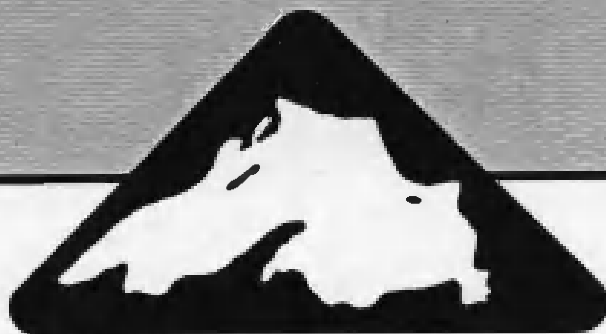


Self-guided geological field trip to the Keweenaw Peninsula, Michigan



By: Theodore J. Bornhorst and William I. Rose



Institute on Lake Superior Geology
Proceedings

Volume 40, Part 2

Proceedings

Volume 40, Part 2

FIRST PRINTING—MAY 1994
SECOND PRINTING—SEPTEMBER 1994

Publisher

Institute on Lake Superior Geology

Distributor

Theodore J. Bornhorst
c/o Department of Geological Engineering, Geology, and Geophysics
Michigan Technological University
1400 Townsend Drive
Houghton, Michigan 49931-1295

ISSN 1042-9964

Volume 40 consists of Parts 1, 2, 3, 4, and 5.

Reference to Volume 40, Part 2 should follow the example below:

Bornhorst, T. J. and Rose, W. I., 1994, Self-guided geological field trip to the Keweenaw Peninsula, Michigan: Institute on Lake Superior Geology Proceedings, 40th Annual Meeting, Houghton, MI, v. 40, part 2, 185 p.

PREFACE

In 1983 we, with the help of Jim Paces, put together a "Field Guide to the Geology of the Keweenaw Peninsula, Michigan" (Bornhorst and others, 1983) for the 29th Annual Institute on Lake Superior Geology held at Michigan Technological University on May 11-14, 1983. At that time, we considered that "It is presumptuous for us to put together a book which is based mainly on the work of others," but we did "because hundreds of people come to the Keweenaw each year to look at geological features and many of them ask us for advice." The 1983 guide was a smashing success and after 10 and 1/2 years a total of 1850 copies were sold to geologists and others. At the time we completed the 1983 guide, we expected to revise and update the guide through new editions. However, this did not happen for a variety of reasons, especially the fact that the 1983 version was done with a typewriter before word processing on computers became popular. Due to the sheer magnitude of changes made to the 1983 guide, including an all new introduction and increasing the number of stops from 24 to 56, this guide is being published as a new publication for the 40th Annual Institute on Lake Superior Geology. The Institute on Lake Superior Geology meeting in May 1994 is the deadline forcing completion of this guide, which will be published under the Institute on Lake Superior Geology name, as would probably have been appropriate for the 1983 guide.

We have designed this guide to make revisions much easier than the 1983 guide. The text, figure captions, etc. are computerized. Maps have been produced to make revisions easier. We really do expect to revise this guide as mistakes are found and we get the momentum to add new stops. We welcome your comments and suggestions.

Starting with Douglass Houghton almost 150 years ago, dozens of geologists have contributed a mountain of geological information on the Keweenaw Peninsula. We have faithfully tried to transmit the ideas within this mountain of information. However, this guide is for people who are doing serious geological field trips.

ACKNOWLEDGMENTS

Mary Larson, an undergraduate student in Scientific and Technical Communication with a geology minor, played a key role in the text of this guide; editing, assembling, and writing a few segments. She undertook this project both as a work study student and for a scientific and technical communications class. Her effort is sincerely appreciated. Jane Cookman, an undergraduate in Geology, prepared many of the maps in the road log. Finally, the senior author (Bornhorst), thanks Laurie, Gail and Ellen for tolerating the extra hours at the office needed to complete this guide.

DEDICATION

This "Self-guided geological field trip to the Keweenaw Peninsula, Michigan" is dedicated to the late Walter S. White, who spent much of his life doing geologic mapping in the Keweenaw Peninsula.

Proceedings
Volume 40, Part 2



Institute on Lake Superior Geology

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Keweenaw Peninsula, Michigan**

By: Theodore J. Bornhorst and William I. Rose
Department of Geological Engineering, Geology, and Geophysics
Michigan Technological University, Houghton, Michigan 49931-1295

Published for
40th Annual Meeting
Institute on Lake Superior Geology
Houghton, Michigan
May 11-14, 1994

ISSN 1042-9964

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USING THIS GUIDE

A NUMBER OF STOPS ARE ON PRIVATE LAND. PLEASE RESPECT PRIVATE PROPERTY. PROBLEMS OF ACCESS ARE MINIMAL, BUT THIS CAN QUICKLY CHANGE IF EVERYONE DOES NOT USE LOW PROFILE OUTDOOR PRINCIPLES AND ASK PERMISSION WHEN POSSIBLE. OLD MINE ROCK PILES ARE HAZARDOUS, SO COMMON SENSE MUST BE APPLIED.

This guide is designed for geologists and geology students. It begins with an introductory description with figures and tables. The road log consists of a main log with sequentially numbered stops, maps, figures, and tables (sequence for figures and tables continues from introductory description) followed by separate legs. Each leg has separate sequentially numbered stops, maps, figures, and tables (leg numbers are preceded by the letter of the leg).

All maps have north to the top. Most maps are 1:24,000 (1 cm = 240 m or 1" = 2000 ft) scale (Figure 1b). Several maps in Legs D and I are 1:168960 (1 cm = 1689.6 m or 3/8" = 1 mile (5280 ft)). Dots follow the road traveled for the main road log, and open circles are used for the legs.

The field trip stops are grouped below in topics to assist in design of your field trip.

TOPIC

Glacial	2, 3, 7, 16, 29, 33, A2, F2, H1, H2, H3, H4, H5, H7, H9
Rift-flanking clastic sedimentary rocks	10, 11, 12, D5, E1, I1
Rift-filling dominantly clastic sedimentary rocks	12, 22, 23, 24, 25, 26, 27, 28, A1, A3, C1, F1, H6, H8
Rift-filling dominantly igneous rocks	1, 4, 6, 8, 14, 15, 16, 18, 19, 20, 21, 30, 31, B1, D1, E1, F3, G1
Native Copper Deposits	5, 8, 9, 13, 15, 16, 17, 18, 28, 30, 32, 34, B1
Scenic	7, 16, 25, D4, D6

We encourage you to be imaginative and make up your own subset of stops. To visit all the stops listed in this guide would take at least five days. We have designed several trips with different emphasis based on about 10 stops per day. Stops are listed in approximate order of visiting.

One-day trip with emphasis glacial features

A2, 7, 33, H1, H2, H3, H4, H5, H7, H9 (requires special permission)

One-day trip with broad coverage of rift geology in the Houghton/Calumet area

4, 5, 6, A1, A3, H8, 10, 12, 13, 15, 16

One-day trip with emphasis on mineral deposits

4, 5, 8, 13, 15, 16, 17, 18, 30, E1

One-day trip with emphasis on igneous geology

4, 6, 15, 16, 18, 19, 20, 31, E1, G1

One-day trip with broad coverage of geology and scenery

4, 7, 10, 12, 13, 15, 16, 18, 24, 25, 27

One-day trip with scenic overview and geology

7, 16, 21, 22, 24, 25, 28, C1, D4, D6

Two-day trip with broad coverage of geology and scenery

4, 5, 10, 12, 13, 15, 16, 18, 20, 21, 22, 25, 28, 30, C1, H8, A3

There are so many excellent stops we almost don't like to make suggestions. We are not sure which stops are the most popular, but our guess is the following: 4, 7, 10, 12, 15, 16, 18, 21, 25, and 27.

If you use this guide, we would really like to hear about your experience. What stops did you like? What stops you don't like? etc. Please drop a letter or postcard in the mail. With your comments and suggestions we can make this guide better.

LIST OF STOPS

The following list of stops can be used to help you design your self-guided geological field trip to 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. We hope you enjoy seeing the Keweenaw and its geology.

STOP	APPROPRIATE MAP	PAGE	STOP DESCRIPTION
MAIN ROAD LOG			
1	(2)	33	Seventh Street, City of Houghton (Portage Lake Volcanics [PLV])
2	(2)	34	Houghton water tower (glacial grooves)
3	(2)	36	Hurontown (glacially carved basalt)
4	(3)	39	South Range Quarry (Portage Lake Volcanics [PLV])
5	(3)	42	Baltic Mine Shaft No. 3 (native copper deposit within Portage Lake Volcanics [PLV])
6	(2)	43	Sheldon Avenue, City of Houghton (Portage Lake Volcanics [PLV])
7	(4)	44	Keweenaw Waterway Overlook
8	(4)	48	Quincy Mine Adit (Portage Lake Volcanics [PLV])
9	(4)	53	Quincy Mine Rock Piles (native copper deposit within Portage Lake Volcanics [PLV])
10	(6)	56	M-26 near Tamarack (Jacobsville Sandstone)
11	(7)	59	Hungarian Falls (Keweenaw Fault)
12	(8)	64	Natural Wall Ravine (Keweenaw Fault)
13	(9)	68	Wolverine Mine Shaft No. 2 (native copper deposit within Portage Lake Volcanics [PLV])
14	(9)	74	Scales Creek (Portage Lake Volcanics [PLV])

LIST OF STOPS (Cont'd.)

STOP	APPROPRIATE MAP	PAGE	STOP DESCRIPTION
15	(9)	74	Allouez (conglomerate in Portage Lake Volcanics [PLV])
16	(9)	75	Bumbletown Hill (Allouez Gap Fault and Portage Lake Volcanics)
17	(11)	82	Cliff Mine (native copper vein deposit)
18	(12)	83	Phoenix Mine (native copper vein deposit and Portage Lake Volcanics [PLV])
19	(12)	87	Eagle River (Portage Lake Volcanics [PLV])
20	(12)	89	M-26, Eagle River (Portage Lake Volcanics [PLV])
21	(12)	89	Eagle River Falls (contact of Portage Lake Volcanics and Copper Harbor Conglomerate)
22	(14)	90	Eagle Harbor Lighthouse (Lake Shore Traps)
23	(16)	93	Silver River (Copper Harbor Conglomerate)
24	(16)	96	Esrey Park (Lake Shore Traps)
25	(17)	98	Brockway Mountain Viewpoint
26	(17)	100	Hebard Park (Copper Harbor Conglomerate)
27	(17)	100	Dan's Point (Copper Harbor Conglomerate)
28	(18)	104	Fort Wilkins State Park (native copper veins within Copper Harbor Conglomerate)
29	(20)	105	Mandan (Mandan esker)
30	(21)	105	Delaware Mine (native copper deposit within Portage Lake Volcanics [PLV])

LIST OF STOPS (Cont'd.)

STOP	APPROPRIATE MAP	PAGE	STOP DESCRIPTION
31	(21)	110	US-41 near Delaware (Portage Lake Volcanics [PLV])
32	(10)	113	Mohawk Mine (native copper deposit within Portage Lake Volcanics [PLV])
33	(24)	114	Calumet (glacial grooves)
34	(24)	116	Osceola Mine (native copper deposit within Portage Lake Volcanics [PLV])
LEG A Redridge			
A1	(A2)	117	Houghton Canal Road (Copper Harbor Conglomerate)
A2	(A2)	117	Cole's Creek (glacial sediments)
A3	(A5)	120	Redridge Cliffs (Freda Sandstone)
LEG B Owl Creek			
B1	(B2)	124	Owl Creek (Portage Lake Volcanics [PLV] and Copper Falls Mine)
LEG C Horseshoe Harbor			
C1	(C2)	131	Horseshoe Harbor (Copper Harbor Conglomerate)
LEG D Eastside of the Keweenaw Peninsula			
D1	(D2)	132	Mount Bohemia (diorite stock within the Portage Lake Volcanics [PLV])
D2	(D1)	136	Bete Grise (white sand beach from Jacobsville Sandstone)
D3	(D2)	137	Haven Park (Portage Lake Volcanics [PLV] near the Keweenaw Fault)
D4	(D1)	139	South Point (view of the tip of the Keweenaw Peninsula)
D5	(D1)	139	Eastern Keweenaw Peninsula (Jacobsville Sandstone)

LIST OF STOPS (Cont'd.)

STOP	APPROPRIATE MAP	PAGE	STOP DESCRIPTION
D6	(D3)	141	Gay (stamp sands)
LEG E 932 Creek			
E1	(E2)	144	932 Creek (Keweenaw Fault)
LEG F Five Mile Point			
F1	(F1)	149	W.C. Verde Roadside Park (Copper Harbor Conglomerate)
F2	(F3)	149	Allouez Gap (kettles)
F3	(F3)	153	North of Ahmeek (Portage Lake Volcanics [PLV])
LEG G Copper City			
G1	(G1)	155	Copper City Rhyolite (Portage Lake Volcanics [PLV])
LEG H McLain State Park			
H1	(H1)	158	Red Jacket (glacial sand and gravel)
H2	(H1)	158	West Tamarack (glacial gravels)
H3	(H2)	161	Cloverland Road (Washburn Stage beach ridges)
H4	(H4)	161	Lake Annie (glacial lake baymouth bar)
H5	(H3)	161	Sand Ridges M-203 (Nipissing beach ridges)
H6	(H3)	165	McLain State Park (Freda Sandstone)
H7	(H5)	165	Till along M-203 (till)
H8	(H6)	168	Hancock Campground (Nonesuch Shale)
H9	(H6)	168	Superior Sand and Gravel (glaciofluvial sediments)
LEG I L'Anse			
I1	(I2)	174	L'Anse Red Rocks (Jacobsville Sandstone)

**Figure 1A:
Route and Stop Map**

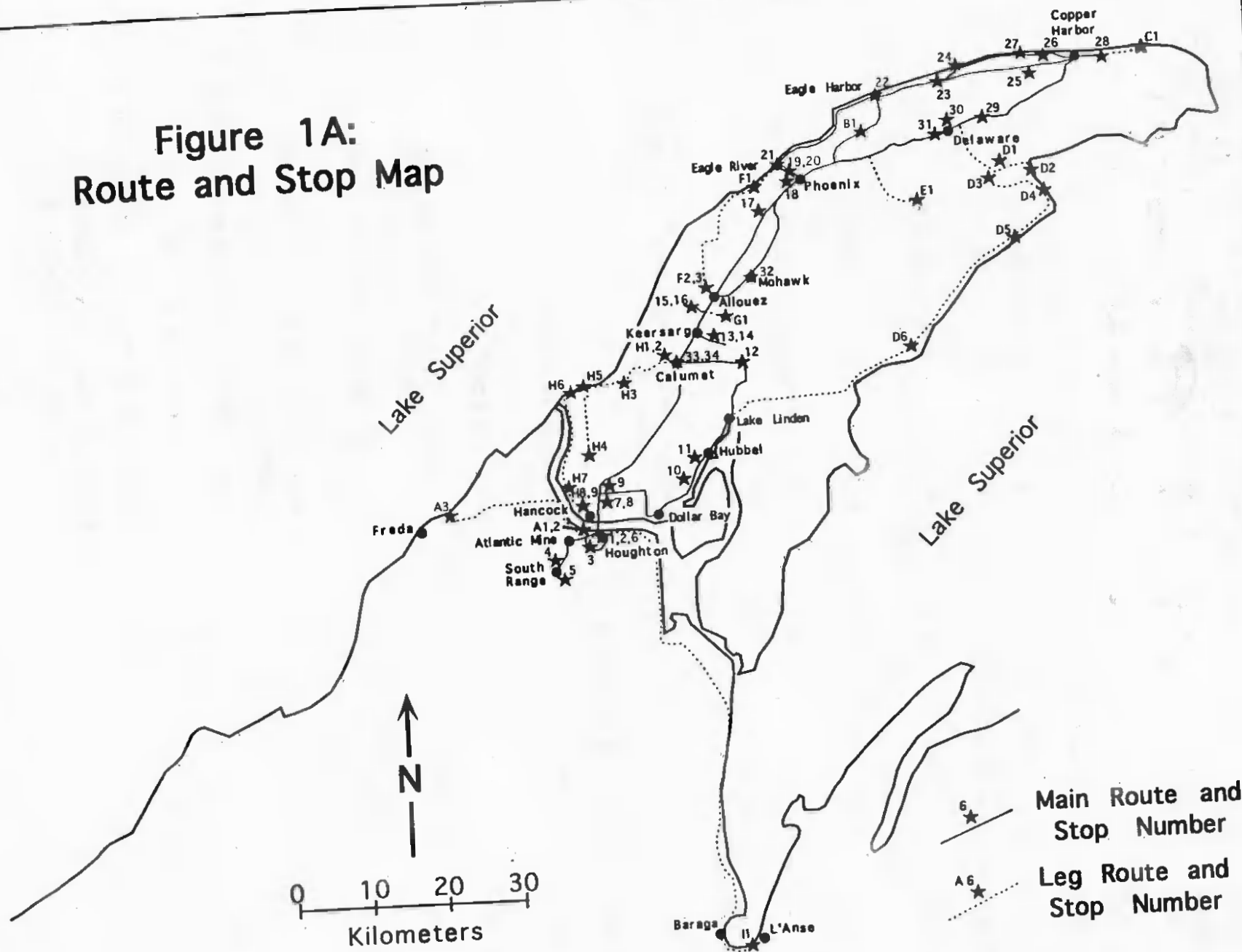
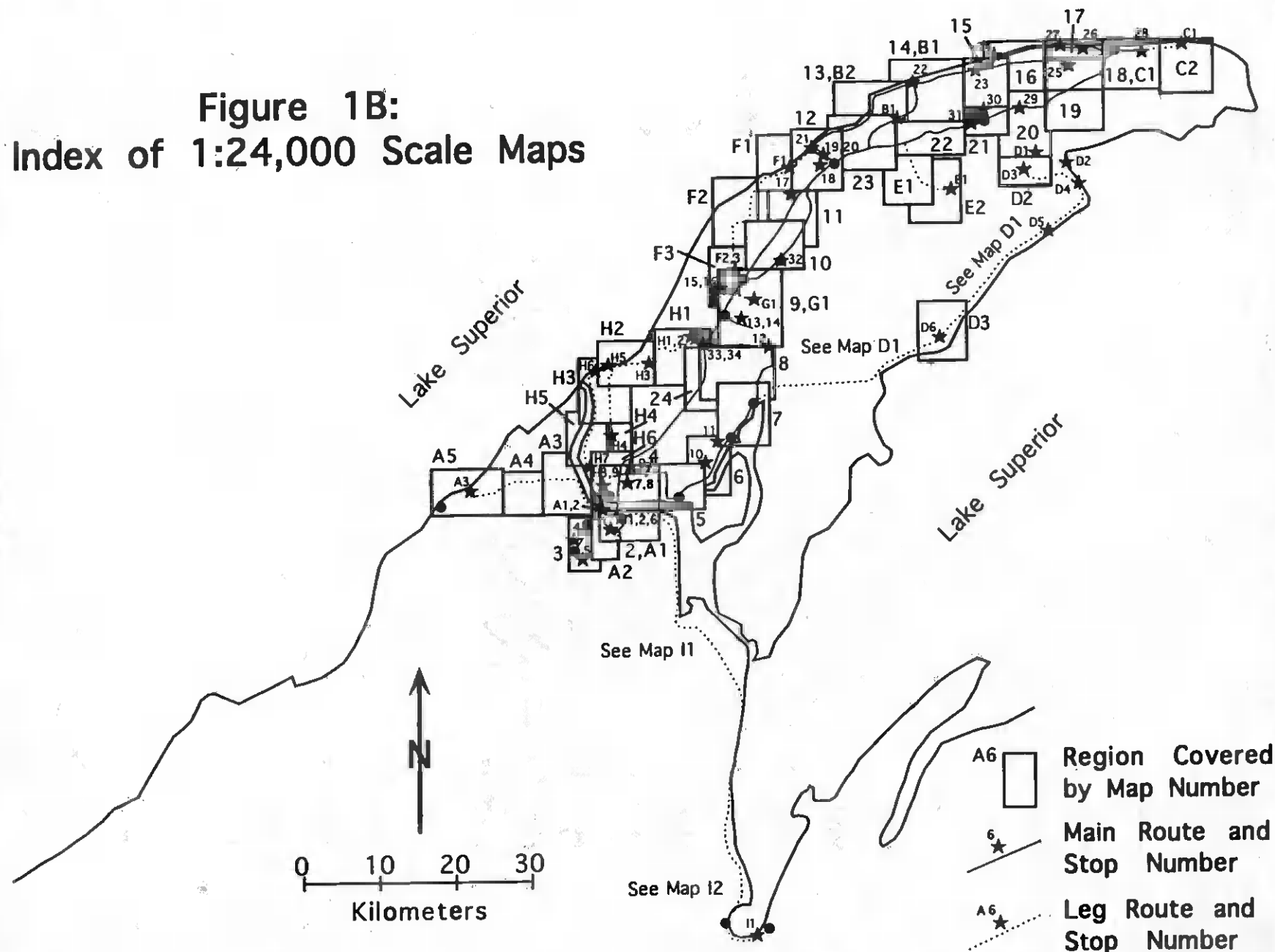


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4	Chassell, Hancock	White, 1956; Cornwall and Wright, 1956a
5	Chassell, Hancock	White, 1956; Cornwall and Wright, 1956a
6	Laurium	Cornwall and Wright, 1956b
7	Laurium	Cornwall and Wright, 1956b
8	Laurium	Cornwall and Wright, 1956b
9	Ahmeek	White and others, 1953
10	Mohawk	Davidson and others, 1955
11	Mohawk	Davidson and others, 1955
12	Phoenix	Cornwall, 1954a
13	Eagle Harbor	Cornwall and Wright, 1954
14	Eagle Harbor	Cornwall and 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
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F3	Ahmeek	White and others, 1953
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H1	Laurium	Cornwall and Wright, 1956b; Hughes, 1963
H2	Hancock, Muggen Creek	Cornwall and Wright, 1956a

H3	Hancock	Cornwall and Wright, 1956a; Warren, 1981
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I1	Michigan DNR-Houghton County	White, 1968
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GEOLOGY OF THE KEWEENAW PENINSULA, MICHIGAN

INTRODUCTION

The Keweenaw Peninsula is located on the margin of Lake Superior. The geology of the Keweenaw Peninsula consists of two quite distinct episodes. The bedrock is composed of consolidated rocks deposited between about 1100 and 1000 million years ago (Ma) as part of the Midcontinent rift system of North America. The bedrock is overlain by unconsolidated glacial sediments deposited during the past 2 million years as part of Pleistocene continental glaciation of North America. The field trip contains stops to view both bedrock and glacial materials. Because the cultural history of the Keweenaw Peninsula is so dominated by the mining of native copper from the bedrock, more emphasis is placed on the geology of the bedrock.

BEDROCK GEOLOGY

This description of the bedrock geology of the Keweenaw Peninsula was taken from a combination of Bornhorst (in press), Bornhorst (1992), and Bornhorst and others (1983) without specific citation or quotation.

Midcontinent Rift System

The Keweenaw Peninsula is on the margin of the Lake Superior segment of the Midcontinent rift system. The Midcontinent rift system extends northeasterly from Kansas to Lake Superior and then southeasterly through lower Michigan (Fig. 2). It was formed at about 1100 Ma by extensional thinning of the rigid Precambrian Superior crustal block. Present day crustal thickness in the Lake Superior region is between 40 and 50 km, which is thicker than adjacent areas (Halls, 1982).

Beneath Lake Superior the rift is filled with more than 25 km of volcanic rocks, including about 10 km of Portage Lake Volcanics (PLV) (Fig. 2) (Cannon and others, 1989; Hinze and others, 1990; Cannon, 1992). The PLV, with a total thickness of about 5 km of rift-filling volcanic rocks, is exposed on the Keweenaw Peninsula. Large volumes of magma were extruded in response to a period of rifting over an asthenospheric mantle plume (Hutchinson and others, 1990). Rift magmatism extended from 1109 to 1087 (Davis and Paces, 1990; Paces and Miller, 1993). The PLV of the Keweenaw Peninsula erupted during a 2 to 3 million year span of time, at about 1095 Ma (Davis and Paces, 1990). It is part of a vast association of igneous rocks of similar age, including the Duluth Gabbro (Fig. 3).

A thick succession of rift-filling clastic sedimentary rocks overlie the rift-filling volcanic rocks, and represent a change from a period dominated by volcanism, to one dominated by sedimentation. While magmatic activity waned, subsidence of the rift basin continued as the thermal anomaly of the asthenospheric plume decayed (Cannon and Hinze, 1992; Hutchinson and others, 1990). A total thickness of up to 8 km of rift-filling clastic sedimentary rocks exist beneath the center of Lake Superior, with a maximum exposed thickness in the western Upper Peninsula of Michigan, of 6 km (Fig. 2) (Cannon, 1992; Cannon and others, 1989). These clastic sedimentary rocks are dominated by red-colored conglomerates (Copper Harbor Conglomerate) and red-colored sandstones (Freda Sandstone), with a thin intervening gray to black shale (Nonesuch Shale). Late in the thermal subsidence phase of the rift, Cannon and others (1989) and Hinze and others (1990) propose that mature red-colored sandstones (Jacobsville Sandstone) was deposited across the entire basin. The age of these rift-filling sedimentary strata is poorly constrained, but is likely between about 1085 and 1060 Ma.

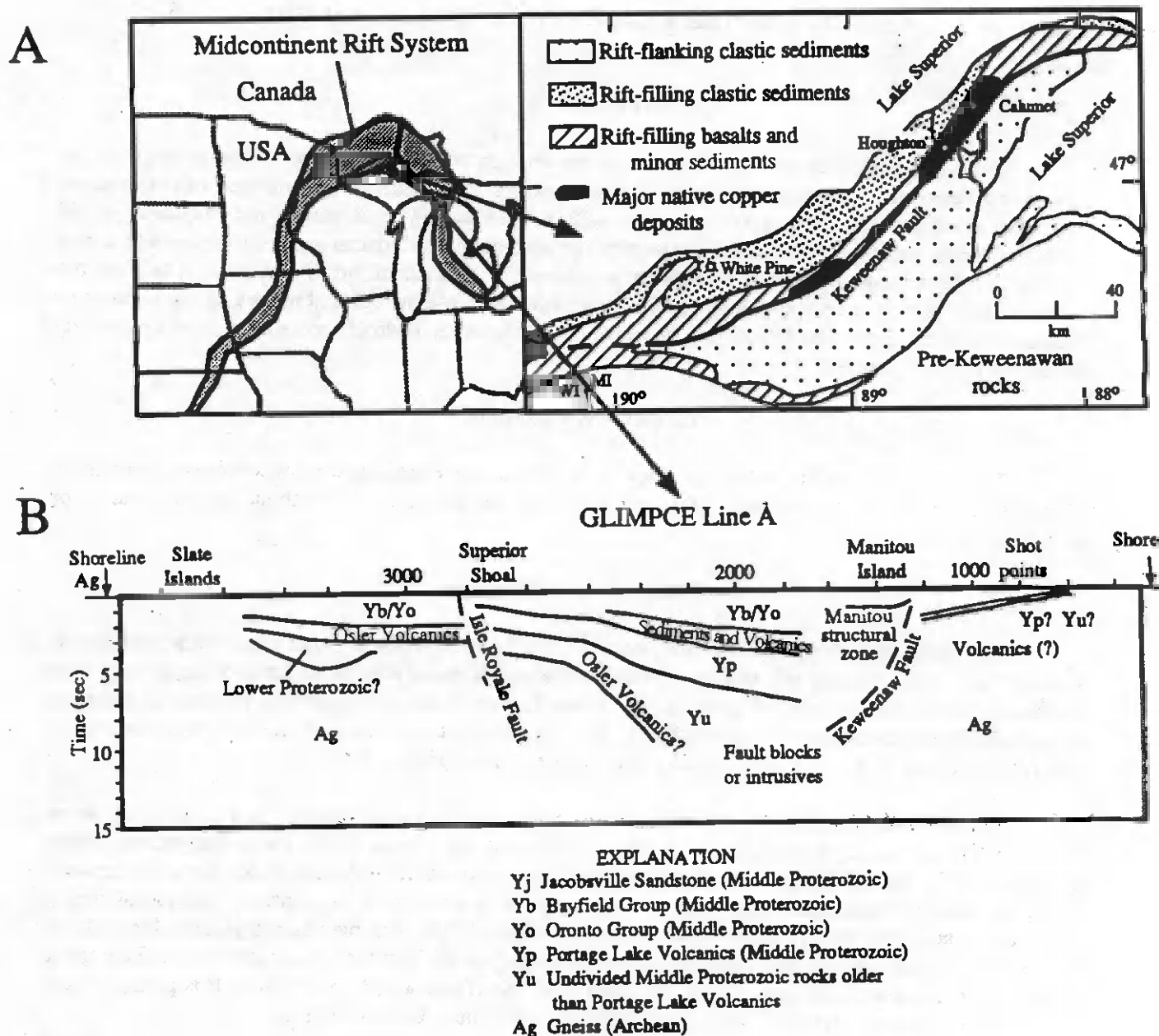
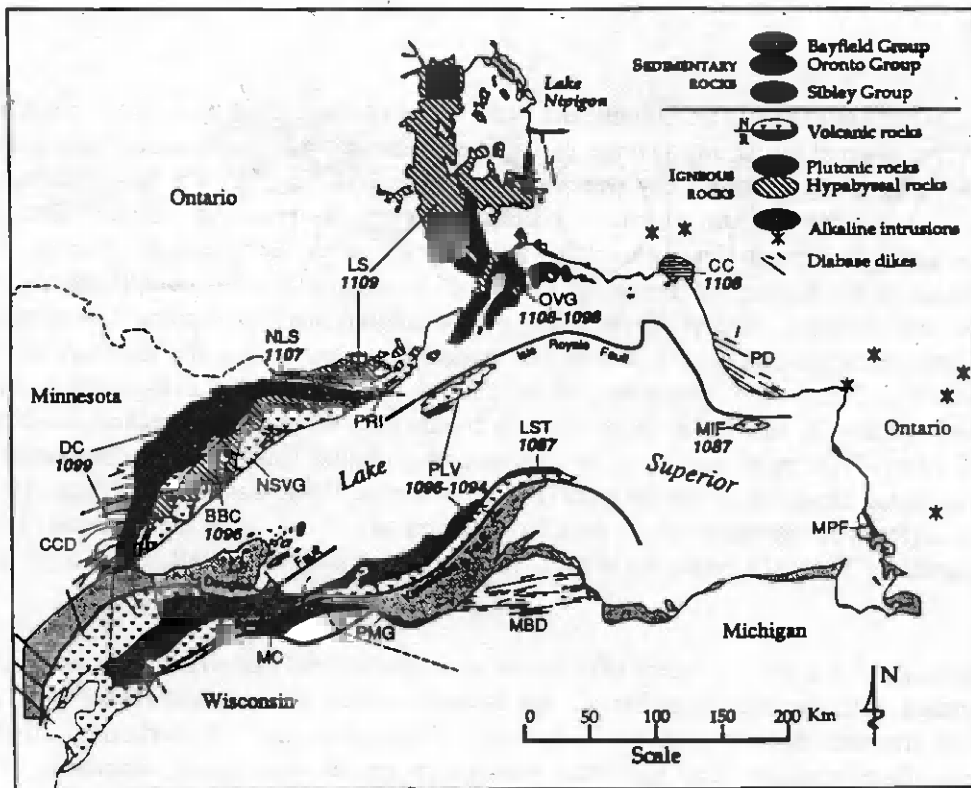


Figure 2: (a) Location of the Keweenaw Peninsula native copper district within the North American Midcontinent rift system (from Bornhorst, in press). The large black area contains all major deposits, the two smaller areas contain minor deposits. (b) Interpretative cross-section across the Lake Superior segment of the Midcontinent rift system by Cannon and others (1989) from seismic-reflection profile Line A.

A



B

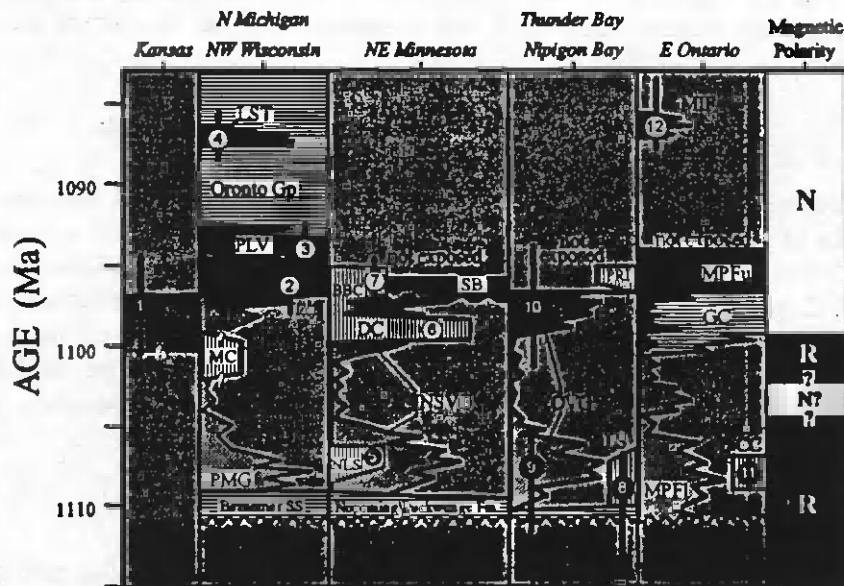


Figure 3: (a) Geology of the Lake Superior segment of the Midcontinent rift system (from Paces and Miller, 1993). High precision U-Pb dates are listed below abbreviated major igneous rock units: BBC, Beaver Bay Complex; CCD, Carleton County dikes; CC, Coldwell Complex; LS, Logan sills; LST, Lake Shore Traps; MPF, Mamainse Point Formation; MBD, Marquette-Baraga dikes; MC, Mellen Intrusive Complex; MIF, Michipicoten Island Formation; NSVG, North Shore Volcanic Group; PRI, Pigeon River intrusives; PLV, Portage Lake Volcanics; PMG, Powder Mill Group; PD, Pukaskwa dikes; OVG, Osler Group. (b) Absolute age correlation for igneous rock units of the Midcontinent rift system (from Paces and Miller, 1993).

The last phase of the Midcontinent rift system was characterized by a transformation of original graben bounding normal faults into reverse faults (Fig. 2 and 4). The Keweenaw Fault is now a low- to high-angle reverse fault, but originally was a major graben bounding growth fault (Cannon and others, 1989). The Keweenaw Fault has several kilometers of reverse displacement which caused steepening of already tilted strata (due to syn-depositional downwarping). Faults, fractures, and broad open folds within rift-filling strata of the Keweenaw Peninsula developed in response to this compressional event (White, 1968; Butler and Burbank, 1929). Over 3 km of red-colored shallow dipping sandstone (Jacobsville Sandstone) was deposited during and after active reverse movement along the Keweenaw Fault in a rift-flanking basin (Fig. 2 and 4). Cannon and others (1993) have determined that high-angle reverse faulting occurred about 1060 ± 20 Ma, based on reset Rb-Sr biotite ages within older Precambrian basement rocks near the Michigan-Wisconsin border. The timing and probable cause of this compressional event is continental collision along the Grenville front (Fig. 5) (Cannon, 1994; Cannon and Hinze, 1992; Hoffman, 1989). This regional compression phase may have started as early as 1080 Ma (Cannon, 1994), and was likely completed by 1040 Ma, based on thermal models (Price and McDowell, 1993; Price and others, in review).

The rocks of the Midcontinent rift system were subsequently overlain by Paleozoic sedimentary rocks associated with the Michigan basin. An isolated outlier of Ordovician limestone at Limestone Mountain and Sherman Hill occurs about 35 km south of Houghton, and is underlain by rift-flanking basin filling Jacobsville Sandstone. The Paleozoic geologic processes were largely atectonic. The Paleozoic rocks were removed by erosion from the Keweenaw Peninsula.

The present day landscape of the Keweenaw Peninsula is strongly influenced by Pleistocene glaciation, especially by features associated with withdrawal of the Wisconsin ice sheet about 15-8 thousand years ago.

Bedrock Stratigraphy of the Keweenaw Peninsula

The bedrock of the Keweenaw Peninsula is composed of subaerial volcanic rocks and clastic sedimentary rocks of the Keweenaw Supergroup (Fig. 6). The volcanic and sedimentary rocks on the northwest side of the Keweenaw Peninsula generally dip moderately toward Lake Superior (Fig. 7) and include the PLV, Copper Harbor Conglomerate, Nonesuch Shale and the Freda Sandstone (Fig. 8). The Jacobsville Sandstone, which fills a rift-filling basin on the southeast side of much of the Keweenaw Peninsula, is in fault contact with the PLV along the Keweenaw Fault. The Jacobsville Sandstone is younger than the Freda Sandstone and related to a late phase of regional compression. The bedrock strata are unconformably capped by Pleistocene glacial deposits.

Portage Lake Volcanics (PLV)

The Portage Lake Volcanics are composed of a succession of more than 200 individual subaerial tholeiitic basaltic lava flows with a total exposed thickness of 2500 to 5200 m on the Keweenaw Peninsula, with the base truncated by the Keweenaw Fault (Butler and Burbank, 1929; Huber, 1975; White, 1968) (Fig. 9). Rhyolitic volcanic and subvolcanic rocks comprise less than 1 volume % of the PLV. Dikes of intermediate composition cut the exposed volcanic pile, but are as a whole uncommon. A diorite stock intrudes the base of the PLV at Mt. Bohemia. Interflow reddish-colored conglomerate and sandstone units total less than 5 volume % of the PLV (Merk and Jirsa, 1982), but increase in abundance toward the top of the formation. These rift-filling volcanic rocks are comparable to the rift zones of East Africa and Iceland (Nicholson, 1992; Basaltic Volcanism Study Project, 1981; Chase and Gilmer, 1973; Green, 1977 and 1982; White 1960 and 1972). Lavas flowed away from feeders along the axis of the rift zone. During intervals of quiescence, sediments were transported from the edges toward the center of the

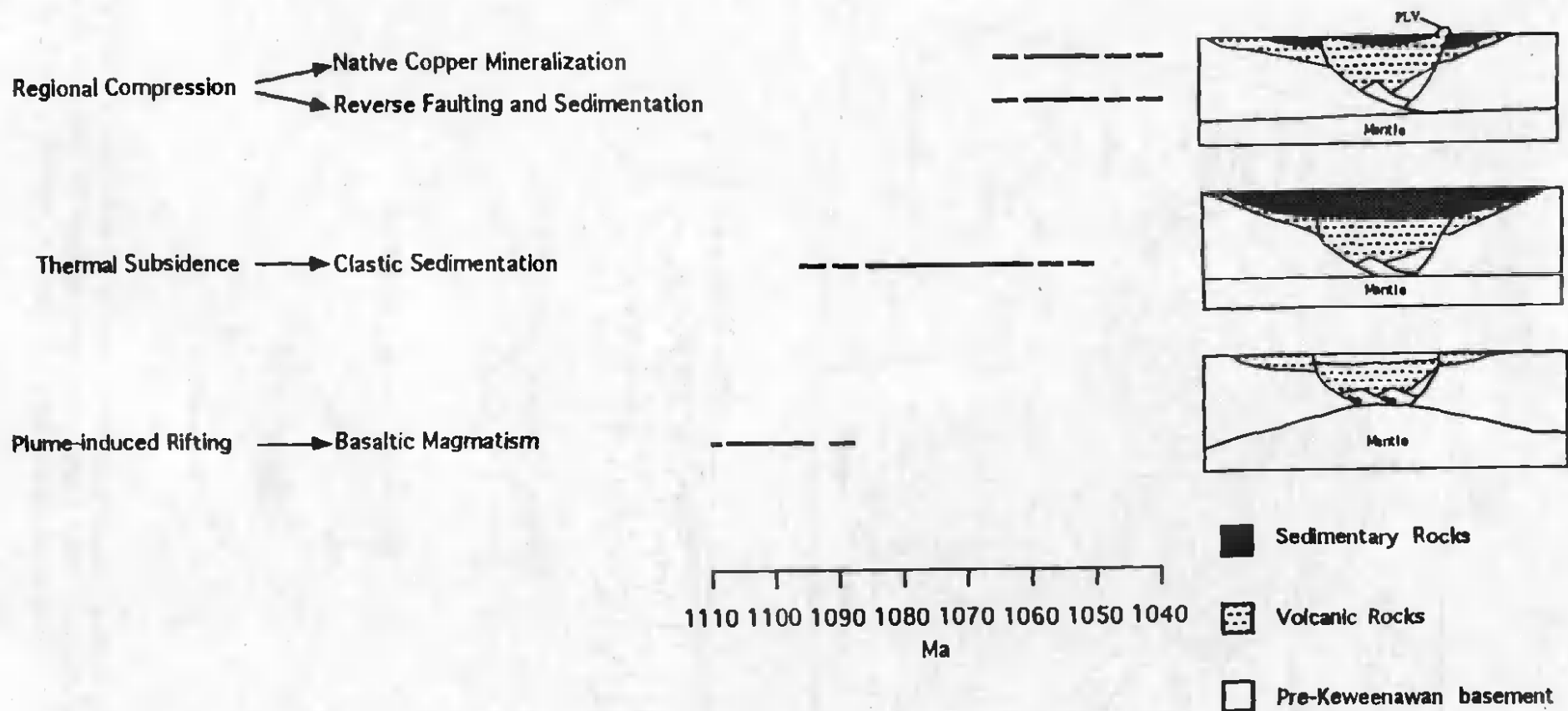


Figure 4: Temporal progression of major geologic events of the North American Midcontinent rift system. Schematic cross-sections of development of the rift from Cannon and others (1989). (a) An initial broad crustal sag filled with volcanic rocks is followed by extension, which results in normal growth faults and eruption of large volumes of plume-induced basalt into the central graben. (b) After volcanism wanes, thermal subsidence continues with the basin progressively filled with clastic sediments. (c) The last phase of development of the rift is regional compression which inverts original graben bounding faults into reverse faults. This results in the uplift of buried rift strata, erosion, and exposure of the PLV in the Keweenaw Peninsula. Compression generated faults/fractures provided for upward movement and focussing of ore fluids into permeable and porous tops of basalt lava flows and interflow sedimentary rocks within the Portage Lake Volcanics (Figure and caption entirely from Bornhorst, in press).

