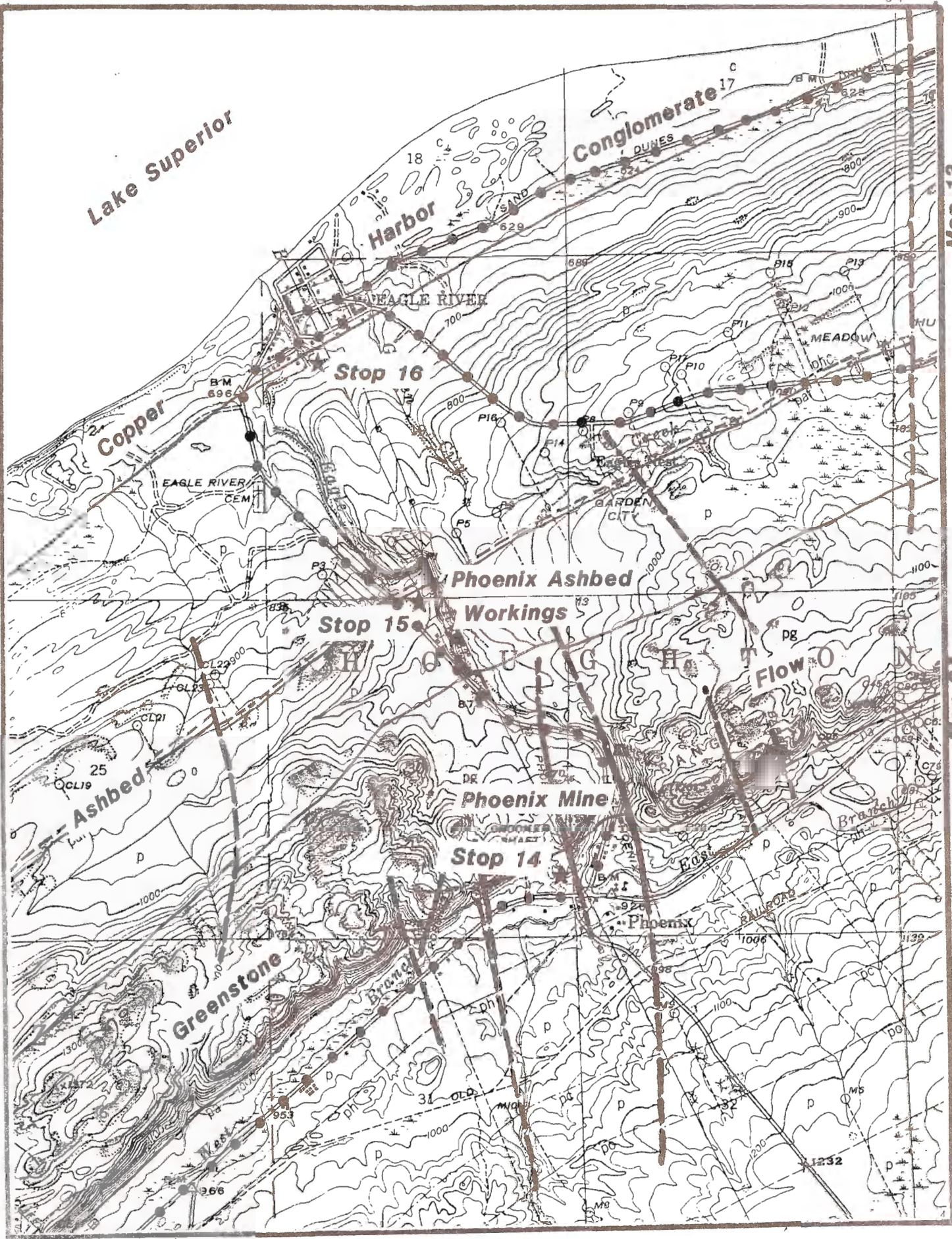
Map 11

MAP 12

Map 25

Map 13

Map 24



To look at the Greenstone Flow you must climb up over the dump and then pass one of the fissure zones just above the shaft. Proceed ahead and climb to the top of the hill where there is a spectacular exposure of the ophitic portion of the Greenstone Flow.

The ophitic zone is the lower ophitic shown in Figure 30. By following the exposures along the cliff the pegmatoid, subophitic and ophitic zones can all be observed. From the top of the Greenstone Ridge there is a view of the strike of the great flow and of the townsite of Phoenix, which had a population of 1,000 from 1877-1887.

The average composition of the unaltered Greenstone Flow, determined from study of Longo (1983) is:

	<u>wt. %</u>		<u>ppm</u>
SiO ₂	46.7	Ba	104
Al ₂ O ₃	15.1	Cr	214
FeO*	12.8	Cu	66
MgO	7.8	La	11
CaO	9.9	Mn	1680
Na ₂ O	2.1	Ni	186
K ₂ O	0.4	Rb	8
TiO ₂	1.2	Sc	28
P ₂ O ₅	0.14	Sn	6
		Sr	259
		V	195
		Y	14
		Zn	84
		Zr	92

The chemistry and petrology of differentiation of the Greenstone Flow was described in papers by Cornwall (1951a, 1951b).

- 54.6 Turn left on M-26 towards Eagle River. Cross Eagle River and begin to drive perpendicular to strike and cross the Greenstone Flow.
- 55.0 Outcrops of the Greenstone Flow to the left of the road. Exceptionally coarse ophitic texture, with individual pyroxenes up to 5 cm can be found on these exposures, which represent the slower cooling middle in the flow.
- 55.4 There is a pull-out on the right hand side of the road. This is an optional stop where the flows above the Greenstone Flow can be seen along Eagle River. Eagle River is about 25 m from the site of the road and in this locality there are many deep pools. You can follow the river downstream from here all the way to Eagle River looking at many flow contacts. This can't be done in the high water periods of the spring. At Stop 15, just up the road, one can also begin a traverse along Eagle River.
- 55.7 There is a poorly maintained dirt road pull-out on the right. In this locality Eagle River crosses the Ashbed flow. There is a very sharp bend in Eagle River north of the Ashbed flow. At this stop it is possible to begin a traverse along Eagle River either upstream or downstream.

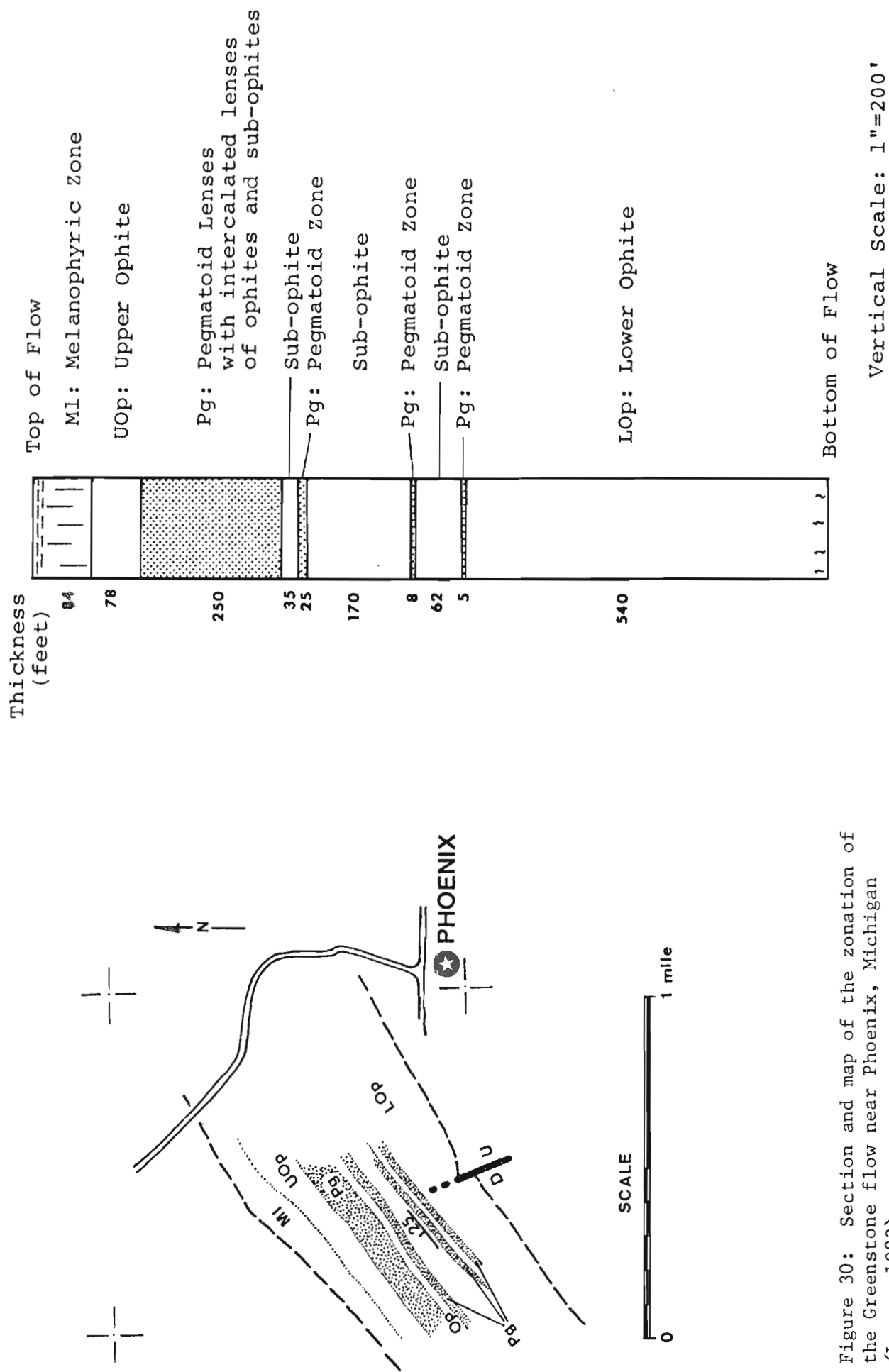


Figure 30: Section and map of the zonation of the Greenstone flow near Phoenix, Michigan (Longo, 1983).

STOP 15. Eagle River

Eagle River, Jacobs Creek and Owl Creek each make excellent stream traverses which are regularly mapped as an introductory exercise in the Michigan Tech field camp. At this point, approximately at the Ashbed amygdaloid, a traverse along the stream north to Eagle River allows excellent observations of the upper stratigraphy of the Portage Lake Volcanics.

The Ashbed is a very distinctive fragmental amygdaloid traced over a distance of almost 100 Km in outcrop and drill holes. It is the second flow top below the Hancock Conglomerate (Fig. 31 and Map 12). The amygdaloid is a jumble of amygdaloid fragments and interstitial brown, fine-grained detrital material. The secondary minerals filling the amygdaloid are calcite quartz, chlorite and minor epidote. Some vesicles contain minute flecks of Cu (White, 1971b). Exposures of the Ashbed are found both in roadcut and within the streambed. Small mines were found along this horizon in many places, from Atlantic Mine (near Stop 3) to Copper Falls (Stop 17).

The stream traverse to Eagle River traverses the section shown in Figure 31. Among the features seen in the traverse are: 1) excellent sections through individual lava flows showing amygdaloidal tops, and massive melaphyric, glomeroporphyritic or ophitic lower portions. 2) Interbedding of sediments with the lava flows, which becomes more prevalent up section. 3) The occurrences of several dikes which cut the section at low angles. These dikes make up a very small portion of the volume of the section and may be analogous to the dikes described in the Tertiary lavas of eastern Iceland by Walker (1975). If you decide to take this traverse, it's best to just resign yourself to wet feet and the traverse is not advisable in the spring because of high water.

The flows just above the Greenstone Flow are compositionally different from most of the Portage Lake Lavas. Although they are tholeiitic basalt like nearly all the PLV, these rocks are distinctly higher in K_2O and other incompatible elements (Fig. 32). Lower in the stratigraphy below the Gratiot flow another zone of K-enriched basalts occur. This caused Rose and Grimes (1979) to divide the PLV into three cycles of basaltic lavas each of which begins with relatively K-enriched basalts. The cycles may reflect different degrees of partial melting or fractionation. It is interesting to note that one of these cycles begins after emplacement of the Greenstone Flow.

- 55.9 There is an outcrop of amygdaloidal basalt on the left side of the road. Further off of the road is a rock dump from the Phoenix Ashbed workings (1855-1862, 1913-1917, 400T Cu).
- 56.6 Entering Eagle River. On the left is the road to Five Mile Point. The stone monument is a memorial to Douglass Houghton who was the first State Geologist of Michigan. He did pioneering geologic studies in the Keweenaw Peninsula. He drowned off Eagle River in 1845.
- 56.8 Cross Eagle River on the Eagle River Bridge. Park NE of the bridge.

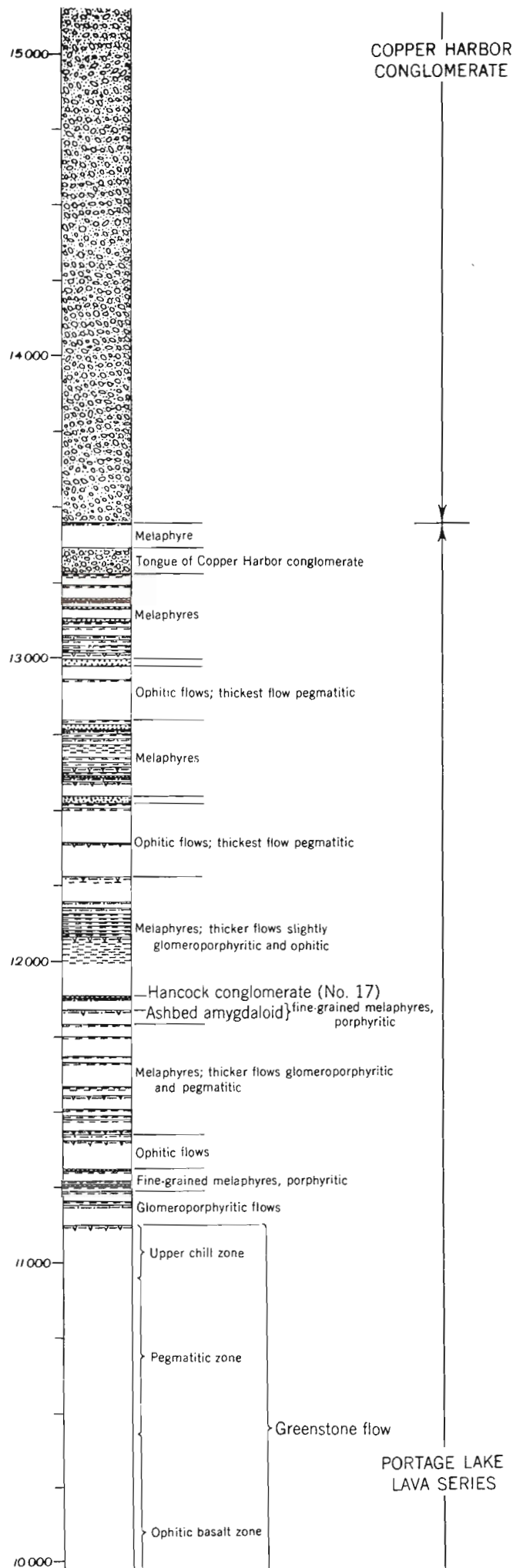


Figure 31: Stratigraphy of the Portage Lake Volcanics above the Greenstone flow in the vicinity of Eagle River and Phoenix, Michigan (from Cornwall and Wright, 1954).

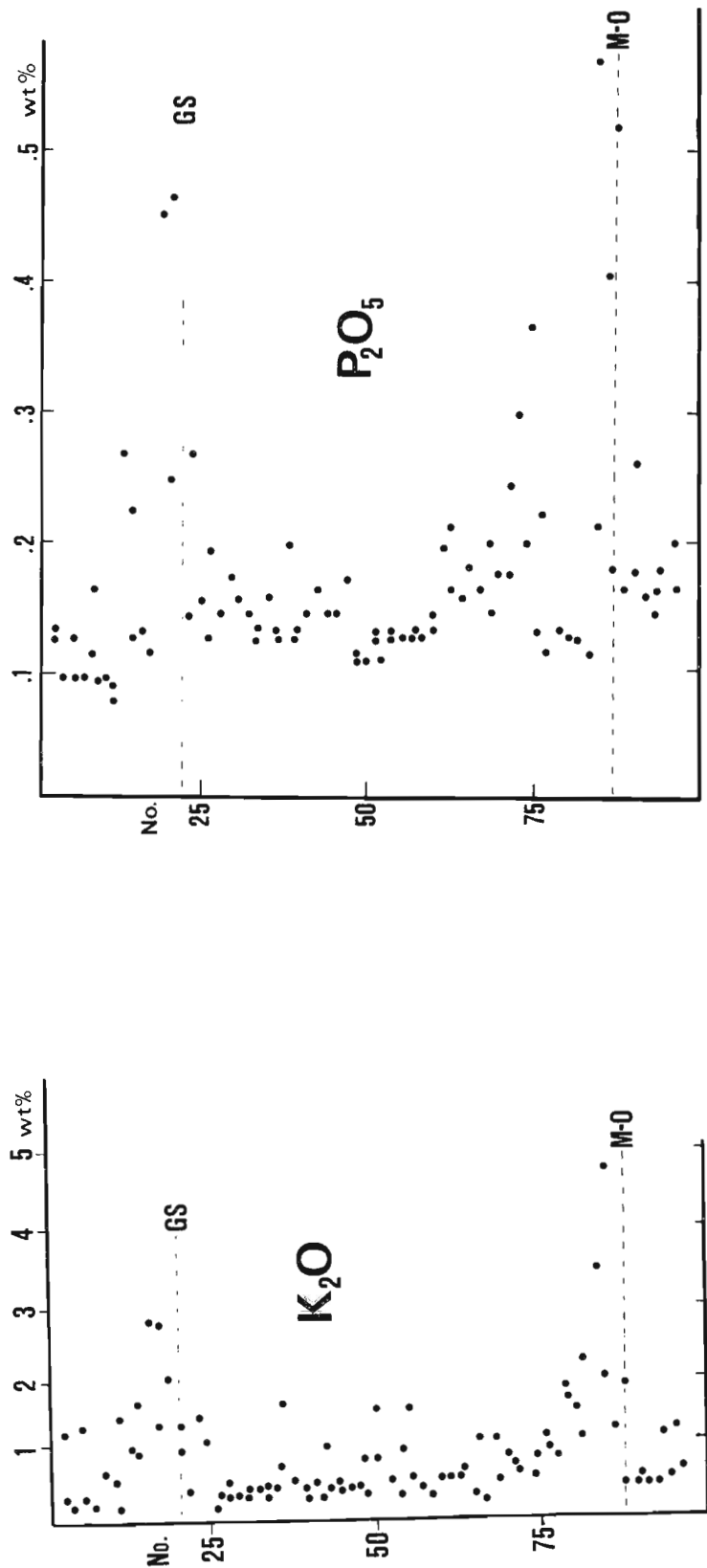


Figure 32: Plot of K_2O and P_2O_5 content of 106 individual PLV flows in stratigraphic order (1 = top) sampled in drill holes across the section in the vicinity of Delaware by W. S. White (pers. comm., 1976) and reported by Rose and Grimes, 1979. GS represents the Greenstone flow horizon, M-O represents the melaphyre-ophite line, a texturally traceable line in the PLV below the Gratiot flow in this area. The stratigraphic position is plotted by flow no. and is not to scale.

STOP 16. Eagle River Falls.

The falls occur at the contact between the top of the Portage Lake Volcanics and the base of the Copper Harbor Conglomerate. There are some spectacular potholes that have developed on this face. If the water is low, like it is sometimes in the summer, you can see ropy surfaces on flows at the top of the Portage Lake Volcanics. The contact dips about 30° NNW. The contact relationships suggest very little erosion between the flow and deposition of the basalt beds of the Copper Harbor Conglomerate. Under the bridge one can get a good view of the lithology of the lower part of the Copper Harbor Conglomerate. It consists of mostly rhyolite pebble conglomerates but includes many sandstone and even some shaley beds.

NOTE: There is an optional route to Eagle Harbor via Sand Dunes Drive given after the Garden City road log.

Eagle River to Eagle Harbor via Garden City Road

MAP 12

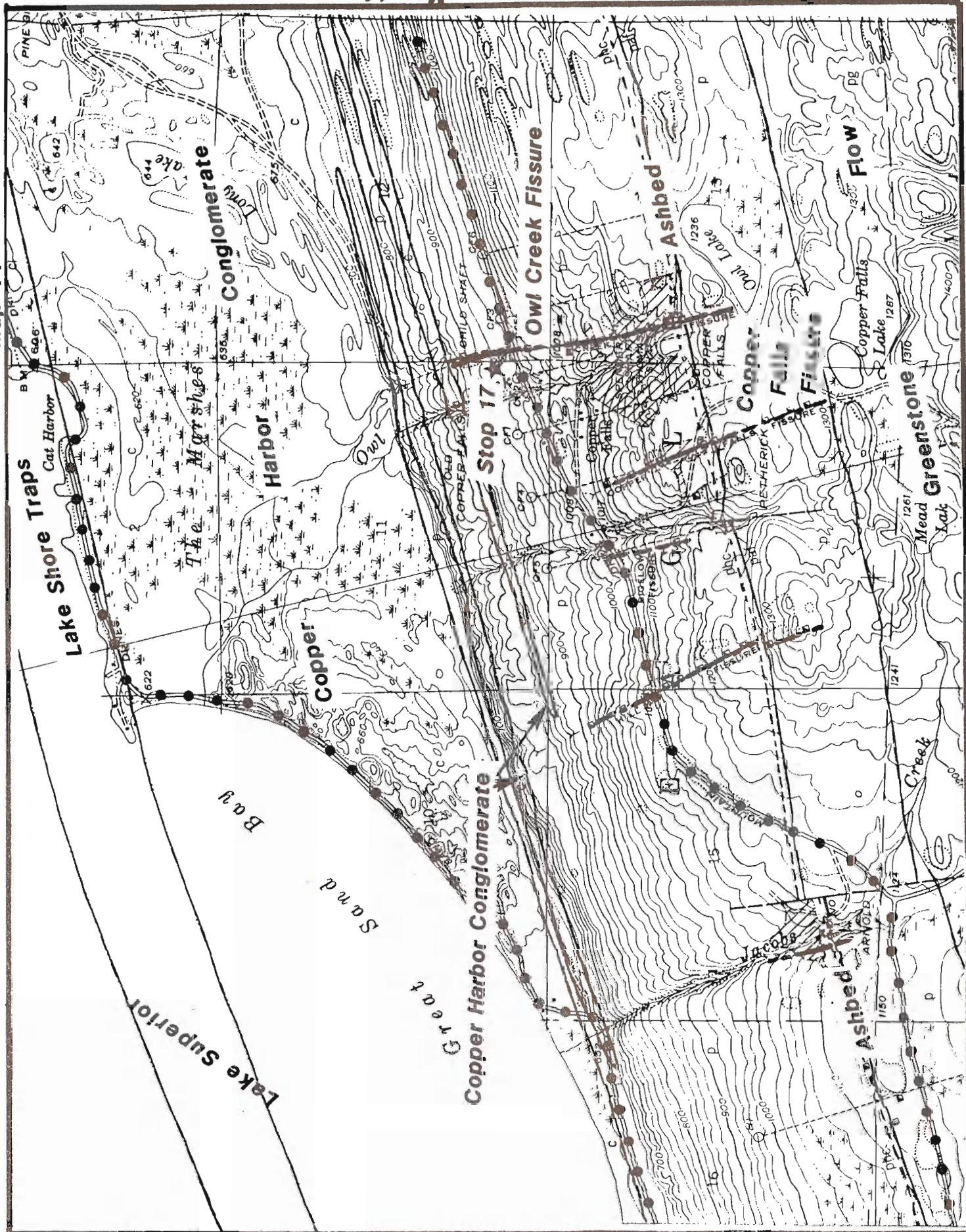
- 56.85 Go straight after crossing the bridge. M-26 goes to the left which is the optional route. Passing in front of the Keweenaw County Courthouse and offices.
- 57.1 Gitche Gumee Bible Camp, continue on paved road.
- 57.2 Pavement ends. This is the Garden City Road.

MAP 13

- 60.2 Junction with paved road. Turn left towards Eagle Harbor.
- 60.3 Cross Jacobs Creek.
- 60.5 Junction of a dirt road on the left. Continue ahead on paved road.

From this road, a short distance to the west, there is access into Jacobs Creek, at the site of the Arnold Mine, along the Ashbed amygdaloid. This is the end of a traverse one can make across the upper part of the Portage Lake Volcanics. It is recommended to begin the traverse at the lower end of Jacobs Creek where it crosses M-26 (Sand Dunes Drive optional route to Eagle Harbor). This is a very tough traverse with many steep and dangerous points within it. There are excellent exposures of many individual lava flows along Jacobs Creek. At the Arnold Mine, one of the nearly conformable massive dikes is exposed in the streambed. Geologic traverses made along Eagle River (Stop 16), Owl Creek (Stop 17 ahead), and Jacobs Creek allow one to look in detail at lateral variations in the upper part of the Portage Lake Volcanics.

Map 14



MAP 13

Map 12

- 61.2 On the left is a roadside park with a tower. From the top of this tower there is an excellent view of Isle Royale on a clear day. You can also see some of the ridge-valley topography due to the dipping lava flows and conglomerates in this part of the section.
- 61.9 Dirt road that slants to the right goes to the old townsite of Copper Falls. Copper Falls was settled in about 1846 and had a population of 500 in 1877. Today there are a handful of residents.
- 62.2 Cross Owl Creek.
- 62.3 Road to the right goes upstream to the dumps of the Copper Falls Mine which is part of Stop 17 described below.
- 62.4 Road to the left goes downhill. If you follow this road several hundred meters, you will reach the 30-mile stampsands which are the tailings dump from the Copper Falls mining operation. From this stampsand you can gain access to the bottom of Owl Creek and can begin a one-hour traverse upstream to the bridge along this road. If you continue upstream beyond the bridge, you will reach poor rock dumped along Owl Creek from the Copper Falls mining operation. By climbing out of the creek bed, to the east, one can reach a dirt road which will come out on the main road at 62.3

STOP 17. Owl Creek - Copper Falls Mine.

Owl Creek is another one of the streams that cut across the upper part of the Portage Lake Volcanics. The traverse begins downstream where the base of the Copper Harbor Conglomerate and top of the Portage Lake Volcanics interfinger. There are excellent exposures of interbedded conglomerate/sandstone and lava flows along the bed and sides of Owl Creek. There are several well exposed amygdaloidal flows.

The Copper Falls Mining Company worked several fissures and the Ashbed amygdaloid. The mine operated from 1847 to 1893. It produced about 18 million lbs. of refined copper from the Ashbed amygdaloid and about 9 million lbs. from fissures, mostly the Owl Creek fissure. Copper Falls was the only mine in the north end of the district above the Greenstone flow that paid dividends but was not a profitable venture (summarized from Butler and Burbank, 1929).

The Owl Creek vein starts near the base of the Copper Harbor Conglomerate and extends through the Portage Lake Volcanic Series, probably into the Greenstone flow. The vein was productive only in the vicinity of the Ashbed amygdaloid. The Ashbed flows are distinctly porphyritic. The amygdaloid is scoriaceous with a notable clastic component. In some localities pebbles and boulders of amygdaloid are set in a sandy matrix. The mineralization of the Ashbed amygdaloid is similar to that found in other amygdaloids in the Keweenaw Peninsula. At the Copper Falls Mine the more abundant minerals are: calcite, quartz, epidote, and pumpellyite. Datolite is abundant in the Ashbed near fissures. Datolite is abundant in fissures such as Owl Creek. Native copper was more abundant toward the top part of the deposit. Other minerals reported in the Copper Falls area include:

laumonitite, prehnite, native silver, adularia, analcite, apophyllite, faugasite, natrolite, stilbite (summarized from Butler and Burbank, 1929; Clarke, 1974b). The Copper Falls Mine is stratigraphically one highest in the Keweenaw native copper district and is near the top of the pumpellyite zone (see Figs. 4b and 9a in the Introduction).

MAP 14

63.75 Crossing Eliza Creek

63.85 There is a dirt road that goes off to the right. From this dirt road just a few hundred meters up hill you can begin a traverse upstream on Eliza Creek to get the exposures of the Portage Lake Lava flows of this region.

64.9 We are at Eagle Harbor where we join back up with M-26. Turn right on M-26.

Eagle River to Eagle Harbor via Sand Dunes Drive (M-26).

MAP 12

0 At Eagle River Bridge make a sharp left turn, follow M-26.

0.1 Sharp right turn.

MAP 13

3.05 Jacobs Creek Falls. From this point one can begin a traverse up Jacobs Creek that ends near the Arnold Mine on the Garden City Road (mileage 60.5). There are excellent exposures of the upper part of the Portage Lake Volcanics along Jacobs Creek. For those who are hardy, the stream offers virtually continuous exposures through thin pahoehoe flows, especially in the first several hundred meters. This is a steep and rough traverse, and should not be attempted in high water periods.

4.9 Great Sand Bay.

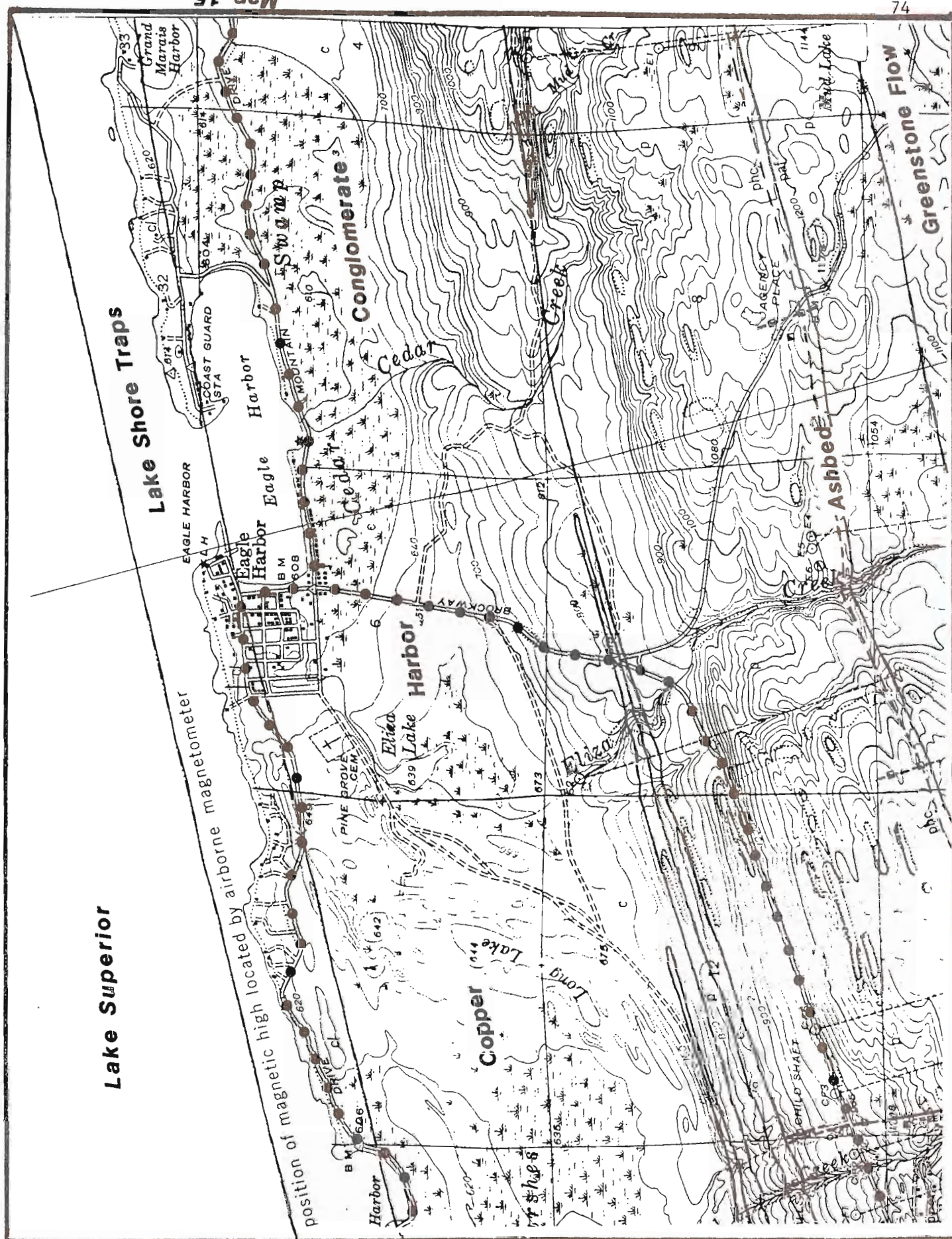
5.9 Cat Harbor. The Lake Shore Traps form the offshore ridge. The Lake Shore Traps are mafic lava flows interbedded with the Copper Harbor Conglomerate.