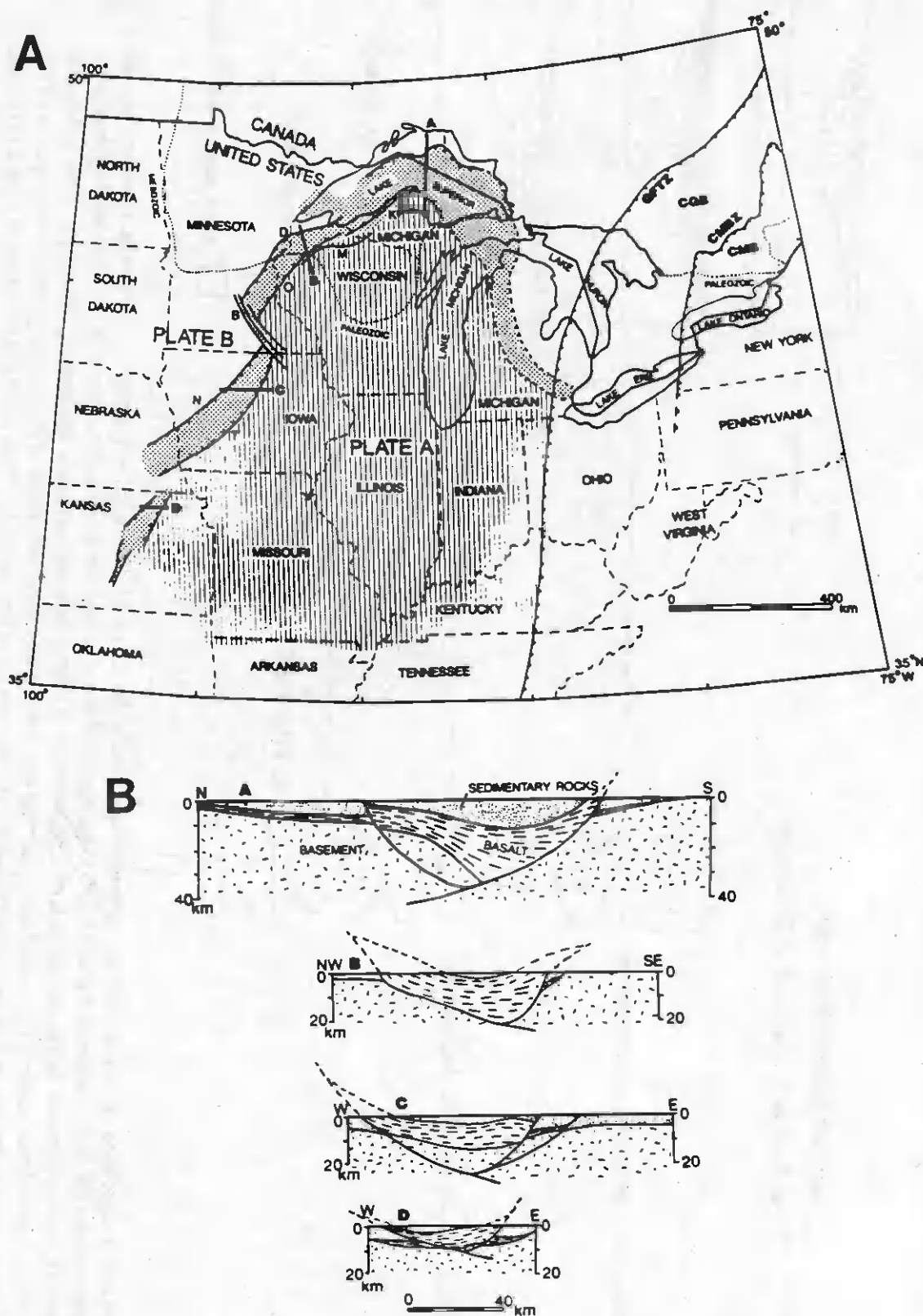


Figure 5: (a) Map showing the Midcontinent rift system in relationship to the Grenville front tectonic zone (GFTZ) (from Cannon, 1994). Compression along the Grenville front was toward the northwest. (b) Cross sections of the Midcontinent rift system of locations given in (a) (from Cannon, 1994).

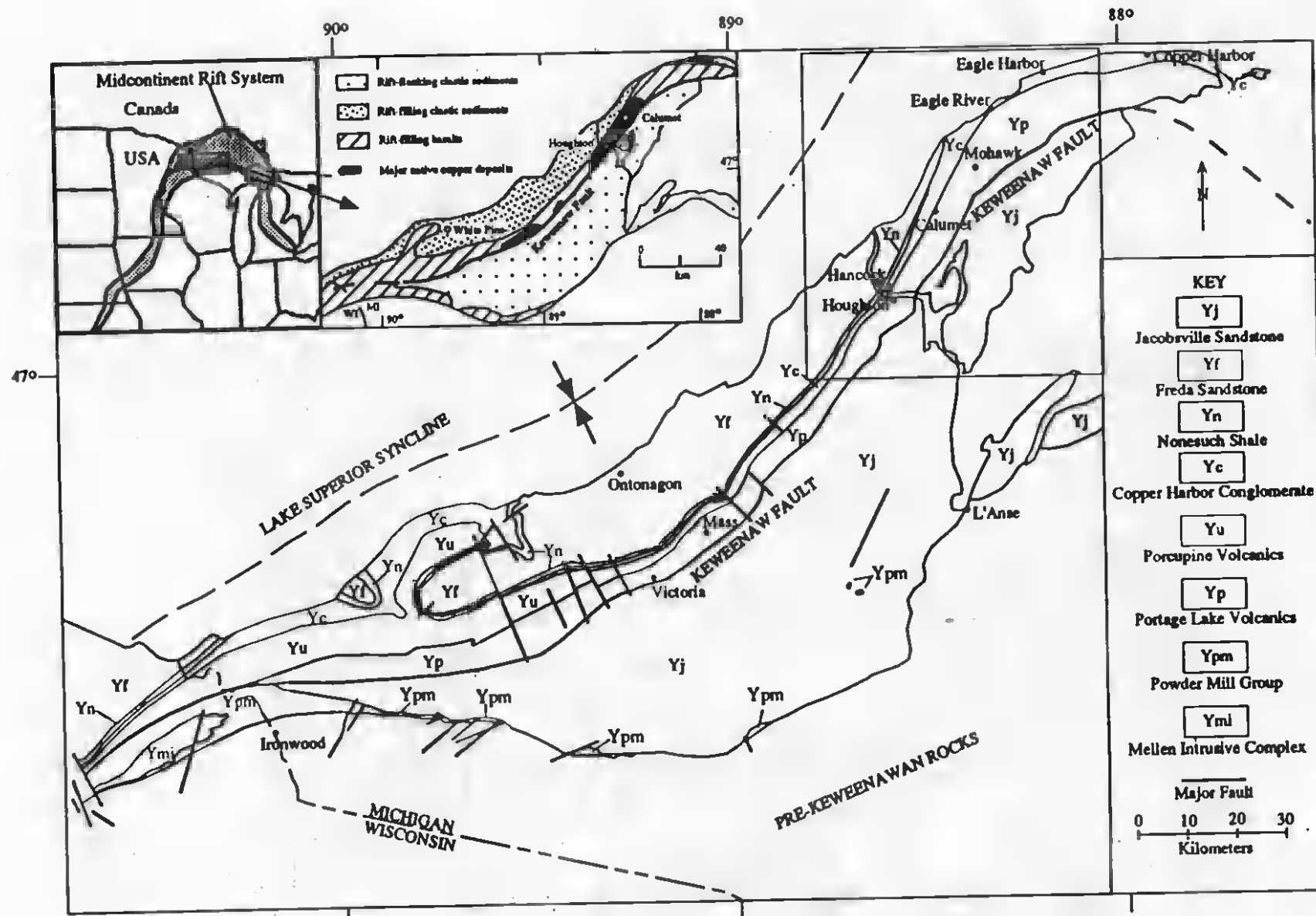


Figure 6: Geologic map of the Keweenaw Peninsula. The box shows the location of Figures 7 and 11 (from Bornhorst, 1992).

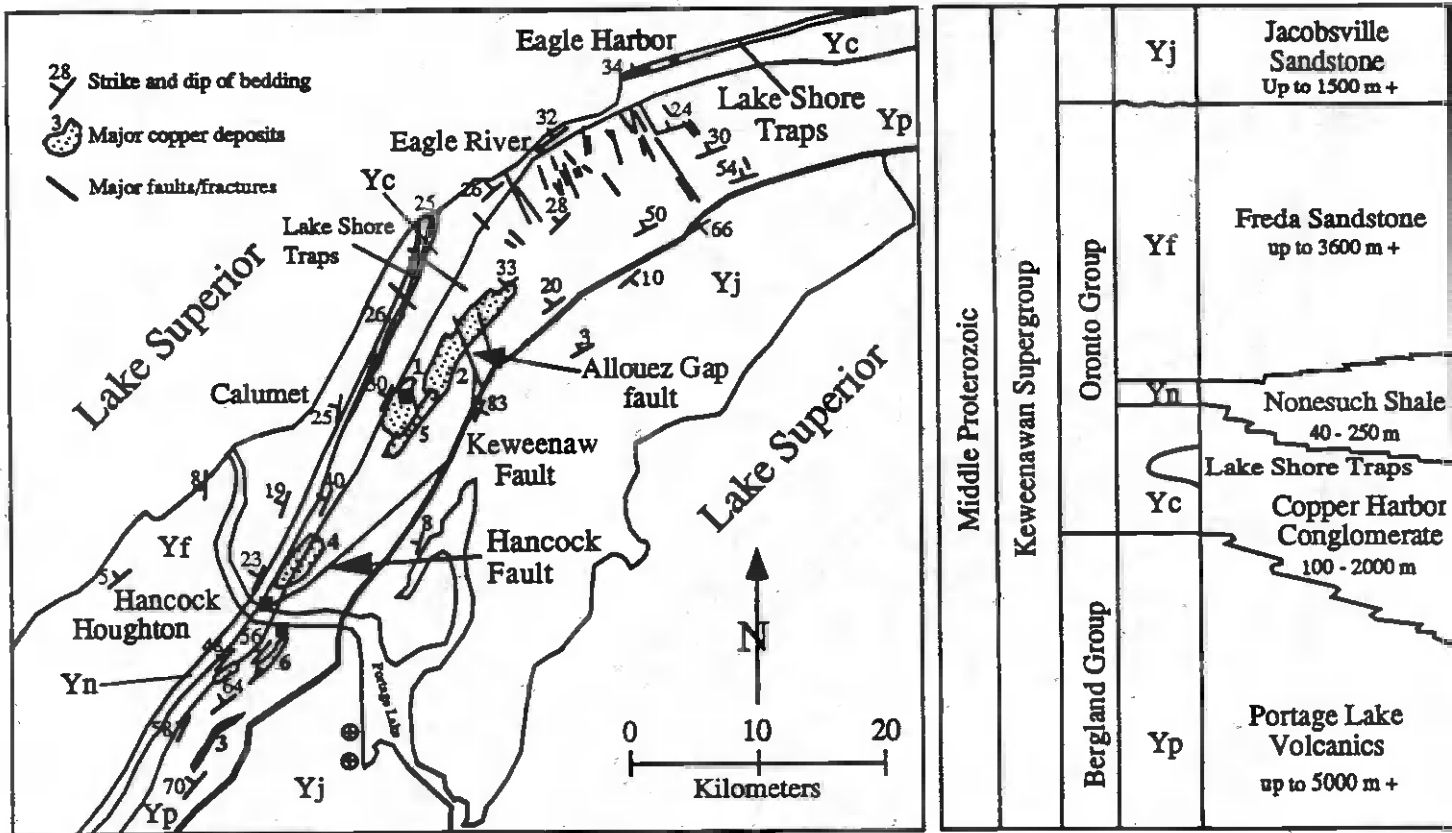


Figure 7: Geologic map and stratigraphic column of the central Keweenaw Peninsula showing attitude of bedding, major faults and fractures, and major native copper deposits (modified from White, 1968; from Bornhorst, 1992). Stratigraphic nomenclature of Cannon and Nicholson (1992). Major native copper deposits (total production of refined copper) are marked by numerals: 1. Calumet and Hecla Conglomerate (1,922 million kg), 2. Kearsarge flow top (1,029 million kg), 3. Baltic flow top (839 million kg), 4. Pewabic flow tops (490 million kg), 5. Osceola flow top (263 million kg), and 6. Isle Royale flow top (155 million kg). Total district production equals 5,013 million kg of refined copper. Location given in Figure 2.

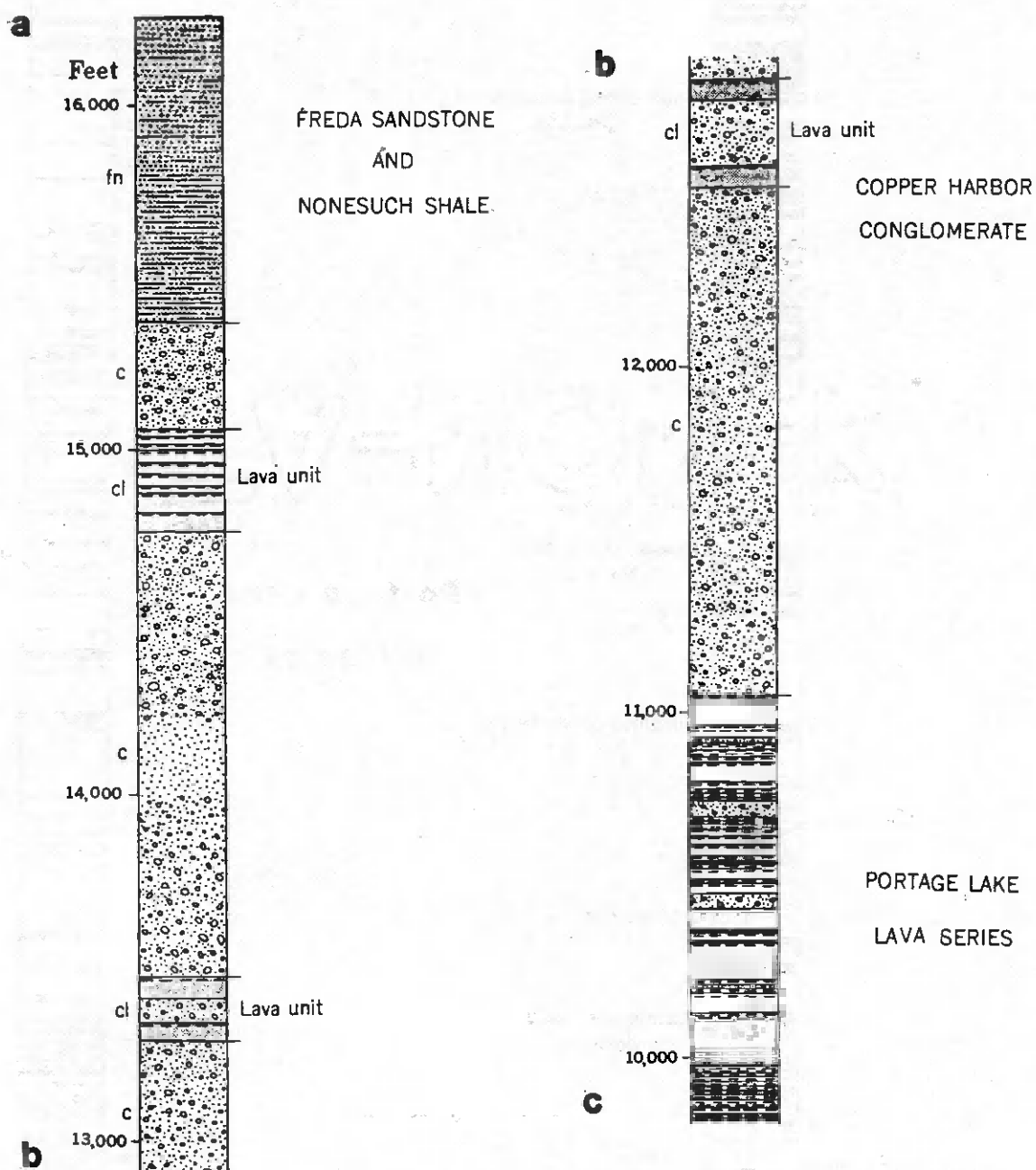


Figure 8: Columnar stratigraphic section northwest of the Keweenaw Fault in the Calumet-Mohawk area (from White and others, 1953).

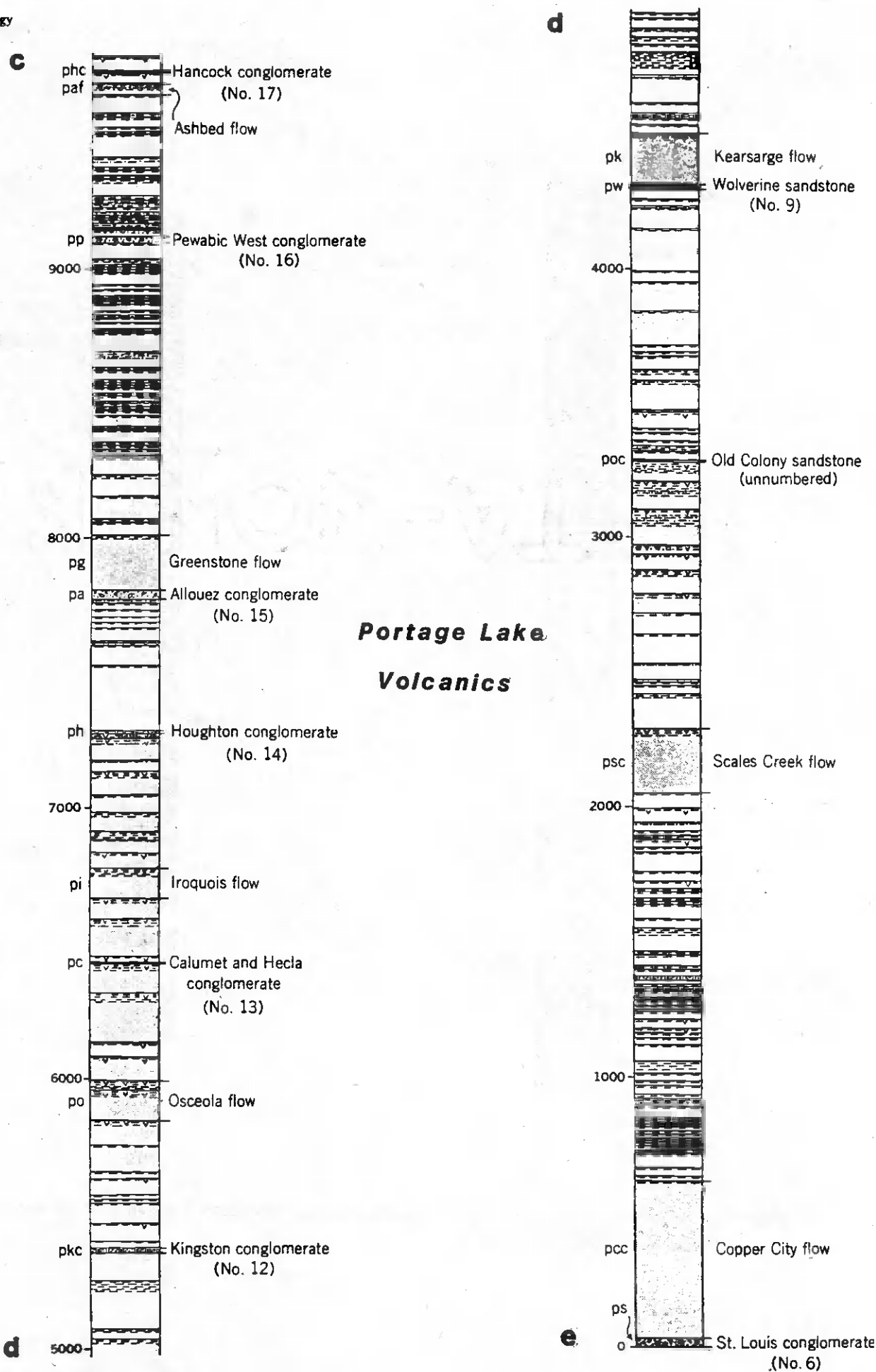


Figure 8 continued.

rift. A complex sub-mature caliche soil profile within the interflow Calumet and Hecla Conglomerate at the Centennial Mine suggests a temperate or tropical climate (Kalliokoski and Welch, 1985).

Basalts of the PLV are relatively primitive, magnesia-rich, high-alumina olivine tholeiites and are typically aphyric (Paces, 1988). Olivine tholeiites are the most abundant, followed by primitive olivine tholeiites, with lesser amounts of quartz tholeiites, and iron-rich olivine tholeiites (Table 1). Also shown in Table 1, are the minor amounts of basaltic andesite, andesite, dacite, and rhyolite that interfinger with the basalts. Geochemical stratigraphy within the basalts is cyclical with minor and major cycles superimposed on an overall trend toward more primitive compositions. Basaltic magmas were apparently derived by partial melting of relatively shallow, sub-continental upper mantle, with younger basalts being more primitive, with little or no contamination by crustal material (Paces and Bell, 1989). The overall compositional trend toward younger, less contaminated primitive magmas can be explained by repeated dike injection and magma eruption at the rift axis that gradually modified the continental crust through which magmas must pass, and by progressive crustal thinning, which provided more efficient transport of magmas to the surface without residence in intracrustal chambers. Model calculations show that major geochemical cycles are due to fractional crystallization and replenishment in large magma chambers near the crust/mantle interface (Paces, 1988). Minor cycles and silicic rocks result from closed system fractional crystallization in small magma chambers within the crust. Eruption in an oxidizing subaerial environment resulted in degassing of volatiles, particularly SO_2 (Comwall, 1951c), that created a sulfur-deficient environment which favored the later deposition of native copper.

Primary magmatic differentiation has long been recognized within tholeiitic flows (Broderick, 1935; Broderick and Hohl, 1935; Comwall, 1951a and b). For example, the Greenstone Flow, the thickest individual flow in the formation (Fig. 9), is chemically stratified due to internal differentiation (Comwall, 1951b; Longo, 1983). The present-day composition of the volcanic rocks was also effected by deuteric or diagenetic 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 (see Fig. 10). The PLV on the Keweenaw Peninsula are a classic locality of abundant and widespread low temperature alteration minerals. Penetrative deformation did not accompany the metamorphic episode, and primary textures are preserved even in the most intensely recrystallized areas.

A typical subaerial lava flow has an average total thickness of about 10 to 20 m (range from 1 to 450 m), and consists of a massive (vesicle-free) interior capped by a vesicular flow top (Paces, 1988; White, 1960). A few of the thicker flows and interflow sedimentary rocks can be traced laterally along strike for up to about 90 km, although many flows have much less continuity in strike direction. The Scales Creek, Kearsarge, and Greenstone Flows are the best documented laterally continuous flows (Fig. 9), with the Greenstone Flow able to be correlated to Isle Royale (Huber, 1975; Longo, 1982). The uppermost 5 to 20% of most individual lava flows is vesicular, with between 5 and 50% vesicles. Because vesicles are commonly filled with secondary minerals, flow tops in local terminology are amygdaloids, and brecciated flow tops are fragmental amygdaloids. White (1968) estimated that 21% of the lava flows in the PLV are fragmental amygdaloids (brecciated). The Copper City Flow (Fig. 9) is dated 1096 ± 1.8 My and the Greenstone Flow is 1094 ± 1.5 My (Davis and Paces, 1990). Based on these data, Paces and Bell (1989) inferred that the PLV was erupted in about 2-3 million years, which represents a rate that is similar to younger rift and flood basalt sequences.

Interflow sedimentary rocks, with thicknesses from a few cm up to about 40 m, are important stratigraphic markers in an otherwise monotonous succession of basalt lava flows. In drill core,

Table 1: Average and representative geochemical data for least altered lavas of the Portage Lake Volcanics (from Paces, 1988). Tholeiites were grouped by Ni content.

	POT	QT1	QT2	IOT	FOT	AND	DAC	RHY
Ni(ppm)	400-300 n=5	300-250 n=9	250-200 n=14	200-100 n=8	100-15 n=6	n=1	n=1	n=1
Wt. %								
SiO ₂	47.82	47.34	48.03	48.55	49.94	56.39	68.44	77.89
Al ₂ O ₃	15.89	15.27	15.32	15.12	13.28	13.78	15.17	12.77
FeO _t	9.77	11.82	12.32	12.86	14.91	9.87	4.46	1.11
MgO	12.44	11.69	9.85	9.06	7.78	5.52	1.14	0.17
CaO	10.58	10.24	10.16	9.65	6.64	5.10	1.40	0.01
Na ₂ O	2.04	2.10	2.25	2.31	2.91	3.94	4.74	3.67
K ₂ O	0.19	0.22	0.33	0.42	1.43	2.27	3.86	4.28
TiO ₂	0.98	1.13	1.35	1.60	2.34	1.83	0.51	0.08
P ₂ O ₅	0.16	0.19	0.22	0.25	0.36	1.00	0.19	0.01
MnO	0.14	0.16	0.16	0.18	0.24	0.30	0.08	0.01
PPM								
Ni	326	279	231	172	54	10	7	5
Cu	37	51	73	86	126	5	13	61
Zr	78	85	101	126	212	430	573	145

FeO_t total Fe as FeO

POT Primitive olivine tholeiite
 OT1 Olivine tholeiite
 OT2 Olivine tholeiite
 IOT Intermediate olivine tholeiite
 FOT Iron-rich olivine and quartz tholeiites
 AND Andesite
 DAC Dacite
 RHY Rhyolite

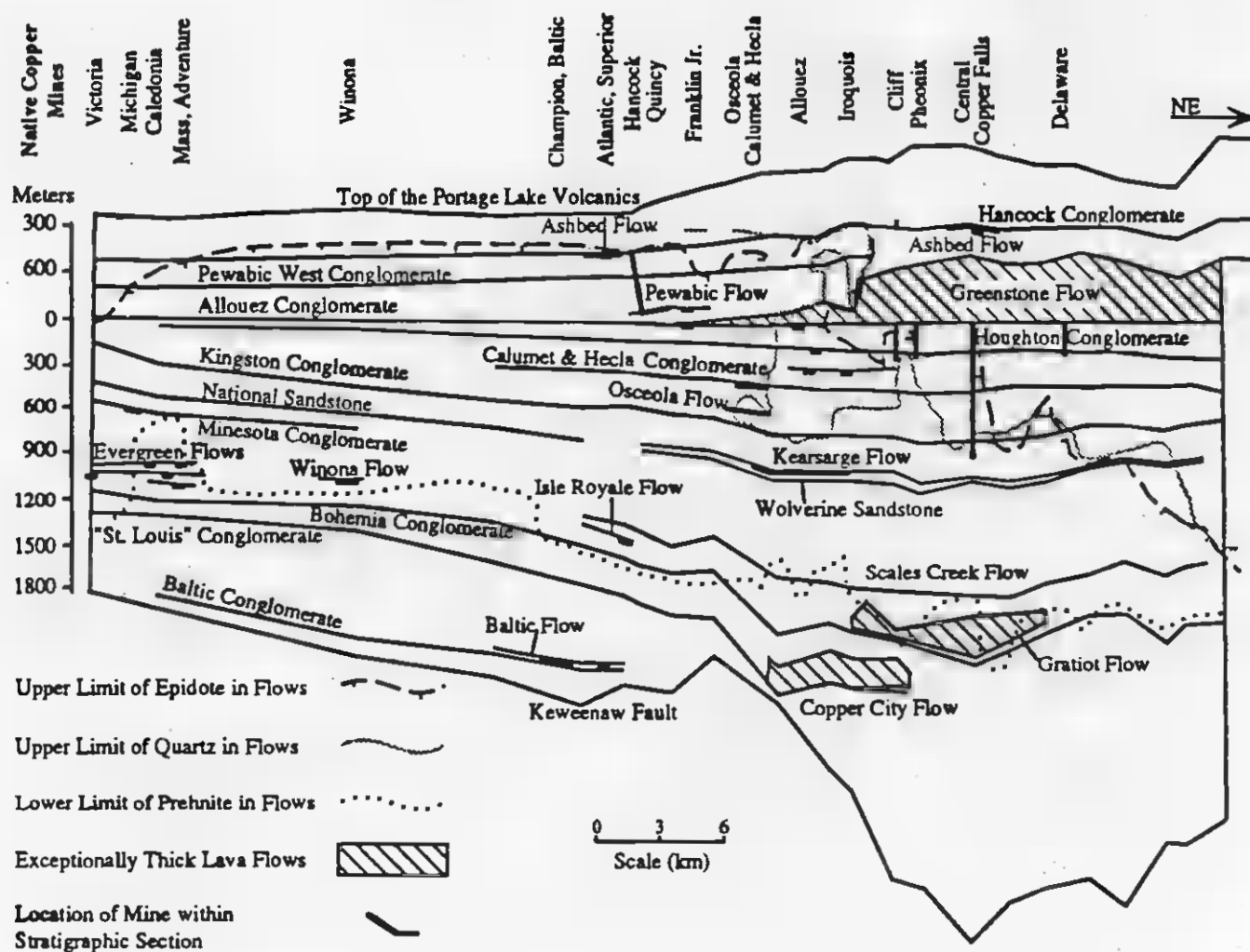


Figure 9: Generalized stratigraphic section of the Portage Lake Volcanics from Victoria to Copper Harbor (modified from Stoiber and Davidson; 1959, from Bornhorst, 1992). Location of the major native copper mines are shown in context with the major stratigraphic marker horizons and with stratigraphic limits of associated amygdule- and vein-filling minerals. See Figure 2 for location of Victoria and Copper Harbor.

sedimentary material in an underlying basalt flow top allows the horizon to be recognized, even where the bed itself is missing (White, 1968). Interflow sedimentary rocks are dominated by well-lithified pebble-to-boulder conglomerate with lesser amounts of interbedded sandstone and occasional significant thicknesses of

siltstone and shale. Conglomerates are characterized by sub-rounded-to-angular pebbles-to-boulders (pebbles typical) in a sandy matrix. Clast lithologies are predominantly felsic, although in detail, considerable variation exists within and between specific beds, reflecting diversity in source terrane. White (1968) interprets most interflow sedimentary beds as alluvial fan deposits laid down on essentially flat-lying lava flows by streams flowing toward the center of the rift basin now under Lake Superior.

The sediment interbeds, in all but the uppermost part of the PLV, have been given names and are shown on the maps included in this self-guided geological field trip (Fig. 8 and 9).

Copper Harbor Conglomerate

The Copper Harbor Conglomerate conformably overlies and locally interfingers with the PLV (Fig. 6, 7, and 8). It is a red-brown basinward-thickening wedge of volcanogenic clastic sediments that varies in thickness from about 100 to 1800 m, and fines distally and upsection, reflecting a waning sediment supply due to progressive erosion of the source area (Elmore, 1984). 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) and Elmore (1984) have interpreted the Copper Harbor Conglomerate as a fining upward prograding alluvial fan complex (Fig. 10). The prevailing climate was likely arid with seasonal high rainfall (Elmore, 1983; Kalliokoski, 1986). Algal stromatolites, which formed in shallow, medial fan lakes and possibly abandoned channels on the alluvial fan surface, occur in the upper part of the Copper Harbor Conglomerate (Elmore, 1983).

The middle portion of the Copper Harbor Conglomerate (northeast of Calumet) includes a succession of lava flows known collectively as the Lake Shore Traps (Lane, 1911) (Fig. 7, see stratigraphic column). The maximum exposed thickness of the Lake Shore Traps is 600 m near the tip of the Keweenaw Peninsula, where the unit is composed of 31 lava flows and one interflow conglomerate (Diehl and Haig, in press). The composition of the Lake Shore Traps is more variable than the PLV; ranging from Fe-rich olivine tholeiites at the base, to Fe-rich olivine-bearing tholeiitic basaltic andesites, to tholeiitic andesites at the top (Paces and Bornhorst, 1985). Geochemical stratigraphic relationships can be explained by a combination of fractional crystallization, parental magma replenishment, and wall rock assimilation. Davis and Paces (1990) report a U-Pb age on zircon of 1087 ± 1.6 Ma for the Lake Shore Traps.

Nonesuch Shale

The Nonesuch Shale, with a maximum thickness of 215 m, is a succession of siltstones; shales; carbonate laminates; and minor sandstones with low-to-moderate amounts of total carbon, that overlie and interfinger with the Copper Harbor Conglomerate (Fig. 7 and 8). Elmore and others (1989) recognize three genetic assemblages: marginal lacustrine (sandflat-mudflat complex), lacustrine (progressively shallowing perennial lake), and lacustrine-to-fluvial. In the lacustrine assemblage, bottom conditions of the lake were anoxic; but became oxic as the lake shallowed. Copper sulfides and native copper in economic quantities are hosted by the Nonesuch Shale at the White Pine Mine (Mauk and others, 1992).

Freda Sandstone

The Freda Sandstone is a cyclic succession of red-brown ferruginous sandstone, siltstone, and mudstone overlying and gradational with the Nonesuch Shale (Fig. 7 and 8). The exposed thickness of

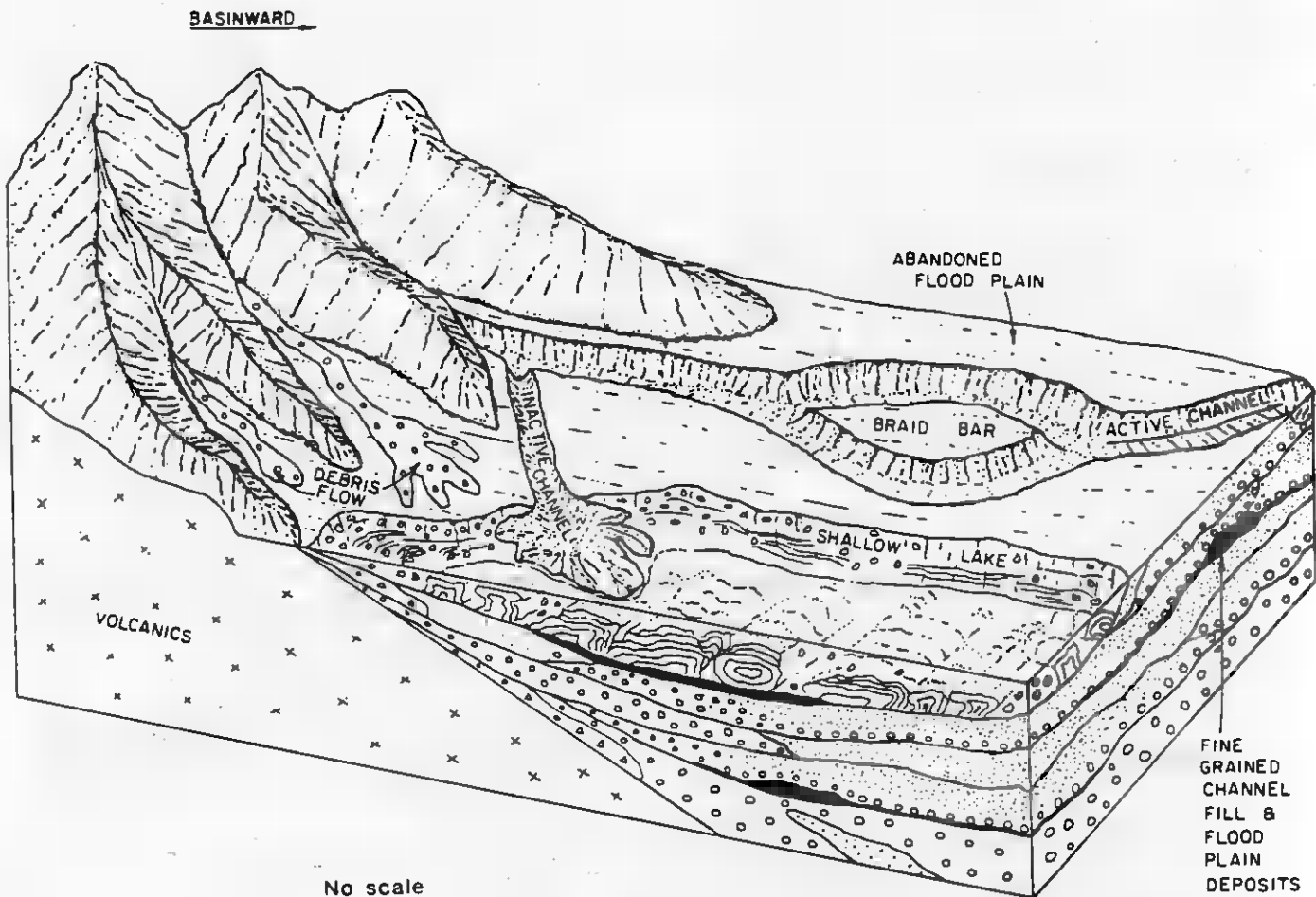


Figure 10: Schematic cartoon of the depositional environment of the Copper Harbor Conglomerate with coalescing alluvial fans, braided stream and flood plain deposits, and shallow ephemeral lakes or abandoned stream channels containing stromatolitic deposits (from Daniels, 1982).

the Freda Sandstone is greater than 3700 m as the top is not exposed. It is dominantly fluvial in origin, with greater compositional maturity than the Copper Harbor Conglomerate (Daniels, 1982).

Jacobsville Sandstone

The Jacobsville Sandstone is a red-to-bleached white coarse-to-fine-grained feldspathic and quartzose sandstone with varying amounts of siltstone, shale, and conglomerate. It is in unconformable contact with Early Proterozoic and Archean rocks to the east, and is in fault contact with the PLV along the Keweenaw Fault on the southeast side of the Keweenaw Peninsula. Some active reverse movement along the fault occurred during deposition of at least part of the formation (Kalliokoski, 1988; Hedgman, 1992). The Jacobsville strata, over 3,000 m thick, are completely devoid of igneous rocks and were fluvially deposited in a rift flanking basin (Kalliokoski, 1982). The rock has been quarried extensively and was used as a building stone in many buildings in the Copper Country and throughout the midwest.

Structure of the Keweenaw Peninsula

The Keweenaw strata dip moderately northwesterly toward the center of the rift (Lake Superior), and their dip angles decrease toward the top of the section (Fig. 7). Angular divergence in dip from the top of the Copper Harbor Conglomerate to the base of the PLV of about 20° , is due to syn-depositional downwarping before deposition of the Nonesuch Shale (White, 1968). A similar amount of syn-depositional downwarping occurred during deposition of the Nonesuch Shale and uppermost Freda Sandstone. The remaining tilting of the beds occurred during reverse movement along the Keweenaw Fault. Bedding in the Jacobsville Sandstone dips less than 5° in most areas, except near the Keweenaw Fault, where dips steepen to vertical in response to drag along the fault.

Dips of specific horizons tend to steepen 20° to 30° along strike from northeast to southwest of the major area of native copper deposits, yielding a gently twisted surface (Fig. 7; White, 1968). The strike of bedding changes to a more east-west orientation at the northern end of this twist.

Broad open synclines and anticlines, with wavelengths of around 10 km and various orientations, are superimposed on the regional dip (Fig. 11). Faults with displacement and mineralized tension breaks are common near the crests of anticlines (Butler and Burbank, 1929). These post-depositional folds are likely related to the Keweenaw Fault (White, 1968).

Faults

The Keweenaw Fault is the major fault in the Keweenaw Peninsula. It is a low- to high-angle reverse fault which marks the border of the main rift-filling volcanic and sedimentary rocks with rift-flanking sedimentary rocks. The Keweenaw Fault was originally a graben-bounding normal fault that, late in the history of the rift, was transformed into a high-angle reverse fault (Cannon and others, 1989). The reverse movement is possibly related to Grenvillian compression (Cannon, 1994).