MAP 14

7.8 Right hand turn by the Eagle Harbor Store.

8.0 We are at the Junction of M-26 and Garden City Road Route. Stay on M-26.

Return to Main Road Log Mileage.

**Map 13**

Map 13

- 65.0 The harbor at Eagle Harbor is controlled by the occurrence of units which are called the Lake Shore Traps. These are basalt flows which are interbedded with conglomerates of the Copper Harbor Conglomerate and form typically resistant ridges. There are excellent exposures of the Lake Shore Traps that occur at the Eagle Harbor Marina and continuing along the shore through Grand Marais Harbor and into Agate Harbor and eastward through Copper Harbor. These are accessible by canoe or small boat from the Marina, but don't try it if the winds are on-shore.
- 65.75 Junction to the left to the Eagle Harbor Marina. Continue ahead on M-26.
- MAP 15
- 66.9 A view of Grand Marais Harbor. On the right hand side you can see the off-shore islands and ridges which are controlled by the occurrence of the Lake Shore Traps. We are driving along a conglomerate ridge.
- 67.5 Road passes along the shores of Lake Bailey on the right hand side of this conglomerate ridge. The ridges throughout the Copper Harbor Conglomerate tend to be held up by the conglomerates, the valleys are underlain by the more easily eroded sandy and shaley members within the conglomerate. On the opposite side of Lake Bailey (on the right) is Mount Lookout. The contact between the Copper Harbor Conglomerate and the Portage Lake Volcanics runs through the back side of Mt. Lookout.
- 67.65 On the left hand side of the road there are exposures of the sandstone members of the Copper Harbor Conglomerate.
- MAP 16
- 69.1 Crossing the Silver River there are excellent exposures of the Copper Harbor at this locality and along the left hand side of the road up Brockway Mountain. This is an optional stop to look at the Copper Harbor Conglomerate. At Eagle River Falls (Stop 16) one had the opportunity to look at the basal beds of the Copper Harbor Conglomerate. At this locality we are stratigraphically in the more central part of the formation, just below abundant interbeds of Lake Shore Traps. At an upcoming stop (20) one will get the opportunity to look at the upper part of the formation. The lithology of the sediments here can be compared to those of other stops. On the south side of the road at this stop a 3 Km trail leads to the summit of Mt. Lookout (Map 15), one of the most spectacular viewpoints in the Keweenaw. The summit is located on conglomerate, but very near the contact with the Portage Lake Volcanics. Allow at least 1½ hours.
- 69.2 Junction to Brockway Mountain Drive. We are going to come back to this point but we are going to first take a side trip to Esrey Park. Go to the left on M-26.
- 69.7 We are now at the shore of Lake Superior where there are shallow dipping lava flows of the Lake Shore Traps. The road follows the shore approximately parallel to the strike of the lava flows.
- 70.0 STOP 18. Esrey Park.

Lake Superior

Lake

Grand Marais Harbor

33

33

33

33

33

33

Map 14

MAP 15

A

Approximate position of magnetic

Traps

Shore

Grand Marais Harbor

33

33

33

33

33

33

Map 14

MAP 15

Bailey

Lake

Harbor

Copper

Conglomerate

Harbor

Copper

Map 15

Mt. Lookout

Ashbed

Greenstone Flow

76

Lake Superior

Agate Harbor Agate Point
 Esrey Park
 North Bay South Bay

ite position of magnetic high located by airbo. **Stop 18^{er}**

Lake Shore Traps

Conglomerate

Harbor

Copper

Lake Shore Traps

Conglomerate

Harbor

Copper

HARBOR

Ashbed

AGATE HARBOR EXPLORATION

Meadow

Map 15

MAP 16

Map 17

The rocks cropping out at Esrey Park are lava flows of the Lake Shore Traps. The Lake Shore Traps consist of a number of lava flows interstratified within the Copper Harbor Conglomerate. The Lake Shore Traps extend from the tip of the Keweenaw Peninsula west and south to just north of Hancock. They lie stratigraphically near the middle of the Copper Harbor Conglomerate. They consist dominantly of mafic flows similar to those of the Portage Lake Volcanics. Some intermediate compositions have also been reported. The Lake Shore Traps represent the waning stages of Keweenaw volcanism in the Keweenaw Peninsula. Several of these flows have been traced offshore by prominent magnetic anomalies.

The large outcrop between the parking lot and the lakeshore is the massive interior of a fine grained basaltic flow which strikes approximately parallel to the shore. The flow's amygdaloidal top can be observed along the lakeshore to the east. The metamorphic grade of these rocks is substantially lower than that of the Portage Lake Volcanic Series, i.e. within the zeolite zone. Note the "fresh" appearance of massive interior basalt (with olivine phenocrysts) and the low temperature amygdaloidal minerals (in order of decreasing abundance): calcite, chlorite, laumontite quartz, adularia and analcite.

- 70.1 Turn around and head back towards the junction of Brockway Mountain Drive.
- 70.9 Sharp left turn onto the Brockway Mountain Drive followed by some more exposures of the sandy conglomerate zones within the Copper Harbor Conglomerate. We will drive for several kilometers along a conglomerate ridge with many conglomerate exposures.

MAP 17

- 75.9 At the summit of Brockway Mountain we take a right turn a short distance to the observation site.

STOP 19. Brockway Mountain Viewpoint.

This high conglomerate ridge reaches an elevation of over 1300 feet and is one of the best known tourist stops in the whole Keweenaw. Excellent views of the ridge and valley topography of the northern shore of the Keweenaw can be had here, because the scrub vegetation allows a 360° panorama. The conglomerate here dips at about 20° to the north. To the west the Lake Shore Traps form prominent drowned ridges in the vicinity of Esrey Park. Lake Bailey (with the small island) and Lake Upsom occupy a topographically low valley of finer grained clastic sediments within the Copper Harbor Conglomerate. Just to the south of Lake Bailey the conglomerate ridge of Mt. Lookout can be seen, marking the contact between the Copper Harbor Conglomerate and the Portage Lake Volcanics. The inland lake almost directly south is Lake Medora, and just beyond the lake is a prominent ridge which marks the stratigraphic position of the Greenstone flow. In the distance, farther to the south across Lake Medora, Mount Bohemia (Stop 21) with a fire tower on top can be seen. To the southwest a distant ridge with white Air Force tracking buildings on it, marks Gratiot Mountain, which is underlain by andesitic dikes and small rhyolite bodies. To the east, Copper Harbor is visible and Lake Fanny Hooe (see Map 18) which occupies the same stratigraphic horizon as Lake Bailey. Beyond Copper Harbor to the east, East Ridge, a conglomerate ridge, is the prominent hill on the skyline. To the north, on the skyline 65 Km away is Isle Royale, easily visible on a clear day. The skyline of Isle



Conglomerate

Harbor 26

Copper 27

28

46 Lake

Traps

Shore

lake

CONGLOMERATE

2046H

Conner

Lake Shore Traps

CLIFF-A-R-B-O

Conglomerate

Harbor

Copper

Ashbeu

Royale is the Greenstone Ridge, underlain by the Greenstone flow, which is apparently a continuous unit all the way from one side of the syncline to the other. It may be the largest single lava flow on earth, with a volume of more than 1500 Km³ (Longo, 1983).

- 75.9 We turn to the right and follow the road straight ahead toward Copper Harbor now going downhill and continuing along the ridge with excellent views all the way down.

MAP 18

- 79.45 There is a pull-out on the right hand side of the road to give an excellent view of Copper Harbor and Lake Fanny Hooe. Copper Harbor is controlled by the occurrence of the Lake Shore Traps. The islands offshore including Porters Island are underlain by lava flows. From the Copper Harbor Marina, with a small boat you can have access to excellent exposures of the Lake Shore Traps along the edges of Copper Harbor. There are exposures of the Copper Harbor Conglomerate along the road descending into Copper Harbor.

- 80.5 Junction at M-26, turn left.

MAP 17

- 81.7 We come to the shore of the lake again at a place called the Devil's Washtub. If you stop here by the right hand side of the road and take a short walk along the conglomerate along the shore, you come to wave washed exposures of the conglomerate at the Devil's Washtub.

- 83.35 STOP 20. Dan's Point.

There is a small gift shop observation tower on the right hand side of the road. Walk just a few yards down to the shore of Lake Superior to look at the lithology of the Copper Harbor Conglomerate and the occurrence of stromatolite in well exposed and wave washed exposures.

Dan's Point consists of a lakeshore outcrop of Copper Harbor Conglomerate that is characteristic of the upper two-thirds of the formation (sometimes called the Outer Conglomerate). As a whole, the Copper Harbor Conglomerate is a red-brown, basin-ward thickening wedge of volcanogenic clastics which attains a maximum thickness of 1830 m (Daniels, 1982). A coarse conglomerate facies consisting of well-rounded, poorly sorted clasts of mafic to silicic volcanic rock fragments directly overlies and locally interfingers with the lavas of the Portage Lake Volcanics (Elmore, 1981). The conglomerate facies is generally clast-supported and contains a ratio of mafic to silicic intermediate clasts of about 2:1. The Copper Harbor Conglomerate fines both distally and upsection so that sandstone interbeds become more frequent in the upper two-thirds of the formation. Sandstones are predominantly subangular to angular lithic graywackes which exhibit current-ripples, festoon trough-cross beds, parting lineations and dessication features. Laminated crystalgal carbonate horizons are interbedded within the conglomeratic and sandstone facies in the upper two-thirds of the formation. Stromatolites occur as laterally-linked drapes over cobbles, as laterally-linked contorted beds in mudstone-siltstone lenses and as poorly developed mats in coarse sandstone (Elmore, 1981).

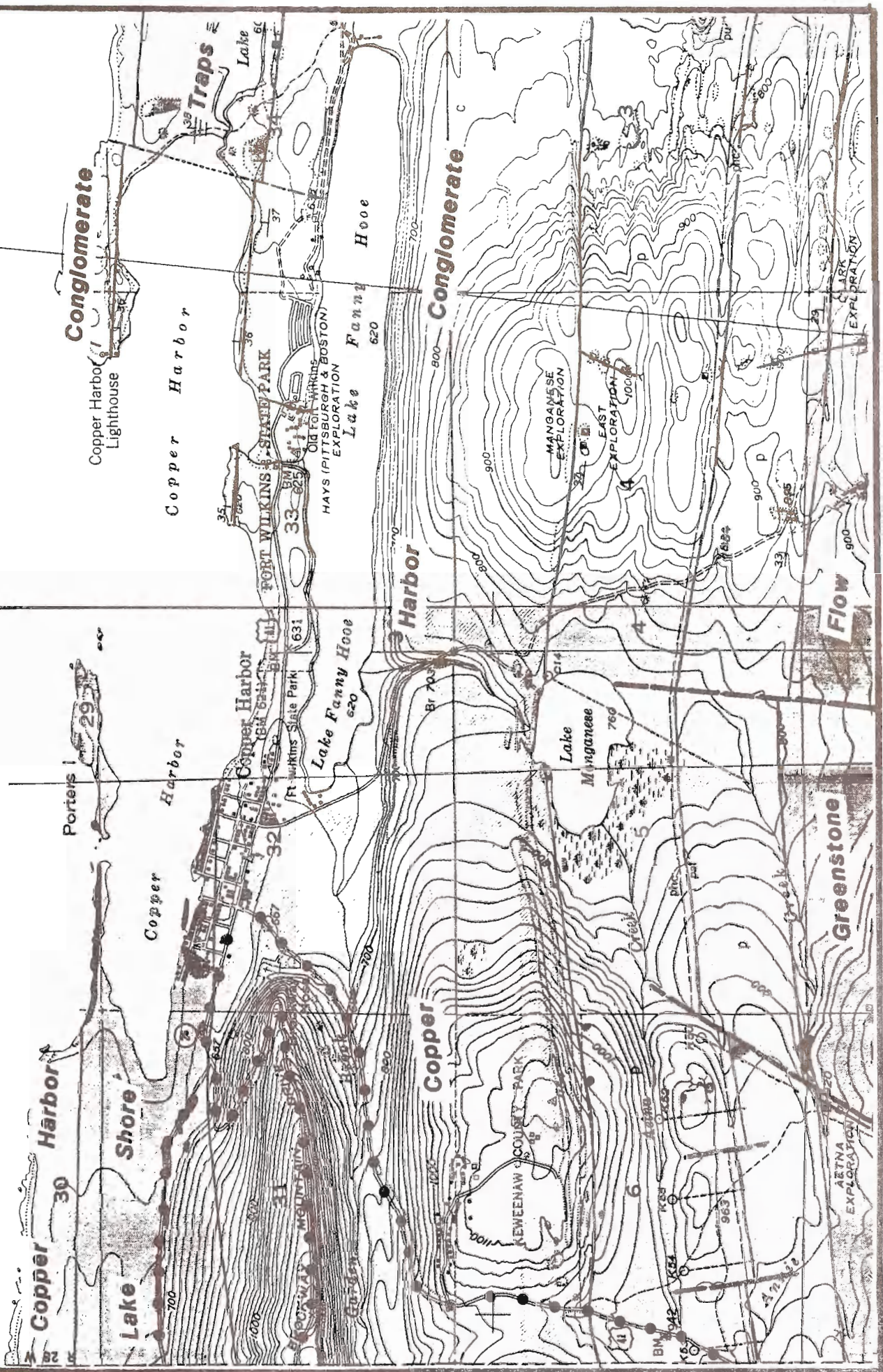
The depositional environment of the Copper Harbor Conglomerate has been interpreted as a prograding alluvial fan complex (Fig. 33) with proximal-to-distal braided stream and sheet flood facies on coalesced alluvial fans and sand flats (Elmore, 1981; Daniels, 1982). Isolated cryptoalgal carbonate and ooid lenses formed in shallow, medial fan lakes receiving very low rates of sediment influx (temporarily abandoned stream channels) (Elmore, 1981). Paleocurrent indicators suggest sediment transport was from the southeast to northwest indicating that a basin was located toward the center of the rift zone (Daniels, 1982).

The stratigraphic section of the "Outer Conglomerate" (that part of the Copper Harbor Conglomerate above the Lake Shore Traps) exposed at Dan's Point consists of about 80-90 ft. of interbedded conglomerates and sandstones (Fig. 34). Predominantly clast-supported conglomerate beds consist of rounded, cobble-to-small boulder-sized clasts with a matrix of coarse sand-sized sub-angular grains cemented with iron oxides. Conglomerate clasts are predominantly felsic volcanics (approx. 70%) with sub-ordinate basalt, pyroclastic, plutonic and metamorphic lithic fragments. Several silty-sandstone interbeds higher in the exposed section exhibit cross-bedding, current lineations, ripple marks, parting lineation and (reduction spots along bedding. In particular one should note the white stromatolite (genus *Colleria*) horizon draping cobbles about one-third of the way up the exposed section. Algal growth occurred during a period of depositional quiescence and was halted by an influx of silty material followed by renewed conglomerate deposition. Please do not remove stromatolite from the outcrop. Good specimens can be found in the pebble beach.

- 83.35 Turn around and go back toward Copper Harbor on M-26.
- MAP 18
- 86.65 Junction, again, to the Brockway Mountain road. To the left is the junction to the Copper Harbor Marina. Continue straight ahead on M-26 to Copper Harbor.
- 87.1 Junction between M-26 and US-41 in Copper Harbor. Turn right on US-41, south out of Copper Harbor.

Copper Harbor was suddenly a boom town in 1843, following the discovery of copper in the vicinity. Porter's Island was the site of the first government land office and in 1844 Fort Wilkins was built on the shores of Lake Fanny Hooe, to protect the miners from potentially hostile Indians. The lighthouse was built in 1866. Fort Wilkins is now a state park with camping facilities and a museum. Much exploration activity took place in the immediate vicinity of the fort and there are shafts and exploration pits all along the land between Lake Fanny Hooe and the Harbor, mostly from exploration in the 1843-46 period. In 1853 and for several decades thereafter mining activity took place south of the fort in a series of workings called the Clark Mine. The mineralization is of the fissure and amygdaloid type and consists of prehnite, epidote, analcite, quartz, laumontite, adularia, microcline, chlorite, datolite, calcite and several copper minerals including chalcocite, cuprite and tenorite as well as native copper. Agates are conspicuous in the amygdaloids here, and the area is well known for datolite collecting. One occurrence of manganese minerals in a fissure accounts for the name of Manganese Lake. The manganese minerals found here were pyrolusite, manganite, brannite and orientite. The Estivant Pine tract represents a part of the Clark Mine lands which were deeded to the C&H Company in 1942 and are now a nature preserve, containing some of the last virgin pine tracts in the Upper Peninsula.