The Keweenaw Fault strikes more or less parallel to the bedding of the PLV (Fig. 6 and 7). Measured dips of the fault plane range from 70° to 20° N and are generally sub-parallel to dips of the PLV (Butler and Burbank, 1929). The Keweenaw Fault is not a single fault, and in places branches diverge up to 0.8 km from the main fault (Butler and Burbank, 1929). Where exposed, the Keweenaw Fault is denoted by up to 4 m of gouge of red clay-to-breccia (Brojanigo, 1984). Basalt flows within several 100s of meters of the fault are broken and brecciated; with fractures filled with calcite, laumontite, and chlorite. In mines opened near the fault, many fractures subparallel to bedding include fillings of native copper. The St. Louis deposit, the target of a recent evaluation, consists of shear-controlled native copper within a fault, about 150 m from, and subparallel to, the main Keweenaw Fault (it has potential open pit reserves

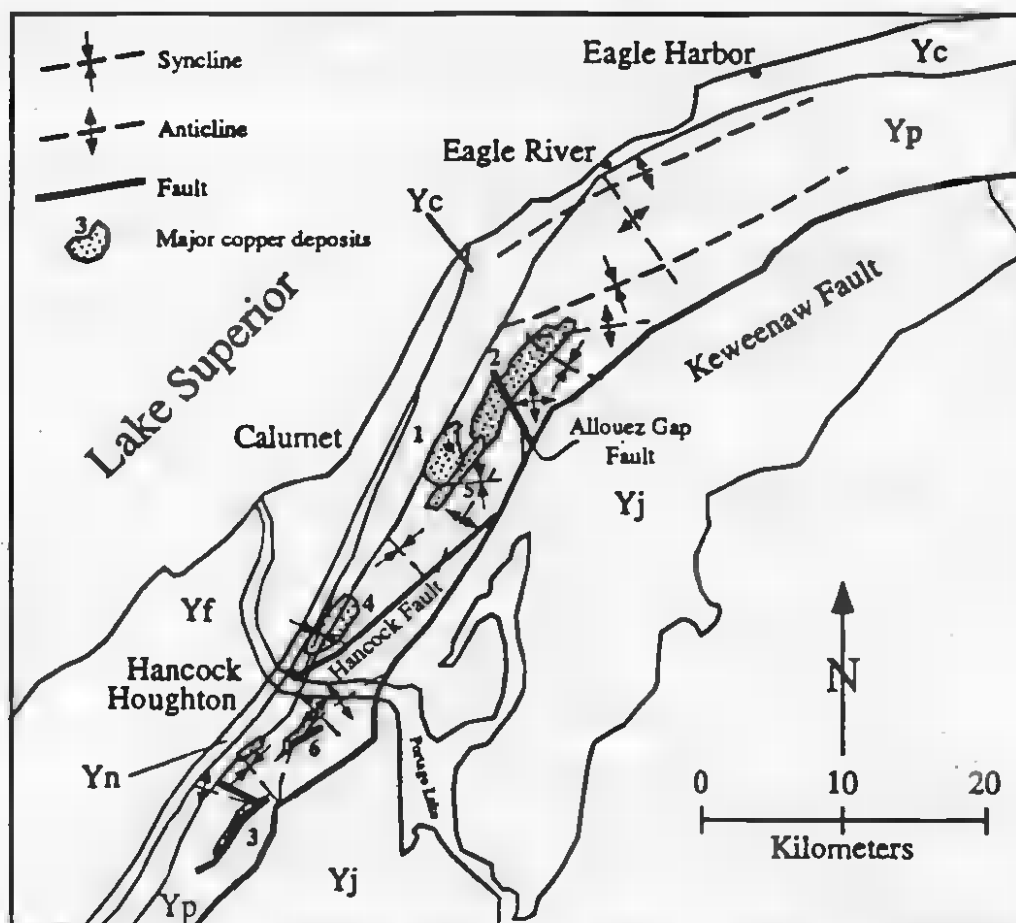


Figure 11: Faults and minor folds in the central Keweenaw Peninsula (modified from White, 1968; from Bornhorst, 1992). Major mines and symbols listed in Figure 7. Location given in Figure 2.

of 8 million tons, grading 0.8 % copper; Northern Miner, 1990).

Several reverse faults, including the Hancock and Isle Royale Faults, cut the PLV at higher angles to bedding than the Keweenaw Fault, with horizontal displacement of 200 m and 50 m, respectively (Butler and Burbank, 1929). High-angle faults striking north-to-northwest are common in the area of the major native copper deposits near the crest of a regional anticlinal (twist) structure (Fig. 7). Displacement along these faults varies from none (tension fractures) to around 100 m (Butler and Burbank, 1929). A number of small tabular vein deposits of native copper-- well known for masses of native copper weighing many tons, but not economically important because of the limited dimensions--are localized along these cross fractures just beneath the thickest basalt flow in the district, the Greenstone Flow. Flow tops and conglomerates are mineralized adjacent to these veins (Butler and Burbank, 1929).

Throughout the PLV, numerous faults or slips exist parallel to the strike and dip of the beds, but these are often difficult to recognize and the amount of displacement is impossible to determine. Such faults, denoted by clay gouge, are common on the top of conglomerate beds, which are perhaps a better slip zone than between basalts (Butler and Burbank, 1929). At the Delaware Mine, red clay fault gouge is a minimum of 20 cm thick at the contact between the Allouez Conglomerate and the overlying Greenstone Flow, and is composed of vermiculite and smectite with minor calcite (Schleiss, 1986).

Mineralization and Alteration

The 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 pounds of refined copper (Weege and Pollack, 1971). Small persistent quantities of native silver (less than 0.1%; White, 1968) accompany the native copper. The major ore producing horizons are geographically restricted to a 45 km-long belt within the PLV in the Keweenaw Peninsula (Fig. 2 and 9). A close relationship in both time and space exists between native copper mineralization and alteration in the PLV (Fig. 12 and 13).

The native copper deposits of the Keweenaw Peninsula are unique in the geological record, except for similar occurrences on a much smaller scale. The uniqueness of the deposit has confounded conventional wisdom from the beginning of exploration (Krause, 1992) when Douglass Houghton believed that the native copper found in float and vein occurrences at the surface reflected supergene alteration of a sulfide ore. Today, even after extensive mining, there is still no agreement among experts about exactly how the deposits formed.

Nature of Ore Bodies

Native copper occurs in brecciated and amygdaloidal flow tops (58.5% of production), interflow conglomerate beds (39.5% of production), and cross vein systems (about 2% of production) (Fig. 7 and 9). The four largest deposits in the district produced 85% of the 5 billion kg total district production at an average grade of about 2%.

Lava Flow Tops

Brecciated flow tops (fragmental amygdaloid) are much more common hosts for native copper deposits than unbrecciated amygdaloidal flow tops (White, 1968). Flow top deposits are between a footwall of barren basalt in the massive interior of the same flow and a hanging wall of barren basalt in the succeeding flow. Deposits in brecciated amygdaloidal flow tops grade downward and laterally to amygdaloidal basalt with low or barren ore grades. Both distribution of brecciated flow top and contained native copper is irregular. Usually native copper is more abundant near the top and bottom of the

brecciated interval of the flow top, but in exceptionally rich ore shoots, the entire brecciated flow top contains significant copper (White, 1968). In some cases, rich ore shoots are located in tongues of brecciated flow top within massive basalt (Weege and Schillinger, 1962). In general, stope heights are from 3 to 5 m. For major ore bodies, the strike length ranges from 1.5 to 11 km, with dip length from 1.5 to 2.6 km (Butler and Burbank, 1929; White, 1968). Ore shoots have a wide variety of shapes, some are elongate with widths of 30 to 150 m, and lengths from 50 m to around 600 m with a preferred orientation, whereas others are irregular with no preferred orientation (White, 1968). Autointrusive bodies in the flow top can localize ore shoots (Weege and Pollack, 1971), and a number of deposits are in the tops of, or just below, exceptionally thick flows (Butler and Burbank, 1929; White, 1968). White (1968) suggested that thicker flows concentrate bedding slip in adjacent layers, resulting in more fracturing.

Conglomerates

Although interflow conglomerate beds make up only a small volume of the PLV (<5%), they host comparatively large amounts of native copper (~40% of district production). Deposits occur as lenticular beds with a hanging wall of massive basalt and a footwall of lava flow top, which commonly contains sand and silt. Usually native copper is concentrated along stratigraphic bands (0.5 to 5 m thick), and rich bands tend to jump from one stratigraphic position to another within the same conglomerate (Weege and others., 1972). Within the Kingston Conglomerate (Fig. 9) ore can occur throughout the 12 m bed, but tends to be concentrated in three zones: footwall (43% of the copper), hanging wall (33% of the copper), and intermediate (24% of the copper) (Weege and others., 1972).

Native copper ore in the Calumet and Hecla Conglomerate (Fig. 9), the largest single native copper lode in the district (production of 1.9 billion kg along a strike length of 4.9 km, and 2.8 km down-dip), occurs where the bed thickens from less than 1 m to up to 6 m (Butler and Burbank, 1929; Weege and others., 1972). Ore grades in the Calumet and Hecla Conglomerate decrease significantly with depth, as the width of the conglomerate unit greater than 1.5 m thick increases; that is, essentially the same amount of copper is distributed throughout a greater volume of conglomerate (Butler and Burbank, 1929). Highest grades occur where up-dip moving ore fluids were focused by the tapering, lenticular nature of the conglomerate (Butler and Burbank, 1929). The highest grade ore in the Calumet and Hecla Conglomerate tends to be where relatively little fine interstitial material exists, or where interstitial spaces are filled with coarse sand or small pebbles (Weege and others., 1972).

Localization of native copper ore in conglomerate beds is dependent on sedimentary and environmental factors, such as grain size and the bedrock paleotopography; the latter controlled the location of paleostreams and variations in the thickness of conglomerate.

Veins

Although the first mines in the district were developed on veins which tend to cut bedding at high angles, vein deposits are of slight economic importance in the district. Distribution of native copper in veins is more erratic than either flow top or conglomerate lodes, but tend to be richest at or near intersections with well-oxidized flow tops (Butler and Burbank, 1929). Native copper can occur as both finely disseminated, and as masses weighing many tons in the same vein. Flow tops and conglomerates are mineralized adjacent to veins. Veins hosting native copper also exist within stratabound lode deposits (Broderick, 1931).

Ore and Gangue Minerals

Native copper represents over 99% of the metallic minerals in the mined orebodies of the

Keweenaw Peninsula. Persistent small quantities of native silver (less than 0.1%; White, 1968) accompany the native copper. Most of the native copper carries a small amount of arsenic in solid solution (less than 0.5% arsenic in total copper + silver + arsenic, typically less than 0.2%; Broderick, 1929). Copper-nickel arsenides, particularly common in the Kearsarge deposit (Stoiber and Davidson, 1959), occur in veins that are paragenetically late (Butler and Burbank, 1929; Moore, 1971). Within the native copper deposits, chalcocite, also paragenetically late, occurs as small veins cutting flow top deposits, and as coatings on joints with calcite in conglomerate deposits (White, 1968).

Several copper sulfide deposits occur in flow tops near the base of the PLV within the Keweenaw Peninsula in association with mafic intrusive rocks (Broderick and others., 1946; Robertson, 1975). Chalcocite is the principal ore mineral with rare, paragenetically late, native copper (Woodruff and others., 1992; Wilkin and Bornhorst, unpublished data). One deposit is now the target of possible new mining activity, with probable reserves of 3.1 million tons, grading 2.95% copper (Northern Miner, 1990). The relationship between these copper sulfide deposits and the native copper deposits is conjecture, and is discussed more at Stop E1.

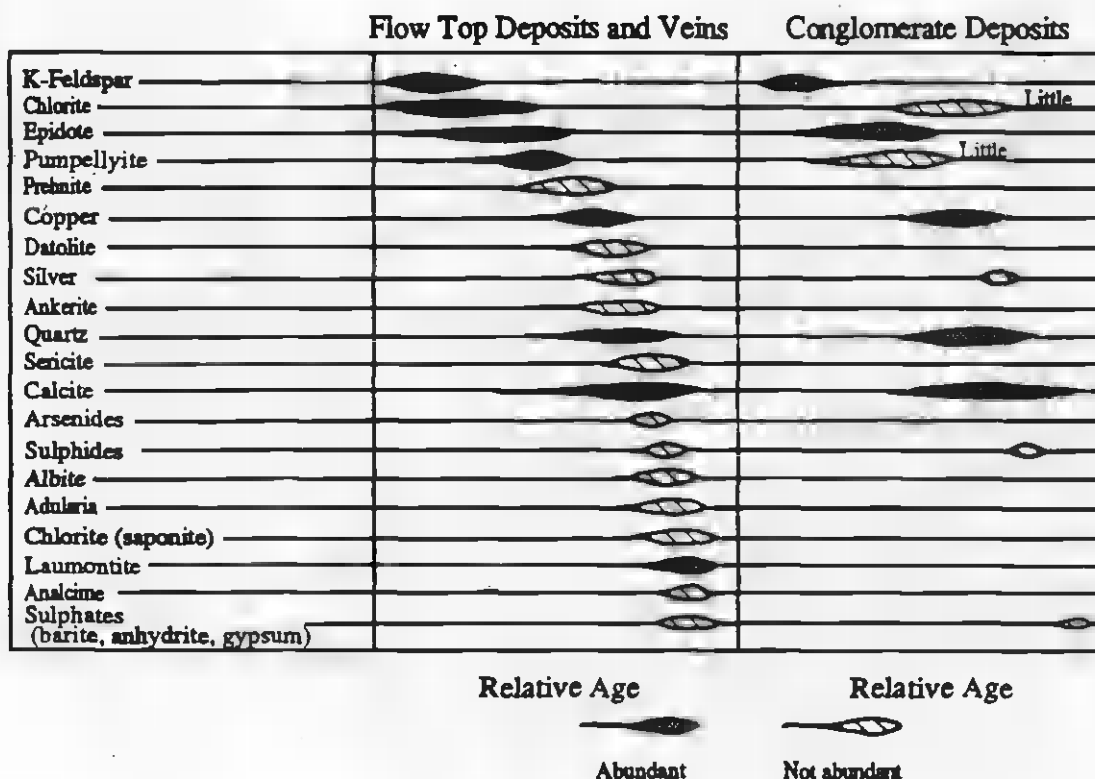
Flow tops and interflow sedimentary rocks were altered pervasively by hydrothermal fluids, producing low-temperature metamorphic mineral assemblages (Fig. 12 and 13). The minerals occur as amygdale and vein fillings, and as whole rock replacements in the most permeable units. Intensity and degree of alteration varies as a function of position within individual flows, position in the volcanic pile, and proximity to cross-cutting fractures. While flow tops are intensively altered, massive interiors of lava flows are much less altered, and hydrothermal alteration is limited to the vicinity of faults and fractures. Some original igneous minerals are present in the massive interiors of flows, but secondary minerals exist in all flows regardless of their thickness (Scofield, 1976; Paces, 1988). The geochemical composition of many flow interiors are only slightly modified by secondary hydrothermal processes, and represent original igneous composition. Thus, the interiors of lava flows acted as aquicludes with respect to the paleohydrothermal system.

A close relationship in time exists between native copper mineralization and secondary minerals formed during alteration of the PLV, although individual deposits may not exactly follow the district-wide paragenesis (Fig. 12). Metamorphic zoning based on distribution of amygdale-filling minerals, equivalent to zeolite and prehnite-pumpellyite facies, varies vertically (Fig. 13) and laterally (Fig. 9) within the PLV. On the tip of the Keweenaw Peninsula (Fig. 6), zeolite minerals exist through most of the stratigraphic section with epidote appearing only in the basal 750 m (Cornwall, 1955; Cornwall and White, 1955), indicating lower metamorphic grades extend deeper into the PLV. The major native copper mines are all within a section containing epidote, and near the appearance of quartz (Fig. 9; Stoiber and Davidson, 1959). A detailed study by Stoiber and Davidson (1959) of the Kearsarge deposit shows that native copper is much more irregularly distributed than secondary mineral zones although a general correlation exists between grade and the variation of quartz and microcline (see Stop 13). Broderick (1929) and Livnat (1983) showed that the metamorphic mineral zones (isograds) within the PLV dip shallowly toward Lake Superior, compared to the volcanic strata which dip moderately, implying that the volcanic units were tilted prior to metamorphism and associated native copper mineralization.

Age Constraints for Native Copper Deposits

Native copper found in both stratabound lodes and in veins is accompanied by the same gangue minerals (Butler and Burbank, 1929; Broderick, 1931; White, 1968), indicating contemporaneous epigenetic deposition. Native copper mineralization is younger than the Copper Harbor Conglomerate, which hosts rare veins of calcite and native copper. White (1968) interpreted the age of native copper mineralization as after deposition of much or all of the Freda Sandstone, and has an undetermined

A



B

Widespread Minerals

albite, calcite, chlorite, epidote, hematite, laumontite, native copper, prehnite, pumpellyite, quartz, sphene

Locally Important Minerals

analcime, ankerite, arsenides, chabazite, chalcedony, clay minerals, datolite, heulandite, native silver, natrolite, orthoclase/microcline, sericite, sulfates, sulfides, thompsonite

Rare Minerals

apophyllite, atacamite, bowlingite, brucite, chlorastrolite, chrysocolla, cuprite, faujasite, fluorite, powellite, serpentine, stilbite, tenorite, tourmaline, whitneyite, wairakiite

Figure 12: (a) Paragenesis of secondary minerals in flow top deposits and veins, and conglomerate deposits (modified from Butler and Burbank, 1929; from Bornhorst, 1992). (b) List of secondary minerals within the Portage Lake Volcanics of the Keweenaw Peninsula (compiled from Butler and Burbank, 1929; Stoiber and Davidson, 1959; Jolly and Smith, 1972).

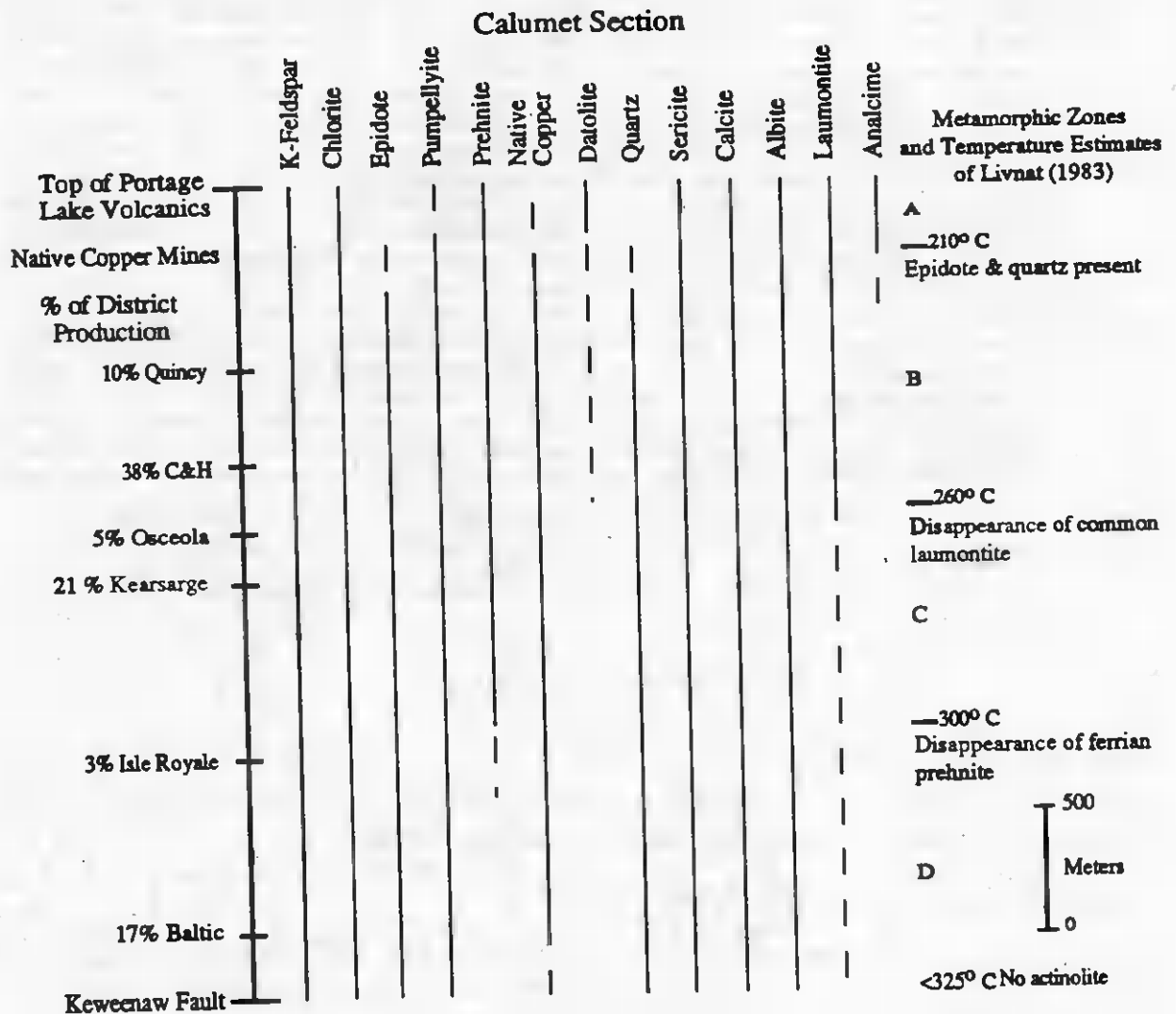


Figure 13: Distribution of amygdule- and vein-filling minerals in the Calumet cross section of the PLV (compiled from Livnat, 1983; Stoiber and Davidson, 1959; from Bornhorst, 1992). Vertical distribution of secondary minerals is similar throughout the area of the major native copper mines listed on the vertical stratigraphic column (see Fig. 7 and 9 for mine locations).

relationship with respect to the Jacobsville Sandstone--although minor amounts of native copper at the bottom of a 1,100 m drill hole within the Jacobsville Sandstone near Rice Lake (Weege, personal communication) suggests that mineralization post dates deposition of at least some of the Jacobsville Sandstone. Broderick (1929, 1931), Butler and Burbank (1929), Broderick and others (1946), White (1968), Weege and others (1972) and other geologists, have pointed out the close connection between native copper mineralization and deformation related to the Keweenaw Fault. At the White Pine Mine, Mauk and others (1992 and this volume) show evidence for two distinct episodes of copper mineralization: 1) main stage copper sulfides and subordinate native copper formed during diagenesis of the Nonesuch Shale, and 2) second stage native copper and subordinate copper sulfide synchronous with thrust faulting. The thrust faults are interpreted as contemporaneous with the Keweenaw Fault, leading to the interpretation by Mauk and others (1992) that second stage copper at White Pine Mine is related to the native copper deposits of the Keweenaw Peninsula. Based on field relations native copper mineralization is younger than deposition of rift-filling volcanic and sedimentary rocks, and likely synchronous with reverse faulting and earliest deposition of rift-flanking sedimentary rocks.

Bornhorst and others (1988) used the Rb-Sr method on amygdale-filling microcline; calcite; epidote; and chlorite to determine the absolute age of mineralization as between 1060 and 1047 Ma ($\pm$ ~ 20 Ma), which is similar to an approximate age of Keweenaw reverse faulting of 1060 Ma (Cannon and others., 1993). Thus, both field relationships and radiometric dating suggest an age of native copper mineralization of about 1060 to 1050 Ma, some 30 Ma after rift-filling volcanism, but contemporaneous with reverse faulting along the Keweenaw Fault (Fig. 4).

Genetic Model For Native Copper Deposits

Genetic models for the native copper deposits of the Keweenaw Peninsula call upon epigenetic ore-bearing fluids related to either magmatic (Broderick, 1929; Butler and Burbank, 1929; Broderick and others, 1946) or burial metamorphic processes (Stoiber and Davidson, 1959; White, 1968; Jolly, 1974). Conclusive evidence does not exist against either hypothesis. The localization of native copper deposits in the Keweenaw Peninsula may favor a magmatic hypothesis, but the widespread distribution of native copper in Keweenawan basalts argues for widespread regional ore fluids related to burial metamorphic processes. The age of mineralization some 30 Ma after most Keweenawan magmatic activity also suggests direct magmatic processes are not important for ore genesis. Stable isotope data are consistent with burial metamorphism, but cannot rule out magmatic hypotheses (Livnat, 1983). Although evidence is not conclusive, cumulative arguments favor formation of ore fluids during burial metamorphism of the rift rocks.

The source of native copper is possibly the rift-filling basalts. Dissolution of only a few ppm of copper from the over 18 km of basalt in the rift during burial metamorphism yields more than adequate amounts of copper (White, 1968). Copper may have been initially tied up in Fe-Ti oxides (Cornwall and Rose, 1957) with subsequent oxidation releasing copper during burial metamorphism of the lava flows in the deep parts of the volcanic pile within the rift (Jolly, 1974). In this way, burial metamorphism of rift-filling basalts at temperatures of 300°C to 500°C could result in the generation of a Cu-rich ore fluid. Stable isotope data on secondary minerals indicate that burial-derived fluids probably were modified evaporated intermontane meteoric water (Kelly, personal communication; Livnat, 1983).

Cornwall (1956) suggested that the ore fluids had much lower sulfur content than magmatic hydrothermal fluids, as copper sulfides are uncommon. Degassing of sulfur from subaerial erupted lava flows would result in low residual sulfur contents, and burial metamorphism of this low sulfur source rock would yield a low sulfur ore fluid. Fluid inclusion studies suggest the ore fluids were Ca-Na brines (5 to 10 weight % salinity) (Livnat, 1983). Copper was likely transported as a chloride complex, and its

abundance in the ore fluids could have been as high as 2,000 ppm, based on assumed amounts of copper and water derived from metamorphism and thermodynamic solubility of copper (Jolly, 1974). However, fluids extracted from inclusions in alteration minerals contained less than about 200 ppm Cu (Livnat, 1983).

Temperature history models (McDowell and others, 1992; Price and McDowell, 1993; Price and others, in review) predict that the PLV in the center of the rift was likely dehydrated as much as 10 to 15 m.y. prior to ore deposition. These fluids could have slowly migrated toward the edge of the filled rift, where millions of years after their generation they were available to be tapped and focused into ore-bearing horizons. Alternatively, temperatures of buried basalt on the flanks of the rift were sufficiently high to have been the source of ore-bearing fluids. A sufficient mass of copper exists in basalt strata on the flanks of the rift, thus the ore fluids need to be tapped only some few (<10) km beneath the present ore horizons.

The fundamental control on the movement of ore fluids to sites of deposition is permeability. Primary permeability includes brecciated and vesicular lava flow tops and interflow sedimentary rocks separated by variably impermeable massive flow interiors. Thus, the vertical section consisted of thin aquifers separated by thin aquicludes. Overlapping of successive lava flows and minor unconformities suggests that *simple* up-dip movement of ore fluids was not likely. Secondary permeability provided by the network of faults/fractures produced during late compression (reverse movement along the Keweenaw Fault) integrated the plumbing system, allowing for upward movement of ore fluids. Since the turn of the century, it was clear that faults played a major role in localization of many of the native copper deposits. Fault brecciated and re-cemented alteration minerals indicate that faults and fractures were principal pathways for ore fluids, and that faulting was synchronous with mineralization.

For the Baltic and Isle Royale flow top deposits (20% of district production), Broderick (1931) concluded that ore fluids moved upward along faults until intersecting with the permeable flow tops at the ore deposition stratigraphic interval. A similar situation exists for the Caledonia, Mass, and Adventure Mines near the town of Mass (Fig. 9). There, native copper is hosted in flow tops in close association with abundant faults and fractures (Bornhorst and Whiteman, 1992). Faulting occurred before, during, and after deposition of native copper. Many faults host native copper, some even, with quite high grades. Native copper occurs in the massive interiors of lava flows in areas where they are cut by faults. For mines near Mass, it is likely that faults were the principal pathways for transport of ore fluids to the flow tops.

The Allouez Gap Fault (Fig. 7) cuts the volcanic succession and connects with the Keweenaw Fault. Almost every permeable horizon near the Allouez Gap Fault contains above average amounts of native copper; nowhere else in the district, are there so many mineralized horizons. R.J. Weege, former chief geologist of C & H Mining Company, suggested in an unpublished company report that the Allouez Gap Fault was the single most important fluid pathway in the district, perhaps linking 60% of the district production. The largest flow top deposit in the district occurs where the Allouez Gap Fault bisects the thickest segment of the Kearsarge Flow along its 55 km strike length (see Stop 13). Higher grades and production occur northeast of the fault, where fractures parallel to the fault are more abundant. The small Kingston deposit (9 million kg of copper) is also bisected by the Allouez Gap Fault. Ore grade and degree of alteration lead Weege and others (1972) to conclude that fluids moved outward from the fault, rather than up-dip. The Houghton and Allouez Conglomerate deposits (50 million kg of copper) are near the Allouez Gap Fault, with local faults and the conglomerates themselves connected directly with the Allouez Gap Fault. The giant Calumet and Hecla Conglomerate deposit (1900 million kg of copper) is a few km west of the Allouez Gap Fault. The axis of the ore body trends at depth toward the fault

(Weege and others, 1972) which is consistent with ore fluid movement up the fault and then up-dip along the permeable conglomerate. The deposit has a higher grade up-dip, where hydrothermal fluids were focused by lateral (strike direction) thinning of the permeable conglomerate (Butler and Burbank, 1929). Within the Allouez Gap Fault zone, brecciated and recemented native copper and alteration minerals (Butler and Burbank, 1929) indicate that movement along the fault occurred before, during, and after deposition of native copper.

Northeast of the major native copper district, small vein deposits are localized just beneath the thickest basalt flow in the district, the Greenstone Flow, with permeable flow tops and conglomerates mineralized adjacent to these veins. A reasonable model is one in which hydrothermal fluids moved up along cross fractures until stopped by the impermeable massive interior of the Greenstone Flow.

Broderick and others (1946) noted that the Keweenaw Fault would make an ideal conduit for ore fluids. Although no deposits are located along the main fault itself, fluid movement along the Keweenaw Fault and adjacent rocks is indicated by highly altered rocks and by several small native copper deposits along nearby subparallel branch faults. It is likely that the Keweenaw Fault was an important factor in the paleohydrologic system with intersecting subsidiary faults or permeable stratigraphic horizons, such as flow top or conglomerates, providing secondary conduits. Like the Keweenaw Fault, in other districts main faults are often not or little mineralized (Sibson, 1987). NW-SE directed regional compression (Fig. 2 and 5) could have caused the generally NE-trending Keweenaw Fault to be under tight compression, whereas perpendicular structures would be under dilation stress and more open for fluid movement.

The intersection of major subsidiary faults with locally thick permeable horizons is a key factor in localization of ore. Faults may have behaved as valves and become highly permeable pathways immediately postfailure (Sibson and others., 1988; Sibson, 1990) with periodic upward movement of hotter, sulfur-poor, burial metamorphic fluids into permeable horizons. Fluid flow in small fractures cutting the massive interior of lava flows (e.g., Deloule and Turcotte, 1989) may have also been an important mechanism for the upward transport of ore fluids. White (1968) suggested that permeability due to fracturing was more important than primary permeability for the movement of ore fluids. At the horizon of ore deposition, fluid pressures were likely greater than hydrostatic, but less than lithostatic (e.g., Powley, 1990). The pressure was dependent on the height of rocks above the horizon of ore deposition ("mountains" in section c in Fig. 4) maintained by compressional uplift rather than stratigraphic depth.

Mixing of ore fluids channeled upward through faults and fractures with cooler, more dilute resident fluids may have been an important mechanism for precipitation of native copper. Oxygen isotope data for calcite shows about a 10 per mil spread at a given stratigraphic depth, and for less data on quartz, the spread is about 5 per mil (Livnat, 1983). This spread could be interpreted as due to fluid mixing. Wells (1925) and Richards and Spooner (1986) suggest that copper deposition resulted from mixing of fluids of different salinities and sources. The needed reducing conditions for precipitation of native copper seems to rule out mixing of ore fluids with oxidized groundwaters. The oxidation of magnetite to hematite and the prograde metamorphic reaction of pumpellyite to epidote occurred along with native copper deposition, and also could have provided reducing conditions needed for the deposition of native copper (Jolly, 1974). Reduction of the ore fluids during deposition of native copper would have yielded copper sulfides if sulfur was present in the fluids, confirming the low sulfur character of ore fluids. Overall, a combination of fluid mixing; fluid-rock interaction; and cooling may have caused precipitation of native copper.

The onset of a compressional phase late in the history of the rift provided a network of faults/fractures that integrated the plumbing system and allowed for easier and more rapid upward movement of fluids. Major faults were principal pathways for focussing of ore fluids where they intersect

locally thick permeable strata. The Midcontinent rift system does not seem unusual in either igneous activity or in geothermal gradient, as compared to other rifts (Hutchinson and others, 1990). Low grade burial metamorphism/alteration of mafic volcanics is observed throughout the world, yet native copper ore deposits of the Keweenaw Peninsula are unique. Major compressional faulting late in the history of the Midcontinent rift distinguishes it from other flood basalt provinces. The superposition of this deformation event on temporally available "burial" metamorphic fluids being generated via the thermal pulse related to rifting, may have provided the critical component in the genetic model of the native copper deposits. The thick section of basalts in the rift and a high geothermal gradient may have also played a role (Nicholson and others, 1992), albeit secondary, in the genesis of the native copper deposits. The localization of large native copper deposits within the Keweenaw Peninsula may be controlled by several factors, including favorable geometric orientation within the regional compression stress field; abundant faults, fractures, and broad open folds as compared with other areas of the rift; and coincidence of flow tops and conglomerates, which are thickest in the Keweenaw Peninsula, with abundant faults and fractures. Since much of the Midcontinent rift system is buried, perhaps another area of native copper deposits remains hidden.

Despite over 100 years of research on the native copper deposits of the Keweenaw Peninsula, there remains many unanswered questions, from a small to a large scale. While our understanding of this district slowly improves, the exact reasons for the large native copper deposits in the Keweenaw Peninsula will likely remain speculative for years to come.

GLACIAL GEOLOGY

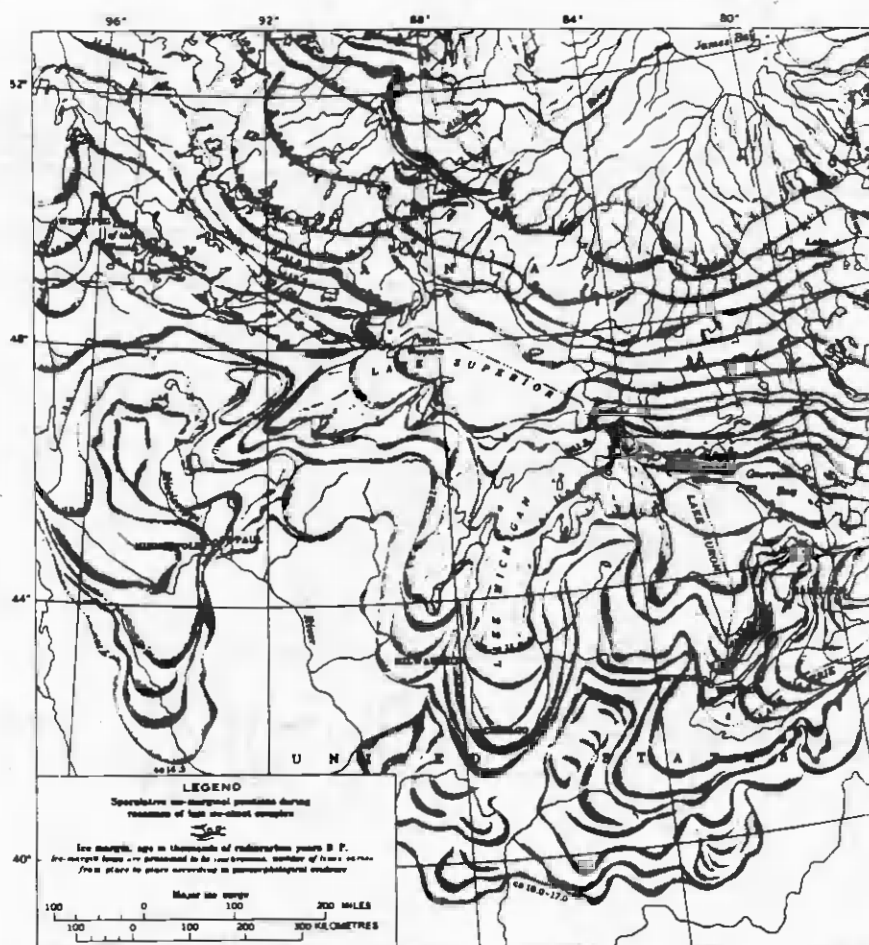
Over the past two million years the Keweenaw Peninsula has been effected by four stages of continental glaciation. Each subsequent glacial advance significantly modified or obliterated the effects of previous glaciations except for major bedrock basins (Warren, 1981). Glacial features of the Keweenaw Peninsula are related to advance and retreat of glaciers of the Wisconsin Stage (the most recent stage of glaciation).

During the maximum extent of Wisconsin glaciation, an ice sheet extended as far south as central Illinois and Ohio (Fig. 14). The entire Keweenaw Peninsula was covered by up to 3000 m of ice during the maximum glaciation (Sugden, 1977). The source area of the ice sheet was in the vicinity of James Bay (Fig. 14). The Keweenaw Peninsula tended to deflect the flow of ice, especially when the ice sheet was thinner during advance and retreat, and caused two major lobes of the ice sheet (Warren, 1981) (Fig. 15). The Keweenaw Bay lobe made the final advance and retreat of the ice sheet about 13,000 years ago. An end moraine (a linear mound of till) marks the limit of this lobe (Fig. 16). The Keweenaw Bay lobe moved from east to west in the vicinity of Houghton, whereas further south, it moved southward (Warren, 1981).

As the ice sheet retreated (melted back), the very large volumes of water filled the Lake Superior basin, turning it into a glacial lake. Shoreline features allows various stages of glacial lakes within the Lake Superior basin to be recognized. The Duluth Glacial Lake was the longest lived of the glacial lakes (Regis, 1993) and was bordered on the east by the Keweenaw Bay Lobe (Fig. 17). There are numerous post-Duluth Glacial Lake Stages of the Lake Superior basin, with 10 stages recognized in the western Lake Superior basin (Table 2). The levels of the glacial lakes depended on the position of the ice front, outlets, and crustal rebound (Regis, 1993). Isostatic rebound after glacial retreat causes the shoreline of the glacial lakes to tilt southward (Warren, 1981). Hughes (1963) documented 5 post-Duluth shorelines in the western side of the Keweenaw Peninsula, and since none of them extend north of Allouez Gap (Fig. 18; see Stop 16) the ice front was in that position (Warren, 1981). The lack of shoreline features in the eastern Keweenaw Peninsula indicates that this area was still occupied by glacial ice (Clark and others,

Table 2: Stages of glacial lakes in the Lake Superior basin (from Farrand, 1960).