Lake Superior



Map 17

MAP 18

Map 19

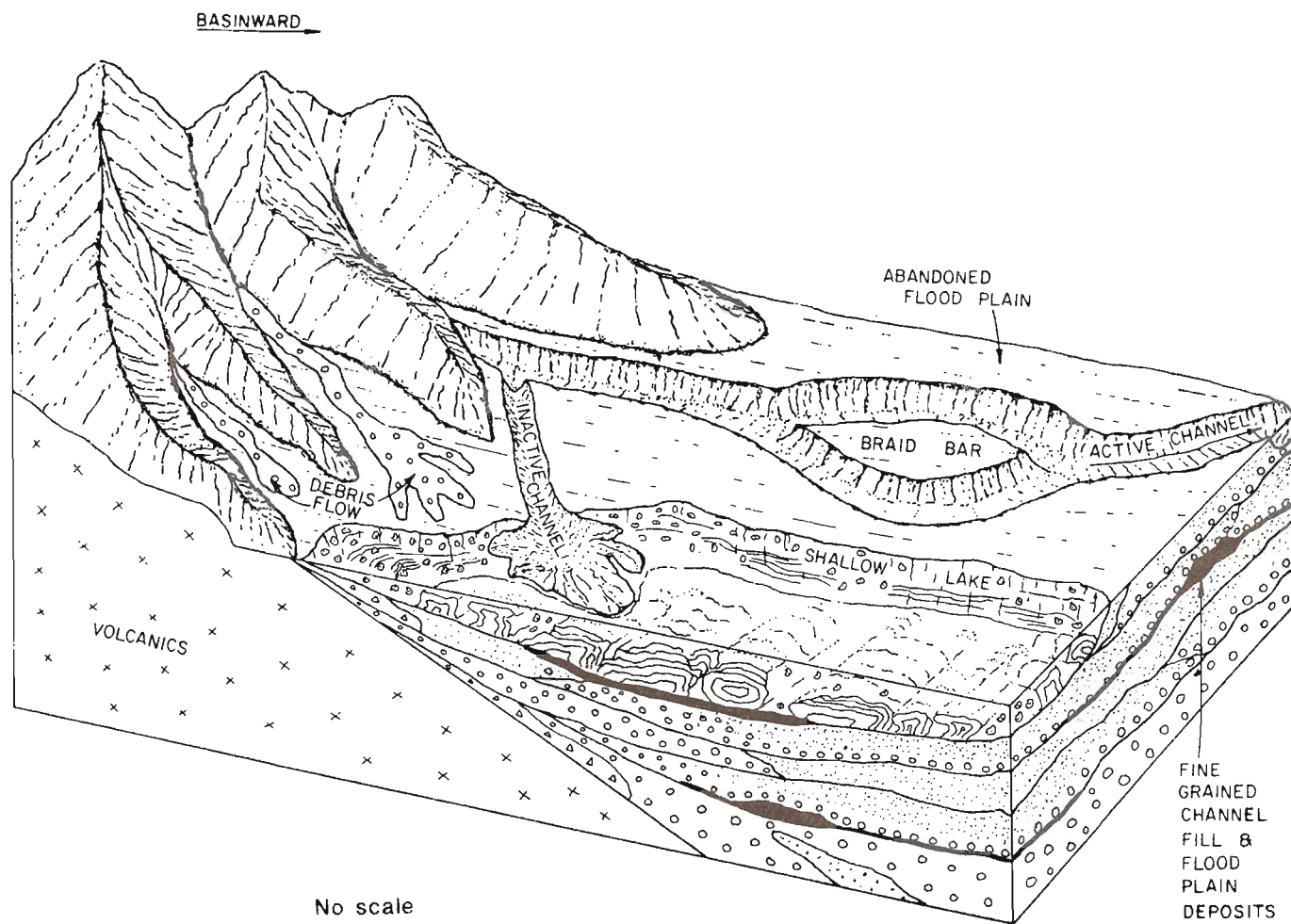
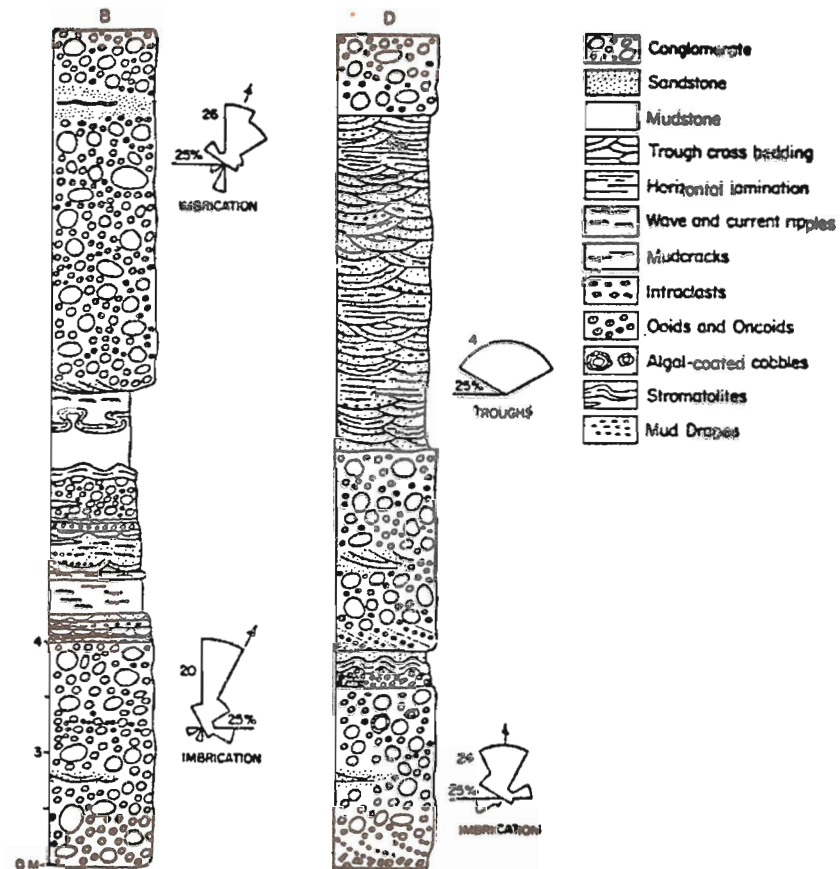
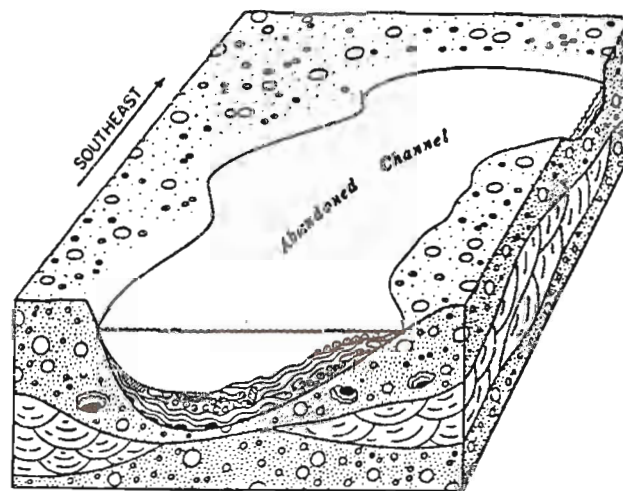


Figure 33. Schematic cartoon of depositional environment of the Copper Harbor Conglomerate showing coalescing alluvial fans, braided stream and flood plain deposits and shallow ephemeral lakes containing stromatolitic deposits (modified from Daniels, 1982).



A.



B.

Figure 34: A. Measured sections from Horseshoe Bay (B) and Dan's Point (D) with current direction rose diagrams. B. Schematic cartoon of the depositional environment which fostered growth of stromatolites in temporarily abandoned medial-fan stream channels (from Elmore, 1981).

Keweenaw Point, Horseshoe Harbor, East Bluff and other points of interest can be reached by taking an unmarked dirt road which goes eastward from the end of US-41. This road is rough and poorly maintained and may be followed around to Mandan. Horseshoe Harbor has excellent exposures of the Copper Harbor Conglomerate (Fig. 34).

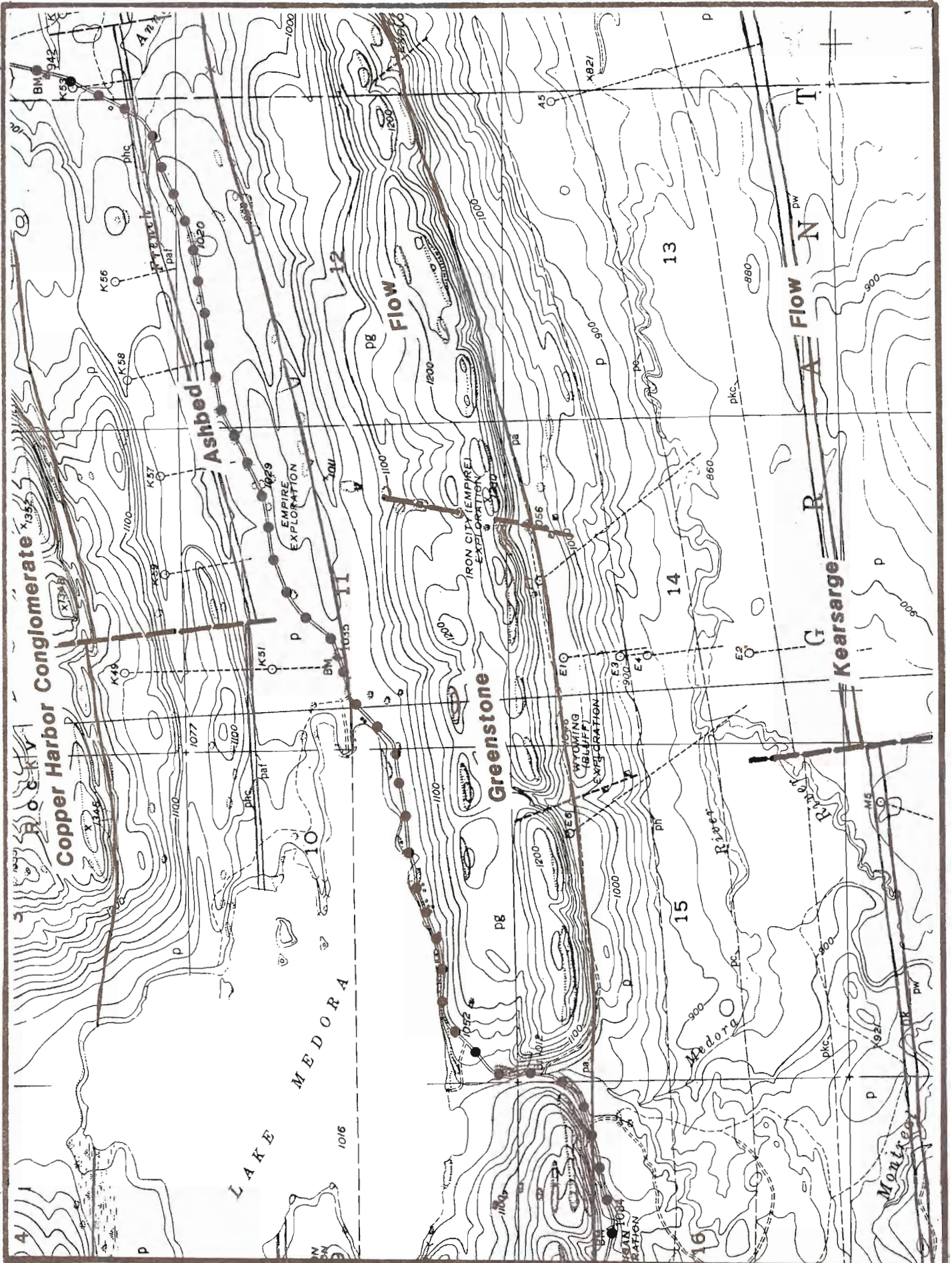
- 88.2 Nice exposures of the Copper Harbor Conglomerate to the left of the road as we are going up the hill.
- MAP 19
91.45 Lake Medora on the right hand side of the road.
- MAP 20
94.3 Junction to the left to Mandan. Mandan now is only a few houses, it had 300 residents in 1910. Continue ahead on US-41.
- 94.55 Road to the left. This is the entrance to the outer portion of the Keweenaw Peninsula, all on poorly maintained dirt roads. To visit Mount Houghton and Keweenaw point, you may exit here.
- MAP 21
97.3 Junction of the road to Lac La Belle. Turn left and continue to Stop 21 at Mt. Bohemia. If you wish to skip this stop, you may jump ahead to mileage 105.45.
- MAP 20
101.4 On the left hand side of the road is a large outcrop of amygdaloidal basalt of the Portage Lake Volcanics. These exposures are flows in the lower part of the formation below the Scales Creek flow (see Fig. 4 and in the Introduction).
- 101.6 Dirt road turning off the main road to the left. This is STOP 21 at Mt. Bohemia. It is about one half mile walk up this road to the summit of Mt. Bohemia; this is a four-wheel drive vehicle road.

STOP 21. Mt. Bohemia.

An intrusive body of diorite and granophyre crops out on the south slope of Mt. Bohemia. The majority of the intrusive body is a massive, medium-grained, miarolitic diorite. The major constituents of the diorite, are oligoclase and hornblende with lesser amounts of orthoclase, magnetite, uranitized augite, apatite, sphene, quartz, sericite, epidote, chlorite, and calcite. The latter are alteration products or are introduced secondary minerals. The central core is a fine- to coarse-grained, miarolitic granophyre. The major constituents of the granophyre are albite, quartz and granophyric intergrowths of quartz and feldspar with lesser amounts of orthoclase, sericite, hornblende, apatite, sphene, magnetite and chlorite. Miarolitic cavities are lined with quartz, albite, calcite, chalcopryrite, and chalcocite (summarized from Cornwall, 1954). The Mt. Bohemia intrusive body yielded a Rb-Sr age of $1,130 \pm 35$ m.y. (Chauduri and Faure, 1968).

The diorite and granophyre at Mt. Bohemia intrude basaltic lava flows of the lower part of the Portage Lake Volcanics. The basalts are slightly metamorphosed at the contact. The intrusive body is cut by the Lac La Belle fissure which trends north-northwest. This fissure is mineralized with copper sulfides, mostly chalcopryrite and bornite and in gangue of calcite, chlorite, and quartz (summarized from Juilland, 1965).

Map 18



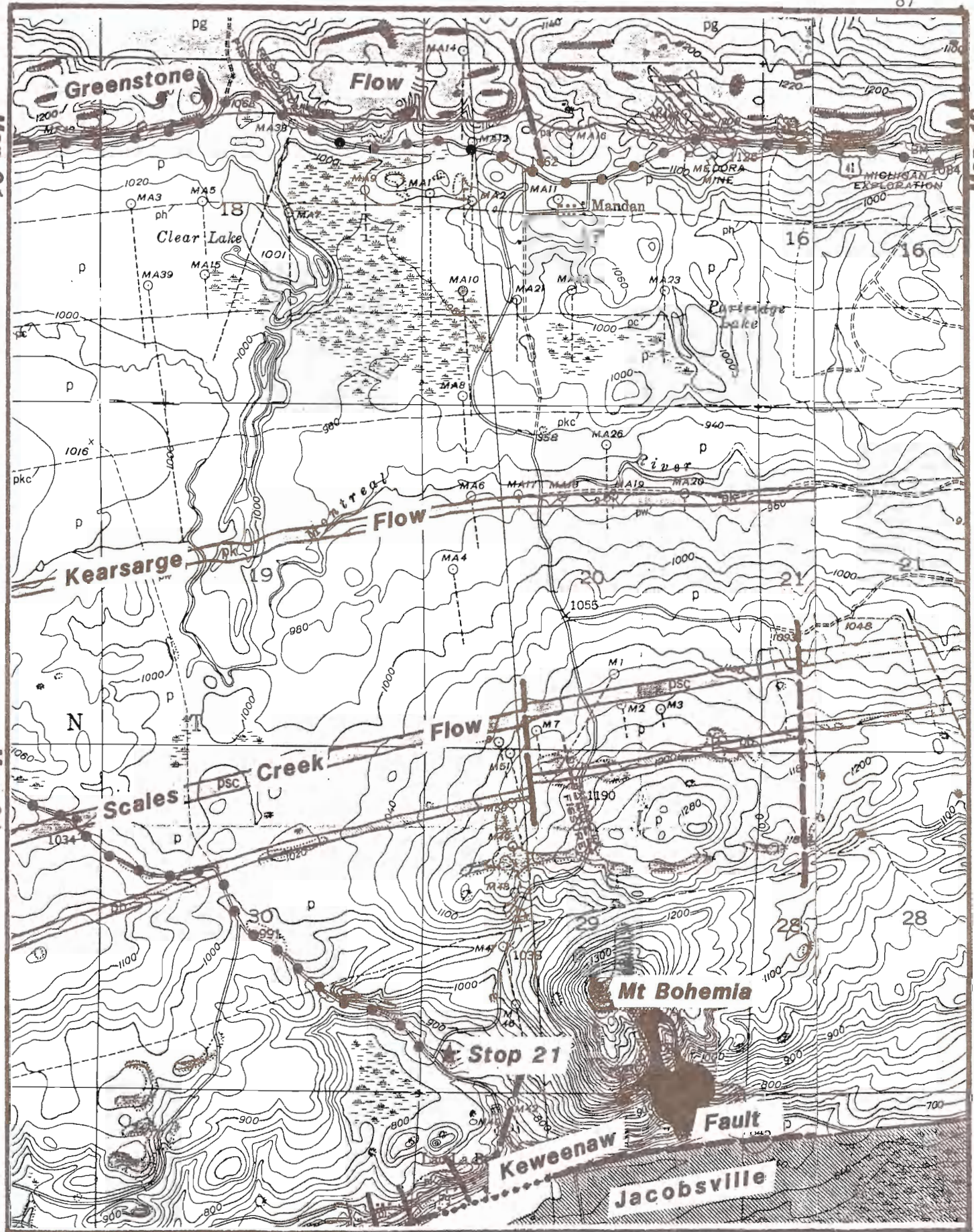
MAP 19

Map 20

Map 21

Map 19

Map 21



MAP 20



MAP 21

Map 23

Map 20

Andesitic dikes are found in the vicinity of Mt. Bohemia (Fig. 35a). They average about 5 m in thickness. The dikes intrude flows of the Portage Lake Volcanics, two flow tops are shown in Figure 35a as alpha and beta. The dikes and amygdaloidal flow tops carry copper sulfides. Copper sulfides in other parts of the district are found typically as fracture fillings. Native copper is typical of amygdaloids. A variety of secondary and opaque minerals are found in the dikes and flow tops (Fig. 35). The paragenetic sequence is consistent with that for the other deposits in the district (compare Fig. 35c and Fig. 9b in the Introduction). Copper sulfides are paragenetically late. The copper and sulfur in this occurrence is believed to be of direct magmatic origin related to the magma source that produced the andesite dikes and Mt. Bohemia intrusive body. The chronologic sequence is: emplacement of flows, subconcordant faulting and fracturing, dike emplacement, renewed movement along subconcordant breaks, regional low-grade metamorphic/hydrothermal alteration, minor folding and faulting, and sulfide mineralization (summarized from Robertson, 1975).

The road up to the summit of Mt. Bohemia crosses flows of the Portage Lake Volcanics. The diorite and granophyre intrusive complex crops out to the southeast of the summit. Intrusive stocks are not common in the Keweenaw Peninsula. Most of these occur in the lower part of the Portage Lake Volcanics and are rhyolitic in composition. Mt. Bohemia is the only occurrence of a diorite stock in the Keweenaw Peninsula.

OPTIONAL SIDE TRIP TO Lac La Belle

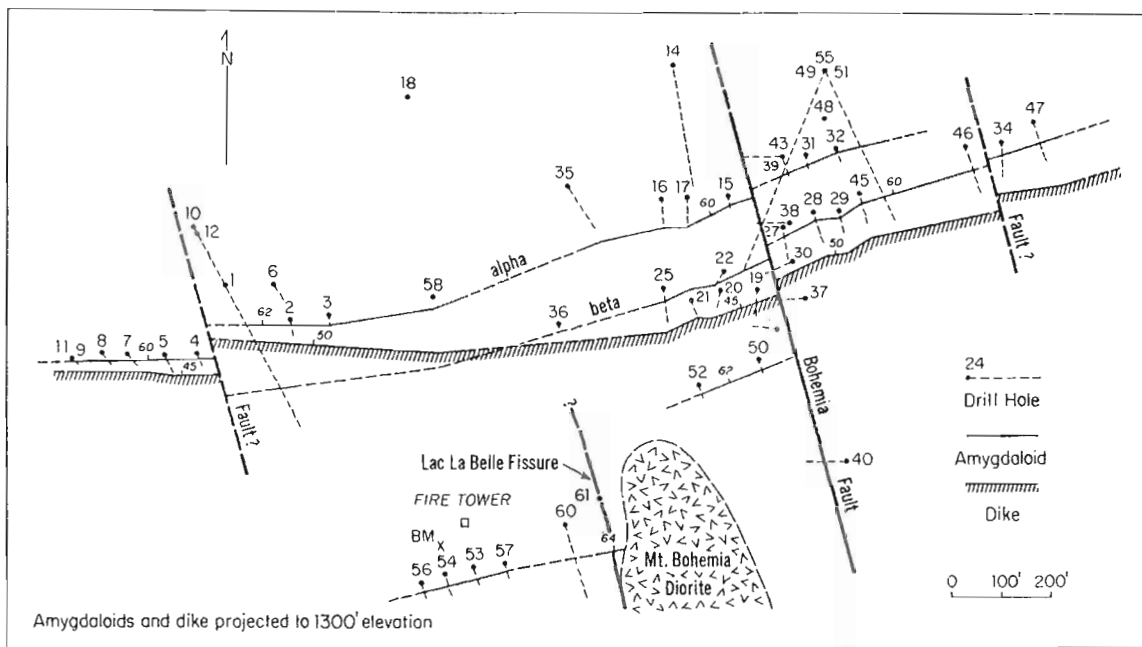
Discussion of complex relationships along the Keweenaw Fault and the Keweenawan rhyolite bodies.

- 0 At turnoff to Mt. Bohemia. Go straight ahead (south) towards Lac La Belle down hill.
- 0.4 Junction of roads to left and right at Lac La Belle.

MAP 21

To Bete Grise turn left. (See Map 22)

Bete Grise is located on the shore of Keweenaw Bay on the Keweenaw Fault. Along the shoreline east of the point where the road reaches the shore are several exposures of the Keweenaw Fault which crosses on and off shore several times. These may be visited in canoe or small boat. Also to the east are several of the rhyolite bodies which are chiefly found in the lower part of the Portage Lake Volcanics. Three tenths of a mile north of Bete Grise, four-wheel drive road continues east of the paved road to Smith's Fisheries. The road intersects the Bare Hill Rhyolite body, a shallow intrusive. Beyond the end of the road at Smith's Fisheries a trail continues eastward along the shore to the mouth of the Montreal River. From here one may traverse up river to several falls over fine outcrops of basaltic flows or continue along the shore to the Fish Cove Rhyolite, a compositionally zoned shallow intrusive (Bornhorst, 1975). Inland and not far from Bete Grise is the Mt. Houghton Rhyolite. This is an extrusive rhyolite dome



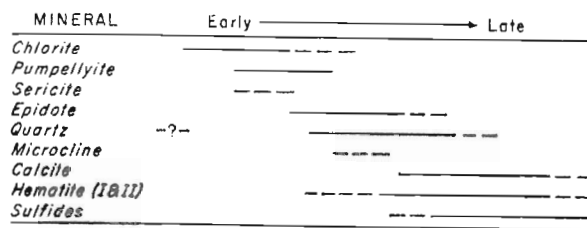
A. General geology and drill hole locations in the Mount Bohemia area (modified from a preliminary Calumet and Hecla Mining Company map).

MINERAL	Secondary minerals in dike matrix	Vesicle- fillings	Fracture- fillings
<i>Chlorite</i>	●	●	○
<i>Epidote</i>	●	●	●
<i>Quartz</i>	○	○	●
<i>Calcite</i>	○	○	●
<i>Sericite</i>	○	—	—
<i>Pumpellyite</i>	○	●	—
<i>Microcline</i>	—	—	○
<i>Hematite</i>	●	○	●
<i>Pyrite</i>	●	●	●
<i>Copper sulfides</i>	○	●	●
<i>Native Copper</i>	—	○	○

● Common ● Minor ○ Rare — Absent

B.

Nonpyrogenic Minerals in the Dikes



C.

Paragenetic sequence of secondary minerals in the dikes.

MINERAL	Pyrogenic	Deuteric	Hydrothermal	Supergene
<i>Magnetite</i>	—	—	—	—
<i>Hematite I</i>	—	—	—	—
<i>Pyrite</i>	—	—	—	—
<i>Chalcocopyrite</i>	—	—	—	—
<i>Galena</i>	—	—	—	—
<i>Sphalerite</i>	—	—	—	—
<i>Pink bornite</i>	—	—	—	—
<i>Purple bornite</i>	—	—	—	—
<i>Digenite</i>	—	—	—	—
<i>Djurleite</i>	—	—	—	—
<i>Chalcocite</i>	—	—	—	—
<i>Hematite II</i>	—	—	—	—
<i>Covellite</i>	—	—	—	—

D.

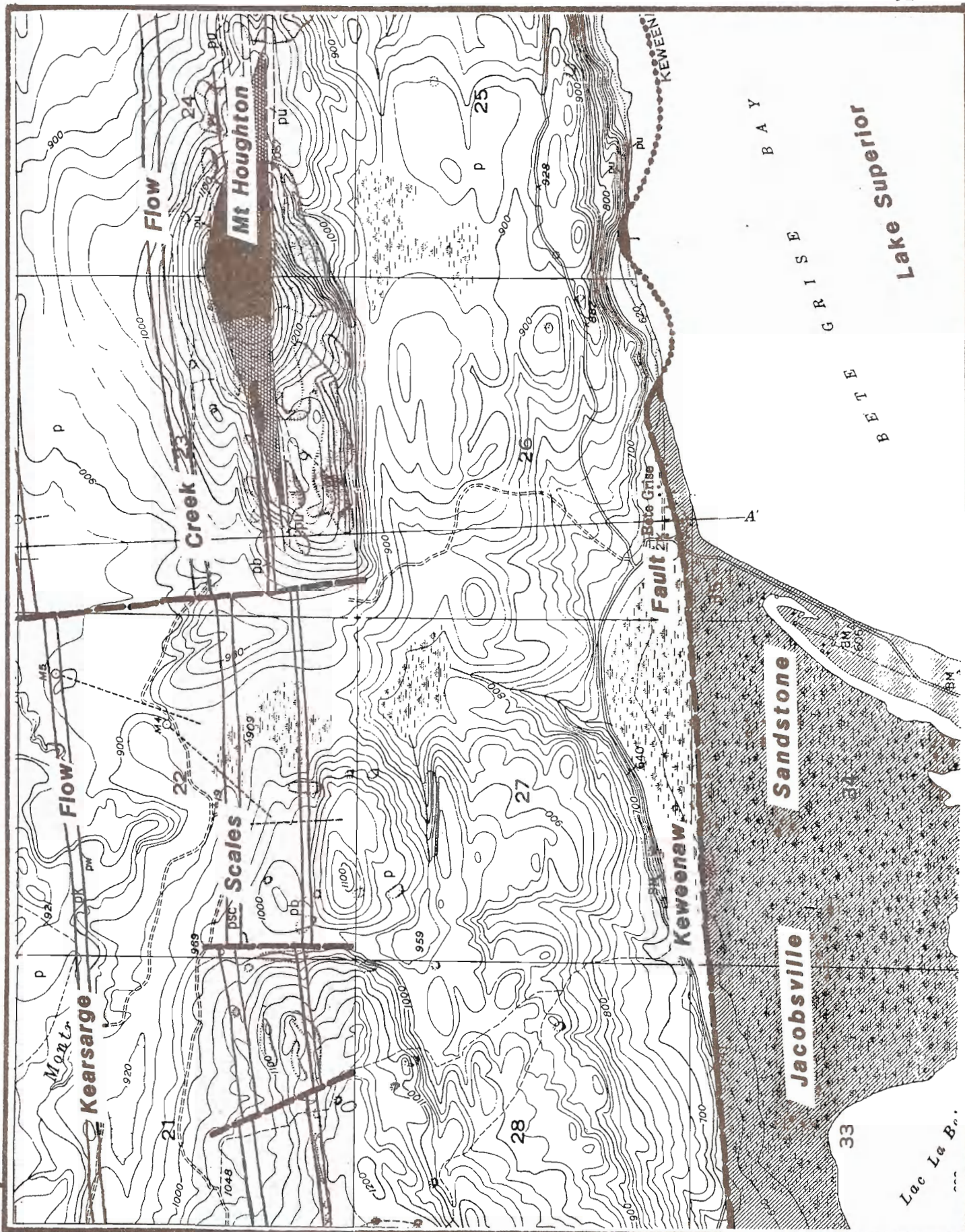
Paragenesis of opaque minerals in dikes and flow tops at Mount Bohemia.

Figure 35: Geologic map showing andesitic dikes near Mount Bohemia and occurrence and paragenesis of secondary and opaque minerals in the dikes (from Robertson, 1975).

Map 19

Map 20

MAP 22



with prominent flow banding and block and ash flow deposits on its flanks. Mt. Houghton is best approached from the Mandan Road (Map 19).

Rhyolites make up less than 1% of the mass of the Portage Lake Volcanics as seen in outcrop on the Keweenaw. Considerable textural variety of rhyolites are found including intrusive and extrusive rhyolite and even small ignimbrites. But the abundance and variety of rhyolitic boulders and cobbles within the interflow conglomerates demands that a large number of rhyolitic source areas must underly the Jacobsville south and east of the Keweenaw Fault.

To Gratiot River. Turn right and proceed ahead 1.2 miles on paved road.

At the west end of Lac La Belle, in the vicinity of Deer Lake, the rocks south of the Keweenaw Fault are Portage Lake basalts (Fig. 36). These rocks may represent the lowest stratigraphic horizons exposed in the Portage Lake Volcanics. The area has been studied by geological and geophysical methods by DeGraff (1976) and his model for the development of this unusual feature is shown graphically in Figure 36. It is still another example of confusing deformation which is typical of this great thrust. A traverse down the Little Gratiot River from the Lac La Belle-Gay Road crosses many outcrops of the basalts. The fault-bounded, tilted body of Portage Lake Volcanics was defined by dense array of magnetic and gravity profiles and a few key drillholes. The attitude of the beds was altered by the faulting, but the rocks, like the rest of the Portage Lake Volcanics, have normal magnetic polarity.

AFTER OPTIONAL SIDE TRIP to Lac La Belle return to main road log.

MAP 21

- 101.6 At Mt. Bohemia turnoff. Turn around and retrace route back to US-41.
- 105.45 Back at the junction of US-41. Make a left turn towards Mohawk.
- 106.5 Dirt road to the right goes to Stop 22 at the Delaware Mine. Turn right on the dirt road and follow the signs to the Delaware Mine.
- 106.2 STOP 22. Delaware Mine.

The Delaware Mine, first known as the Northwest Mine, has had a long and unprofitable history. It was operated by various companies from about 1847 to 1887. The mine mostly worked veins for mass copper. Three shafts were opened in 1881 to mine copper from the Allouez Conglomerate (#1, #2, #3). The Allouez Conglomerate was seen at Stop 13. Total production from the Delaware Mine was about 7.5 million lbs. of refined copper. As with other vein deposits in the Keweenaw, the Delaware Mine is a notable locality for datolite. Other minerals reported from the Delaware Mine poor rock piles include (not in order of abundance): chlorastrolite, prehnite, calcite, laumontite, analcite, chlorite, epidote, native copper and native silver (summarized from Clarke, 1975; Zelenka, 1978).