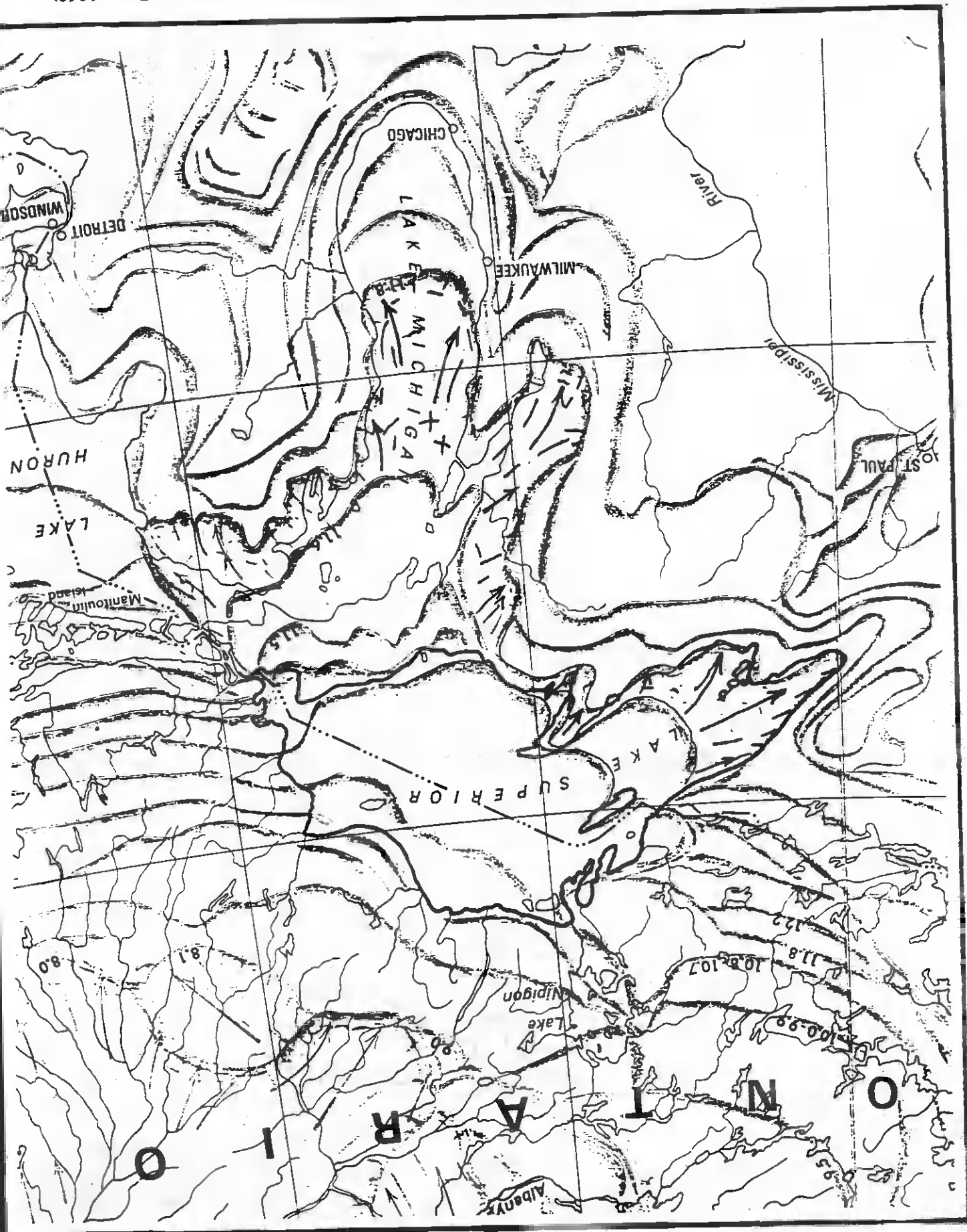
Lake Stage	Elevation at Mnong	Elevation at Allouez Gap	Age (BP)	Ice Border
Lake Superior	608	608	---	-----
Sub Jault	a	b	1000	-----
Jault	a	b	2000	-----
Algoma	611	614	3200	-----
Nipissing	631	638	4100	no ice sheet
Houghton Low Stage	544	541	8500	on "height of land" (?)
Dorion	590	613	9000	on "height of land" north of lake
Upper Post-Mnong	a	651	8500	
Mnong	658 658	670 690	9200	North shore ice border
Beaver Bay	691 712 738 777 819 847	724 750 774 813 855 883	10,000	Post-Valders ice border - (Pigeon R. to Keweenaw Peninsula - "Marquette-Sturgeon- Newberry" moraines)
Manitou	905	941		
Manitou	949	985		
Washburn	1022 1044	1058 1080		
Moquash	1087	1123		
Highbridge	1131	1167		
Sub-Duluth	1178	1214		
Duluth	1224 1256 1273 1284	1269 1292 1304 1320	10,220 (N-359) (C-14)	Early Valders retreat



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

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



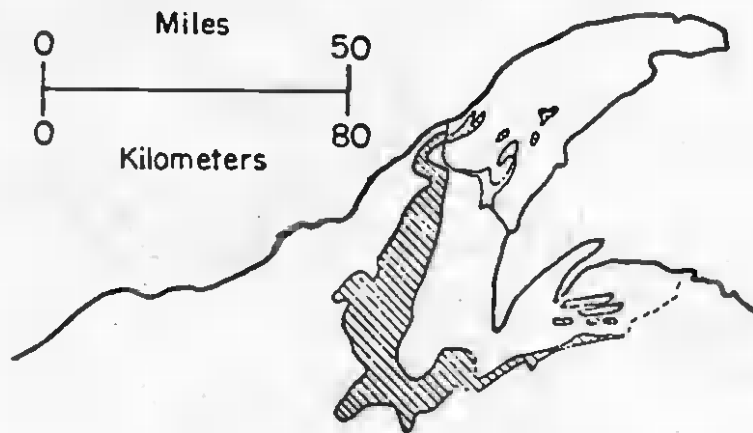


Figure 16: End moraine of the Keweenaw Bay lobe glacier (from Kalliokoski, 1976; Warren, 1981).

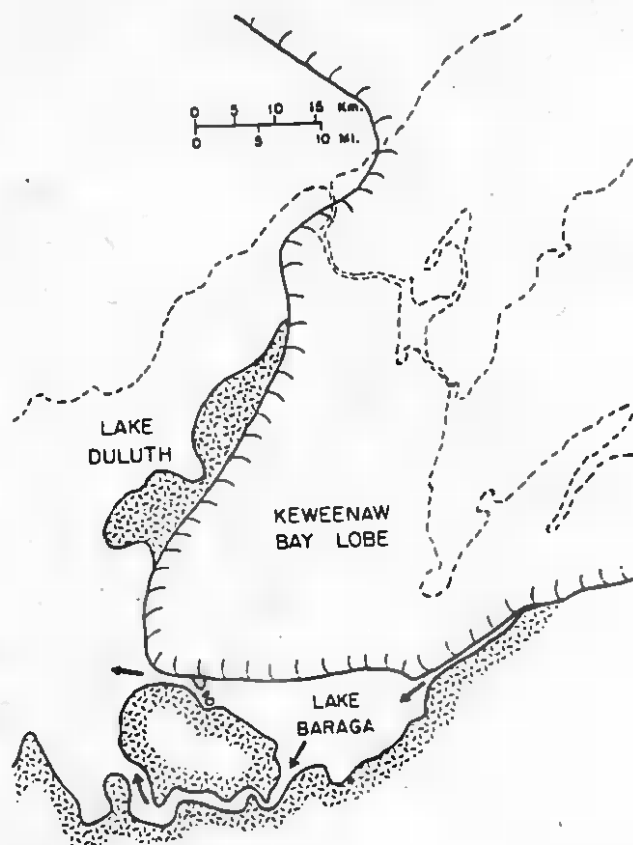


Figure 17: Keweenaw Bay lobe glacier and position of glacial Lake Duluth at the 1250 foot elevation (from Warren, 1981).

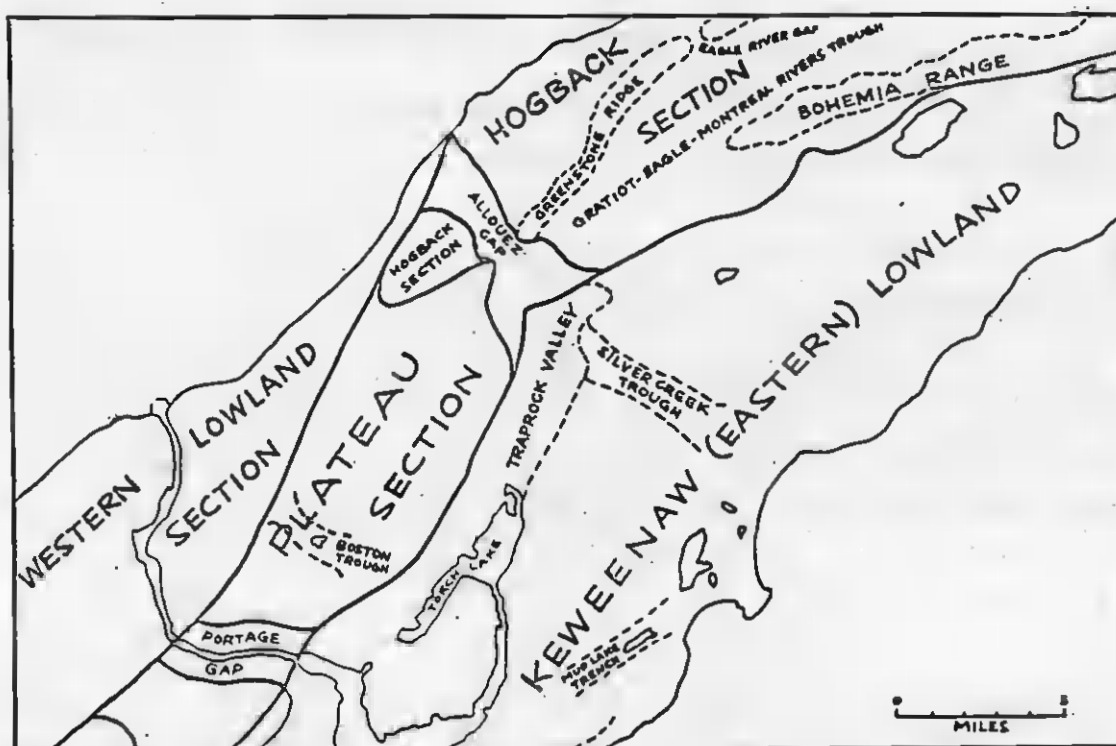


Figure 18: Physiographic divisions of the central Keweenaw Peninsula (from Hughes, 1963).

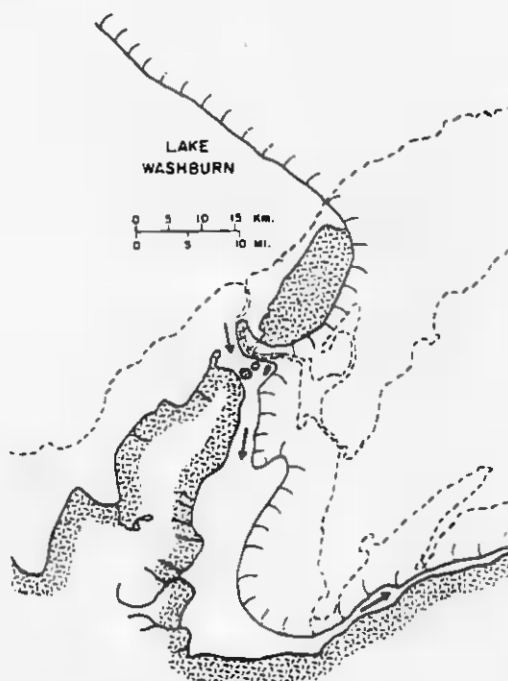


Figure 19: High level drainage through the Portage Gap during the Lake Washburn stage of the Lake Superior basin (from Warren, 1981).

1994). As the water level dropped from its Lake Duluth high, water drained through the Portage Gap (Fig. 19). Warren (1981) provides evidence of this drainage in the form of terraces and water-scoured surfaces. The Huron Creek Channel is the drainage through Portage Gap (see Map A2). After the Wisconsin glacier retreated from the Lake Superior basin, the level of water receded to the level of Lake Superior.

Many glacial features are evident in the Keweenaw Peninsula, both erosional and depositional. Erosional glacial features include smoothed bedrock surfaces (very common in the Keweenaw Peninsula), grooves, striations, and chatter marks. Depositional features include sediments directly deposited from the melting glacier (till) and those sediments deposited by glacial meltwaters. Various types of moraines (accumulation of glacial deposits) are made of till. Although an end moraine is present in the Keweenaw Peninsula (Fig. 16), an estimated 80% of the Keweenaw Peninsula is covered by hummocky, boulder-rich glacial sediment ground moraine (Hughes, 1963). Glacial deposits of water-laid origin include: outwash, eskers, deltas, kames, channel deposits, and more (Regis, 1993).

MAIN ROAD LOG AND STOP DESCRIPTIONS

Reminder. The notes throughout all the logs on the bedrock of the Keweenaw Peninsula were compiled from Bornhorst (in press), Bornhorst (1992), and Bornhorst and others (1983) without specific citation or quotation to these particular references.

The **Seaman Mineral Museum**, The Mineralogical Museum of Michigan, is located on the campus of Michigan Technological University (see campus map on back cover page). The museum has the world's finest display of minerals from the Keweenaw Peninsula native copper district. We highly recommend a visit to the museum either before or after your field trip. Plan to spend at least two hours in the museum (Map 1).

CUMULATIVE MILEAGE (mileage from previous entry)

MAP 1

- 0.0 Assemble at the Memorial Union Building on the campus of Michigan Technological University. Begin the field trip from the circular drive located on the northeast side of the Memorial Union Building. The Michigan Tech campus is located on a kame terrace to the south of Portage Lake. Turn right out of the circle drive.
- 0.05 Turn left.
- 0.1 Immediately after, turn right on Townsend Drive/US-41. The Quincy Mine can be seen on the skyline ridge.
- 0.45 Left turn on Agate Street, and up the steep hill on the south side of the Portage Lake channel. We are climbing off the kame terrace to an area of scattered bedrock outcrops of the PLV covered by varying thicknesses of glacial sediments.

MAP 2

- 0.7 Turn right on Seventh Street.
- 0.9 **STOP 1: Seventh Street, City of Houghton (Portage Lake Volcanics [PLV])**

This stop is marked by a prominent ridge of ophitic basalt; an outcrop of the Scales Creek Flow. It is one of the great Keweenaw lava flows which can be traced continuously for a strike length of more than 160 km along the Peninsula. It is about 70 m thick, has an amygdaloidal top which is typically not resistant to erosion, and a prominent, ridge-forming, ophitic massive interior. The ridge at this site can be followed down hill all the way to Shelden Avenue, where it is covered by glacial deposits, and can be traced across the valley where it passes beneath the Ripley School, a prominent brick building across Portage Lake. This bearing, about N30°E, is the regional strike of the PLV, which dip about 50° to the NW. Another clue to the attitude of the rock is given by the Quincy #2 shaft house on the horizon, which heads up an inclined shaft. It is down-dip along the amygdaloidal ore bodies of lava flows and over 2000 m higher in the PLV section. Throughout the PLV section between Baltic and Mohawk, most amygdaloid and conglomerate zones are effected by well developed zeolite and prehnite-pumpellyite facies metamorphism and by widely variable native Cu mineralization. At this site the amygdaloids just below the Scales Creek Flow are strongly mineralized. One mine, the Shelden Columbian, operated just a few hundred meters to the east in the early 1900's. This same horizon is exploited by a series of shafts called Isle Royale Mines (see mileage 3.75 for description), for several kilometers to the SW.

Bedrock Geology

Seaman Mineral Museum
(5th floor)

Memorial Union

Geology

(3rd floor)

Portage Lake

Portage

Lake

Volcanics

Jacobsville Sandstone



Michigan Technological University
Houghton, Michigan 49931-1295

- | | |
|---|---------------------------------------|
| 1 Administration and Student Services | 36 Coed Hall Food Service |
| 4 ROTC | 40 East Coed Hall |
| 6 Academic Office | 41 Central Heating Plant |
| 7 Electrical Energy Resources Center | 42 Facilities Management Storage |
| Seaman Mineral Museum (EERC) | 43 Lakeside Laboratory |
| 8 Alumni House/Michigan Tech Fund | 44 Storage Service (Pool Cars) |
| 11 Walker Arts and Humanities Center | 48 Weber House |
| 12 Minerals and Materials Engineering | 49 Waste Management Resources |
| Institute of Materials Processing | Recovery |
| 13 Hamar House | 50 Gatae Tennis Center |
| 14 Grover C. Dillman Hall (Civil-Geology) | 53 Mont Ripley Ski Hill |
| 15 Fisher Hall | 58 U.S. Forest Engineering Laboratory |
| 16 Forestry Annex | 74 Waste Chemical Storage |
| 17 J. R. Van Pelt Library | IMP Visitors' Parking Area |
| 18 Forestry Institute of Wood Research | P Pay Parking Lot |
| 19 Chemistry/Metallurgy | |
| 20 R. L. Smith Mechanical Engineering- | |
| Engineering Mechanics | |
| 24 Student Development Complex (SDC) | |
| 25 Sherman Field Press Box | |
| 31 Douglass Houghton Hall (DHM) | |
| 32 Daniell Heights Apartments | |
| 34 Memorial Union | |
| 37 Wadsworth Hall | |
| 38 West Coed Hall | |
- Not appearing on map:
Fire Hall, Houghton
Ford Forestry Center, Alberta
IMP Storage, Houghton
Keweenaw Research Center,
Memorial Airport
Lahli Building, Hancock
Portage Lake Golf Course, Houghton



Portage Lake valley is the most obvious geomorphological feature, and its origin was thoroughly investigated by Warren (1981). The valley formed in a fault zone typical of that which crosscuts the Keweenaw stratigraphy elsewhere. 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 Peninsula, 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.

1.0 Turn left on Portage Street.

1.15 Grand Portage Mine rock piles on the left.

1.35 We are near the Houghton water tower. Walk toward the metal triangular structure (used for surveys) on the left side of Portage Street (east).

STOP 2: Houghton water tower (glacial grooves)

The exposed basalt has a glacially smoothed surface with a number of parallel glacial grooves that trend about N65°E, which is consistent with Stop 3. The grooves near the tower are about 10 cm deep and 15 cm wide.

At this stop, the Scales Creek Ridge (flow) is exposed higher on the south slope of the Portage Lake valley. To the east of the prominent ridge, many mine openings from the series of Isle Royale shafts exist. Adams Township takes its water supply from mines lower in the stratigraphic section which are now filled with water, and is the source of water for Hancock and several other towns. Using water from mines for drinking is only possible because the local rocks are almost completely devoid of any minerals, such as pyrite, that break down in oxidizing surface and groundwaters to produce acid waters. The lack of acid waters keeps most ore and gangue minerals in the rocks and remain immobile. Therefore, the water from the mine is of drinking quality.

1.45 Turn right on Sharon Avenue. Across Sharon Avenue is the City of Houghton fire station.

1.95 Turn left at the flashing light on Main Street, heading into Hurontown.

2.2 Turn right on Frederick Street.

2.25 On the left side of the road just before Huron Street are low exposures of basalt.

STOP 3: Hurontown (glacially carved basalt)

The small knobs of basalt represent excellent examples of glacially carved and smoothed basalt within the Keweenaw Peninsula. The knobs are asymmetric with a gentle, smooth slope on one side and a steep, irregular side opposite. This morphology is that of a roches moutonnees, formed by glacial abrasion on the gentle smooth slope with plucking steepening the opposite side as ice moves over the ridge. Glacial grooves and the roches moutonnees indicate ice movement from N60°E.

Return to Main Street.

- 2.35 Turn right on Main Street toward Dodgeville.
- 3.0 Charter Township of Portage water tower on the right.
- 3.55 Entering Dodgeville. On the right side of the road is one of the prominent Isle Royale Mine rock piles.
- 3.75 Center of Dodgeville. At this time (May, 1994), the Isle Royale Mine rock piles from Shaft No. 4 and 5 are visible on the right side of the road (west), but these piles of mine rocks are slowly being removed as crushed rock. The mine rocks are relatively inert, containing no acid generating minerals such as pyrite. Native copper, the dominant metallic mineral in the rocks, is stable in the surface oxidizing environment. Further, the mine rocks contain only background levels of pollutants such as Pb. Thus, these mine rocks can be used as ordinary crushed stone. **These mine rocks are off limits to collecting.**

Rocks from these Isle Royale Mine rock piles are scattered throughout the City of Houghton for decorative purposes and to minimize erosion. While the rock piles themselves are off limits for collecting, excellent specimens can be gathered from the public right-of-way in the City of Houghton. A description of the Isle Royale Mine is provided as a general background.

The Isle Royale Mine worked the top of the Isle Royale Flow. Production from the Isle Royale Amygdaloid began in 1855, and the mine closed in 1948. A total of about 160 million kg 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 22 to 46 m thick and lies just below the Scales Creek Flow discussed in Stop 1. The flow dips about 50 to 60° to the northwest (Fig. 20), with a gentle fold accounting for the curvature, and is characterized by a fragmental zone; banded amygdaloid; a foot inclusion zone; and a massive main trap. The fragmental zone consists of irregular fragments of amygdaloid and fine-grained basalt ranging from small grains to tabular blocks several meters 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 with amygdules 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 zone grades into massive basalt practically devoid of amygdules (summarized from Butler and Burbank, 1929).

Stoiber (unpublished data) studied rock piles from four shafts of the Isle Royale Mine and made the following estimate of the percentage of alteration minerals: 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. Good specimens of alteration minerals, and less commonly native copper, can be collected from the mine rock throughout the Houghton area.

- 4.25 The junction to the Green Acres Road. Turn right.
- 4.6 On the left is the location of the former Isle Royale Shaft No. 6. As of 1994, the once large mine rock pile is nearly gone.
- 5.45 The junction of M-26 at the Copper Country Mall. Make a left turn.

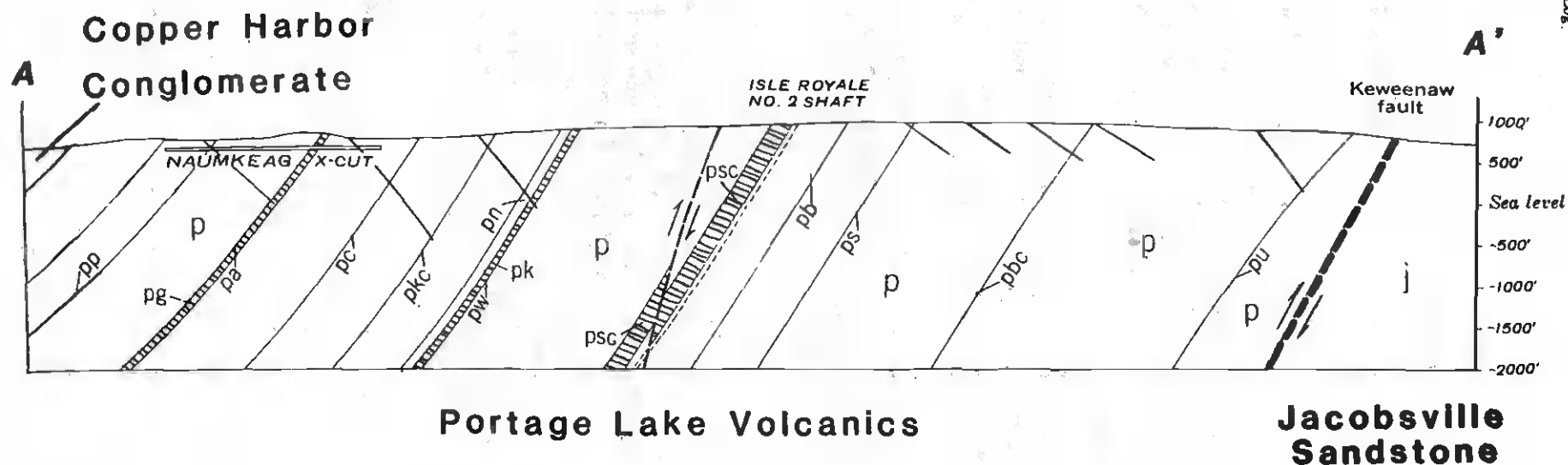


Figure 20: Cross section A-A' on Map 2 (from White, 1956). Abbreviations are as follows for the Portage Lake Volcanics (P) and its subunits: Pewabic West Conglomerate (pp), Greenstone flow (pg), Allouez Conglomerate (pa), Calumet and Hecla Conglomerate (pc), Kingston Conglomerate (pkc), National Sandstone (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).

MAP 3

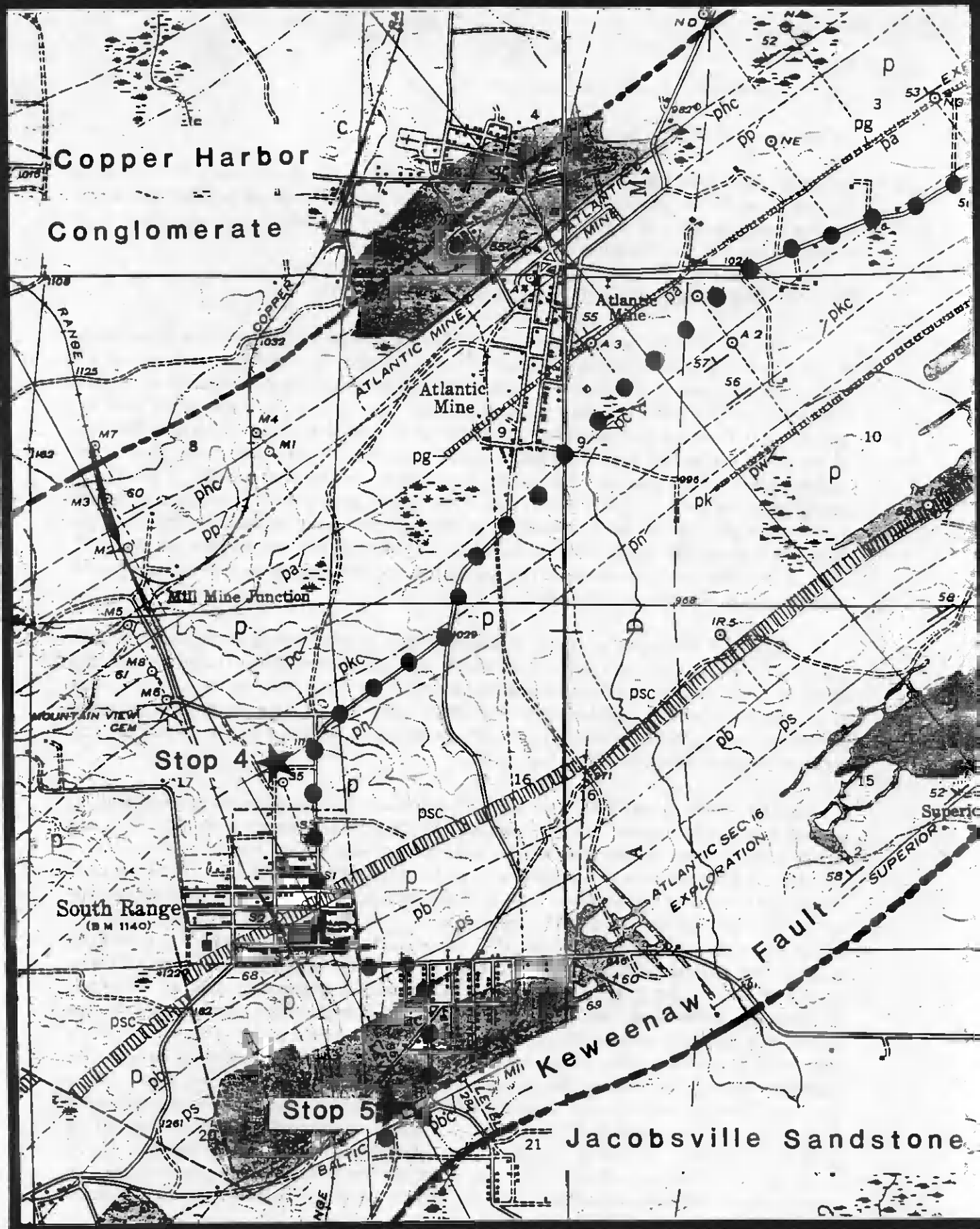
- 7.05 Atlantic Mine is on the right. Continue on M-26.
- 7.8 An outcrop of PLV is on the right.
- 8.4 Turn right onto a dirt road about 200 m before the sign that says: South Range Village Limit. Proceed about 150 m (a church is on the left) to an open "parking" area on the right, just before the road goes up hill. At the far end of the open area is a path which goes up a steep slope through a notch up the hill another 60 meters to Stop 4.

STOP 4: South Range Quarry (Portage Lake Volcanics [PLV])

Volcanic textures and structures typical of moderate-to-thick subaerial lava flows within the PLV are well exposed in this old quarry. As one traverses up-section into and through the quarry (Fig. 21), one crosses over a 4 m thick interflow conglomerate bed exposed in the path, overlain by an 18 m thick lava flow (the amygdaloidal flow top is exposed just as you enter the quarry itself), followed by a complete section through a 42 m thick ophitic basalt flow (the bulk of the quarry walls), and finally, the lowermost 17 m of the overlying ophitic lava flow (at the northwest end of the quarry). The quarry is positioned in about the middle of the PLVs' stratigraphic section. Locally, lava flows strike approximately N45°E (subparallel to the northwestern shoreline of the Keweenaw Peninsula) and dip toward the center of the rift (Lake Superior) at about 60°. In the cross section of the PLV through this area, all dips are about 60°. Dips in the sedimentary section overlying the PLV to the NW flattens to subhorizontal on the shoreline of the Keweenaw Peninsula.

Laterally continuous interflow sedimentary beds provide critical stratigraphic markers within an otherwise uniform volcanic pile (PLV). The unit exposed below the quarry has been correlated with the National Sandstone, a marker bed in the Mass-Rockland area. This marker is a massively bedded, pebble-cobble framework conglomerate, composed of silicic-with-subordinate mafic, volcanic subangular-to-subrounded clasts, within a matrix of poorly-sorted medium-to-coarse sand of similar composition.

The basalts in this portion of the PLV are mainly olivine tholeiites erupted as thick, ponded subaerial lava sheets. The principal lava flow exposed in the quarry walls illustrates many of the volcanological features observable in cross section. The top and bottom of this lava flow are exposed at the two ends of the quarry and consist of aphanitic chilled basalt. It was deposited directly on top of the underlying lava flow, so its base occurs where amygdules disappear abruptly in the top of the underlying flow. The upper surface of the main flow was brecciated slightly by movement of lava after the formation of an upper crust, but rapidly grades downward to an unbrecciated, highly vesicular flow top. Note the variation in vesicle size and distribution downward in the flow. The flow top breccia (locally called fragmental amygdaloid) is laterally discontinuous for this flow. Slow cooling of the lava flow caused solidification toward the flow interior at a rate which allowed development of subophitic to ophitic textures (large oikocrysts of clinopyroxene enclosing a felted framework of An-rich plagioclase and intergranular olivine). The resulting massive, non-vesicular flow interior constitutes about two-thirds of the flow. Before final solidification, small amounts of volatile-rich, differentiated residual liquid were concentrated in thin discontinuous zones and lenses. Many of these are subparallel to the bottom and top surfaces of the flow. A typical pegmatoid zone consists of a 4 cm to 1.3 m core of vesicular basalt surrounded by a 4 to 9 cm border zone at the top and bottom. The vesicular core of the pegmatoid zones contains coarse laths of Ab-rich plagioclase, prisms of Fe-rich clinopyroxene and



MAP 3

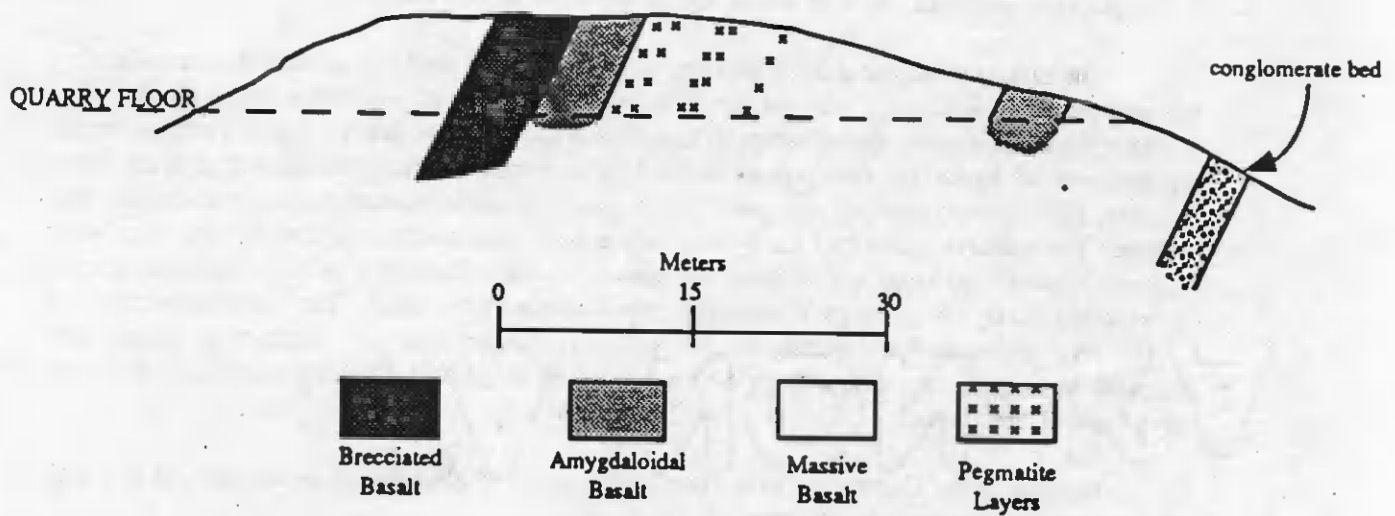


Figure 21: Geologic profile of the South Range quarry along the northeast wall (modified from Cornwall, 1951; White, 1971b; from Bornhorst, 1992). Location of the quarry is shown in Map 13, Sec. 17, T54N, R34W.

abundant Fe-Ti oxides, as well as accessory minerals such as apatite and zircon. The border zone is composed of a medium-to-coarse grained aggregate of albite/oligoclase, augite, ilmenite, and magnetite. Pegmatoid zones toward the top of the flow are more vesicular. Zircons extracted from pegmatoids within thick PLV basalt flows have yielded high-precision U-Pb dates (e.g., Davis and Paces, 1990). Numerous thin pegmatoids are exposed in the quarry walls, as well as in the glacially-polished surfaces above and to the north of the quarry.

The effects of regional hydrothermal alteration can be observed within the vesicular flow top and pegmatoid zones. Vesicles are filled with a variety of secondary minerals including quartz, epidote, prehnite, calcite, pumpellyite, chlorite and traces of native copper. Pseudomorphic replacement of basalt by fine-grained secondary minerals in the prehnite-pumpellyite facies (epidote, olive green; pumpellyite, pale bluish green) is most intense where permeability was highest. The massive interior of the flow is only a little altered except in the vicinity of selected fractures. Alteration along the interior fractures is characterized by a green-to-red cherty rock, representing nearly complete pseudomorphic replacement of the basalt. The massive interior was a relatively impermeable horizon in the paleohydrologic system. Fracturing during late compression (reverse movement along the Keweenaw Fault) provided limited pathways for upward movement of ore fluids.

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.

- 8.7 Return from Stop 4. Take a right turn on M-26, going into the town of South Range.
- 9.2 At the stop sign in South Range, take a left turn.
- 9.4 Turn right at the church, immediately followed by a left turn (the whole road jogs to the left).
- 9.5 Entering the town of Baltic.
- 9.6 Turn right.
- 10.0 The main road turns to the left, but go to the right on a small paved road, driving past a concrete building toward some very large mine rock piles.
- 10.2 **STOP 5: Baltic Mine Shaft No. 3** (native copper deposit within Portage Lake Volcanics [PLV])

The Baltic, Champion, and Trimountain Mines worked the Baltic Flow top deposit. Native copper is irregularly distributed through the flow top, ranging from minute specks to masses weighing several tons. The Baltic Mine, third largest producer in the Keweenaw native copper district, opened about 1898, while the remaining two mines which worked this flow top opened in 1902. Total production from the Baltic Mine was about 840 million kg of refined copper. The amygdaloid was mined for about 7 km along strike, and to the 38th level (1000 m) in the Baltic Mine. The lode dips 70°NW and had an average stoping width of 5 to 8 m.

The massive interior of the Baltic Flow is ophitic and varies considerably in thickness from about 50 to 70 m. The flow top is breccia with a thickness of 17 m or more where mineralized, to less than 1 m of vesicular to massive basalt where unmined. The abundant minerals associated with copper are quartz, pumpellyite, epidote, and carbonate. Paragenetically late copper sulfides, chalcocite, some bornite, and rare chalcopyrite are unusually abundant

compared to the district as a whole. The sulfides occur in fissures associated with carbonate that dip 75° to 90°, and strike nearly parallel with the lode. Most of the rock pile at this stop is amygdaloidal basalt, with the following estimated percentages of amygdale-filling minerals: calcite, 91%; quartz, 5%; epidote, 3%; chlorite, 1% (R.E. Stoiber, unpublished data). Paragenetically, epidote and chlorite are early; calcite, quartz, and native copper are intermediate; while copper sulfides and carbonates are late (Fig. 12 Introduction). Excellent specimens of chalcocite can be found on this rock pile, along with native copper.

Butler and Burbank (1929) recognized two distinct periods of alteration within the Keweenaw Peninsula native copper district. The earliest alteration was oxidation, causing the development of hematite, which in turn, 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. It 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; and 3) a final stage of copper sulfides and arsenical copper accompanied by calcite, sericite, quartz, chlorite, and specular hematite occurring in numerous veinlets.

- 10.4 Retrace route through Baltic.
- 10.9 At the stop sign in Baltic, turn left to go back in the direction of South Range.
- 11.1 Turn right, immediately followed at the church by a left turn.
- 11.3 In the center of South Range, take a right turn off M-26.
- 11.8 Passing the South Range Quarry, Stop 4.
- MAP 2
- 14.75 On the right is the Green Acres Road to Dodgeville that we previously followed.
- 15.6 Stoplight at Sharon Avenue. Continue straight ahead.
- 16.05 The Canal Road junction. This road is used in Leg A - Houghton Canal Road.
- 16.5 Between the Junction of M-26 and US-41, stay right and continue ahead on US-41 (Marquette) past the gas stations on the right.
- 16.95 An excellent outcrop of basalt with exposed vesicular flow top (amygdaloid) on both sides of the road. Move to the far left lane.
- 17.1 Make a left U-turn back onto US-41, going one way back through the City of Houghton. Stay in the left lane.
- 17.2 Turn off US-41 into the Burger King parking lot.

STOP 6: Sheldon Avenue, City of Houghton (Portage Lake Volcanics [PLV])

West of the restaurant, an unbrecciated amygdaloidal flow top with an underlying massive

interior is well exposed (also to the south along the highway). The flow top is strongly altered with amygdule minerals characteristic of the prehnite-pumpellyite facies. The green color is due to the abundance of epidote. The massive flow interior below the altered flow top, is essentially unaltered except where thin pegmatoid zones cross it. Pegmatoid zones are discussed at Stop 4. This stop is an alternate to the South Range Quarry Stop 4.

- 17.65 Turn right on US-41/M-26 and cross the Portage Lake Lift Bridge into Hancock.

The bridge was built in 1957, and is designed to accommodate Great Lakes ore boats, whose captains prefer the Keweenaw Waterway route (Portage Lake) 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

- 17.9 Turn left on US-41 into Hancock.

- 18.1 Turn right, immediately followed by US-41 going to the left, but go straight at 17.4.

- 18.25 Bear to the left on White Street.

- 18.75 The junction between White Street and Lincoln Drive which is US-41; turn right.

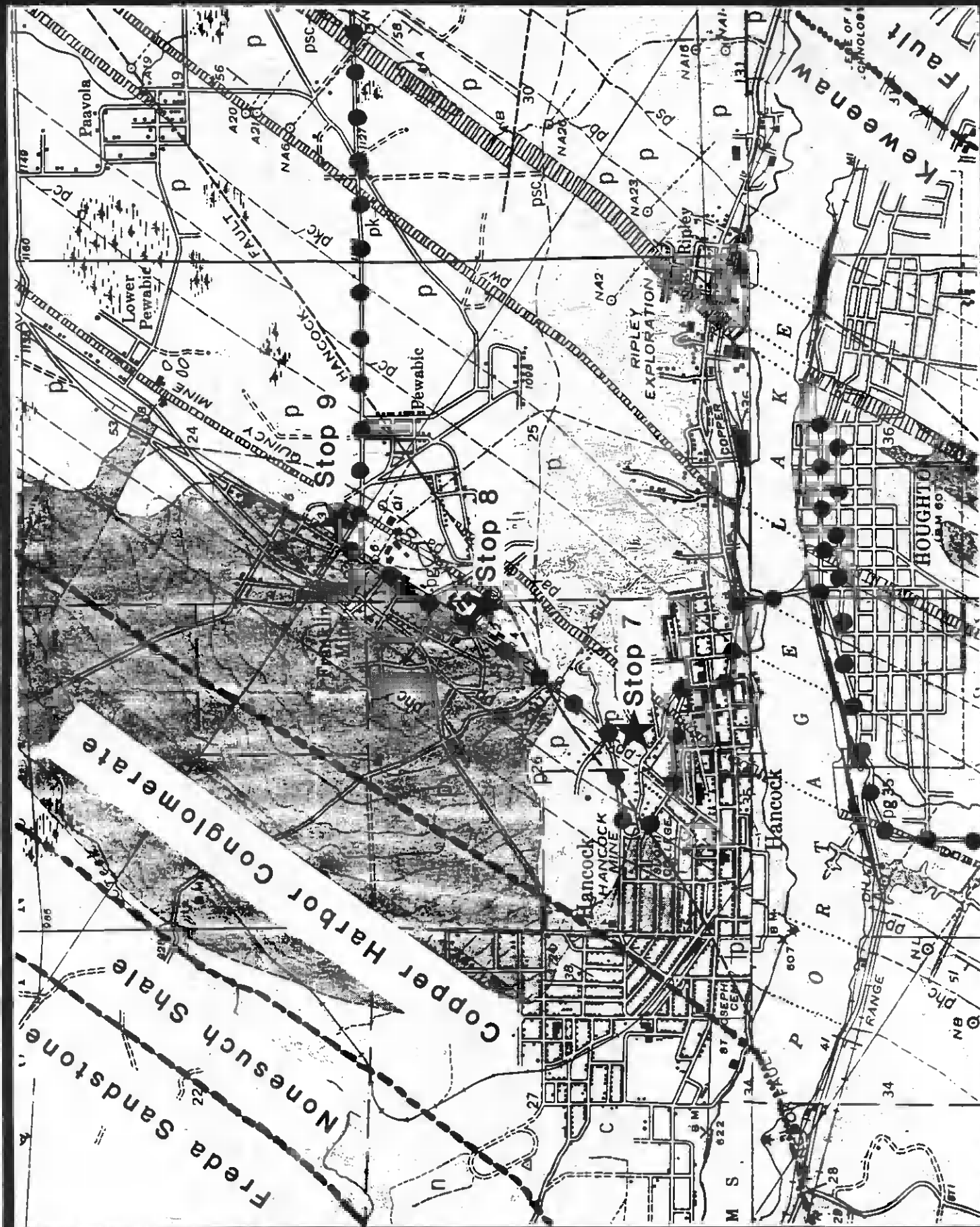
The fenced ground near this locality surrounds an area of caved ground, which is thought to be related to shallow stopes of the Hancock Mine. The detection and distribution of such openings is a problem of considerable concern to local authorities since many mines had shallow workings, since towns grew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

- 19.05 Turn off US-41 to the right to the overlook of the Keweenaw Waterway or Portage Lake, which is Stop 7.