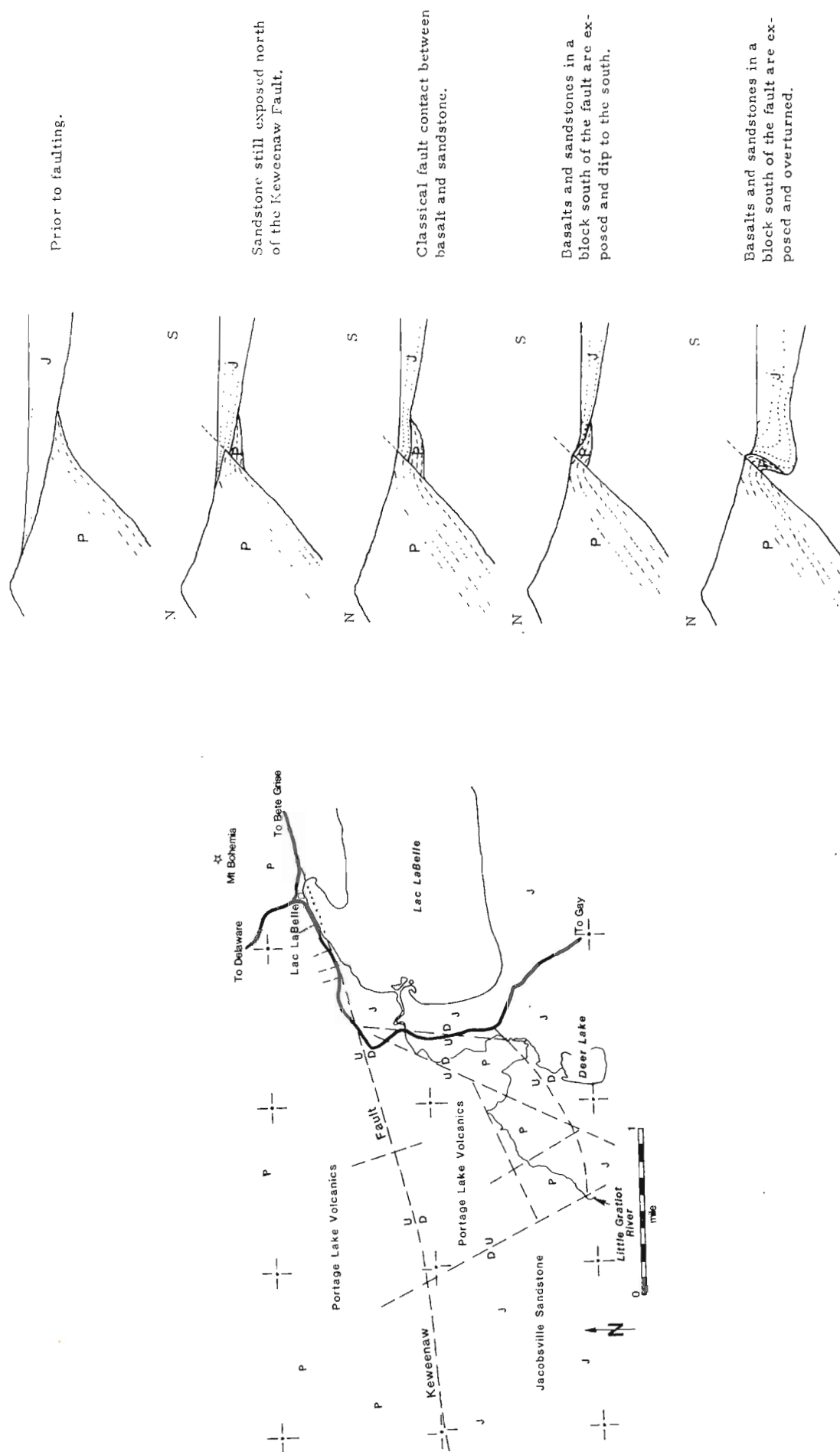


Figure 36: Sketch map of part of the Keweenaw Fault in the vicinity of Deer Lake, where the Portage Lake Volcanics are found south of the Keweenaw Fault. At right successive cross sections show stages in the development of the Keweenaw Fault at Deer Lake as envisioned by DeGraff (1976).
 P = PLV, J = Jacobsville.

The Delaware Mine is open to tours for tourists during the summer months. It is owned and operated by Jack and Tom Poynter. At this stop one has the opportunity to look at the dumps from the Delaware Mine and to visit (for a fee) the underground workings.

- 106.35 Junction of Delaware Mine and US-41. Left turn on US-41 and continue ahead towards Phoenix.

MAP 23

- 109.0 Ahead we can see cliffs of the Greenstone flow. Road nears the basal contact of the flow.
- 110.3 Exposure of one of the flows beneath the Greenstone flow.
- 111.1 To the right one can see the Greenstone ridge in the background. In the foreground is the ghost town of Central and its associated dump piles.
- 111.45 Junction of paved roads to the right and left. Continue ahead on US-41. The road to the left goes to Gratiot Lake and an Air Force Base; road to the right goes toward the ghost town of Central and the Central dump piles.

The Central Mine worked a fissure vein striking nearly at right angles to bedding and dipping steeply to the east. The mine operated from 1854 to 1898 and produced about 52 million lbs. of copper. The fissure extends from just below the Greenstone flow to the Kearsarge Conglomerate. A strike fault at the Kearsarge Conglomerate offsets the vein to the west and below this it is not mineralized.

The town of Central, settled in 1854, was settled mainly by Cornish immigrants. Although the area was mostly abandoned after the mine closed, the descendants of these immigrants now living all across the country, hold a yearly reunion in July at the townsite. Later immigrant groups to the copper mining towns included: Italian, German, Croatian and Finnish people.

MAP 24

- 112.8 Junction of road to the right. Continue ahead on US-41. The road to the right connects with an earlier part of this field trip at Jacobs Creek (mileage 60.3).
- 113.9 Another view of the ENE striking Greenstone flow holding up the prominent ridge.
- 114.6 Again another excellent view of the Greenstone flow ridge.

MAP 12

- 115.4 Junction of M-26 and US-41 at Phoenix.

There is an optional route from Phoenix to Ahmeek via US-41/M-26 given after the Five Mile Point road log.

**Map 24**



Phoenix to Ahmeek via Five Mile Point (a scenic route along the Lake Superior shore).

MAP 12

115.4 Right turn toward Eagle River.

117.4 Left turn on to the road to Five Mile Point.

MAPS 25 and 26

112.2 On the right hand side of the road is a turn-off to the Five Mile Point lighthouse. You must get permission to enter this area. In the front yard of the lighthouse, there is a thin lava flow of the Lake Shore Traps with the Copper Harbor Conglomerate bed above and below it.

121.5 Five Mile Point beach turn-off at the right hand side of the road. Along this beach there are many exposures of the Copper Harbor Conglomerate.

MAP 27

126.9 Cross the Gratiot River.

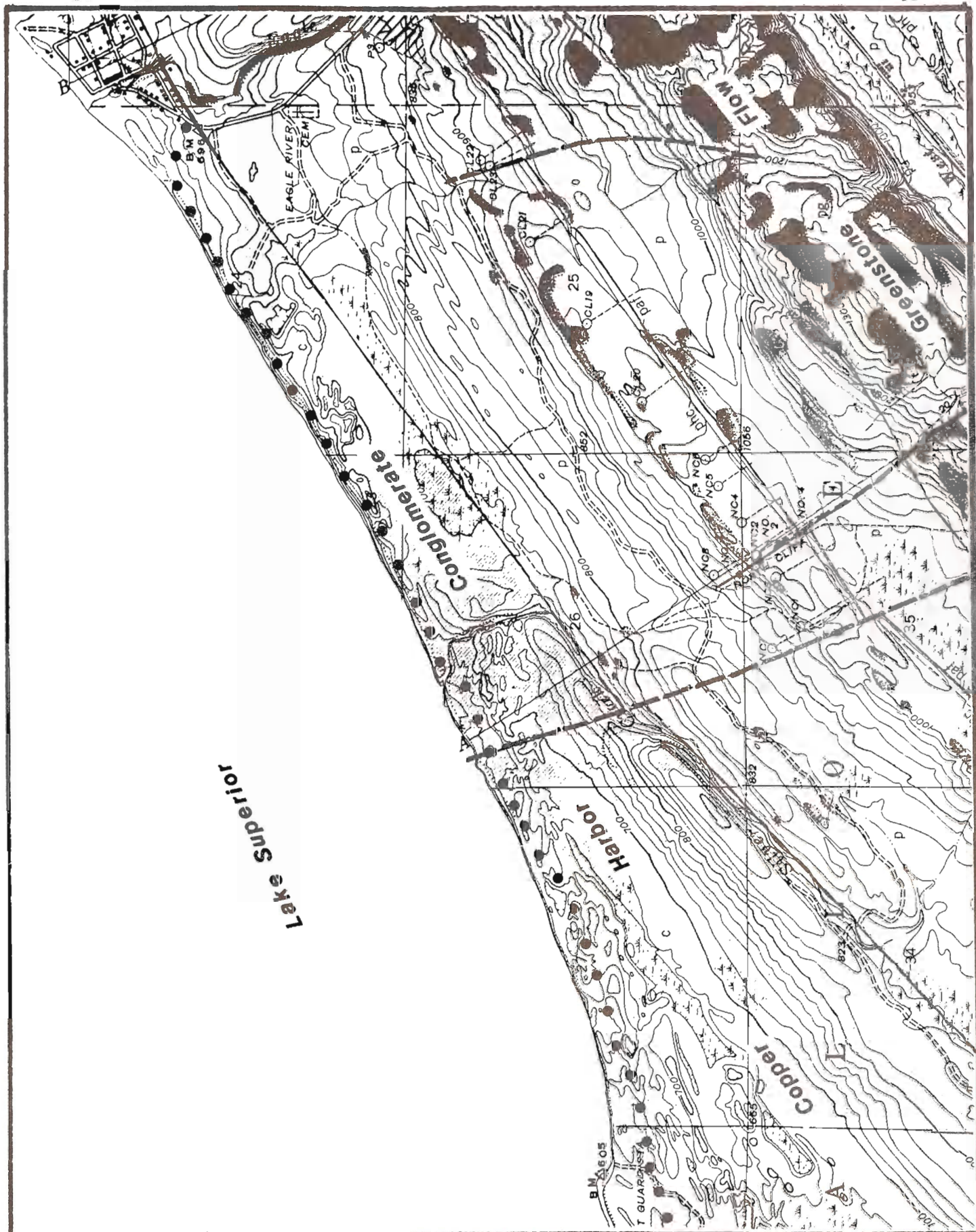
128.45 A thin basalt flow, from a position just above the Greenstone flow, forms an outcrop here which displays a well-developed columnar jointing. The Greenstone flow itself shows spectacular columnar jointing in some areas, most notably along the Palisades shown on Isle Royale where columns 2 m or more in diameter are found. In a few areas the colonade/entablature jointing pattern described in Columbia River flood basalts is well-developed in the Greenstone. On the Keweenaw columnar jointed exposures in thin flow sequences are rare, probably because the underlying horizons were not water-saturated when covered by the next lava flow.

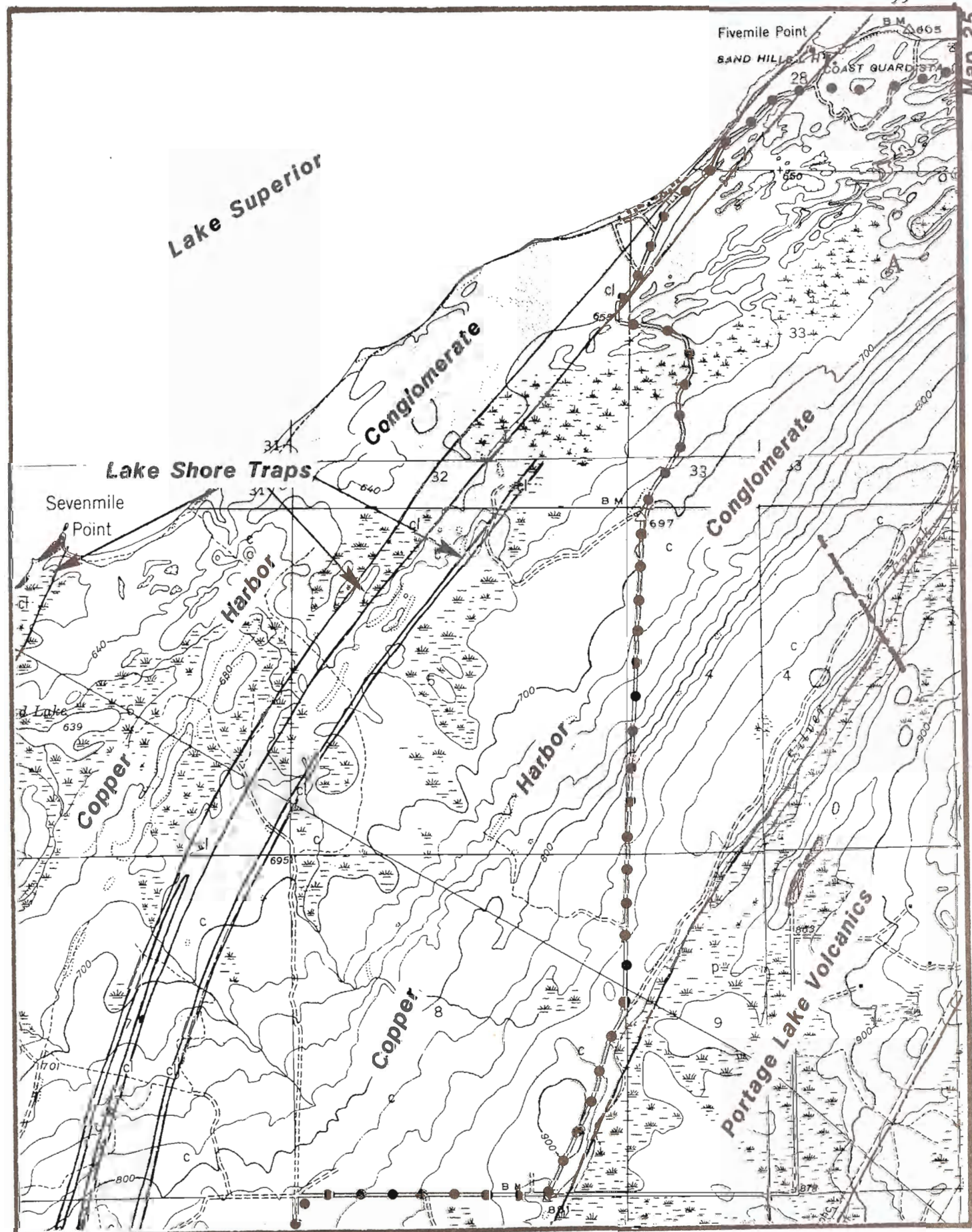
128.7 Stop sign. Go straight ahead.

128.8 Another stop sign. Turn left followed in block by a right turn.

130.0 Right turn which is immediately followed by a stop sign in front of a church. Join US-41 with a right turn. Directly ahead at about 11:00 is the Kingston Mine. This is a shallow mine that worked the Kingston Conglomerate. The Kingston ore body was discovered in 1962. Total production was about 20 million lbs. of copper until mining stopped in 1968 (Weege and Pollack, 1971). The mine was left open as a research operation in the late 1970's.

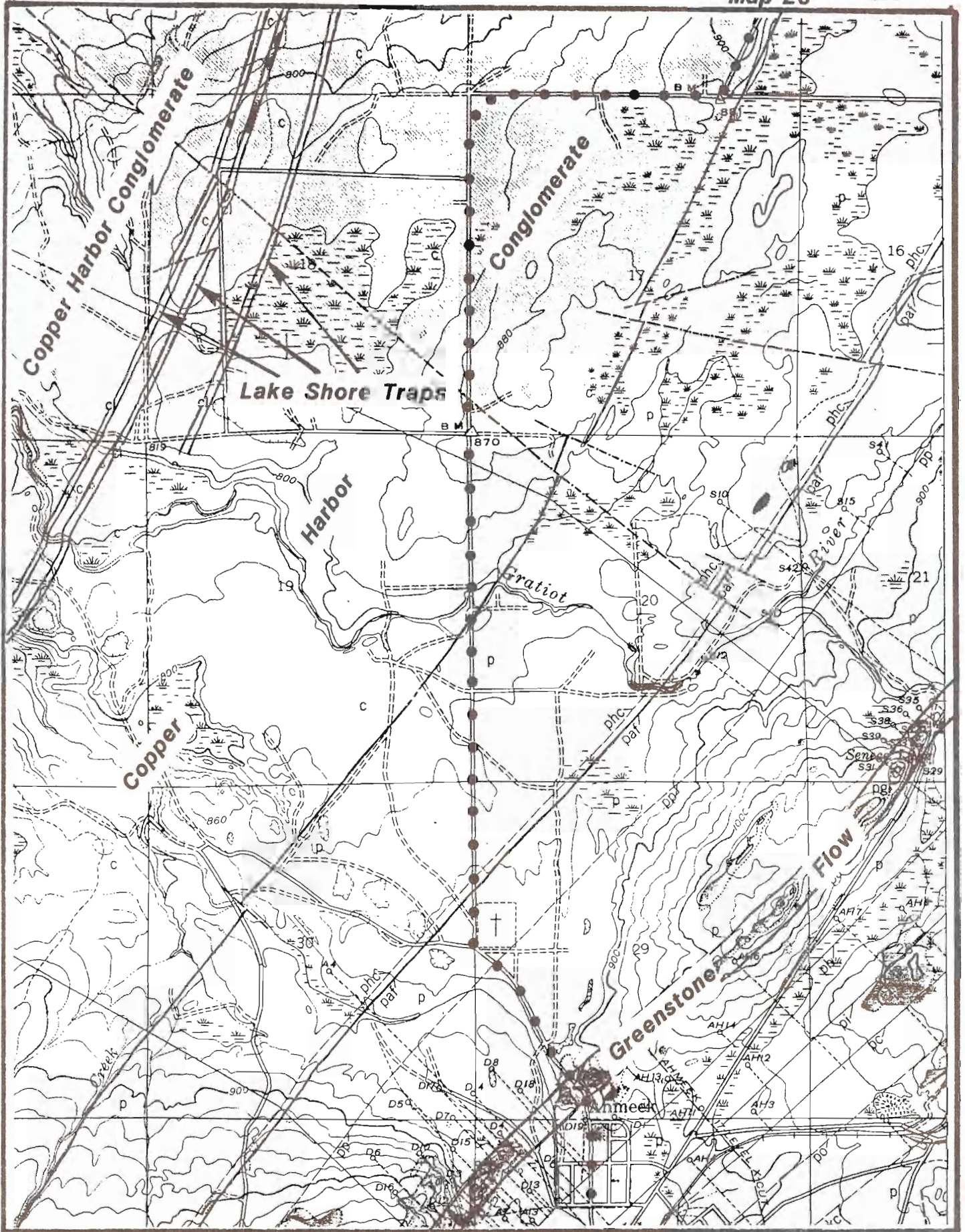
The Kingston Conglomerate is stratigraphically about midway between the Calumet Conglomerate and the Kearsarge amygdaloid. It is overlain by a 60 m thick ophitic basalt flow. A bedding plane fault separates the overlying basalt from the Kingston Conglomerate. The conglomerate rests on a scoriasceous amygdaloid. The Kingston Conglomerate can be traced along strike for over 100 Km and ranges in thickness from 0.3 to 30 m. In vicinity of the ore body it averages about 13 m. Where the bed is thick it consists of a lower layer of shale and siltstone, 10-15 cm thick and an upper conglomeratic layer (summarized from Weege and Pollack, 1971).





Map 27

MAP 26



The Kingston Conglomerate is typical of rhyolite pebble conglomerates. Pebbles are largely subangular to subrounded quartz-feldspar porphyry. Quartz-free porphyritic and nonporphyritic rhyolite pebbles, common in other conglomerates, are not present in the Kingston. Interstitial sand and sand lenses are common. Sandstone composition is similar to the pebbles. The intensity of mineralization is related to the amount of matrix present which is an indication of the original permeability. The main alteration minerals are kaolinite and chlorite. Introduced calcite and copper are found as fillings in healed fractures, interstitially filling voids and replacing the matrix. A few individual pebbles are replaced by copper. Economically important copper is found as rims around clasts and as matrix replacement or filling. Matrix filling takes place along texture bands parallel to bedding. Epidote and quartz are also found as introduced minerals. Bleached rock is commonly associated with mineralization in the Keweenaw native copper district but is not present in the Kingston ore body. The abrupt thinning of the conglomerate bed localized the ore body with high grade ore nearest the pinch-out (Fig. 37) (summarized from Weege and Pollack, 197; Brumleve, 1976).

PHOENIX TO AHMEEK VIA US-41/M-26.

MAP 12

- 0 Continue straight ahead on US-41/M-26.
- 0.5 Junction of US-41 and Cliff Drive. Bear left on US-41/M-26. Another excellent view of the Greenstone flow ridge.

MAP 10

- 5.2 Lumber mill on the left side of the road.
- 6.0 Entering Mohawk.
- 6.1 On the left hand side of the road are mine dumps from the Mohawk Mine. The Mohawk Mine worked the Kearsarge amygdaloid which is described at Stop 11.
- 7.0 The hill on the skyline with the four towers on it is Bumbletown Hill, the location of Stop 13.

MAP 9

- 7.9 Junction of US-41/M-26 and Cliff Drive in Ahmeek.
- 8.0 Junction of US-41/M-26 and the road from Five Mile Point.

RETURN TO MAIN ROAD LOG MILEAGE.

- 130.0 Junction of US-41/M-26 and the road from Five Mile Point.
- 134.1 Junction of US-41/M-26 and M-203.

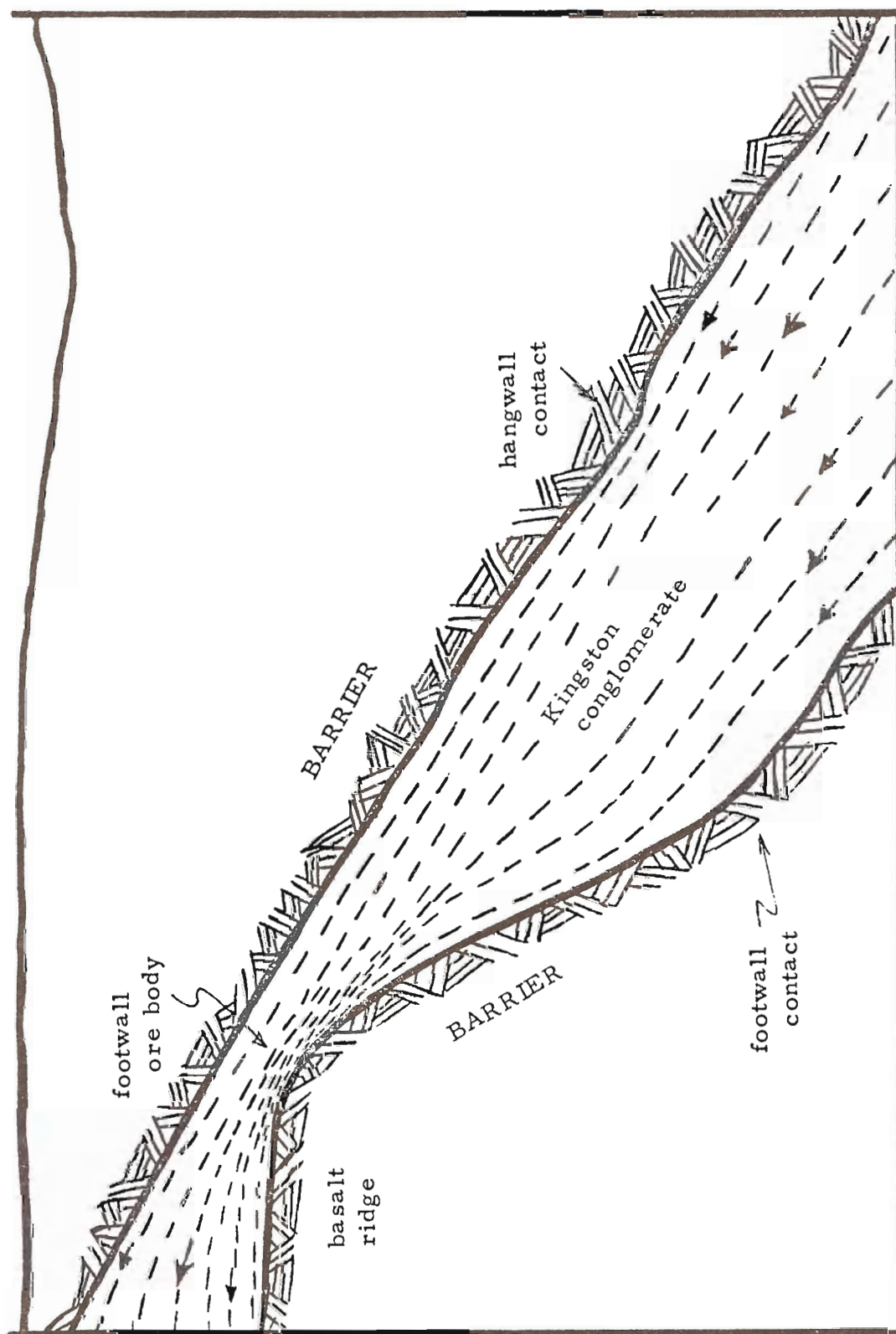


Figure 37: Schematic illustration of the funnelling effect on mineralizing fluids causing localization of ore deposition (modified from Butler and Burbank, 1929 by Brumleve, 1976).

There is an optional route from Calumet to Hancock via M-203/McLain State Park given after the US-41/M-26 road log.

Calumet to Hancock via US-41/M-26.

134.1 Continue straight ahead on US-41/M-26.

MAP 28

134.8 Flashing light. Continue straight ahead. A right turn leads to the center of Calumet.

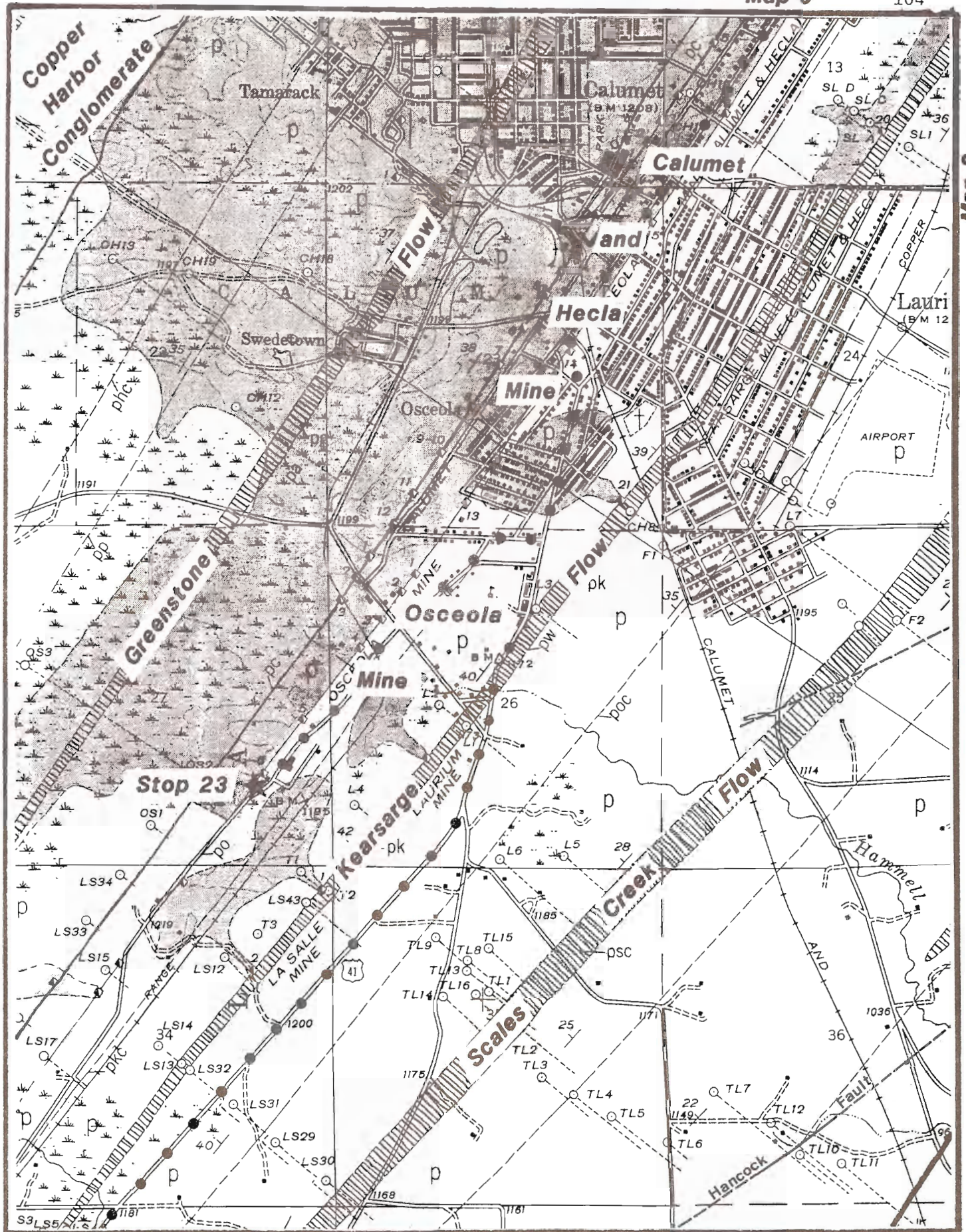
135.7 Southern edge of Calumet. The Osceola Mine Shaft No. 13 can be seen on the right hand side of the road behind the Holiday gas station. Follow the roads on Map 28 if you wish to go to Stop 23. Mileage is not logged to this stop.

STOP 23. Osceola Mine Shaft No. 6.

The Osceola Mine worked the Osceola amygdaloid in the Calumet area. Production from the Osceola amygdaloid began in 1879 and continued until 1920 when mining activity stopped. The mine reopened between 1925 to 1931. The mine reopened in 1925 and production continued until 1968. A total of about 600 million lbs. of refined copper was removed from this mine which ranks fifth in the Keweenaw native copper district. The amygdaloid was developed for about four miles along strike and to a depth of 4,500 ft. along incline (2,700 ft. vertically) (summarized from Weege and Pollack, 1971).

The Osceola flow is an ophitic basalt and varies in thickness from 35 to 210 feet. The thickest part of the flow, near Calumet, has been the most productive. The Osceola flow has been traced from the Cliff Mine to the Arcadian. In the Calumet area the flow strikes N35°E and dips around 37°NW. The top of the flow is a well developed fragmental amygdaloid consisting of well oxidized, reddish, angular fragments of vesicular lava which typically range in size from a few inches up to a foot in diameter. The lode ranged in thickness from 1 ft. up to and sometimes greater than 60 ft. Amygdules and the voids in the brecciated flow top are filled mostly with calcite, epidote, K-feldspar, chlorite, and native copper. Quartz is present in certain areas and there is also minor amounts of prehnite, pumpellyite, laumontite, and analcite. The fragmental amygdaloid is frequently interrupted by sill-like layers of dense basalt which may have been emplaced by injection of lava from the interior of the flow into the solidified, brecciated crust. These dense basalt layers provided barriers to the movement of mineralizing solutions. Native copper in the Osceola ranges from disseminated to small masses up to an inch in diameter to large masses weighing hundreds of lbs. (summarized from Weege and Pollack, 1971; Butler and Burbank, 1929).

The Osceola Shaft No. 6 is at the southwest end of the ore body and was the richest part of the deposit. A barrier zone is believed to have funnelled mineralizing solutions moving up dip resulting in the high copper contents. Textures and colors characteristic of fragmental amygdaloid can be seen in this dump. Stoiber (unpublished data) made an estimate of the percentages of secondary minerals in the dump as a



Map 8

To Hancock

MAP 28

whole: calcite, 59; microcline, 29; prehnite, 4; epidote, 1; quartz, 1; chlorite, 5. These and pumpellyite, laumontite and native copper can be found on this dump. Bleaching of the basalt in vicinity of native copper can be seen in individual specimens.

135.7 Continue ahead on US-41/M-26 towards Hancock.

No Maps Until Hancock

145.45 Junction of White Street on the left. Turn left on White Street.

145.9 Right turn on Tezcuco Street in Hancock.

146.0 Stop sign at Quincy Street. Go straight ahead through this stop sign one more block to Hancock Street where you make a left hand turn.

146.55 Middle of the Portage Lake Lift Bridge.

146.8 Junction of US-41/M-26. Stay left on US-41 to the left past the Mobil and Erickson gas stations.

148.1 Left hand turn off Townsend Drive back into the Michigan Tech Campus.

CALUMET TO HANCOCK VIA M-203/McLain State Park.

0 Junction US-41/M-26 and M-203 on the edge of Calumet. Make a right hand turn on M-203.

No Maps Until Near McLain State Park.