STOP 7: Keweenaw Waterway Overlook

This overlook, near the crest of Quincy Hill, allows a broad overview of the Keweenaw Waterway. From east to west (left to right), the features which can be seen are (Fig. 22):

- 1) On the skyline across Keweenaw Bay, the knobby terrain of the Huron Mountains. The mountains are underlain by Archean gneisses and granites of the Michigan portion of the Wawa subprovince of the Superior Province of Canada.
- 2) In the foreground, the flat topography is characteristic of areas of Jacobsville Sandstone, which has typical dips of less than 10°. The Jacobsville extends from the Keweenaw Fault, which crosses the waterway at the east end of the MTU campus, across Keweenaw Bay, and to the north of the Huron Mountains.
- 3) Within the town of Houghton, several ridges of resistant massive interior basalt lava flows can be traced downhill. The most prominent ridge is the Scales Creek Flow horizon, where Stop 1 was made. The attitude of the Portage Lake Flows and the alteration of resistant flow interiors and interflow conglomerates with less resistant tops, makes site investigation work critical for some construction projects. Investigations are necessary to accurately determine depths to bedrock, and to make hydrologic interpretations. For



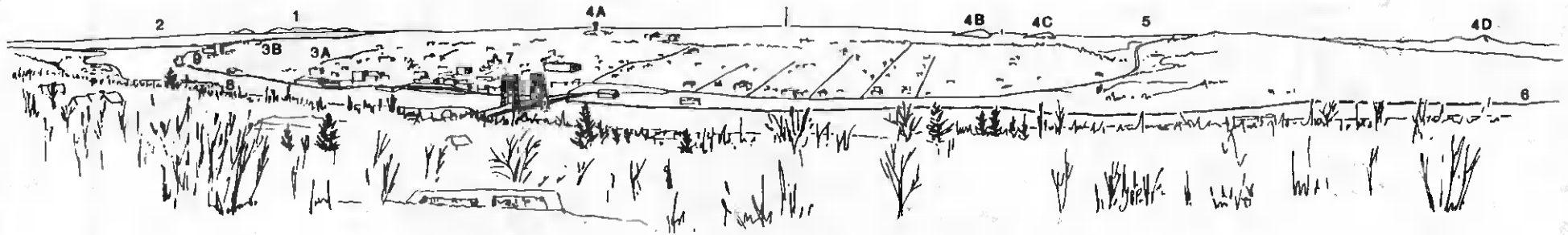


Figure 22: View from Portage overlook facing south (from Bornhorst and others, 1983). Notable features include: 1) Huron Mountains, 2) Flat-lying Jacobsville terrain, 3A) Scales Creek Flow ridge, 3B) Michigan Technological University Student Development Complex, 4A) Houghton water tower at Isle Royale Shaft #1, 4B) Isle Royale mine rock pile #4, 4C) Isle Royale mine rock pile #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.

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 at Michigan Tech (Stevens, 1971; Hase, 1973). A general map, showing the detailed bedrock geology of the City of Houghton (Holcomb, 1975) is used by developers in the area.

- 4) On the skyline directly on the opposite side of the waterway, and beginning at the Houghton water tower (black, orange and yellow), is a series of mine waste-rock piles from the Isle Royale Mine (flow top deposit) that extend into the distance along the strike of the PLV. The knob on the skyline is Wheelkate Bluff near South Range, just south of Stop 4, which is one of several resistant bedrock highs.
- 5) To the north of the divided state Highway 26, are glacial-fluvial deposits.
- 6) To the right, the waterway extends across the upper contact of the PLV to the Copper Harbor Conglomerate, Nonesuch Shale, and Freda Sandstone. Leg A follows the Houghton side of the waterway with stops observing the Copper Harbor Conglomerate (along the waterway), and the Freda Sandstone (along the Lake Superior shoreline at Redridge).

This, and other major bedrock valleys in the area, were formed by stream superposition as ancient rivers eroded through flat-lying Paleozoic rocks and into the tilted Keweenaw strata. The valleys were greatly deepened by glacial erosion during the Pleistocene. During a pause in the retreat of the Keweenaw Bay sub-lobe at the end of the Wisconsin glaciation, a waterway was established that allowed eastward drainage across the peninsula toward 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 the 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, 1981).

The Keweenaw Peninsula was named after an Indian word for portage route. Dredging, completed in 1873, was necessary at both the northern and southern ends, to make Portage Lake accessible to Lake Superior shipping.

Houghton was named for Douglass Houghton, the geologist who sparked the Michigan copper mining boom by publishing his Michigan State Geologist Report in 1841. The town was settled in 1852 and is the site of several historic buildings, the most important of which is the Houghton County Courthouse (1887). It's a prominent yellow brick building with Jacobsville Sandstone facing and a copper roof that sits on the hill above the main part of town.

Hancock was settled in 1859. Across the road and just slightly uphill is the Quincy Hill House (1871), the Quincy Mine manager's house. The Quincy No. 6 Mine shaft house (flow top deposit) dominates the skyline behind the viewpoint. A map of the Quincy operations in its heyday is given in Figure 23. The inclined No. 2 shaft descends at nearly a 45° angle, more than 3 km (1.7 km vertical) below the surface. The surface projection of the area mined is shaded on Map 4.

- 19.05 Turn right, back onto US-41 going up the hill.
- 19.5 A prominent outcrop of basalt with glacial grooves.
- 19.6 Turn right to Stop 8.
- 19.7 Quincy Steam Hoist.

We're in the center of the Quincy Mine area at Shaft No. 6 and the Quincy Steam Hoist (Fig. 23). The Quincy Steam Hoist 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 the building as well. The hoist can be visited during the summer months for an admission charge. Tours of the Quincy Mine Adit, connecting with the Quincy workings, start at the hoist and is operated by the Quincy Mine Hoist Association. For an admission charge, vans shuttle visitors to the underground workings, where excellent cross-sections of lava flows with native copper-mineralized rock can be observed. The Quincy Mining Company earned the name "Old Reliable" because it paid dividends so regularly. Lankton and Hyde (1982) provide an outstanding historical account of the Quincy Mining Company. The geology of the Quincy Mine and connecting adit is described below as Stop 8.

STOP 8: Quincy Mine Adit (Portage Lake Volcanics [PLV])

The Quincy Mine Adit connects with the Quincy Mine (Fig. 24) and is owned by the Quincy Mine Hoist Association. The Michigan Tech Mine (the mine adit) description is revised from Bornhorst and McDowell (1992) and Bornhorst and others. (1986).

The Quincy Mine Adit was once a drainage tunnel for the Quincy Mine. Michigan Tech students in Mining Engineering expanded the adit (since 1976) to its present size. The adit intersects old workings of the Quincy Mine, one of the major producers in the district with 10% of total district production. The adit is 700 m in length; 5 x 5 m in cross-section; and leads to the No. 5 shaft area on the seventh level of the Quincy Mine, where it divides into several drifts that are used for mining and rock mechanics research and teaching (Figs. 24).

Exposed at this site of the Keweenaw Peninsula native copper district (Figs. 2 and 4) are two classic aspects: 1) in an inclined sequence of basaltic flows, a long, high open stope follows a major horizon of mineralized flow tops (Pewabic); and 2) an oblique fault (Hancock Fault) offsets the basalts and forms the southwestern limit for the Pewabic orebody. A segment of this fault was mineralized and mined at the Hancock Mine, where about 365 m of the fault was opened down to the 12th level (300 m vertical). This fault may have been a feeder through which the mineralizing solutions reached the favorable Pewabic Flow tops.

The Quincy Mine began operations on the Pewabic Flow tops in 1856 and ended in 1967. The mine was developed along a series of parallel flow tops by 8 shafts--on 85 levels--to a vertical depth of 1675 m. The orebodies decrease in dip from 55° at the surface, to 35° at the bottom levels (Fig. 25). By 1925, the mine had sold about 330 million kg of copper and 2×10^9 g (71×10^6 oz) silver. Production to 1968 totaled 490 million kg of copper, ranking it fourth in the district. The Pewabic Flows at the Quincy Mine are relatively thin and are difficult to follow, unless the top of the flow has been mapped in detail (Butler and Burbank, 1929). The flows are texturally distinctly porphyritic with large feldspar phenocrysts, and some of the thicker flows

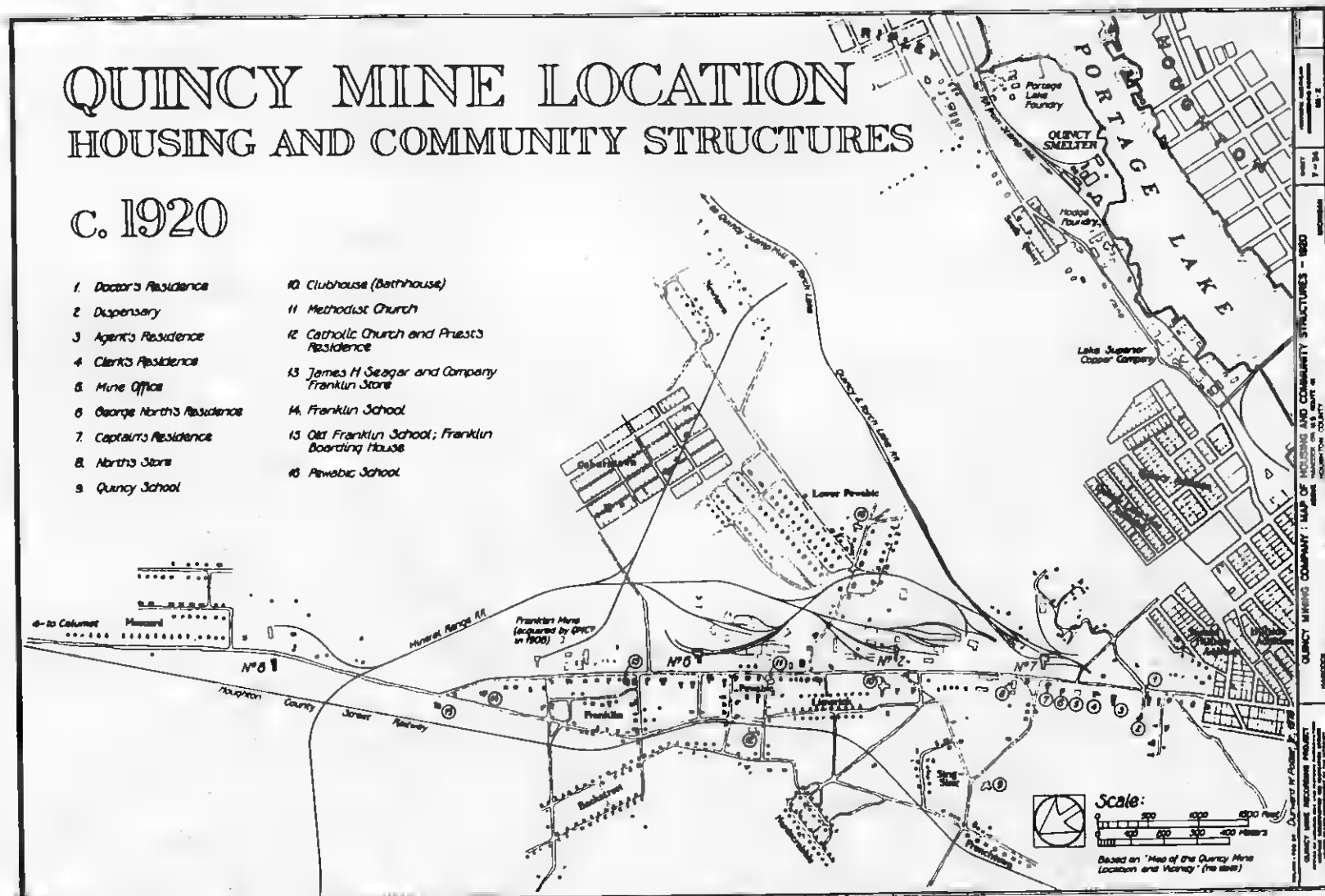


Figure 23: The Quincy Mine location (from Lankton and Hyde, 1982).

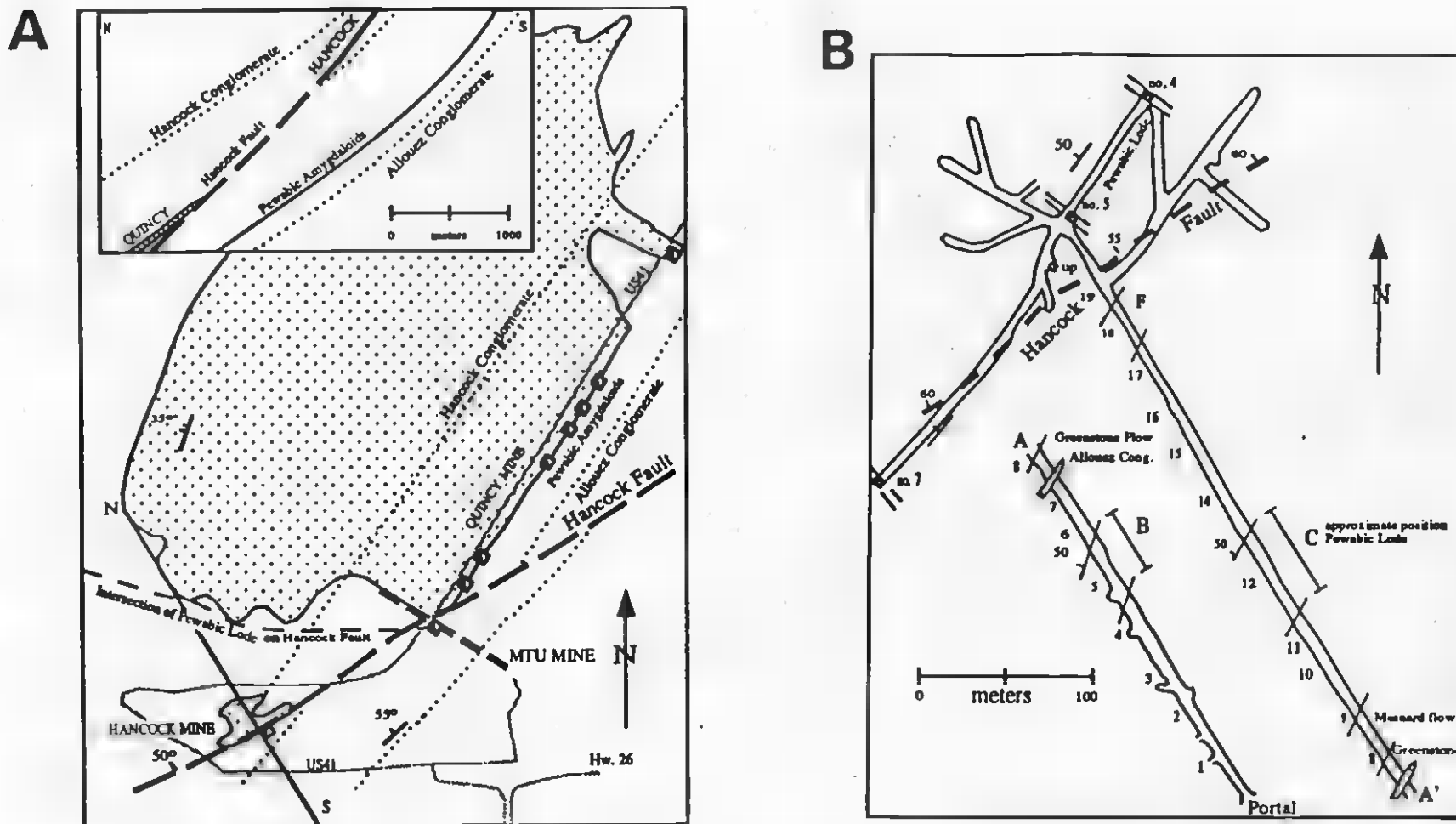


Figure 24: (a) Sketch map of the Quincy and the Hancock Mines (from Bornhorst and others, 1986). The Quincy Mine workings follow several parallel flow tops (Pewabic). These flow tops are not mineralized south of the Hancock Fault. The Hancock Mine operated on the Hancock Fault. Stippled pattern represents projections of mine workings to the horizontal. The Quincy Mine Adit (MTU Mine on figure) provides access to the Allouez Conglomerate, the Hancock Fault, and open stipes of the Pewabic deposit. Same scale for map and N-S section. (b) Geology of the Quincy Mine Adit with the portal-to-A section joining the remainder of the adit at A' (from Bornhorst and others, 1986). The old stipes on the Pewabic deposit extend only short distances southwest of the No. 5 shaft; mineralization terminates at the Hancock Fault such that neither the fault nor the southern portion of the Pewabic flow tops contain significant native copper. The stipes in the vicinity of the No. 7 shaft follow an amygdaloid 200 m stratigraphically above the Pewabic deposit. B, C, and F refer to thick flows in the adit.

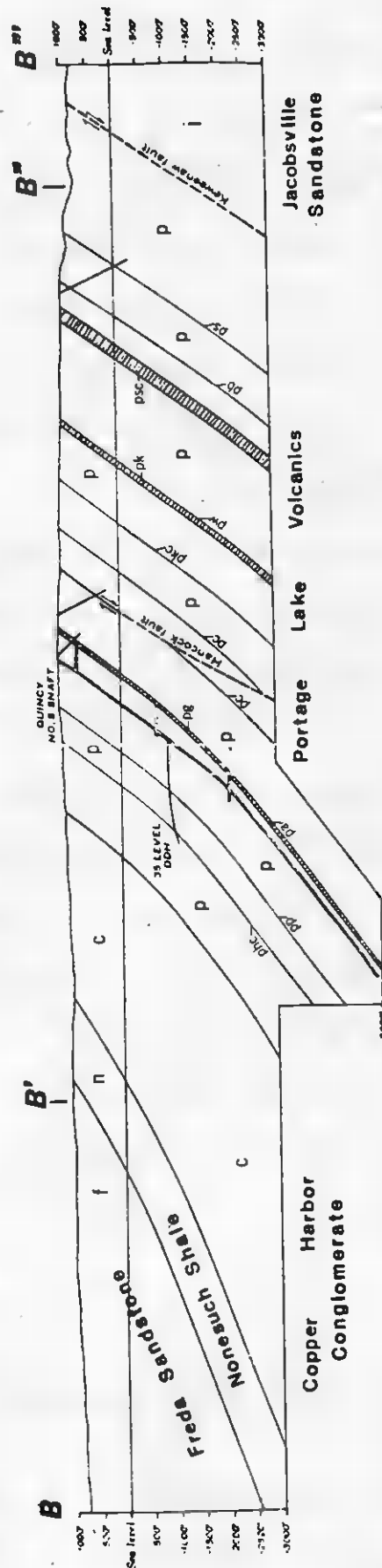


Figure 25: Geological cross section from B to B' on Map H6, B' to B'' on Map 4, B'' to B''' on Map 5. This cross section illustrates the general geologic relationships of the Keweenaw Peninsula. The Portage Lake Volcanics are overlain successively by the Copper Harbor Conglomerate, the Nonesuch Shale, and the Freda Sandstone. The Portage Lake Volcanics are in fault (reverse) contact with the younger Jacobsville Sandstone (see Fig. 2 Introduction). Abbreviations for the Portage Lake Volcanics (p) are as follows: Hancock Conglomerate (pc), Pewabic West Conglomerate (pp), Greenstone flow (pg), Allouez Conglomerate (pa), Calumet and Hécla Conglomerate (ps), Kingston Conglomerate (pkc), Kearsarge flow (pk), Scales Creek flow (psc), Bohemia Conglomerate (pb), St. Louis Conglomerate (ps).

have an ophitic texture. The flow tops are characterized (Butler and Burbank, 1929) by cavernous zones or layers 1 to 1.5 m thick, large gas cavities, and coalescing vesicles. Layers can form connected openings for 3 to 30 m, and a series of such openings provided an almost continuous path for the flow of mineralizing hydrothermal solutions. Where coalescing is well developed in the Pewabic Amygdaloid, there may be 2 to 10 layers. There is every gradation from coalesced layers of vesicles, to those that show only a moderate tendency to collect in layers. Brecciated flow tops are not characteristic of the Pewabic Flows as they are for other flow top deposits. Quartz and calcite are abundant cavity- and amygdule-filling secondary minerals, with pumpellyite and epidote less abundant. Chlorite is present in amygdules in the base of the flows, except near veins where it is replaced by quartz or calcite. Prehnite is present but not common, and laumontite is mostly confined to veins. Datolite was reported from upper levels of the mine, but not lower levels. Several prominent veins extend through the mine, dipping at high angles. The veins are mostly filled with calcite, laumontite, quartz, and epidote and are similar to minerals found in the flow tops (Butler and Burbank, 1929). These veins probably help integrate the paleohydrologic system for the movement of ore fluids.

The adit exposes 12 lava flows beneath the Allouez Conglomerate, dipping about 50° northwest, with several thick flows noted on Figure 24. The Greenstone Flow, which lies directly above the Allouez Conglomerate, can be traced for 50 km northeast--where it is 430 m thick--and to Isle Royale on Lake Superior, 100 km north. An excellent example of a clay gouge associated with a bedding plane fault of unknown displacement occurs at the top of the Allouez Conglomerate. Such faults are found throughout the district, especially on the top of conglomerate beds.

At the Quincy Mine, the Pewabic Flow tops are about 100 m stratigraphically (120 m horizontally) above the Allouez Conglomerate. About 12 lava flows occur in this interval in the adit, but the Pewabic Flows are barren at this location on the south side of the Hancock Fault. Above the Allouez Conglomerate, 14 more lava flows occur before the Hancock Fault is reached; about 425 m from the entrance. The Hancock Fault is marked by a distinctive clay gouge (almost pure corrensite) and a green corrensite-rich, brecciated alteration zone adjacent to the gouge. The fault is best exposed in the small drift leading to the No. 7 shaft area, where small exploratory stopes were made in a flow top that occurs 200 m stratigraphically above the Pewabic lode on the southwest side of the Hancock Fault. No native copper-rich flow tops occur at the stratigraphic position of the Michigan Tech adit southwest of the Hancock Fault. In the flow tops of the adit, amygdule-filling minerals include quartz; calcite; pumpellyite; epidote; chlorite; laumontite; and native copper. Rimmed amygdules suggest early prehnite and chlorite, followed by quartz, then chlorite, and lastly calcite (Bumgarner, 1980). Some of the Pewabic lode has been mined by students so they can run experiments. The ore grade is about 1.75% copper.

Return to the main road.

19.85 Turn right on US-41.
MAP 4

21.05 Turn right on Arcadian Road. On the left side, immediately after the turn, are some of the Quincy Mine rock piles, nearest to Shaft No. 1. This is Stop 9. Please respect private property signs and stay within the public right-of-way.

STOP 9: Quincy Mine Rock Piles (native copper deposit within Portage Lake Volcanics [PLV])

Refer to Stop 8 for a description of the Quincy Mine, which worked the Pewabic

Amygdaloid. In the Pewabic, quartz is the most abundant secondary mineral associated with native copper, but 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.

However, the majority of the rock at this stop is amygdaloidal-to-massive basalt. Secondary minerals 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.

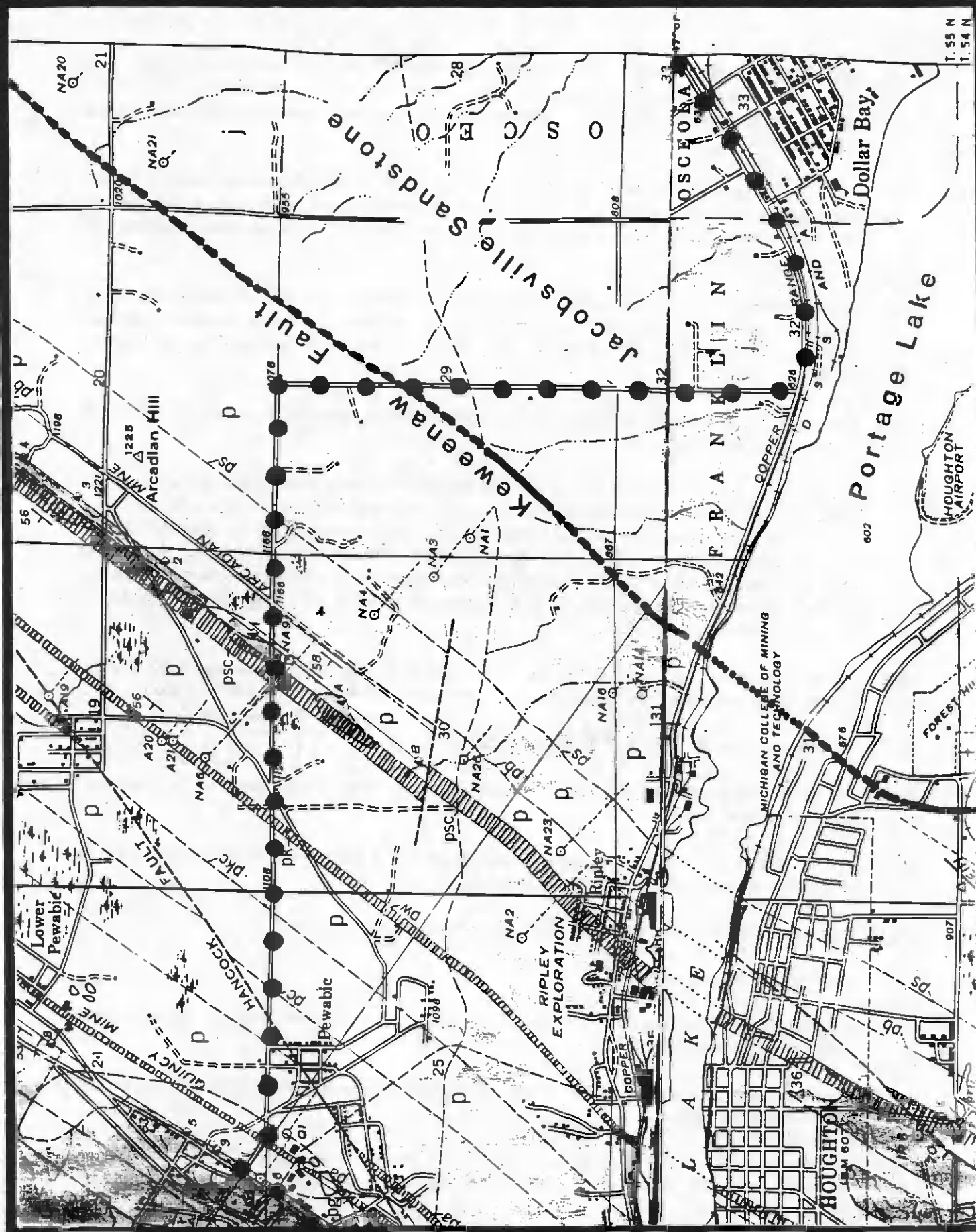
MAP 5

- 20.5 Entering Pewabic, another one of the communities that sprung up around the Quincy operations, with 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.
- 21.45 There is a "Y" in the road; take the right hand branch, which is essentially a straight road, with a sign saying Arcadian Scenic View.
- 21.7 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 data) studied the rock pile from Shaft No. 1 and estimated the percentages of non-metallic secondary minerals: calcite, 43%; prehnite, 25%; quartz, 16%; K-feldspar, 8%; epidote, 6%; pumpellyite, 1%; chlorite, 1%; and laumontite, trace.
- 22.4 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.
- 22.6 The road turns to the right and changes to gravel.
- 22.8 We're descending off the Portage Lake Volcanic Series by crossing the Keweenaw Fault and onto Jacobsville Sandstone.
- 24.0 We are descending the hill and have a view of the Isle Royale sands across Portage Lake in Houghton; they are tailings from the Isle Royale Mine.
- 24.15 The junction with M-26; take a left turn at the Portage Lake Coal Dock.
- 24.6 Entering Dollar Bay on M-26.

MAP 6

- 26.2 An exposure of flat-lying cross-bedded redbeds of the Jacobsville Sandstone on the left side of the road (northwest side).
- 26.9 Entering the small town of Mason. Mason was the site of company housing for the Quincy Mill operations from 1890.
- 27.5 On the right 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, which was bought by the Quincy Mill in 1955 and used until 1967.

Map 4





You may pull to the right of the road and view the dredge at your leisure. This is the Torch Lake Superfund Site. The site was used as a giant tailings pond for both the Calumet & Hecla and Quincy operations. Torch Lake has been more than 20% filled with stamp sands from both the amygdaloid and conglomerate ore bodies of the district. The relatively inert stamp sands have a much stronger aesthetic impact than a chemical one. On stamp sands, little vegetation grows, and on the surface of poorly drained ponds, toxic levels of Cu may be found. Other trace elements that may be elevated and of environmental concern include Cr, As, and Ag.

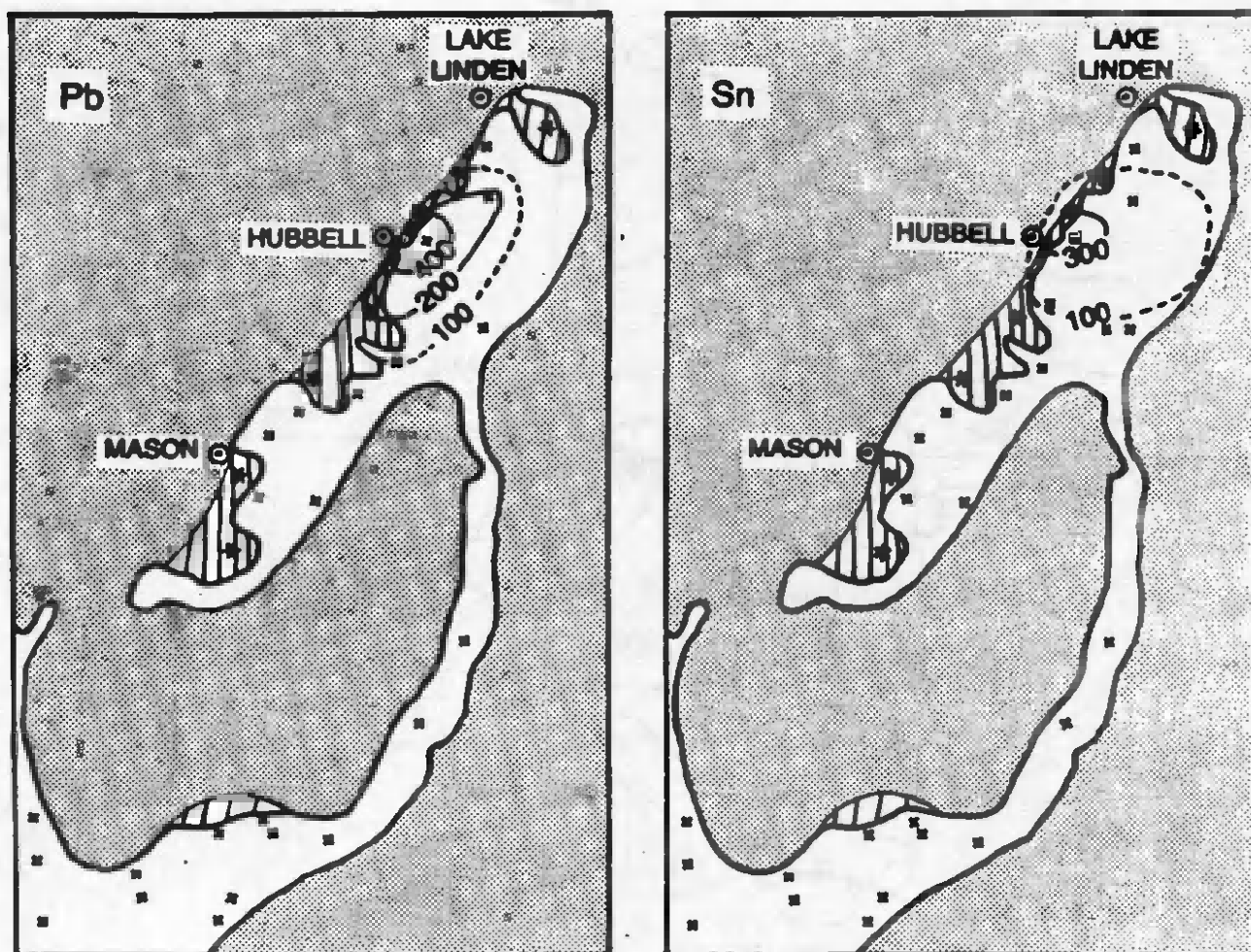
In the 1970s, tumorous sauger caught by fishermen in Torch Lake were the focal point of environmental concern, and the site was eventually designated as a superfund site. No cause for the tumor was ever definitively determined, and sauger, which live in murky water, are no longer found in Torch Lake, which is less turbid now than it was when tailings was entering it regularly. One interesting result of the environmental studies on the lake, was the observation of a bottom sediment plume in the lake (Fig. 26) which was highly enriched in Sn and Pb. These enrichments are not part of the geochemistry of native Cu deposits, and are believed to be due to mill wastes which date to the post war era (1945-68) when electrical wastes from a large part of the midwest were channeled through the Calumet & Hecla mill at Tamarack.

- 27.7 Now we pass the remains of the main buildings of the Quincy Mill, built in 1890 to accommodate steam stamps. The mill was required when the Quincy operation expanded to the Pewabic Lode.
- 28.0 Along the road on the left are more outcrops of flat-lying Jacobsville Sandstone.

STOP 10: M-26 near Tamarack (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. 27) filling a rift-flanking basin (Kalliokoski, 1982). There are no interbedded lava flows or cross-cutting dikes. The age of the Jacobsville is inferred on the basis of geologic evidence to be about 1070 to 1030 m.y. old. The Jacobsville Sandstone is in fault contact with the PLV along the Keweenaw Fault on the southeast side of the Keweenaw Peninsula. Some active movement along the fault occurred during deposition of at least part of the Jacobsville Sandstone (Kalliokoski, 1988; Hedgman, 1992). Ancient 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. 21b). West of Lake Gogebic, thickness and current directions suggest another deep part to the basin. East of Calumet, near the Keweenaw Fault (Stop 12), the Jacobsville Sandstone contains boulders of basalt--which suggests a topographic high in the PLV north of the fault during this period of Jacobsville sedimentation--due to reverse movement along the Keweenaw fault. Jacobsville sedimentation was the last event associated with the development of the Mid-continent rift system in the Keweenaw Peninsula and was preceded by a long period of cratonic stability.

Lithology of sandstones of the Jacobsville Sandstone 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



**TORCH LAKE SEDIMENT
ANOMALIES IN ppm**

Figure 26: Contoured concentrations of Pb and Sn in sediment and stamp sand in Torch Lake and vicinity (from Rose and others, 1986).

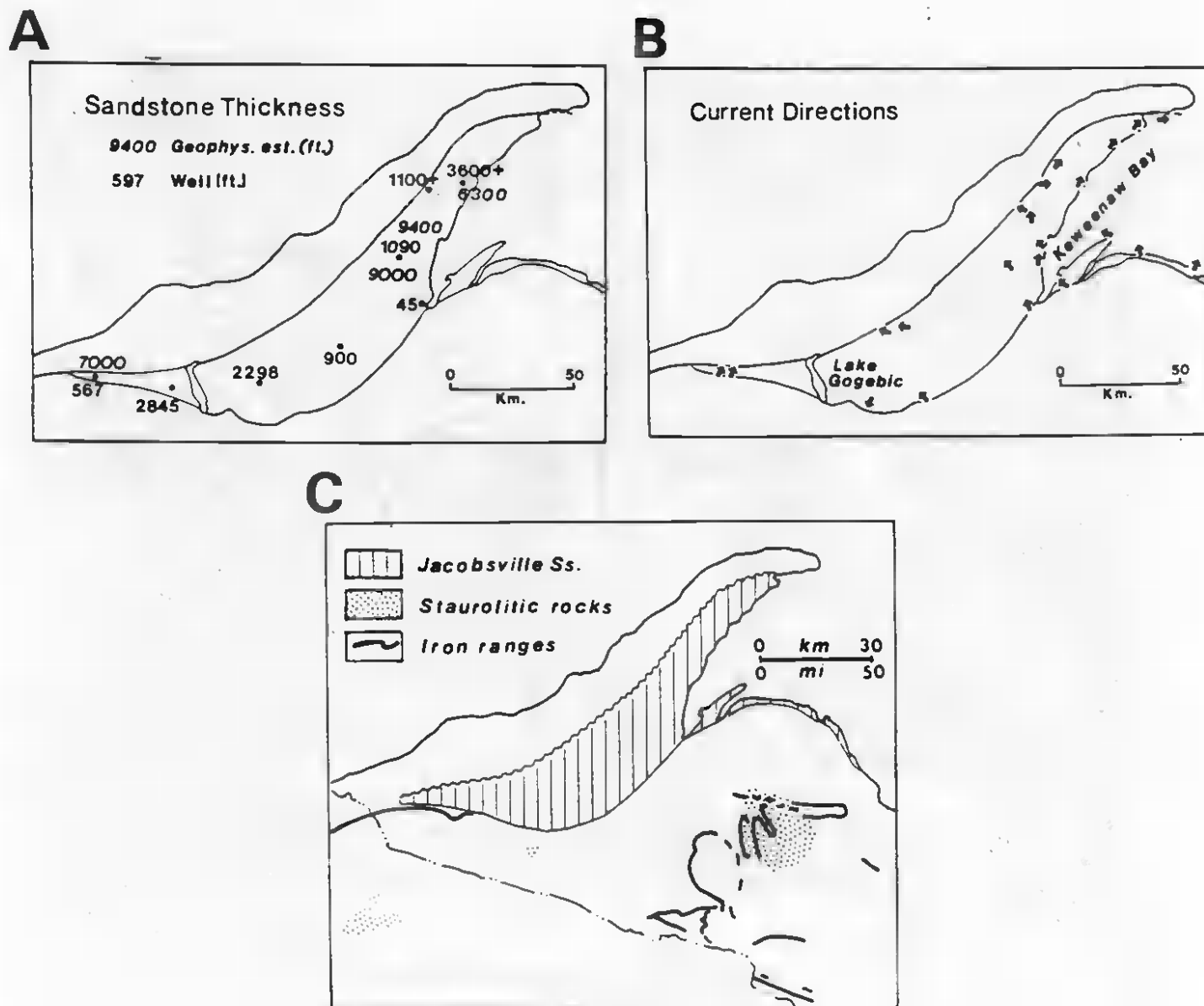


Figure 27: Relationships of Jacobsville Sandstone (from Kalliokoski, 1982). A. Thickness of Jacobsville Sandstone with minimum thickness denoted by '+'. B. Current directions in the Jacobsville Sandstone. C. Location of possible source areas of iron formation and of staurolitic metasedimentary clasts.

Kalliokoski, 1982).

The outcrop at this stop (Stop 10), about 120 m long and 3 m high, displays features characteristic of the fluvial Jacobsville Sandstone. At the northeast end of the outcrop, the section exposes red shale and red-brown siltstone at the level of the highway. They are overlain by two fining-upward sequences of conglomerate and red, red-brown, and white crossbedded sandstone. The lower conglomerate bed is planar and can be traced 30 m to the southwest, along with the underlying shale and siltstone. Farther to the southwest, the section is almost entirely crossbedded red sandstone, in beds 0.2 m to 1.0 m thick, some of which are contorted, conspicuously crossbedded, and color mottled. Crossbeds show a northeasterly transport direction.

The sandstone consists of almost equal parts of rounded-to-subrounded quartz, feldspars, and lithic fragments. Clasts in the lower conglomerate are predominately subangular, felsic volcanic in composition, with subordinate mafic volcanic rocks. The entire section can be interpreted as a shaly flood plain sequence overlain by sandy fluvial deposits. The Jacobsville Sandstone fills a rift-flanking basin southeast of the rift proper.

At this stop, the character of the Jacobsville Sandstone can be compared and contrasted to Jacobsville that will be seen at Stop 11 and Stop 12.

28.3 On the right is Torch Lake.

28.7 Enter Tamarack City. On the right side of the road are tailings which have been revegetated. The tailings are part of the mill operation of the Calumet & Hecla Company Mines and of the Calumet region, which have major mills located at Tamarack and Hubbell.

29.15 On the left side of the road are the footings from one of the Tamarack Mills.

MAP 7

29.6 On the right side of the road are the remains of a steam stamp mill.

29.7 Turn left, going up the hill toward Stop 9. Follow the paved road which jogs a little to the left and goes up the hill.