0.5 Village Limit of Calumet. Continue straight ahead.

2.5 Junction of road to Calumet Township Waterworks Park.

4.2 Bear right on Y with another paved road.

4.6 Nice view of Lake Superior.

MAP 29

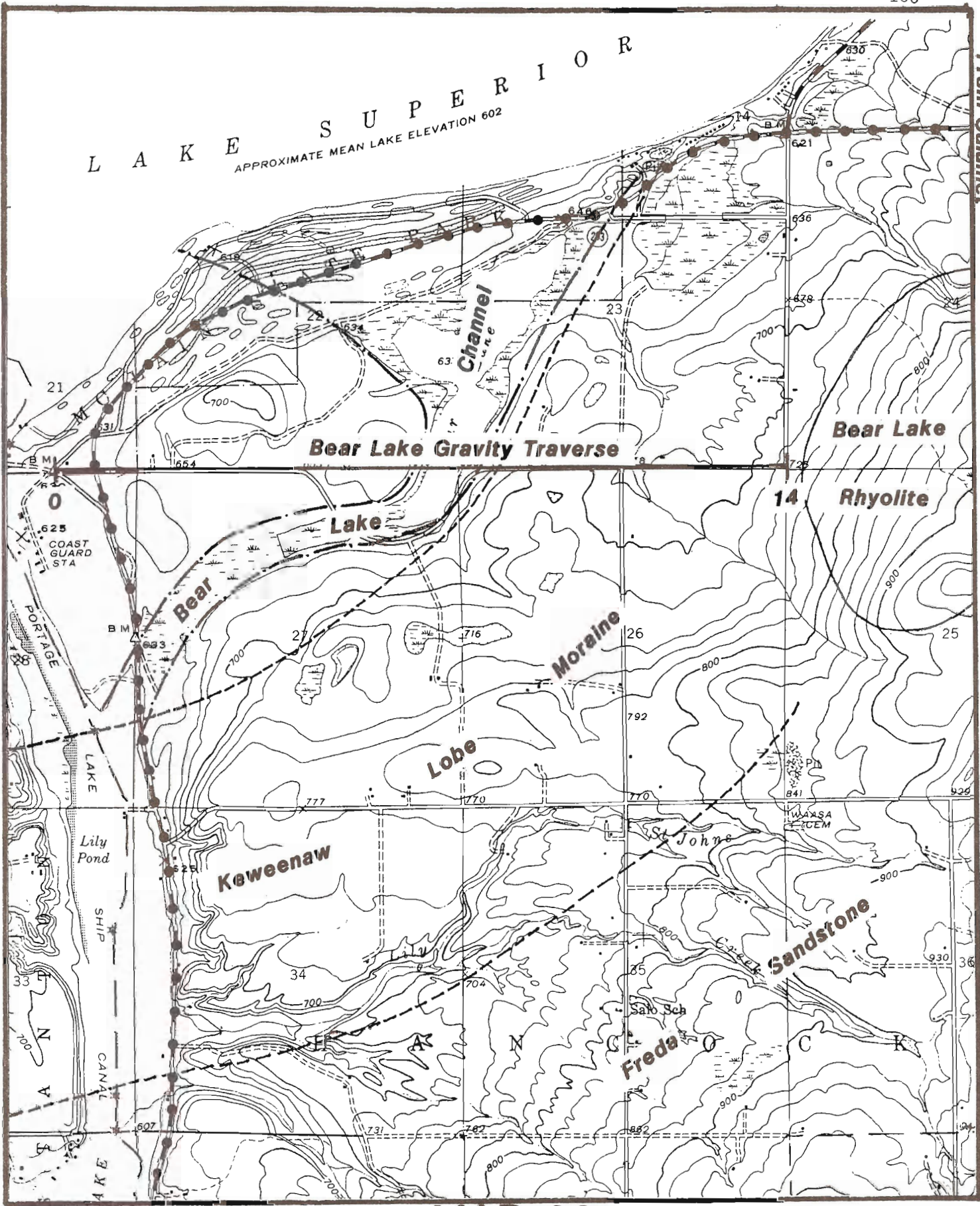
6.7 Continue on M-203. Road to the right is Lakeshore Drive which goes to Calumet Township Waterworks Park; road to the left is Salo Road to the Bear Lake Rhyolite. The Bear Lake Rhyolite cuts the Freda Sandstone bedrock. It is the youngest known igneous activity in the Keweenaw Peninsula. The Bear Lake Rhyolite is a minimum of 1054 ± 34 m.y. years old based on a K/Ar age date (White, 1968).

7.0 Exposures of sand dunes on the right.

7.5 Bear Lake on the left hand side of the road. Cross on top of the filled glacial Bear Lake Channel.

L A K E S U P E R I O R
 APPROXIMATE MEAN LAKE ELEVATION 602

From Calumet



To Hancock

MAP 29

The Bear Lake Channel (Map 29) represents a deep bedrock valley, the extension of the Keweenaw Waterway. Although the Waterway was dredged to the west of McLain Park, because the distance was less, the Bear Lake Channel is a much more profound feature, with more than 600 feet to bedrock. The definition of this and other similar bedrock valleys is shown by gravity data. One such traverse, plotted on the map, is displayed as Figure 38. See also the discussion of the origin of the Keweenaw Waterway under Stops 1, 5 and 6.

- 8.4 Entrance to McLain State Park and the other edge of the Bear Lake Channel. Camping facilities are located here.
- 9.2 Continue on M-203. Road to the right is to the Coast Guard Station; road to the left is the Bear Lake Road, location of gravity traverse.
- 10.6 Access road to Lily Pond.

At this point the End Moraine of the Keweenaw Lobe, a great mass of glacial ice which was stabilized here during the Wisconsin glaciation, is crossed. The regional distribution of this moraine is plotted in Figure 14. The positions of lobes as they retreated at the end of the Wisconsin period are shown in Figure 15.

- 13.5 High Point Road, continue ahead on M-203.

MAP 30

- 16.1 Cross Swedetown Creek. To the northeast along Swedetown Creek there are exposures of Freda Sandstone. If one is interested in looking in more detail at the Freda Sandstone, excellent exposures can be found elsewhere. In the local area excellent exposures of Freda Sandstone are present along the shore of Lake Superior between Redridge and Freda. Redridge/Freda can be reached by following the Houghton Canal Road which begins on the west side of Houghton (see Fig. 17).
- 16.55 Access to Hancock Campground. The Nonesuch Shale is exposed in an abandoned quarry located just NE of the boat launch. This is Stop 24 and mileage is not logged from the main road to the quarry.

STOP 24. Hancock Campground.

As a whole, the Nonesuch Shale consists primarily of siltstone with subordinate amounts of shale and sandstone. It can be distinguished from the formations above and below by its generally grayish color. Most Nonesuch is a rippled, laminated siltstone with reddish-gray partings. Lithologically siltstones and sandstones of the Nonesuch are composed of around 30 to 40 percent rock fragments and 60 to 70 percent mineral grains. The rock fragments are mostly volcanic with a 2:1 ratio of mafic to silicic + intermediate composition (Daniels, 1982). The Nonesuch is stratigraphically between the Copper Harbor Conglomerate and Freda Sandstone (Fig. 5).

The Nonesuch crops out around the margin of the quarry at this stop. It is a fine- to medium-grained, gray to reddish brown sandstone with subordinate interbedded, reddish-brown laminated siltstone and shale (Cornwall and Wright, 1956). The attitude of bedding here is about N30°E, 25°W.

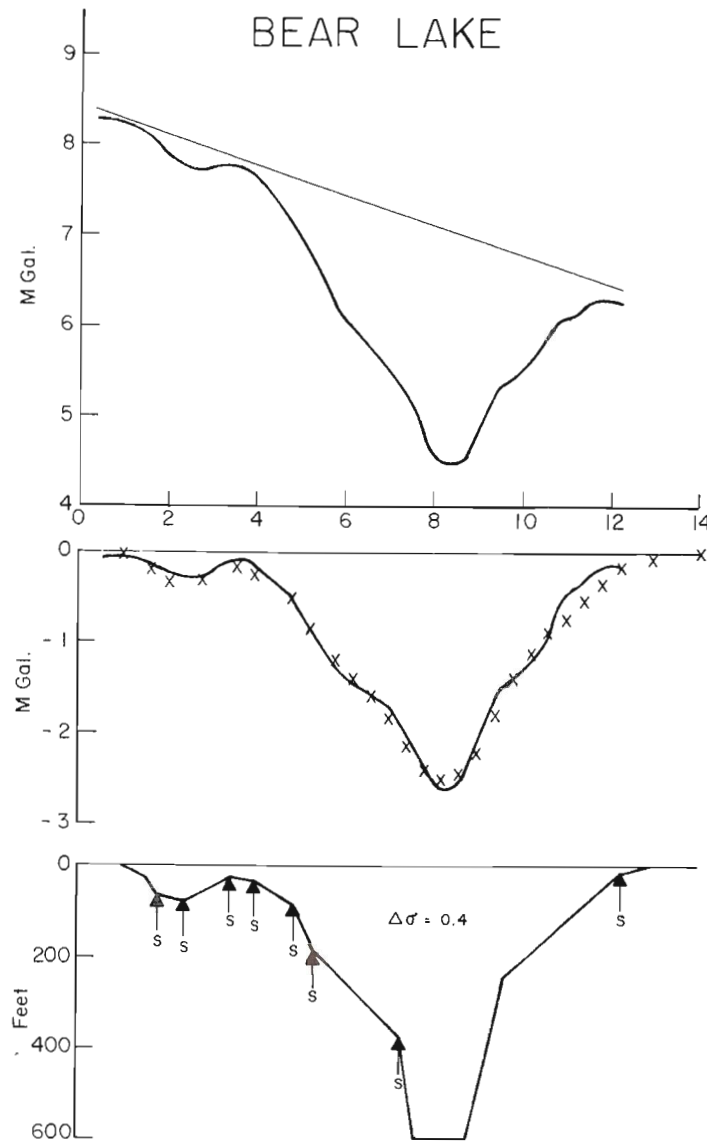
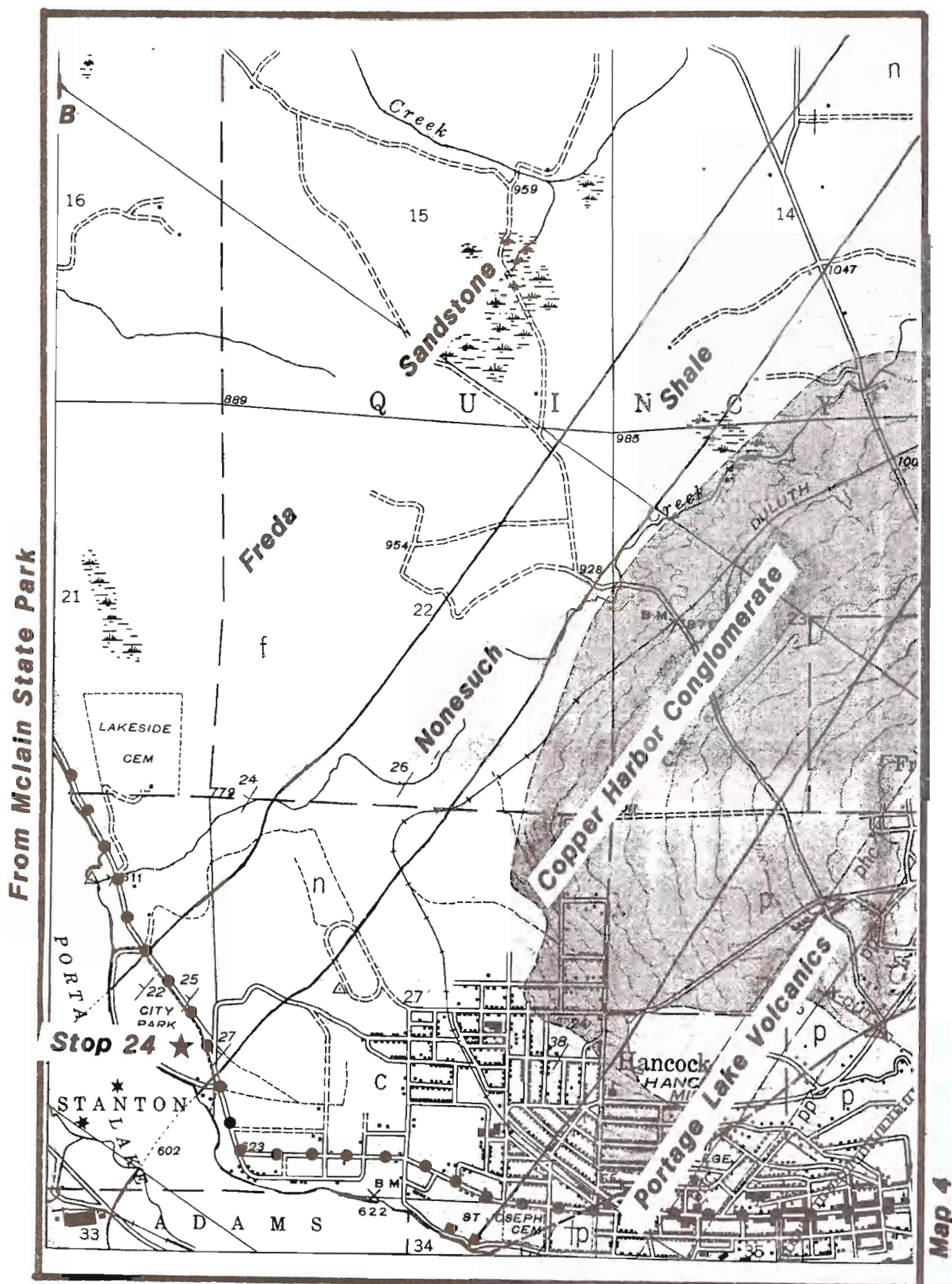


Figure 38: Results of gravity measurements across the Bear Lake traverse plotted in Map 29. At top is Bouguer anomaly with regional trend. In the middle the regional trend is subtracted to get the solid line which is compared with the modelled topography (X's). Below is the model of the valley and the density difference of the bedrock (Freda Sandstone) and the valley fill (Warren, 1981).



MAP 30

- 16.7 Hancock Beach.
- 16.85 Sharp left hand turn on M-203. Edge of Hancock.
- 17.9 Junction M-203 and US-41. Turn right on the one-way road. Follow south US-41 back to the Michigan Tech Campus.

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<u>Map No.</u>	<u>Quadrangle</u>	<u>Reference</u>
1	Chassell	White, 1956
2	South Range, Chassell	White & Wright, 1956; White, 1956
3	Chassell	Warren, 1981
4	Chassell, Hancock	White, 1956; Cornwall & Wright, 1956a
5	Chassell, Hancock	White, 1956; Cornwall & Wright, 1956a
6	Laurium	Cornwall & Wright, 1956b
7	Laurium	Cornwall & Wright, 1956b
8	Laurium	Cornwall & Wright, 1956b
9	Ahmeek	White & Others, 1953
10	Mohawk	Davidson & Others, 1955
11	Mohawk	Davidson & Others, 1955
12	Phoenix	Cornwall, 1954a
13	Eagle Harbor	Cornwall & Wright, 1954
14	Eagle Harbor	Cornwall & Wright, 1954
15	Delaware	Cornwall, 1954b
16	Delaware	Cornwall, 1954b
17	Lake Medora	Cornwall, 1954c
18	Lake Medora, Fort Wilkins	Cornwall, 1954c; Cornwall, 1955
19	Lake Medora	Cornwall, 1954c
20	Delaware	Cornwall, 1954b
21	Delaware	Cornwall, 1954b
22	Lake Medora	Cornwall, 1954c
23	Eagle Harbor	Cornwall & Wright, 1954
24	Eagle Harbor	Cornwall & Wright, 1954; Cornwall, 1954a
25	Phoenix	Cornwall, 1954a
26	Phoenix, Mohawk, Ahmeek	Cornwall, 1954a; Davidson & Others, 1955; White & Others, 1953
27	Ahmeek	White & Others, 1953
28	Laurium	Cornwall & Wright, 1956b
29	Hancock	Cornwall & Wright, 1956a; Warren, 1981
30	Hancock	Cornwall & Wright, 1956a
	MTU Campus Map (Cover Page)	White, 1956; Hase, 1973

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Figure 1B: Index of 1:24,000 scale maps



12 Stop number

Figure 1A: Route and stop map