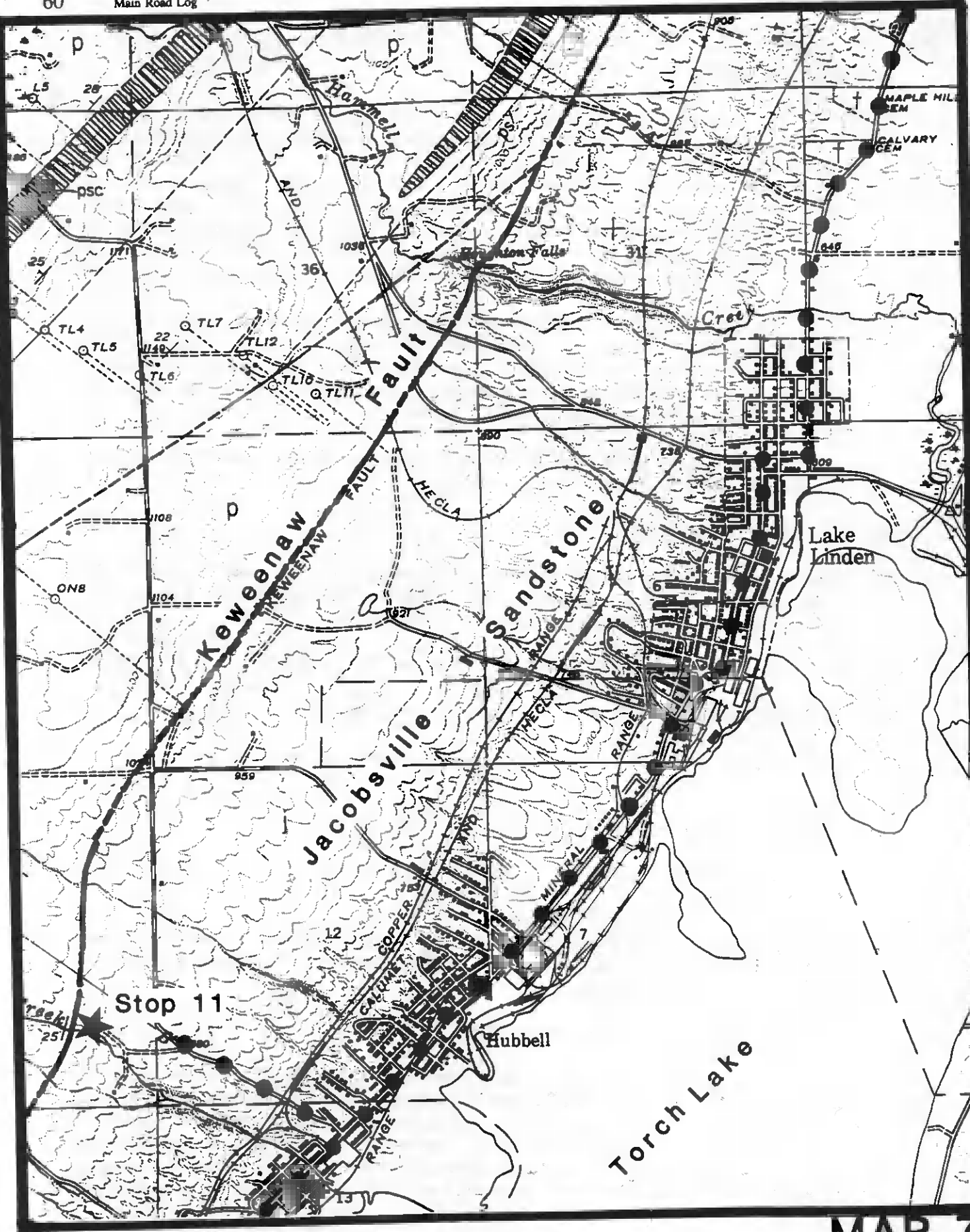
29.85 Cross the old Copper Range railroad grade.

30.0 A sign indicating the Hungarian Falls. This is the lower part of the falls, continue going up the hill, straight ahead.

30.25 The junction of a four-wheel drive road is to the left. Stop here and walk toward the Tamarack Reservoir/Hungarian Falls upper part, where excellent exposures of Jacobsville Sandstone are found near the Keweenaw Fault.

STOP 11: Hungarian Falls (Keweenaw Fault)

Hungarian Falls is located near the Keweenaw Fault (Fig. 28). The Keweenaw Fault is a reverse fault that juxtaposes older PLV 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 25. At the surface, the Keweenaw Fault varies from a single fault plane to a more complex fault zone, such as described near Lac La Belle (Leg D, mileage 5.85). The structural relationship of beds near the fault also varies from steepened dips to folds. In general, the dip of the PLV and



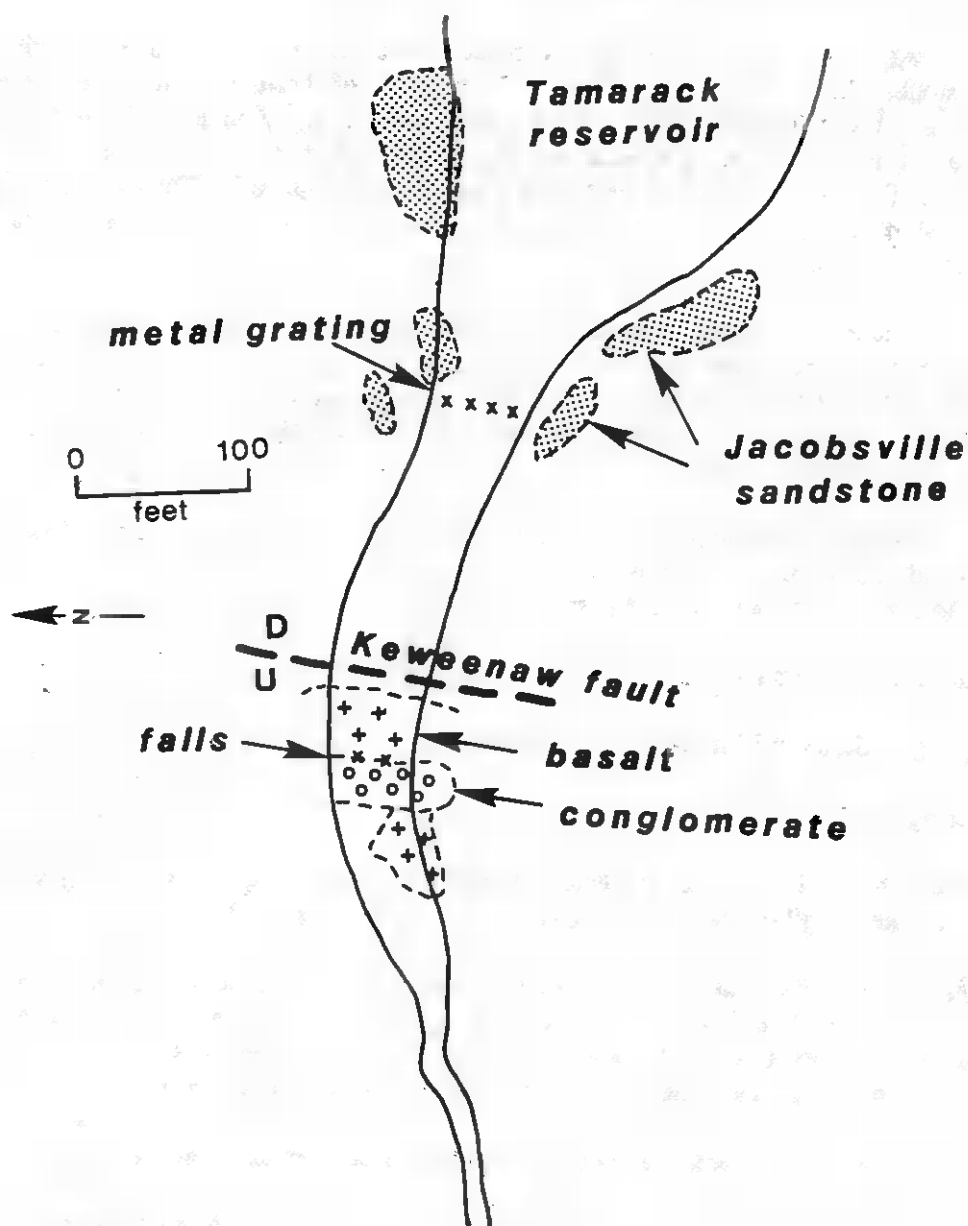


Figure 28: Geologic sketch map of the Hungarian Falls area (unpublished map by J.M. Robertson, 1973, from Bornhorst and others, 1983). Basalt and conglomerate are part of the Portage Lake Volcanics. Note that north is toward the left margin of the page.

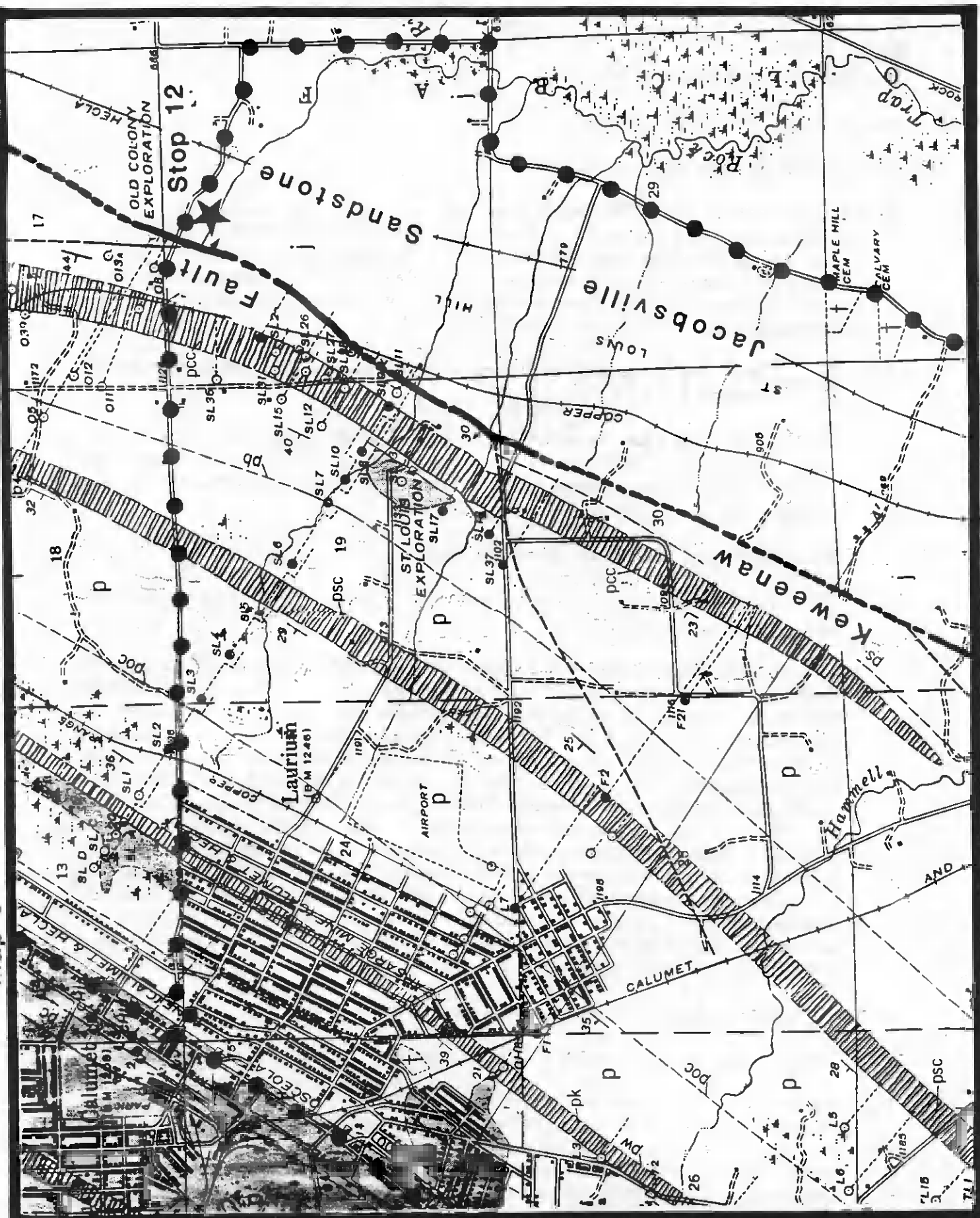
Jacobsville Sandstone steepen appropriately as one approaches the fault.

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 at Hungarian Falls and that at the Natural Wall, Stop 12 (the next stop), is striking, and illustrates the structural variability of rocks along this major feature.

The PLV 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 PLV and are found as relatively thin, widely separated beds. However, here and at a number of other localities in the Keweenaw Peninsula, conglomerates within the PLV 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 conglomeratic horizons; and many typical arkosic redbed sedimentary rocks.

- 30.25 Go back to the cars and go back down the hill to Tamarack City.
- 30.8 Stop sign. Stamp mill remains are straight ahead. Turn left on M-26.
- 30.9 Entering Hubbell.
- 31.5 On the right are the Calumet & Hecla Mill buildings that are now being used for small industries. Torch Lake is still on the right with many of the tailings in the lake.
- 32.4 Entering the town of Lake Linden. The Houghton County Historical Museum is on the right side of the road. The building (1917) was donated by the C&H (Calumet and Hecla) 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.
- 33.2 Turn right on Ninth Street (the so-called Bootjack Road) in Lake Linden.
- 33.35 Turn left two blocks after 32.2. Follow the signs to the Lakes Drive-In Theater. This is Gregory Street.
- MAP 8
- 34.3 On the left side of the road is the Lake Linden cemetery. The road heads north along the Trap Rock River Valley. On the left side of the road, at the top of the steep slope, is the Keweenaw Fault. On the right side of the road, is flat-lying Jacobsville terrane. The Trap Rock River follows another of the glacially eroded, deep bedrock valleys described by Warren (1981).
- 35.5 Pavement ends.
- 35.6 The gravel road bears to the right.
- 35.9 Cross a bridge over the Trap Rock River.



Map 24

MAP 8

Man 7

- 36.0 Turn left at the Trap Rock Schoolhouse.
- 36.0 Cross the Trap Rock River again.
- 36.7 Turn left on another dirt road that begins to go up hill.
- 37.1 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 until the first major valley, and then walking up the stream valley. The traverse begins in Jacobsville Sandstone, crosses the Keweenaw Fault, and ends in the PLV at the head of the stream valley. As the road parallels the stream valley a few hundred meters to the north, it is recommended that one return via overland and the road.
- 37.2 Poor exposures of flat-lying conglomerate beds within the Jacobsville Sandstone are on the left side of the road.
- 37.4 Stop here and follow a path on the left side of the road, about 200 m, for an overlook of the Natural Wall Ravine. The bottom of the ravine provides an excellent traverse across the Keweenaw Fault. To gain access to the bottom of the ravine, go back down the road 0.3 miles to mileage 36.1.

STOP 12: Natural Wall Ravine (Keweenaw Fault)

There is a ravine overlook about 200 m south of the gravel road at the top of a steep slope.

This locality is in Jacobsville Sandstone and just east of the Keweenaw Fault (Fig. 29). The Natural Wall is a vertical bed of resistant trough-bedded sandstone that forms an erosional wall on the south side of the ravine. The Jacobsville Sandstone in this area consists of conglomerate; sandstone; and shaly horizons, possibly accumulating as the lower portion of the formation dragged along the Keweenaw Fault. The attitudes of beds in the creek bottom change from flat-lying, about 1 km to the east of the fault; to east-dipping; and finally to vertical, and then the beds are folded as the Keweenaw Fault is approached. West of the fault the PLV dip to the WNW at 35-40°. The latest movement on the Keweenaw Fault is reverse, but the fault originated as a major normal growth fault on the southeast margin of the Midcontinent rift system (Cannon and others, 1990). Deposition of the Jacobsville Sandstone was controlled by the same compressional tectonism that produced the Keweenaw Fault. Also at this locality, the Jacobsville Sandstone contains abundant boulder sized clasts of felsic and mafic volcanic rocks, similar to Keweenawan volcanic rocks. The Keweenawan volcanic rocks were exposed and undergoing erosion during Jacobsville sedimentation as a result of uplift along the Keweenaw Fault.

- 38.95 The beginning of pavement; we are entering the town of Laurium.
- 39.7 Turn left, followed immediately by a right turn at the next stop sign on School Street.
- 39.8 The 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 the site of the Calumet & Hecla headquarters. Here, Edwin Hurlbut discovered the Calumet Conglomerate load in the early 1860's, which was to become the most important ore body in the whole district. Greater Calumet (including Red Jacket, Blue Jacket, Yellow Jacket, Laurium and Rambaultown) had a population

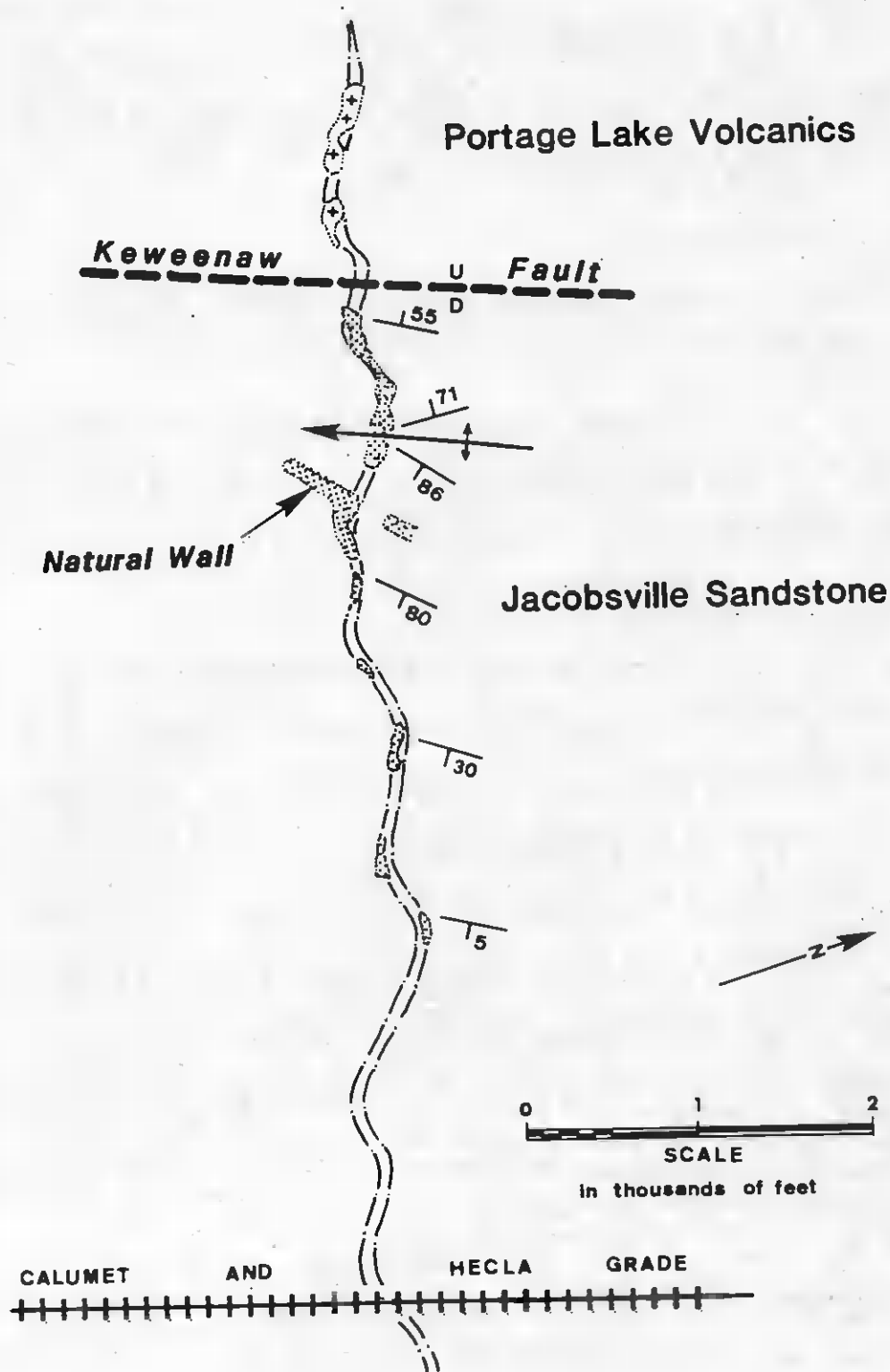


Figure 29: Geologic sketch map of the Natural Wall Ravine (from Bornhorst and others, 1983). Note that north is toward the right margin of the page.

of 33,000 in 1910. Among the many historic buildings, are the Calumet Theater (1900) and the C&H Community Library Building (1898). Immediately behind the Calumet High School and the blue water tower is the surface location of the great Calumet & Hecla Conglomerate, the "Mother Lode" of the district and the principal ore body where more than one third of all Michigan copper was mined. Excavations of a cross section of this great ore body is planned as part of the new Keweenaw National Historic Park.

MAP 9

41.0 Entering Centennial.

- 41.3 On the left 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, but the 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 1.9 billion kg 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 5 billion kg). The C&H lode had the highest average grade in the district of 2.85% 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 the conglomerate at Centennial are almost all quartz-feldspar phenocrystic rhyolite. The pebbles in the main channel conglomerate are quite a 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 it's thicker. Outside of the 1.5 m 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 1.5 m 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 important in exploring the conglomerate ore bodies (summarized from Weege and Pollack, 1971).

41.6 Entering Kearsarge, Michigan.

- 42.1 A stone boat on the right side of the road.

- 42.3 Turn right onto Water Street, just before the Wolverine Market. Continue straight ahead on the main paved road.

- 42.5 Park along the road and walk about 100 m to the north. Mine rock piles are on both the right and left sides of the road. Keep to the left side; the ones on the right side of the road (south)--on the

other side of some old buildings--are dangerous because of bad ground. Mining in this area was very shallow (Shaft No. 3). **BEWARE: STAY ON THE PATHWAYS** because these are OLD mined areas.

STOP 13: Wolverine Mine Shaft No. 2 (native copper deposit within Portage Lake Volcanics [PLV])

The Kearsarge Flow top deposit was worked by the Wolverine Mine and seven other mines: Centennial, South Kearsarge, North Kearsarge, Ahmeek, Allouez, Mohawk, and Seneca (Fig. 30). Production of copper from the Kearsarge Flow top began in 1887 and stopped in 1967. About 1026 million kg of refined copper were produced at an average grade of 1.05% Cu, making the Kearsarge deposit the largest flow top deposit and the second largest ore producer in the district. Underground workings are continuous for more than 12 km and extend down-dip as much as 2,500 m. The Kearsarge deposit is one of the best documented orebodies in the district (Stoiber and Davidson, 1959; Butler and Burbank, 1929).

The Kearsarge Flow has been recognized for a distance of about 55 km along strike. It lies directly above the Wolverine Sandstone and dips between 35 and 40° NW (Fig. 30). Stratigraphic and textural relationships make this flow easily recognized. It has an amygdaloid top that ranges from near zero up to 10 m in thickness. In the productive area, the flow top is a breccia. Individual fragments are generally less than 15 cm in greatest dimension, and contain numerous small amygdules. The flow top breccia makes up the uppermost part of the flow, grading downward into layered cellular amygdaloid, with amygdules abundant at certain horizons. This zone grades downward, first, into a zone of fewer and larger amygdules with fewer layered structures, and then into massive basalt (Table 3). Just below the flow top is a distinct plagioclase porphyritic basalt. The 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. Specimens with abundant plagioclase phenocrysts can be found on this rock pile. The porphyritic zone grades downward into massive aphyric basalt. The top of the Kearsarge Flow in the mined area has an average thickness of around 2 m.

The basalt in the Kearsarge Flow is well oxidized and has been affected by two types of alteration: albitization and pumpellyitization. Albitized basalt is about 60% 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 gangue minerals in the Kearsarge deposit are generally (in order of most to least abundant): calcite, epidote, K-feldspar, quartz, and lesser amounts of chlorite, prehnite, pumpellyite, laumontite, and sericite. Native copper is closely associated with the secondary amygdule minerals (Stoiber and Davidson, 1959). The secondary mineral assemblages vary both temporally and spatially within the productive area. Paragenetically, chlorite; epidote; microcline; and prehnite are early-formed minerals, and the latest-formed minerals are quartz; native copper; calcite; and chlorite (Fig. 31). A zonal stratabound arrangement of amygdule minerals in the Kearsarge deposit is seen in the Ahmeek Shaft No. 3 (Fig. 32 and Table 4). The zones are approximately parallel to bedding but irregularly distributed laterally. From the bottom to the top of the flow top, are five major mineral assemblages: 1) chlorite $\pm$ calcite $\pm$ microcline, 2) quartz-epidote, 3) calcite-epidote, 4) calcite-microcline $\pm$ epidote, and 5) chlorite-calcite $\pm$ microcline. The last assemblage is found in the

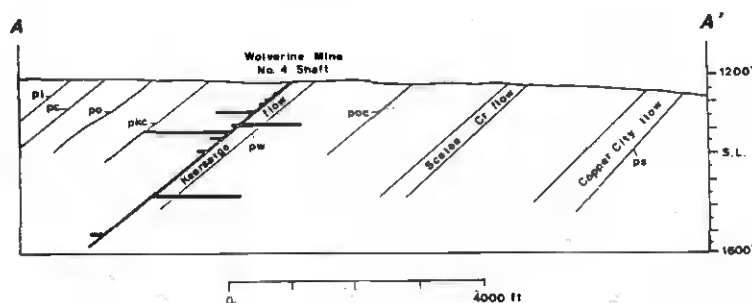
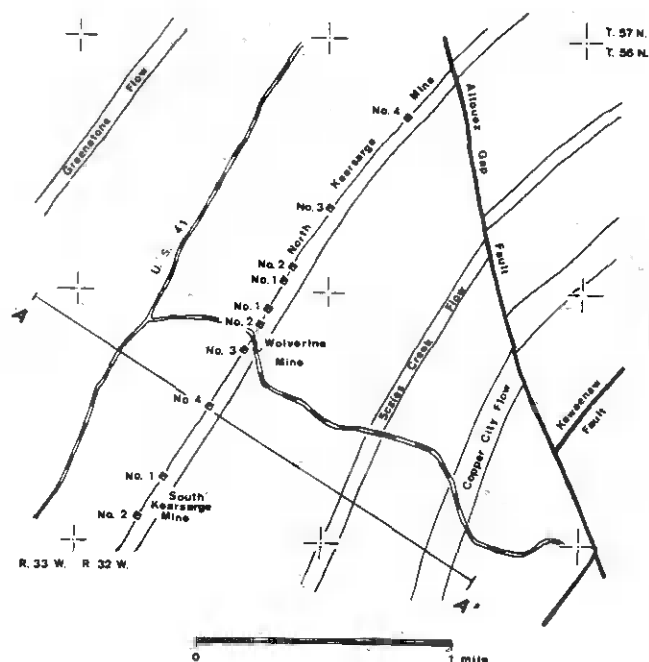


Figure 30: Geologic map and cross section showing the Kearsarge Flow, Wolverine Mine, and vicinity (modified from White and others, 1953; from Bornhorst and others, 1983). Stop 13 is the Wolverine Mine Shaft No. 2 mine rock pile. Abbreviations are as follows: Iroquois flow (pi); Calumet and Hecla Conglomerate (pc); Osceola flow (po); Kingston Conglomerate (pkc); Wolverine Sandstone (pw); Old Colony Sandstone (poc); St. Louis Conglomerate (ps).

Table 3: 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

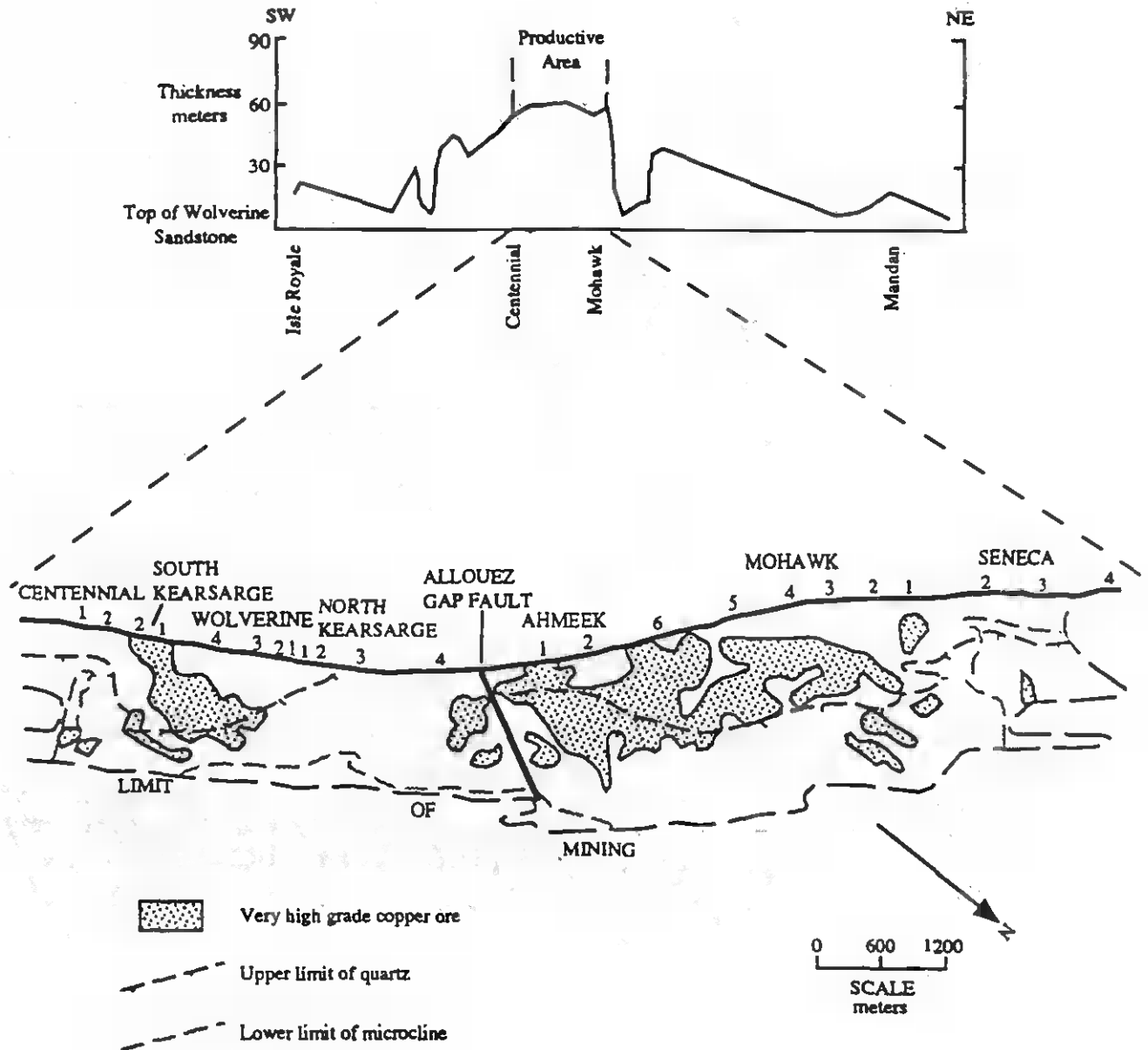


Figure 31: Thickness of the Kearsarge flow (top) from Isle Royale to Mandan (south of Copper Harbor) showing location of the productive area (modified from Butler and Burbank, 1929; from Bornhorst, 1992) (see Fig. 7 and 9 for location). The mined Kearsarge flow top (largest flow top deposit, with 1026 million kg of refined copper production) is bisected by the Allouez Gap Fault (bottom) with the high grade copper zone northeast of the fault associated with abundant subparallel faults and fractures. Distribution of amygdule-filling quartz (over 10% on hatched side) and amygdule-filling K-feldspar/microcline (absent below line) roughly correlates with native copper (modified from Stoiber and Davidson, 1959; from Bornhorst, 1992). Amygdule-filling calcite and epidote are present throughout the mine. The Kearsarge flow dips about 35° to 40° northwest and all data projected to a horizontal plane.

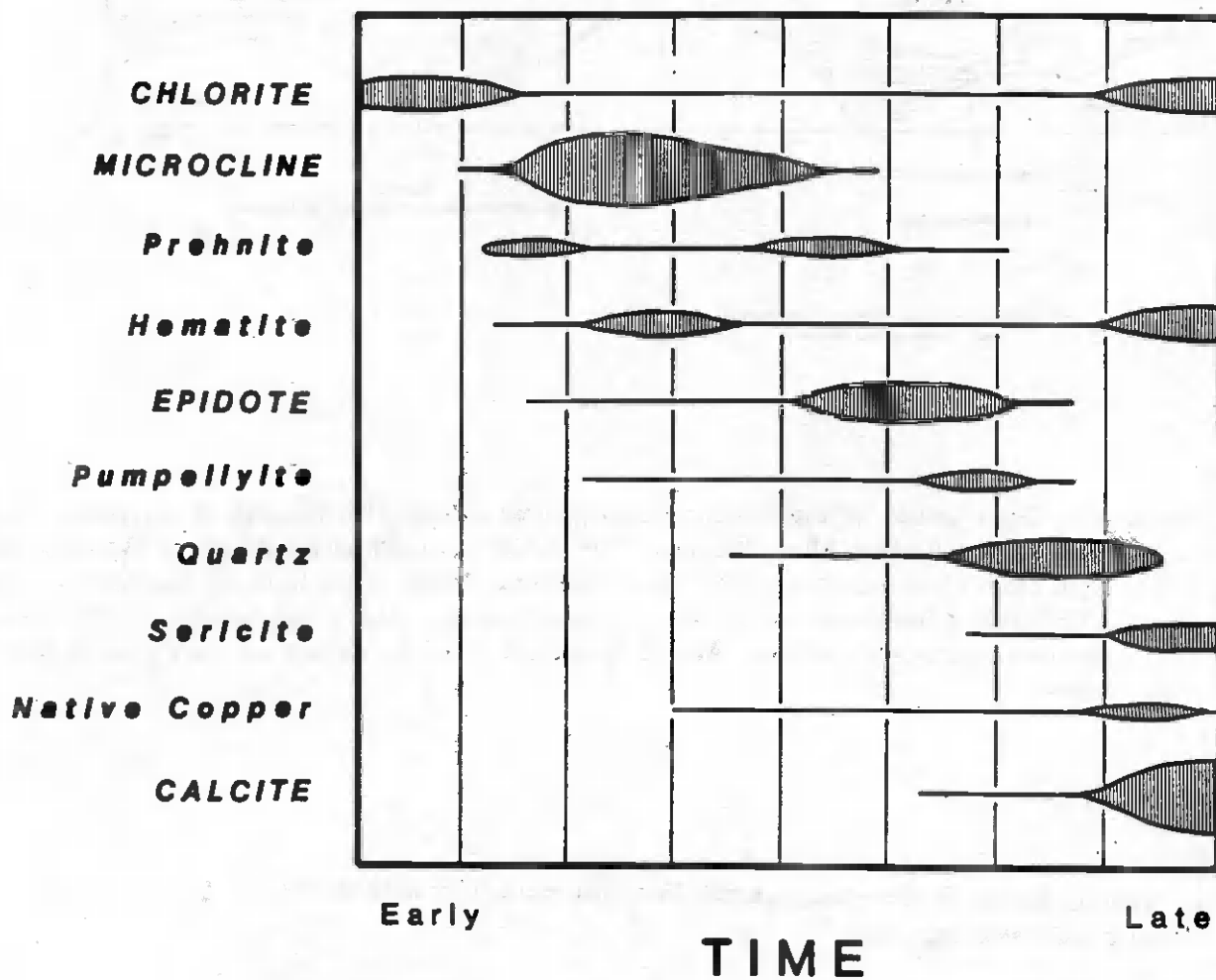


Figure 32: Paragenesis of secondary minerals in the Kearsarge Amygdaloid at the Wolverine Mine Shaft No. 2 (from Bornhorst and others, 1988). The relationships are based on a megascopic and thin section study of samples from the Shaft No. 2 mine rock pile. Compare to district-wide synthesis of paragenesis given in Figure 12.

SOUTH

NORTH

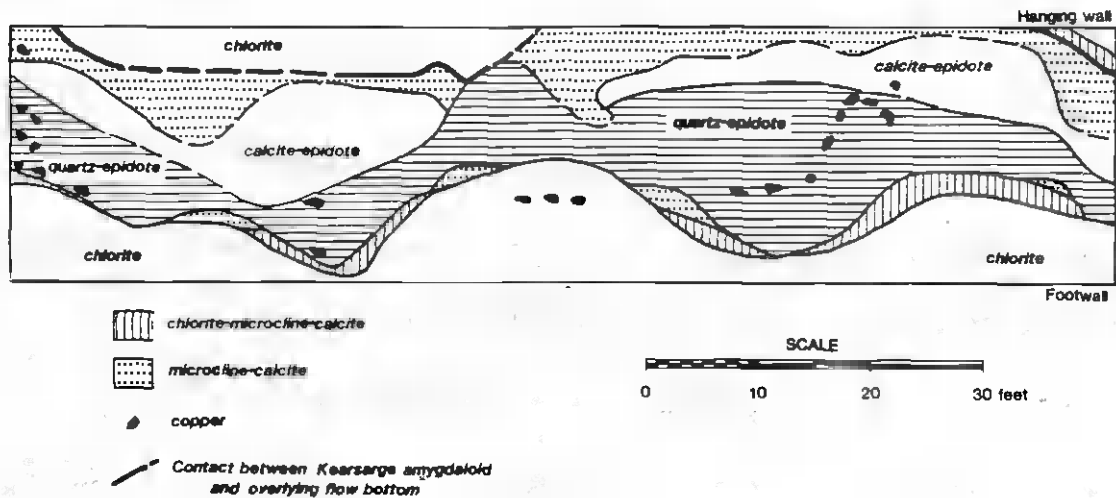


Figure 33: Cross section of the Kearsarge Amygdaloid showing the banding of amygdule mineral assemblages, Ahmeek Mine, 35th level, 399 to 500 feet south of the Kearsarge Flow (modified from Stoiber and Davidson, 1959; from Bornhorst, 1992). Data from the back and walls are projected to a horizontal plane. In one mapped locality, Stoiber and Davidson (1959) found a laumontite-quartz-calcite zone. Amygdule mineralogy of the various zones are given in Table 4 below.

Table 4: Volume percent of amygdule minerals from mapped assemblages shown in Figure 33 (from Stoiber and Davidson, 1959).

Mineral Assemblage Band	Chlorite	Chlorite- Microcline- Calcite	Microcline- Calcite	Quartz- Epidote	Calcite- Epidote
Volume Percent Amygdule 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

base of the overlying flow (north hanging wall corner in Fig. 32). The zoning 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 limits 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 observation is consistent with the paragenetic relationships seen in individual samples. No strict correlation exists between the stratabound zoning and the grade of native-copper mineralization (Stoiber and Davidson, 1959).

The amygdule minerals and grade of copper mineralization vary with depth. The quartz content is considerably less than 10% at shallower depths, and generally averages about 15% within the quartz zone. An irregular increase in quartz content occurs within the quartz zone with increasing depth. The amount of native copper present is much more irregular than the depth variation of the mineral zones. The richest copper ore appears to follow the boundary for >10% quartz. The lower limit of microcline may also mark the limit of significant copper mineralization. On a regional scale, the Kearsarge Flow lies within the quartz and prehnite zones. Detailed data suggests that quartz- and prehnite-free "islands" are present within the regional zones.

Microcline, calcite, chlorite, and epidote separated from amygdules from rocks collected off of this rock pile were used by Bornhorst and others (1988) to provide an absolute age of mineral precipitation. The microcline, calcite, and epidote all precipitated simultaneously with native copper, as indicated by textural evidence such as inclusions of native copper and cross-cutting veinlets. Application of the Rb-Sr method to these minerals suggests an age of mineralization of between 1060 and 1047 m.y. (+/- ~ 20 m.y.). These results are consistent with other data from the Midcontinent rift system.

The Allouez Gap Fault bisects the thickest segment of the Kearsarge Flow along its 55 km strike length (Fig. 33). Higher grade and production occur northeast of the fault where fractures parallel to the fault are more abundant. Within the Allouez Gap Fault zone, early epidote and quartz were brecciated and recemented by more calcite; quartz; and native copper. Finally, after another major episode of brecciation, the fault zone was recemented with calcite; quartz; and lesser laumontite (Butler and Burbank, 1929). The data are clear indications that movement along the fault occurred before, during, and after deposition of native copper. The fault apparently provided ore fluids to the permeable flow top. The coincidence of the fault with the relatively thick flow top resulted in the second largest deposit in the district.

At the Wolverine Mine Shaft No. 2 rock pile, you will have the opportunity to see a variety of mineral assemblages and their paragenetic relationships. For the Shaft Nos. 1 and 2 rock piles as a whole, Stoiber (unpublished data) estimated the following percentage of amygdaloidal minerals: calcite, 51%; microcline, 38%; epidote, 10%; prehnite, 1%; and quartz, trace. In the vicinity of the Shaft Nos. 2 and 3 rock piles, one can find outcrops of the Kearsarge Flow interior. Native copper can be found in specimens from this rock pile. This, and other Kearsarge Mine rock piles, illustrate the complexity of flow top ore bodies in the Keweenaw Peninsula native copper district.

- 42.5 Continue on the same road and in the same direction as before (east), away from Kearsarge.
- 43.1 Stop at the dirt road junction to the right. 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 22 km to the south, in Houghton.

STOP 14: Scales Creek (Portage Lake Volcanics [PLV])

This stop provides an opportunity to view the Scales Creek Flow, a regionally extensive basaltic flow. It has been traced for more than 30 km along strike in the Keweenaw Peninsula. Outcrops of the Scales Creek Flow can be seen on both sides of the main road and along Scales Creek, just north and paralleling the road. This flow was studied, from drill cores northeast of here, by Scofield (1976). The Scales Creek Flow is characteristically ophitic, with an amygdaloidal top and base, and a massive interior. The massive interior is, for the most part, geochemically unaltered (Table 5), with the following estimated modes: plagioclase, 40%; pyroxene, 48%; olivine, 10%; and opaque oxides, 2%. Primary plagioclase; pyroxene; and opaque oxides can be found, but olivine is pseudomorphically replaced by talc; serpentine; and/or chlorite. Although the massive interior of the flow contains both primary and secondary minerals, it remained a chemically closed system except for water flowing away from fractures that cut the interior. The massive nature of the interior inhibited movement of hydrothermal fluids. In the amygdaloidal flow top, no primary minerals are present; 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).

- 43.1 Turn around and retrace the route back to US-41.
- 43.7 Passing the Wolverine Mine rock piles (Stop 11).
- 43.9 Turn right on US-41 at Wolverine Market.
- 45.2 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 PLV. It will be seen at Stop 16.
- 45.4 Turn left on a paved road called Bumbletown Road, just before a gas station.
- 45.6 Stay on the main paved road, bearing right.
- 45.75 Park on the right at the dirt road. Walk the road to the mine rock piles of the Allouez Conglomerate Mine.

STOP 15: Allouez (conglomerate in Portage Lake Volcanics [PLV])

The rock piles here are from the Allouez Conglomerate Mine, which operated from 1869 to 1892 and produced about 1.2 million kg of copper. The Allouez Conglomerate is one of a small number of interflow sedimentary horizons within the PLV (Fig. 9). These sedimentary horizons are important for stratigraphic correlations within the otherwise monotonous pile of basalt lava flows of the PLV. This bed can be traced along strike from the tip of the Keweenaw Peninsula west and south, to at least the Mass area, a strike length of more than 120 km. It is one of the most continuous sedimentary horizons in the Keweenaw Peninsula. The Allouez Conglomerate is exposed in underground workings at Stop 8--Quincy Mine Adit, Hancock--and in underground workings at Stop 30--the Delaware Mine. It is stratigraphically just below the Greenstone Flow, the thickest flow in the PLV--prominent in the northern half of the Keweenaw Peninsula. Like other interflow conglomerate beds within the PLV, the Allouez Conglomerate consists of mostly conglomerate with lesser amounts of sandstone and siltstone. These red-colored

clastic sedimentary rocks where deposited in a terrestrial alluvial fan environment with dominant transport of sediment from the margins of the rift, toward the center (current center of Lake Superior) during a hiatus of volcanic activity.

The rock piles from the Allouez Conglomerate illustrate features of interflow sedimentary beds of the PLV. The rock piles provide an excellent view of "clean" conglomerate. The largest boulders in this conglomerate are about 65 cm in diameter, and the median size is about 8 cm. A pebble count of boulders more than 20 cm across gave the following results: mafic rock, mostly amygdaloidal, 16%; quartz porphyry, 36%; feldspar porphyry, 11%; and granophyre, 37% (White, 1971b). The heterogeneity of this assortment suggests a less restricted source terrane than the one that supplied the Kingston and Houghton Conglomerates in this area. For example, the Kingston is made up almost entirely of fragments of quartz-feldspar porphyry, but bedded red sandstone can also be found in some specimens.

Little evidence of native copper mineralization is present in this rock pile. Occasionally, one can find a specimen with native copper filling the void space between clasts and grains. Calcite and chlorite are the dominant pore-filling secondary minerals. In slabs, almost every feldspar phenocryst is associated with a tiny speck of native copper (Kalliokoski, personal communication, 1988). Thin black veinlets cutting the Allouez Conglomerate are calcite, full of chalcocite dust. Supergene alteration resulting from the downward percolation of groundwater is rare in Keweenaw native copper deposits of the Keweenaw Peninsula. Here however, the effects of supergene alteration is quite visible as chrysocolla; malachite; and cuprite are present in numerous samples.

45.75 Continue on the main paved road to the top of Bumbletown Hill.

46.1 Turn right on Cedar Street.

46.3 The top of Bumbletown Hill near the communication towers. The hill is visible to the northwest while traveling from Calumet to Allouez.

STOP 16: Bumbletown Hill (Allouez Gap Fault)

Bumbletown Hill is located on the southwest side of the Allouez Gap, a north-trending valley. The valley follows the Allouez Gap Fault, a zone of faults and fractures, along which the PLV and Keweenaw Fault are offset. At this gap, the strike of the PLV swings from about N35°E to N50°E.

From this location on a clear day, Isle Royale may be seen--80 km to the northwest--and the Huron Mountains may be seen beyond Keweenaw Bay--60 km to the southeast. The land slopes very gradually to the northwest toward Lake Superior, as it does throughout most of the length of the Keweenaw Peninsula. The southeast flank of the Keweenaw Peninsula has a steeper slope at the skyline, following approximately the line of the Keweenaw Fault. The low-lying plain between the fault and Keweenaw Bay, is underlain by flat-lying Jacobsville Sandstone.

Looking northeast along the strike of the PLV, one can see the cuesta form of the ridge upheld by the Greenstone Flow. At Bumbletown Hill, this flow is only 85 m thick, but it thickens abruptly to more than 400 m at the near end of the cuesta ridge. To the right of the Greenstone ridge, the more distant hills are formed by lava flows lower in the section.

The Allouez Gap Fault follows the SE trending valley, near the relatively new headframe. Almost every permeable horizon near the Allouez Gap Fault contains above average amounts of native copper; nowhere else in the district are there so many mineralized beds. About 60% of the district production can be linked to the fault as a primary pathway for ore fluids. The fault bisects the Kearsarge deposit, which is the second largest producer in the district (Fig. 32). The line of rock piles demarking its location is a little more than 1500 m southeast of Bumbletown Hill. The large "new" headframe, 2000 m east of the hilltop, is the Kingston Mine. This small deposit produced 9 million kg of copper (1963-1968), and is bisected by the Allouez Gap Fault (Fig. 34). About 1200 m of the hilltop is a deposit, at N65°E, which produced 15 million kg of copper (1944-1964) from the Houghton Conglomerate and the Iroquois Flow top. The rock piles just below the hill top at Stop 15 are from mines in the Allouez Conglomerate which produced 34 million kg of copper.

The outcrops on the top and upper slopes of Bumbletown Hill represent a series of basalt and andesite flows; some flows are slightly porphyritic. They range up to 20 m in thickness, and as a group are stratigraphically equivalent and lithologically similar to those whose tops were mined at the Quincy Mine, just north of Hancock. Unlike the basaltic flows found below the Houghton Conglomerate, these flows have little lateral/strike direction continuity. Two flows pinch out on the top of Bumbletown Hill (Fig. 35) (White, 1971b).

Some of the exposed flow tops on Bumbletown Hill are slabby pahoehoe layers which have experienced runout of much of the mass of the lava flows.

The Greenstone Flow is exposed in a series of outcrops 160-300 m southeast 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.

Allouez Gap is an important physiographic feature of the Keweenaw Peninsula (Fig. 18). It contains the largest accumulation of glacial sediments north of Portage Lake. The gap is the lowest elevation that cuts across the peninsula between Portage Lake and the tip of the peninsula (Regis, 1983). A number of kettles along a northwest trend occur within the gap (Fig. 36).

Retrace the route back to US-41.

47.2 At the junction with US-41, turn left and cross into Keweenaw County from Houghton County.

48.1 Entering Ahmeek.

48.4 The junction to Cliff Drive. Turn left on Cliff Drive.

MAP 10

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

51.7 At this point, the Greenstone Flow abruptly thickens to nearly 400 m (Fig. 37). It dips northward at about 25° toward the center of the Midcontinent rift. 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 rift. Thus, the areal extent of this great flow exceeds 5000 km², and its volume is on the order of 800-1500 km³, according to White (1960)



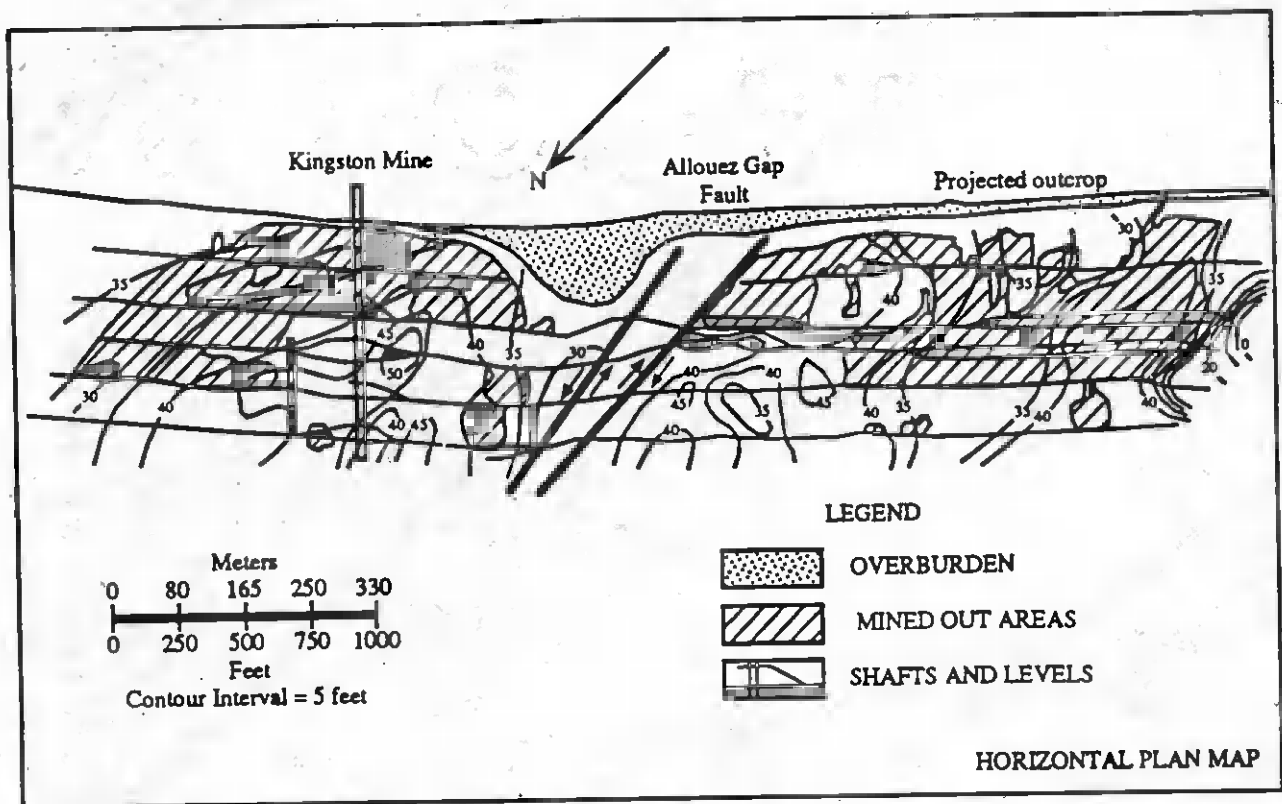


Figure 34: Thickness of the Kingston Conglomerate at the Kingston Mine showing the bisecting Allouez Gap Fault (modified from Weege and others, 1972; from Bornhorst, 1992). Ore ends abruptly at the thickness pinch-down on the southwest end of the deposit with some of the highest grades in the mine next to the pinch-down whereas the eastern edge of the orebody is gradational. The bottom level is 350 m deep on the incline at 40°.

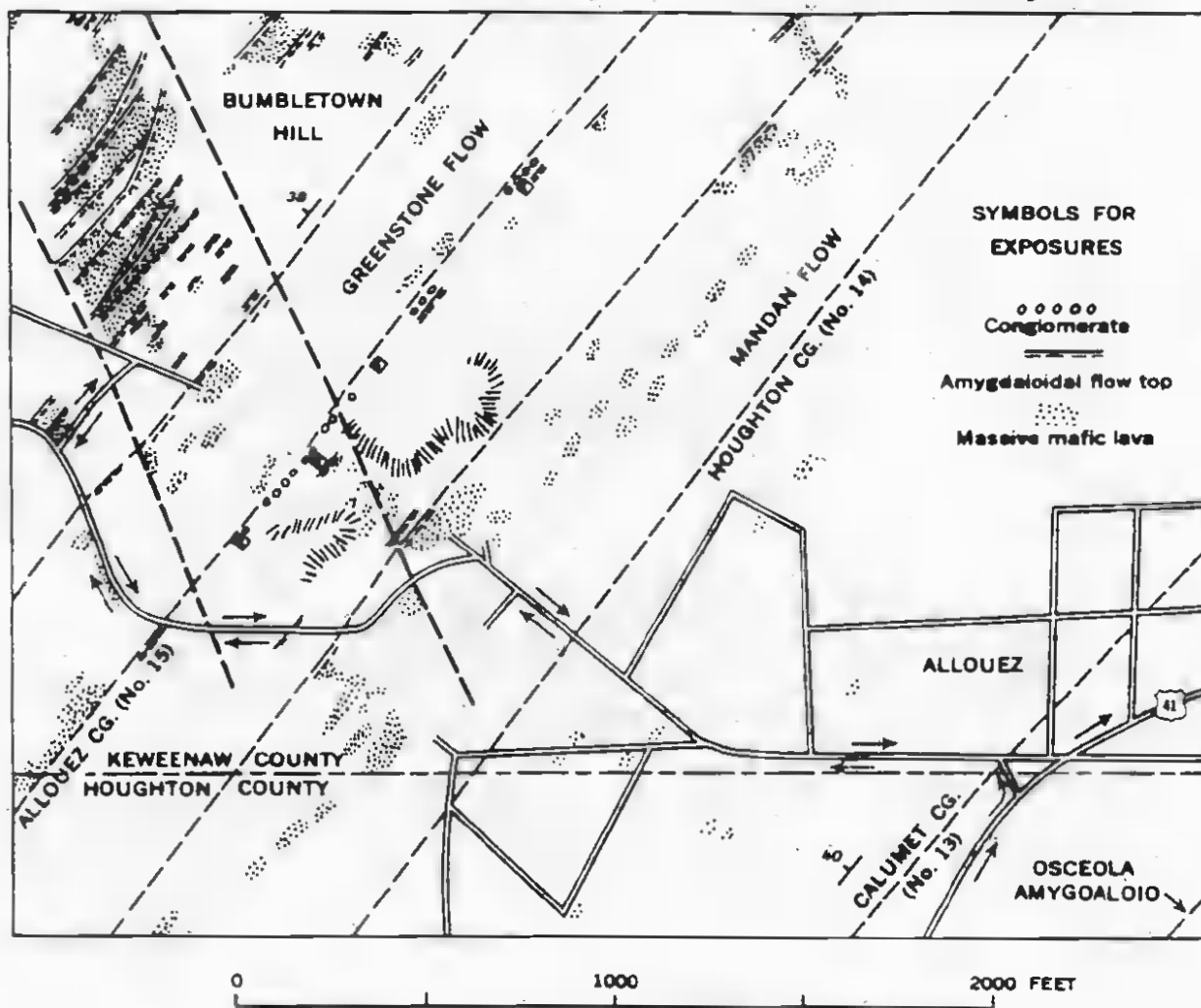


Figure 35: Outcrop map of the Allouez-Bumbletown Hill area (from White, 1971b).

Table 5: 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

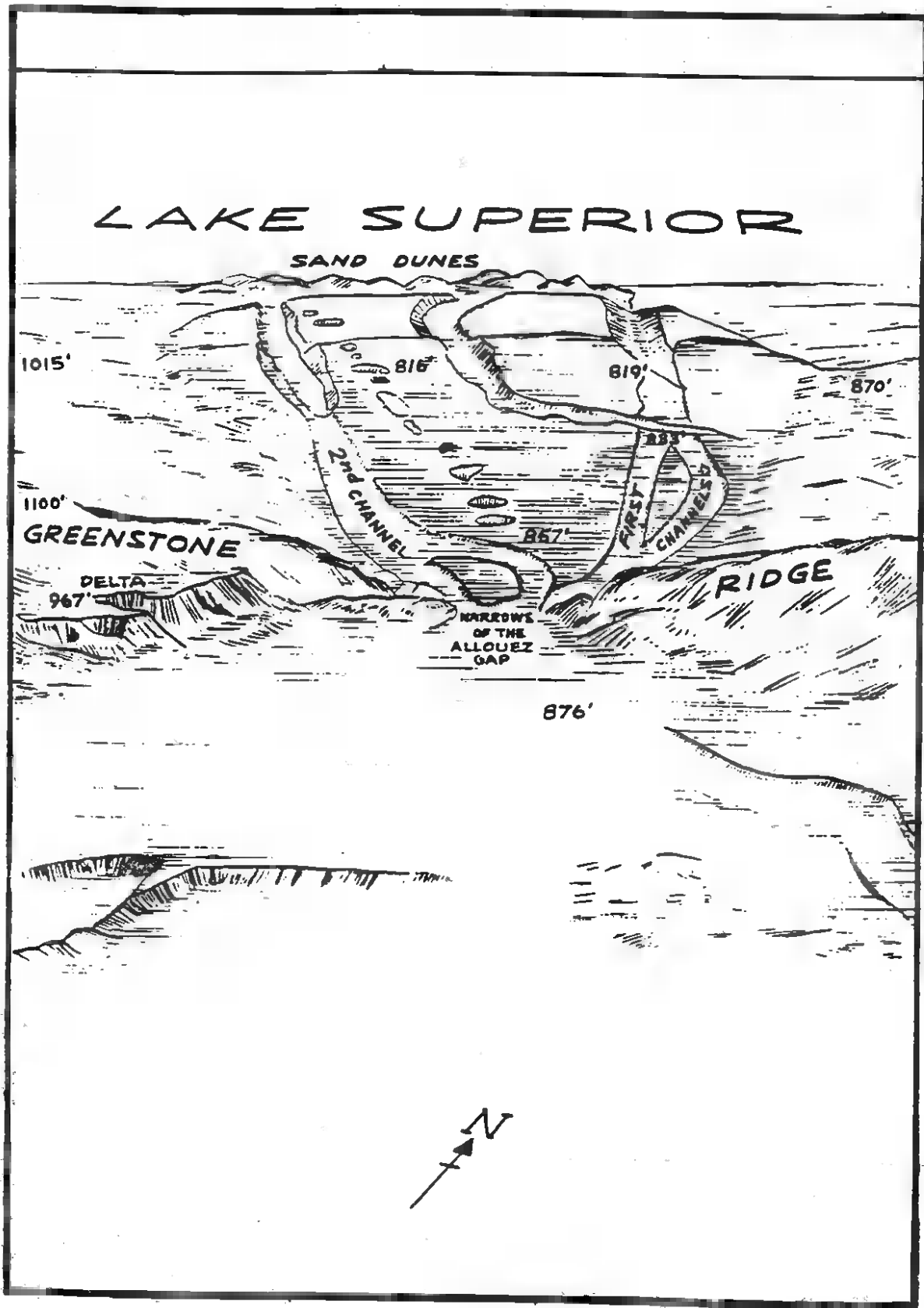


Figure 36: Physiographic and glacial features of Allouez Gap (from Hughes, 1963).

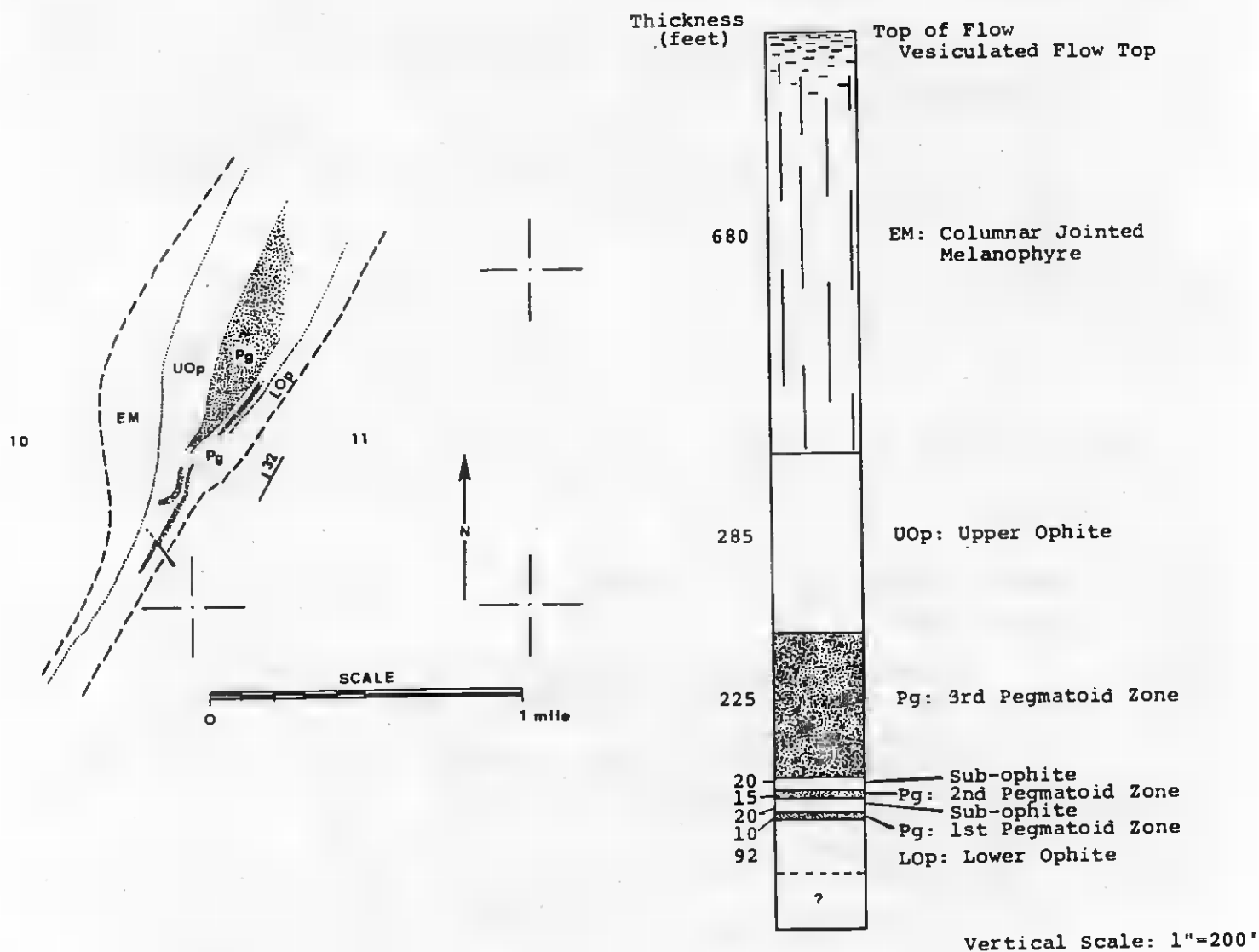


Figure 37: Geologic sketch map and stratigraphic section showing vertical zones within the Greenstone flow between Seneca and the Cliff Mine (from Longo, 1983).

and Longo (1983). It rivals the composite Roza Flow (Columbia R.) as the largest known lava flow on Earth. The Greenstone Flow typically shows spectacularly developed pegmatites, ophitic horizons, and columnar jointed areas. The pegmatoid zone within the Greenstone Flow near this location is unusually thick (Fig. 37), and the ophitic zones are relatively unaltered. 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 Flow at this point 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 10 and 11

52.1 Crossing the Gratiot River.

MAP 11

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

54.6 This is the site of the Cliff Mine, which was the first mine in the district, and operated discontinuously from 1845 to 1887. The rock piles and old footings for the mine building are mainly on the left side of the road and the town site, of which little remains, is on the right side of the road.

STOP 17: Cliff Mine (native copper vein deposit) (see cover photo)

The Cliff Mine worked the Cliff Fissure from 1845 to 1887, and produced a total of about 38 million lbs. of refined copper; the productive portion 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 (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. One large 100 ton mass could not be blasted, so it had to be cut by hand into smaller pieces (Clarke, 1976). Among the fissures, the Cliff was the most productive of silver. In addition to native copper and silver, the Cliff Mine produced the following minerals (not in order of abundance): calcite, epidote, chlorite, laumontite, prehnite, datolite, thomsonite, chlorastrolite, galena, apophyllite, adularia, gypsum, sphalerite, pyrite, and surface oxidation minerals.

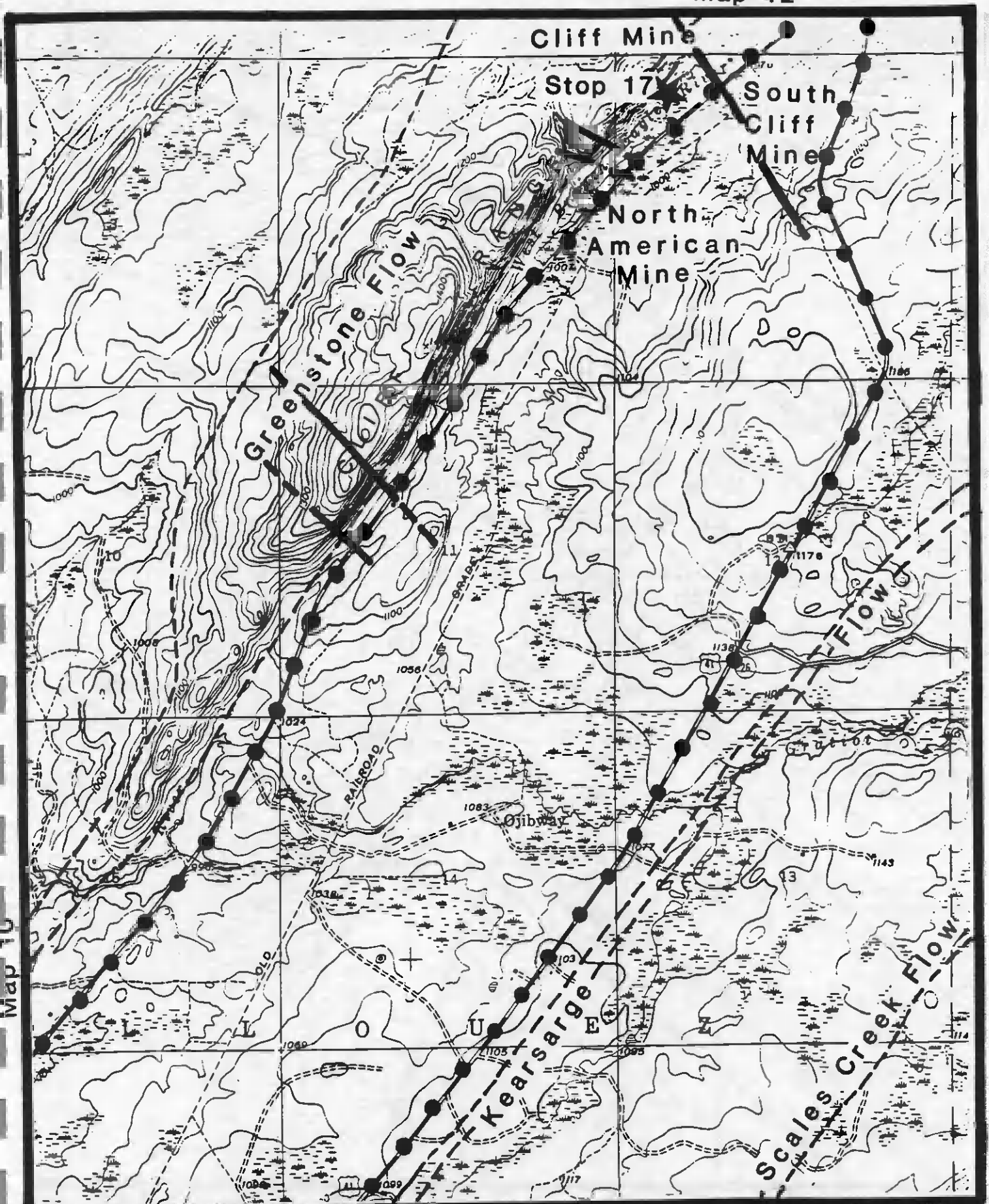
The Greenstone Flow at this locality is mainly ophitic basalt and sometimes shows quite well developed coarse columnar jointing. The Greenstone Flow is described in more detail at mileage 50.7.

55.2 The junction of US-41/M-26. Turn left (north).

MAP 12

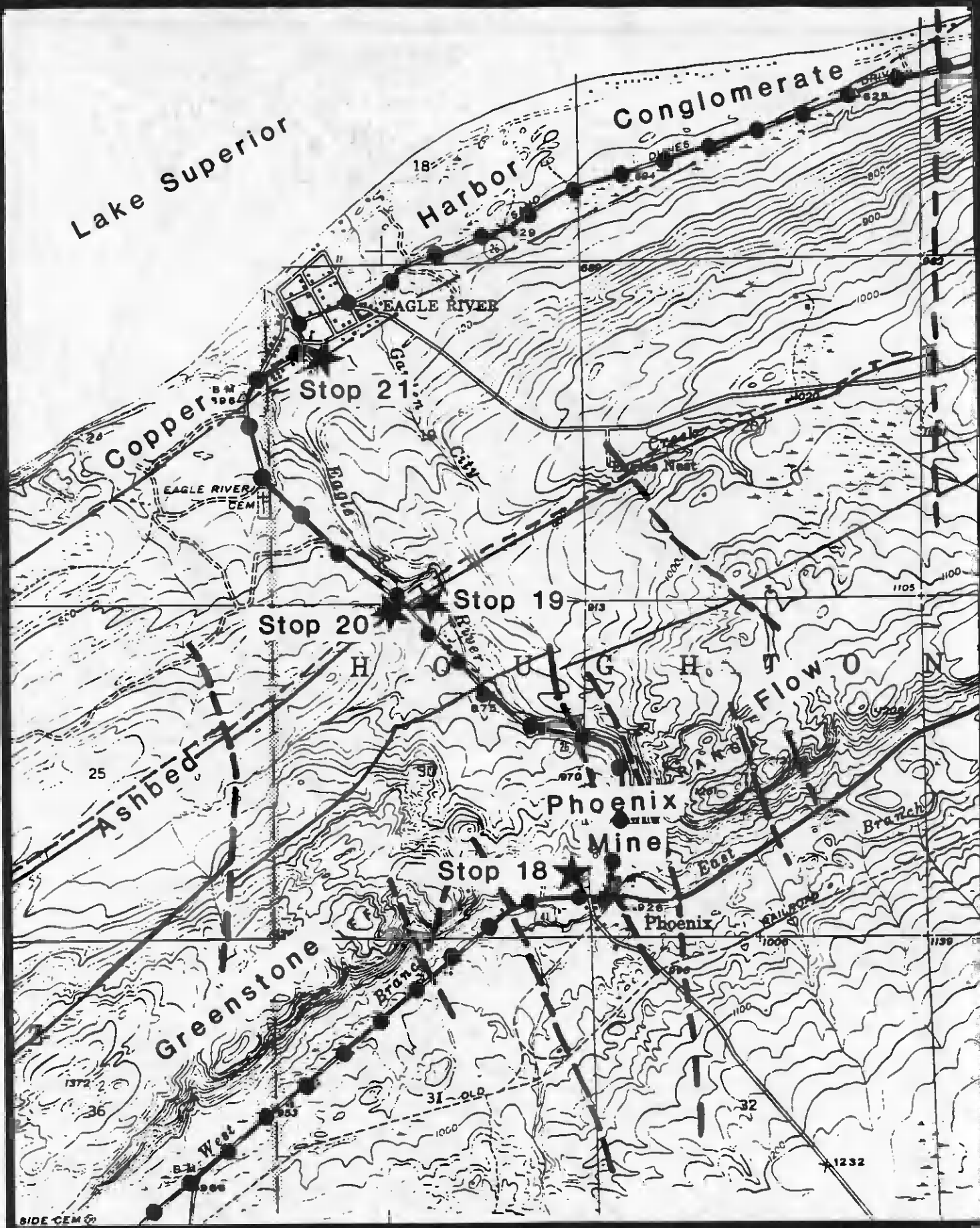
55.5 Entering Phoenix.

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



Map 10

MAP 11



Map 11

MAP 12

STOP 18: Phoenix Mine (native copper vein deposit and Portage Lake Volcanics [PLV])

The Phoenix Mine worked numerous veins below the Greenstone Flow. Like the Cliff Mine discussed at Stop 17, the Phoenix Mine was one of the earlier mines in the district and operated off and on from 1849 to 1917. The vein was worked to a vertical depth of about 300 m, with varied grade (average grade around 1.5%). Since the vein cuts thin lava flow tops, no mining was done on adjacent mineralized flow tops. The Phoenix Mine produced a total of about 17 million lbs. of refined copper (Butler and Burbank, 1929). It also worked the Ashbed Amygdaloid where it is mineralized, in the vicinity of vein copper occurrences. The Phoenix Mine rock pile is notable for halfbreeds (native copper plus native silver), spectacularly, crystallized analcite and chlorastrolitic pumpellyite (Michigan "greenstone"). Listed below are some other minerals that have been reported in the Phoenix Mine area (Clarke, 1974a): pumpellyite, chlorite, natrolite, and apophyllite.

To look at the Greenstone Flow you must climb over the rock pile and then pass one of the fissure zones just above the shaft. Proceed ahead and climb to the base of the steep cliffs, which are composed of a portion of the massive flow interior of the Greenstone Flow, an enormous lava flow over 400 m thick, and perhaps representing the greatest single outpouring of lava on Earth.

A very coarse ophitic zone occurs near the base of the Greenstone Flow (Fig. 38). 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 this great flow and of the town site of Phoenix, which had a population of 1,000 from 1877-1887.

The Greenstone Flow has been identified for a distance of 90 km along the length of the Keweenaw Peninsula, as well as throughout the length of Isle Royale, 90 km northwest on the opposite limb of the Lake Superior Syncline. The extent is 5000 km² with volume of 800 to 1500 km³ (Longo, 1983; White, 1960). Very slow solidification of this great mass of magma allowed extensive *in-situ* magmatic differentiation, resulting in a massive, ophitic zone at the base of the flow; an overlying zone of intercalated subophitic and pegmatoidal layers; an upper ophitic zone; and a fine-grained, vesicular flow top (Cornwall, 1951a and b). The lower ophitic zone experienced rates of undercooling low enough to allow growth of clinopyroxene oikocrysts up to 5 cm in diameter.

The geochemical composition of the Greenstone Flow magma is more evolved than typical olivine tholeiites; which constitute the greatest volume of the PLV. Primitive olivine tholeiite and quartz tholeiite occur between the Greenstone Flow and the top of the PLV. Generally, magmas become more primitive and less crustally contaminated with time during the Midcontinent rift development, reflecting changes in magmatic and tectonic processes. A model of magmatic and rift evolution based on PLV data involves primitive parental magma modification by complex, open-system fractional crystallization in large reservoirs at the base of the thinned crust (Paces, 1988). The resulting olivine tholeiite magma is either erupted at the surface or supplied to smaller chambers at higher levels where further crystallization produces evolved tholeiites and silicic rocks.

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

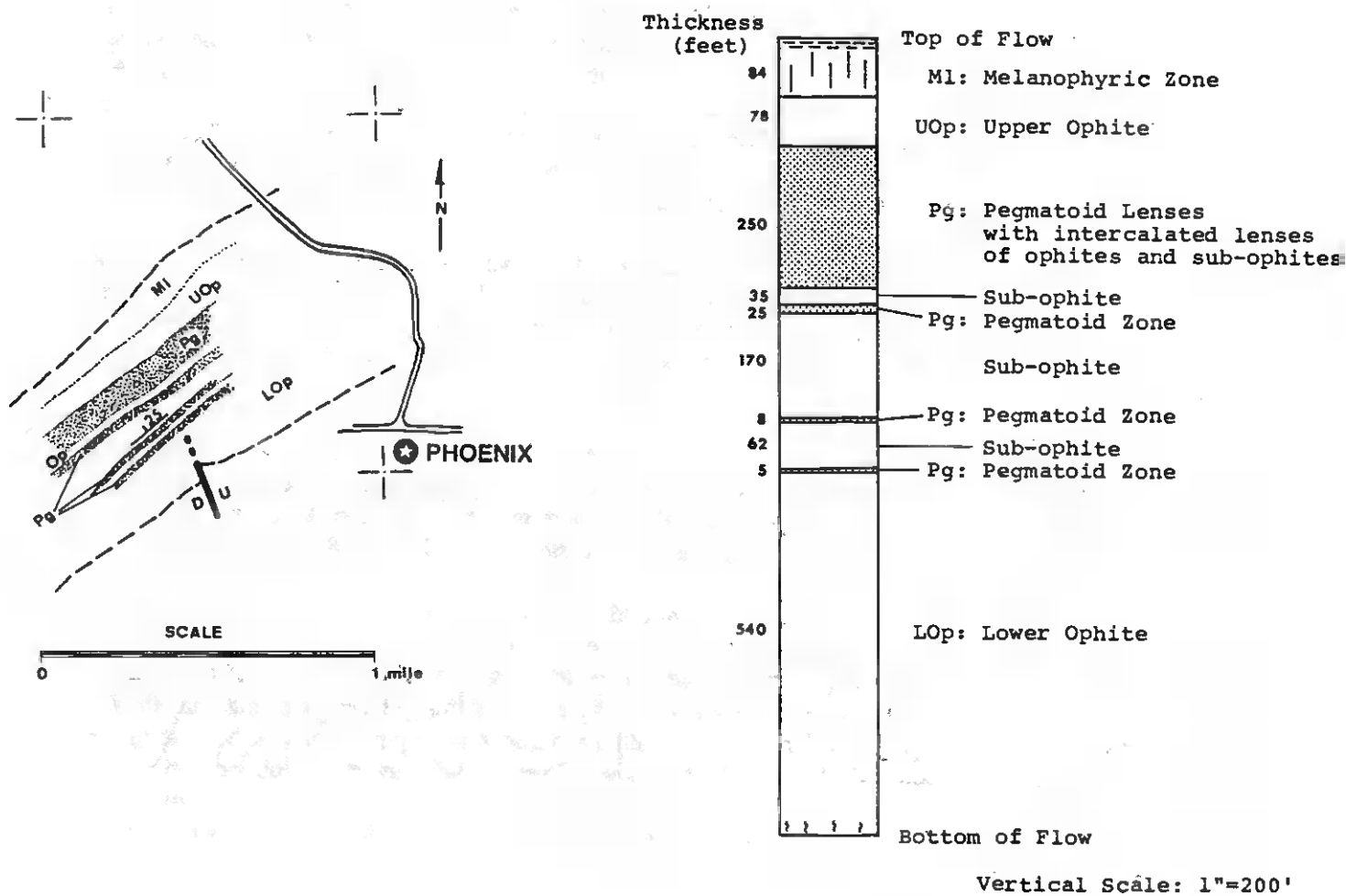


Figure 38: Geologic sketch map and stratigraphic section showing zonation of the Greenstone flow near Phoenix, Michigan (from Longo, 1983).

Table 6: Average composition of the Greenstone Flow (Longo, 1983).

	<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
		Y	14
		Zn	84
		Zr	92

* Total Fe as FeO.

- 56.8 Turn left on M-26 toward Eagle River. Cross Central Creek and begin to drive perpendicular to strike and cross the Greenstone Flow.
- 56.9 At 9:00 (on the left), the Phoenix rock piles and cliffs of the Greenstone Flow are readily visible.
- 57.1 Cross Eagle River.
- 57.2 Outcrops of the Greenstone Flow are 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 of the flow.
- 57.6 There is a pull-out on the right hand side of the road. Flows above the Greenstone Flow can be seen along Eagle River. The river is about 25 m from the side 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 spring. At Stop 19, just up the road, one can begin a traverse along Eagle River.
- 57.9 Pull over at a poorly maintained dirt road pull-out on the right. At this locality, Eagle River crosses the Ashbed. There is a very sharp bend in Eagle River north of the Ashbed Flow. From here it is possible to begin a traverse along Eagle River either upstream or downstream.

STOP 19: Eagle River (Portage Lake Volcanics [PLV])

Eagle River, Jacobs Creek, and Owl Creek each make excellent stream traverses of the PLV. At this point, approximately at the Ashbed, a traverse along the stream north to Eagle River allows excellent observations of the upper stratigraphy of the PLV. The Ashbed is described at Stop 20.

Eagle River traverses the section shown in Figure 39; along the traverse, you see: 1) excellent sections through individual lava flows showing amygdaloidal tops, and massive melaphyric, glomeroporphyritic, or ophitic flow interiors; 2) the best section of entablature columnar jointed basalt in the Keweenaw Peninsula, which can be reached overland by walking

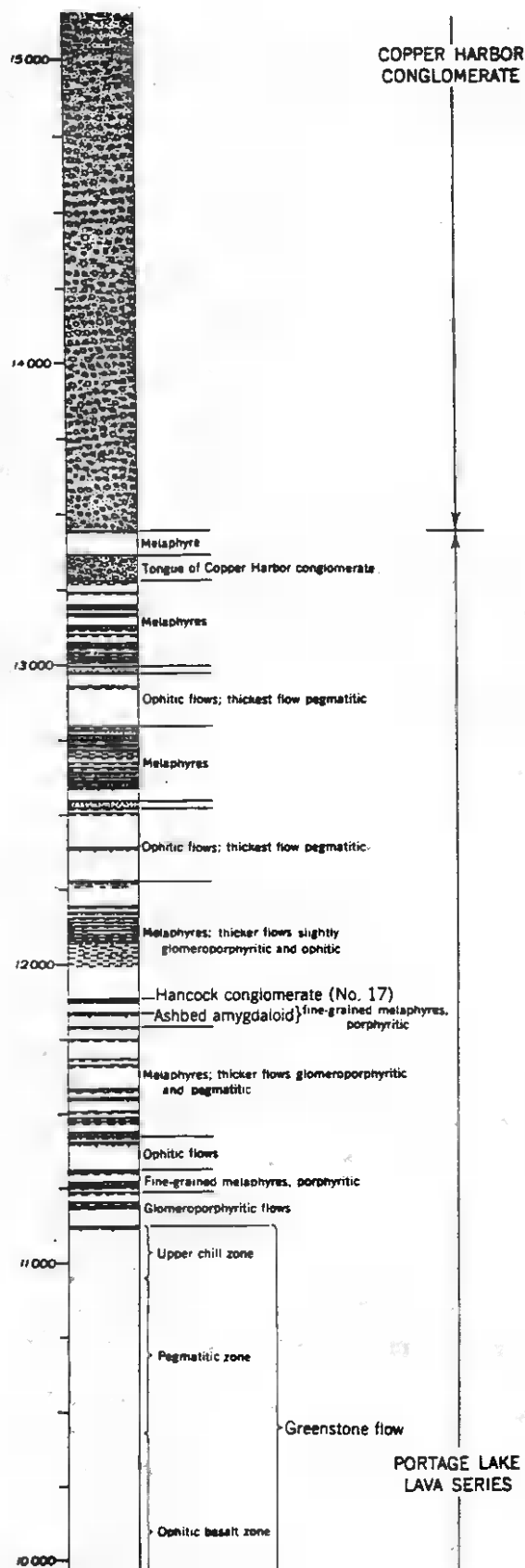


Figure 39: Stratigraphy of the Portage Lake Volcanics above the Greenstone flow in the vicinity of Eagle River and Phoenix, Michigan (from Cornwall and Wright, 1954).

a few hundred meters downstream; and 3) interbedding of sediments with the lava flows, which becomes more prevalent up section. If you decide to take this traverse, it's best to just resign yourself to wet feet. The traverse is not advisable in the spring because of high water.

- 58.0 Pull over opposite to the outcrops on the left side of the road.

STOP 20: M-26, Eagle River (Portage Lake Volcanics [PLV])

The Ashbed is a very distinctive horizon that can be traced over a distance of almost 25 km in outcrop and drill holes. It is the vesicular zone below the Hancock Conglomerate (Fig. 39 and Map 12). The Ashbed is exposed on the SE end of the outcrop (away from Lake Superior), and is overlain on the NW end by the massive interior of the overlying basalt lava flow dipping about 25°NW (toward Lake Superior). The weathered outcrop has a rubbly appearance, but in the water-washed low exposures in the drainage ditch alongside the road, 5 to 15 cm diameter clasts of vesicular basalt set in a fine matrix is clearly visible. The clasts are subrounded, and in general, the Ashbed is a jumble of vesicular basalt fragments and an interstitial brown-to-gray, fine-grained matrix. The secondary minerals filling the void spaces are calcite, quartz, chlorite, and minor epidote. Some vesicles contain minute flecks of Cu (White, 1971b). Small mines were found along this horizon in many places, from Atlantic Mine (near Stop 3) to Owl Creek (Stop B1).

The Ashbed includes rocks characterized as pyroclastic, and those interpreted by Johnson (1985) as hyaloclastite. On Eagle River, the Ashbed is only the pyroclastic horizon and stratigraphically separate is another horizon consisting of a pillowed lava sequence overlain by hyaloclastite (Johnson, 1985). The pillows are about 50 cm in diameter with red oxidized margins.

- 58.3 Go downhill toward Lake Superior, which is visible at the treeline.
- 58.6 The Evergreen Cemetery on the left was established in 1843.
- 58.9 Entering Eagle River. On the left is the road to Five Mile Point (begin Leg F - Five Mile Point here). 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. In 1845, he drowned off Eagle River.
- 59.1 Cross Eagle River on the Eagle River Bridge. Park NE of the bridge.

STOP 21: Eagle River Falls (contact of Portage Lake Volcanics and Copper Harbor Conglomerate)

The falls occur at the contact between the top of the PLV 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 PLV which indicate the flow was erupted from a vent to the north (the center of the rift now under Lake Superior). The contact dips about 30° NNW. The contact relationships suggest very little erosion between the flow and deposition of the conglomerate 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 shale beds.

Follow M-26 with a sharp left turn, just after the bridge.

59.2 Sharp right turn.

MAP 13

62.15 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. There are excellent exposures of the upper part of the PLV 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.

64.0 Great Sand Bay. The sand dunes at the road level are remains of the Lake Nipissing Stage of the Lake Superior Basin.

65.0 Cat Harbor. The Lake Shore Traps form the offshore ridge, they are mafic to intermediate lava flows within the Copper Harbor Conglomerate.

MAP 14

66.9 Turn right by the Eagle Harbor Store.

66.95 M-26 makes a sharp bend to the right. Continue straight toward the Eagle Harbor Lighthouse.

67.0 Make a sharp left to the lighthouse.

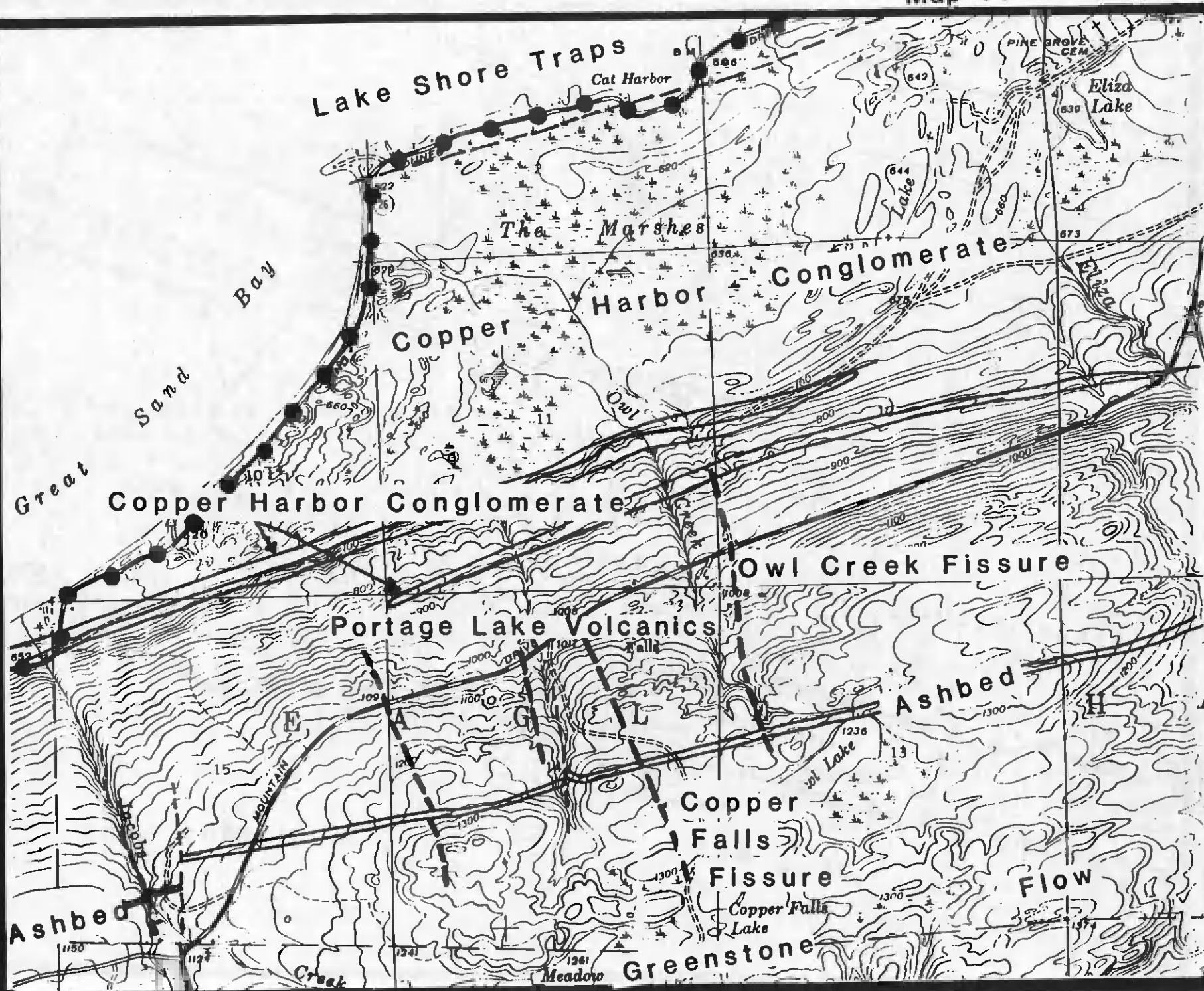
67.1 The Eagle Harbor Lighthouse parking lot.

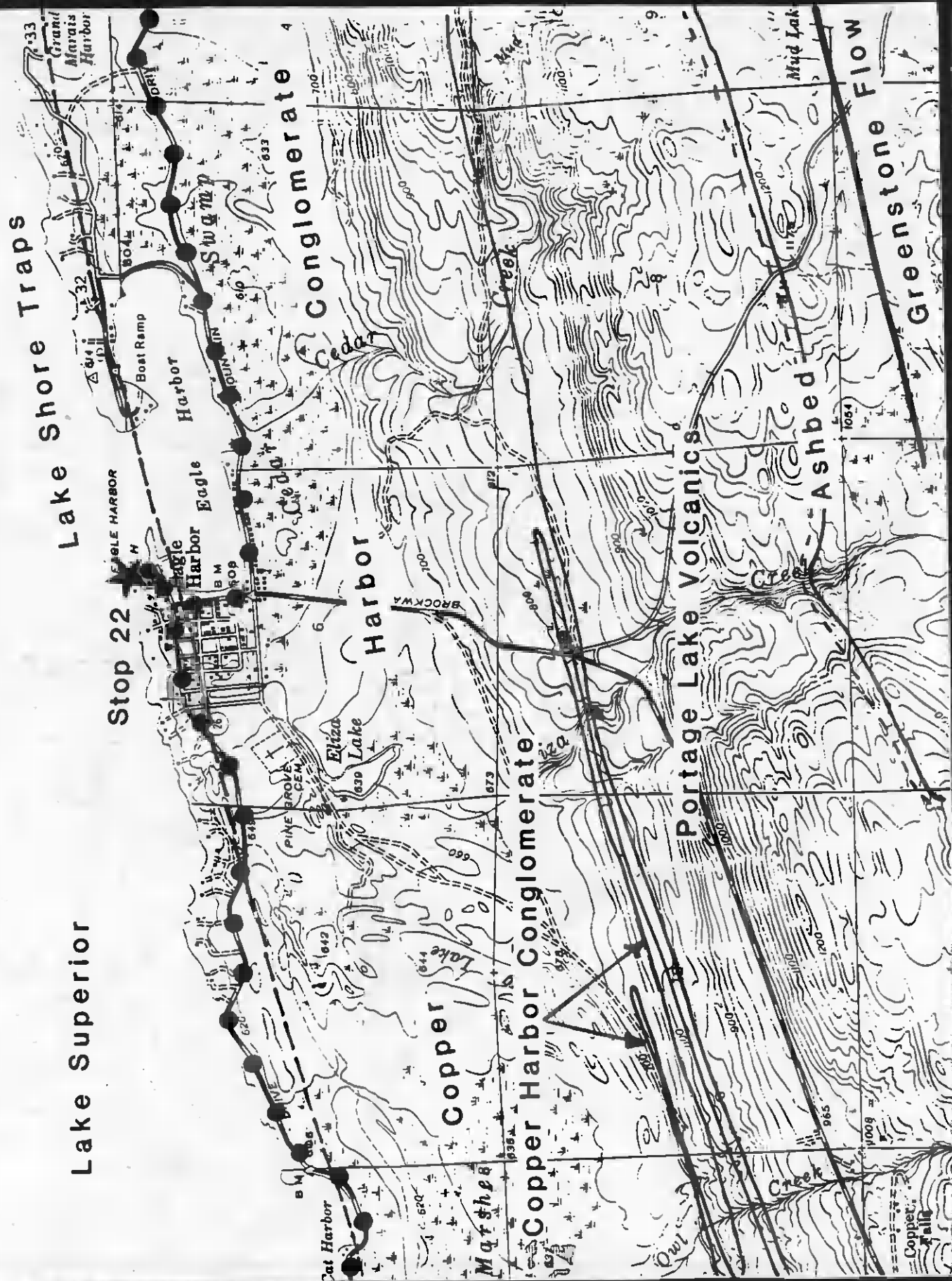
STOP 22: Eagle Harbor Lighthouse (Lake Shore Traps)

PLEASE DO NOT USE ROCK HAMMERS AT THIS SITE.

The Eagle Harbor Lighthouse is maintained as a museum by the *Keweenaw County Historical Society*. A lighthouse began operation here in 1851, four years prior to the completion of the Soo Locks, and two years after the Copper Harbor Lighthouse. The current building was constructed in 1871, and the light was automated in 1980. The position of the lighthouse; the shape of the harbor; and the many islands and shallow rocks along the shore facing the big lake (climb the wooden steps northwest of the lighthouse for the best view) are controlled by the Lake Shore Traps. The traps are a series of resistant basaltic lava flows that occurs within the Copper Harbor Conglomerate and which outcrop along the Keweenaw shore for more than 14 km, from Great Sand Bay to Agate Harbor. These lavas are dated at 1087 m.y., about 7 m.y. younger than the PLV, and together with the Michipicoten Island Formation, represent the youngest Keweenawan igneous rocks known (Paces and Miller, 1993).

Start at the west end of the parking lot, about 25 m from the Maritime Museum. A small ravine occurs here because the well-exposed Lake Shore Traps are cut by a number of small veins up to about 2.5 cm wide, in a zone about 30 cm wide trending N-S, perpendicular to the shoreline. The Lake Shore Traps are dipping about 25°N toward Lake Superior, although bedding is not obvious. Prominent joints in the massive interiors of flows sometimes approximate the attitude of bedding. From the parking lot toward Lake Superior, a massive interior of a flow is visible, and grades into a vesicular-to-brecciated flow top at the lakeshore. Further west, just beyond the fence, is a ridge of massive basalt which is the interior of the overlying lava flow. More flows are visible along the shoreline, and east of the lighthouse provides an excellent view of Eagle





Map 13

MAP 14

Harbor and outcrops of the Lake Shore Traps.

The amygdaloidal mineralization and alteration seen in the Lake Shore Traps is generally lower grade zeolite facies than the PLV, but mineralization includes zeolites; calcite; chrysocolla; chlorite; datolite; and abundant agate. The flows have segregation cylinders and numerous sandstone dikes, and also have numerous mineralized slickenside surfaces that could reflect the subsidence of the rift sequence.

At the Lake Breeze Resort, just south of the lighthouse (PLEASE, ask permission, and NO HAMMERS), the point that projects into the harbor has an exposure of beautifully preserved pahoehoe surfaces.

Return to M-26.

67.25 Turn left and follow M-26 along Eagle Harbor.

67.4 The junction of M-26 and Garden City Road. Stay on M-26. The Owl Creek Leg (Leg B) begins here.

67.5 The harbor at Eagle Harbor is controlled by the occurrence of units which are called the Lake Shore Traps. These basalt flows are a member of the PLV, is interbedded with conglomerates of the Copper Harbor Conglomerate, and typically form resistant ridges. There are excellent exposures of the Lake Shore Traps that occur at the Eagle Harbor Lighthouse, continue along the shore through Grand Marais Harbor, into Agate Harbor, and eastward through Copper Harbor.

68.25 The junction to the left goes to the Eagle Harbor Marina. Continue ahead on M-26.

MAP 15

69.4 A view of Grand Marais Harbor. On the right hand side, you can see the offshore islands and ridges which are controlled by the occurrence of the Lake Shore Traps. We are driving along a conglomerate ridge.

70.0 The road passes along the shores of Lake Bailey on the right side of this conglomerate ridge. The ridges throughout the Copper Harbor Conglomerate tend to be held up by the conglomerates, and the valleys are underlain by the more easily eroded sandy and shaly 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 PLV runs through the back side of Mt. Lookout.

70.15 On the left side of the road there are exposures of the sandstone members of the Copper Harbor Conglomerate.

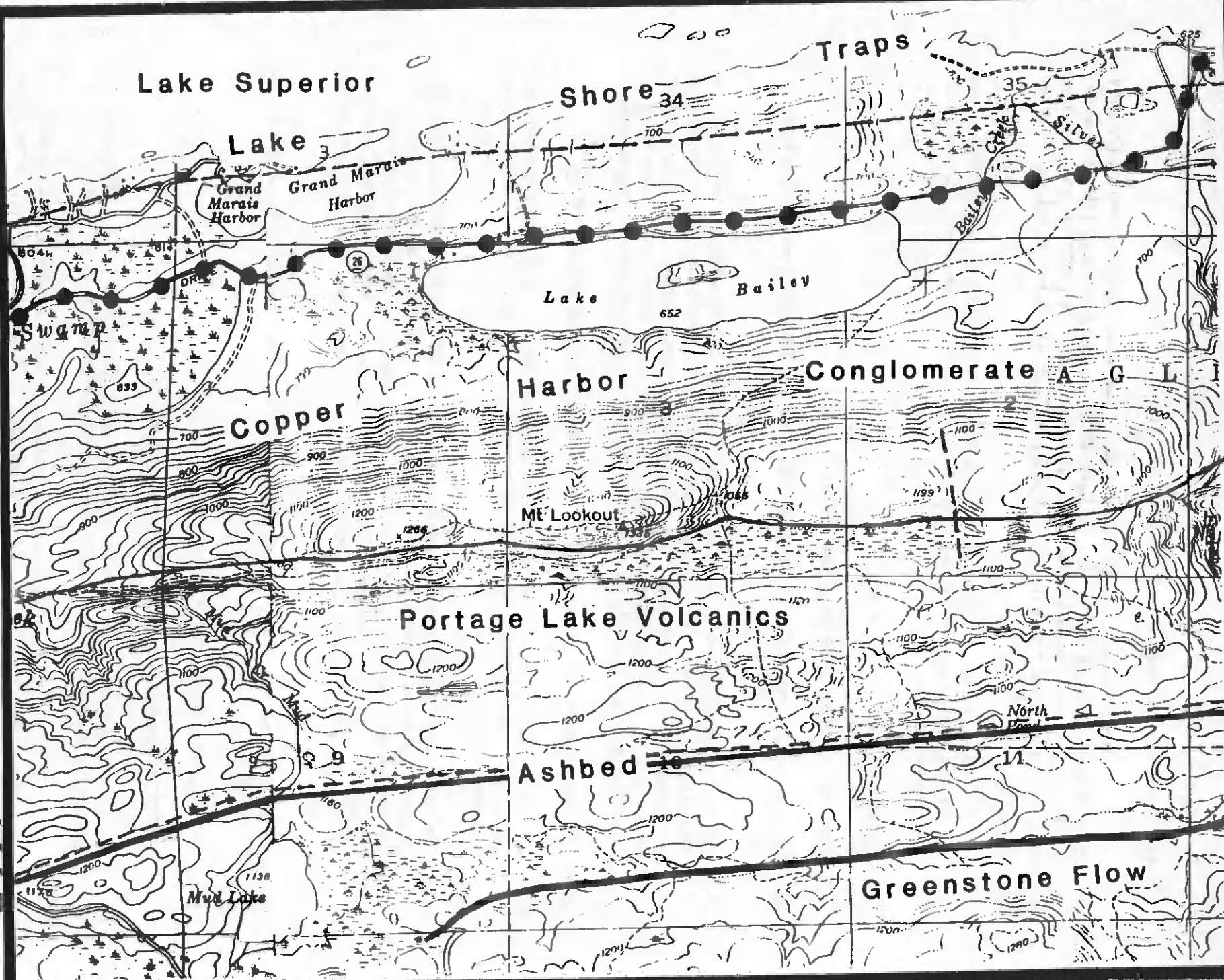
MAP 16

71.55 Crossing Silver River. Pull over for Stop 23.

STOP 23: Silver River (Copper Harbor Conglomerate)

This stop consists of excellent exposures, here at Silver River and 0.1 miles east of the Junction of M-26 with the Brockway Mountain road, on the left side of the road.

The Copper Harbor Conglomerate is well exposed in this area along the Silver River. At Eagle River Falls (Stop 21), one had the opportunity to look at the basal beds of the Copper



Lake Superior

Agate Harbor

Agate Point

North Bay

South Bay

Lake Shore Traps

Esrey Park

Stop 24

Stop 23

Copper

Harbor

Conglomerate

Upon

Creek

Lake Upon

Upon

Creek

Copper

Harbor

Conglomerate

A G L E H A R B O R

Portage Lake Volcanics

Gulf Lake

Ashbed

Meadow

Lake

Map 15

MAP 16

Map 17

Main Road Log

95

Harbor Conglomerate. Now, we are stratigraphically in the more central part of the formation, just below lava flow interbeds of the Lake Shore Traps. At Stop 26 and 27, 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.

Exposures along the Brockway Mountain road provide a strike section within the Copper Harbor Conglomerate, allowing one walking along the outcrop to observe lateral facies changes. The first large exposure on the west end is about 5 m high, and at the base is a red colored, very fine-to-medium grained sandstone, about 3.5 m thick, overlain by massive conglomerate. The conglomerate is clast-supported with mostly pebbles, and occasional boulders up to 20 cm in diameter. The pebbles tend to be composed of subequal amounts of mafic and felsic lithologies, whereas the boulders tend to be rhyolite or granophyre. The conglomerates of the Copper Harbor Conglomerate are part of an alluvial fan complex with sediments being shed off of the flanks of the rift into the center, i.e., toward Lake Superior.

- 71.65 The 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.
- 72.15 We are now at the shore of Lake Superior, where there are dipping lava flows of the Lake Shore Traps. The road follows the shore approximately parallel to the strike of the lava flows.
- 72.45 Pull left into Esrey Park.

STOP 24: Esrey Park (Lake Shore Traps)

The basalts cropping out at Esrey Park occur within the Copper Harbor Conglomerate, some 800-1000 m above the PLV. They are a part of a succession of Fe-rich olivine tholeiite, basaltic andesite, and andesite lava flows known collectively as the Lake Shore Traps (an informal member within the Copper Harbor Conglomerate) (Fig. 40). This succession is thickest at the tip of the Keweenaw Peninsula (approximately 600 m), and thins toward the east (on Manitou Island) and toward the west-southwest, where the lava flows pinch out near Calumet (a total strike length of about 90 km). Individual lava flows vary in thickness from about 4 to 40 m and exhibit volcanological features similar to flood basalts of the PLV. The lowermost mafic flows were deposited as ponded sheets while upper andesite flows may have formed a low, positive topographic feature such as a shield volcano.

Magmatic variation within lava flows at the tip of the Keweenaw Peninsula imply that fractional crystallization of plagioclase, clinopyroxene, olivine, Fe-Ti oxide, apatite, and zircon played an important role in the petrogenesis of the Lake Shore Trap magmas (Paces and Bomhorst, 1985). Additional processes of parental magma replenishment and possible wall rock assimilation however, are required to explain geochemical-stratigraphic relationships.

The large outcrop between the parking lot and the shore is a massive flow interior of fine-grained, Fe-rich olivine tholeiitic basalt. The flows strike parallel to the shoreline and dip 20-30° toward the lake. The upper portion of this flow is not exposed, but the top of the underlying basalt flow can be seen at the shoreline on either side of the large outcrop. Because of its higher stratigraphic level within the rift-fill sequence, the degree of metamorphism/alteration in the Lake Shore Traps is much lower than in the PLV. Zeolite facies metamorphism, as opposed to prehnite-pumpellyite, affected the flow top and deposited chalcedony; laumontite; analcite; calcite; and smectite in amygdules. Massive flow interiors of the Lake Shore Traps often retain relict

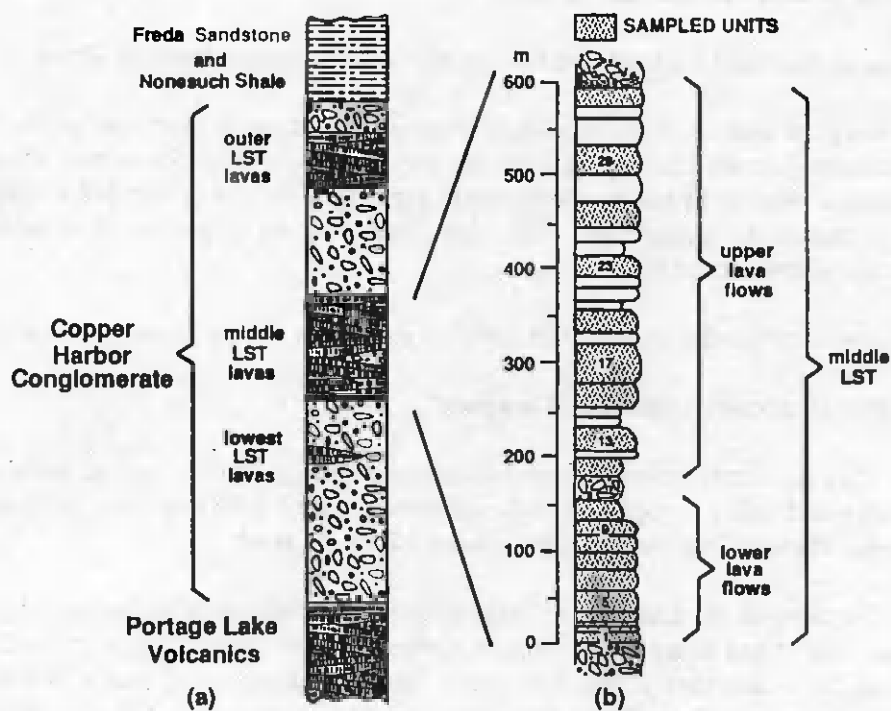


Figure 40: Stratigraphic column of the Lake Shore Traps [LST] from the eastern tip of the Keweenaw Peninsula (from Diehl and Haig, in press).

olivine and glassy, intersertal mesostasis in contrast to the PLV, where both olivine and intersertal glass are invariably replaced by Mg-Fe phyllosilicates.

From the east end of the large basalt ridge next to the parking lot, walk about 100 m east along the shore to see the flow top of the underlying flow. This well exposed flow top is composed of vesicular basalt, typical of a pahoehoe flow top. The vesicles are partially filled with laumontite, chlorite, calcite, and quartz.

72.55 Turn around and head back toward the junction of Brockway Mountain Drive.

73.35 Take a sharp left turn onto the Brockway Mountain Drive, more exposures of the Copper Harbor Conglomerate described at Stop 23, can be seen. We will drive for several kilometers along a conglomerate ridge with many conglomerate exposures. In spring and fall a very diverse hawk migration occurs along this ridge. The ridge summit allows very close observations because the birds often follow the ridge top.

MAP 17

78.35 At the summit of Brockway Mountain, take a right turn in a short distance, to the observation site.

STOP 25: Brockway Mountain Viewpoint

This high conglomerate ridge reaches an elevation of over 400 m, with excellent views of the ridge and valley topography of the northern shore of the Keweenaw Peninsula. Underfoot, the Copper Harbor Conglomerate dips about 20° to the north.

To the west, the Lake Shore Traps form island chains on a prominent ridge in the vicinity of Agate Harbor and Esrey Park. Copper Harbor Conglomerate is found in the drowned valleys and along the outer ridge jutting into Agate Harbor and projecting into a smaller island chain. The reefs of the Lake Shore Traps and Copper Harbor Conglomerate along the Keweenaw's north shore are the site of numerous shipwrecks.

Lake Bailey (with the small island) and Lake Upsom occupy a topographically low valley on a finer-grained clastic horizon within the Copper Harbor Conglomerate.

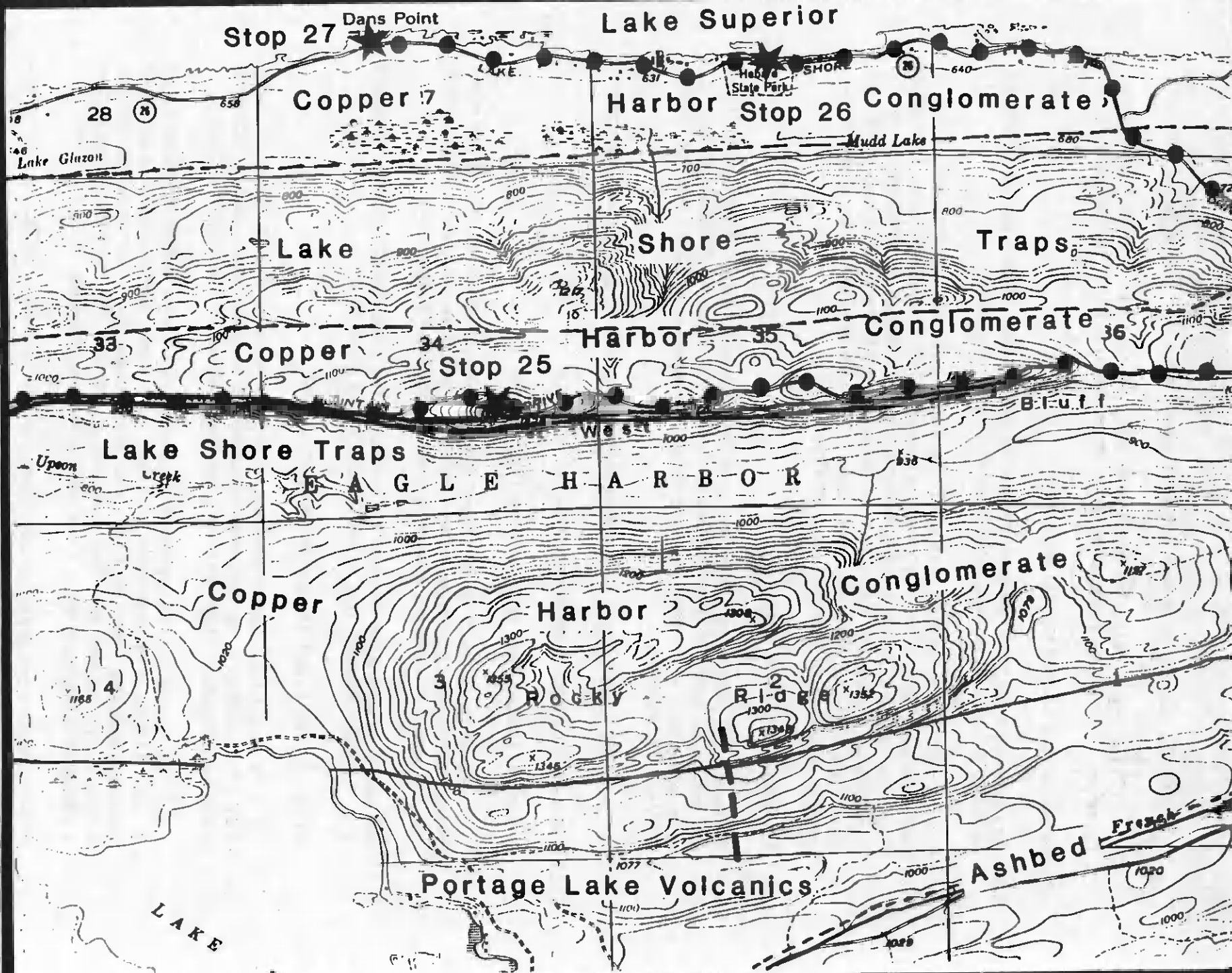
Just to the south of Lake Bailey, is the conglomerate ridge of Mt. Lookout, marking the contact between the Copper Harbor Conglomerate and the PLV.

The inland lake almost directly south, is Lake Medora, and just before 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, is Mount Bohemia, a dioritic stock-sized intrusion.

To the southwest, a distant ridge with white buildings on it marks Gratiot Mountain, which is underlain by andesitic dikes and small rhyolite bodies that cut the PLV.

To the east are the communities of Copper Harbor and Lake Fanny Hooe, both of which occupy the same stratigraphic horizon as Lake Bailey. Copper Harbor was a boom town in 1843, following the initial discovery of native copper in the Keweenaw Peninsula. In 1844 Fort Wilkins was built on the shores of Lake Fanny Hooe; it is now a state park. The lighthouse was built in 1866.



To the east on the skyline, beyond Copper Harbor, lies East Ridge, a prominent conglomerate hill.

To the north on the skyline 65 km away, is Isle Royale, which is visible on a clear day. The skyline of Isle Royale is formed by the Greenstone Flow, as it is on the Peninsula.

Follow the road downhill toward Copper Harbor.

- 78.35 Turn to the right and follow the road straight ahead toward Copper Harbor, going downhill and continuing along the ridge which has excellent views all the way down.

MAP 18

- 81.9 There is a pull-out on the right hand side of the road that gives 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.

- 83.0 At the junction at M-26, turn left.

MAP 17

- 84.7 We come to the shore of the lake again, past the blowhole called the Devil's Washtub. If you stop here by the right 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. (This is PRIVATE PROPERTY.)

- 85.25 On the left is a public access to the lake shore and exposures of the Copper Harbor Conglomerate.

- 85.55 Pull over on the right at the Keweenaw County Park.

STOP 26: Hebard Park (Copper Harbor Conglomerate)

Excellent exposures of the Copper Harbor Conglomerate are exposed at this public locality. At this point, the Copper Harbor Conglomerate is stratigraphically above the Lake Shore Traps. See Stop 27 for further description of the Copper Harbor Conglomerate.

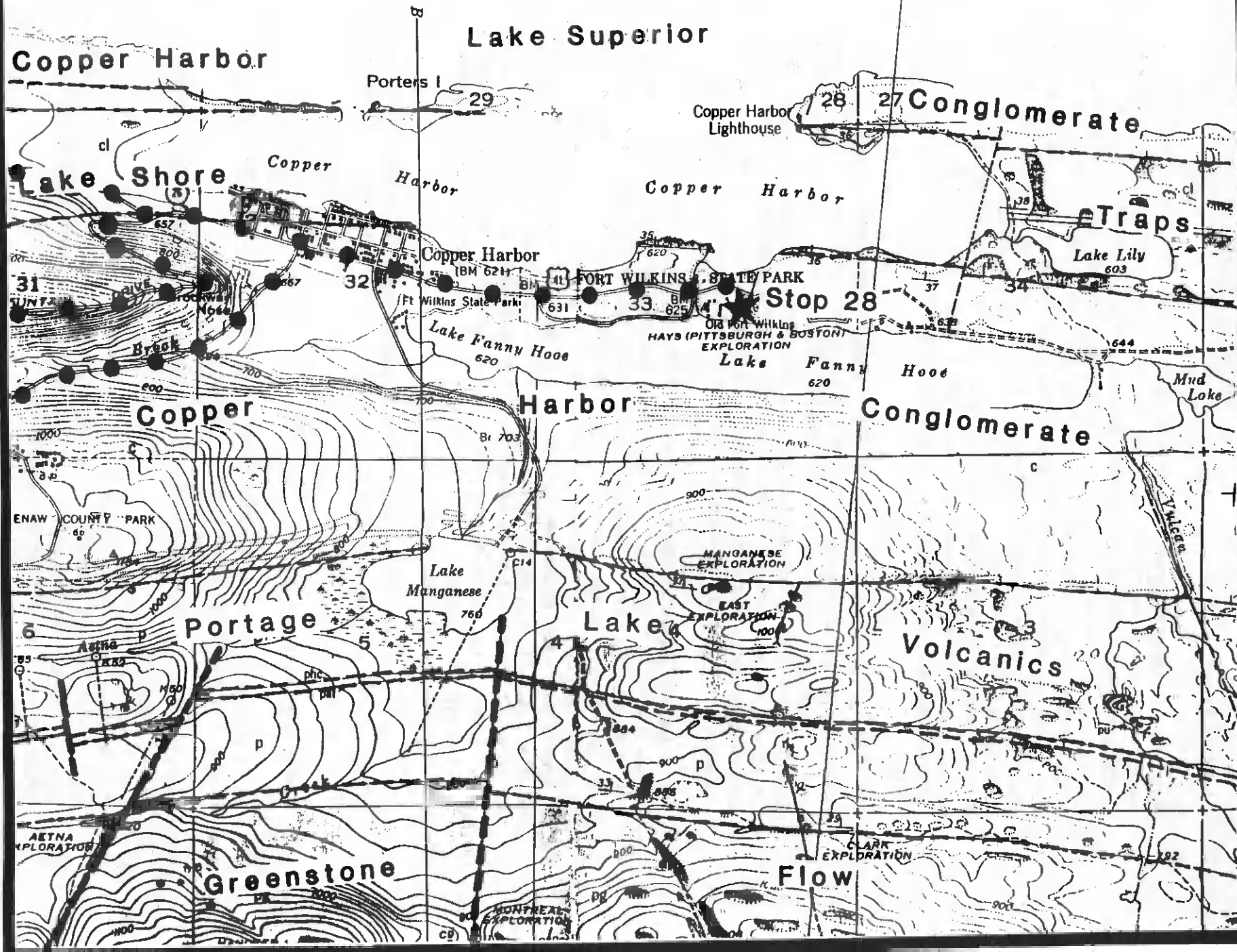
- 86.35 Pull over to the right at the gift shop. The next stop is PRIVATE PROPERTY. Ask permission at the gift shop. DO NOT USE ROCK HAMMERS AT THIS STOP.

STOP 27: Dan's Point (Copper Harbor Conglomerate)

Walk about 20 m to the shore of Lake Superior, to look at the lithology of the Copper Harbor Conglomerate and an occurrence of stromatolites in wave washed exposures. Please do not remove stromatolites from the outcrop, specimens can be found on the pebble beach.

The Copper Harbor Conglomerate ranges from 490 m thick near the Wisconsin border, to about 1310 m in the Keweenaw Peninsula. As a whole, the formation is a red-brown, basinward-thickening wedge of fluvial siliciclastic conglomerates and sandstones that was deposited in the rift basin after flood basalt volcanism (PLV). The Dan's Point outcrop shows a proportion of lithologies that is characteristic of the upper two-thirds of the formation.

Directly above, and locally interfingering with the lava flows of the PLV, is a thin-to-thick



bedded, coarse basal conglomerate facies consisting of well-rounded, poorly sorted clasts of mafic-to-silicic volcanic rock fragments. These, and the higher conglomerates, generally are clast-supported and show a ratio of mafic-to-silicic intermediate clasts of about 2:1 (Elmore, 1984). The sandstones are predominantly red-brown, subangular-to-angular lithic graywackes which exhibit current-ripples; foreset and trough-cross beds; and parting lineations. Minor shale and siltstone interbeds show desiccation features. In the conglomerate and coarse sandstones, the abundant calcite cement probably was deposited as vadose carbonate or caliche (Kalliokoski, 1986). In the upper two-thirds of the formation on the Keweenaw Peninsula, represented by this outcrop, sandstone interbeds are more abundant. There are also laminated cryptoalgal carbonate horizons occurring as laterally-linked stromatolites, that are draped over cobbles, as laterally-linked contorted layers in mudstone-siltstone and as poorly developed mats in coarse sandstone (Elmore, 1983).

The depositional environment of the Copper Harbor Conglomerate has been interpreted as a prograding alluvial fan complex (Fig. 10) with proximal-to-distal braided stream and sheet flood facies on coalesced alluvial fans and sand flats (Elmore, 1984). The region was nearly equatorial in geographic position and the climate was probably arid with a seasonal rainfall pattern conducive to flashy streams and to the development of vadose carbonate (Kalliokoski, 1986). Isolated cryptoalgal carbonate and ooid lenses formed in shallow, medial fan lakes and possibly abandoned or low-water stream channels which received very little sediment (Elmore, 1983).

The stratigraphic section of the Copper Harbor Conglomerate exposed at Dan's Point consists of about 30 m of interbedded conglomerates and sandstones (Fig. 41). Clast-supported conglomerate beds consist of rounded, cobble- to boulder-sized clasts with a matrix of coarse sand-sized subangular grains cemented with carbonate and iron oxide. Clasts are predominantly of silicic volcanics, with subordinate basalt; pyroclastic; plutonic; and metamorphic lithic fragments. Several finer grained interbeds higher in the exposed section exhibit crossbeds, current lineations, current ripples, parting lineation, and reduction spots. In particular, one should note the calcite-rich zones that represent vadose carbonate or paleocaliche, and the white stromatolite (genus *Colleria*) horizons. Along one of these calcite zones, algal growth occurred during a period of depositional quiescence and was halted by an influx of silty material followed by renewed conglomerate deposition.

Several sites for public access to the lakeshore and the Copper Harbor Conglomerate occur for up to about 0.6 miles west of Dan's Point. We will retrace our route back toward the Brockway Mountain Drive junction.

86.35 Turn around and go back toward Copper Harbor on M-26.
MAP 18

89.7 At the junction of Brockway Mountain Drive. To the left is a junction to the Copper Harbor Marina. Continue straight ahead on M-26 to Copper Harbor.

90.15 The junction between M-26 and US-41 in Copper Harbor. Continue straight ahead toward Fort Wilkins State Park.

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 (Stop 28) was built on the shores of Lake Fanny Hooe, to protect the miners from potentially hostile Indians. The lighthouse was built in 1866.

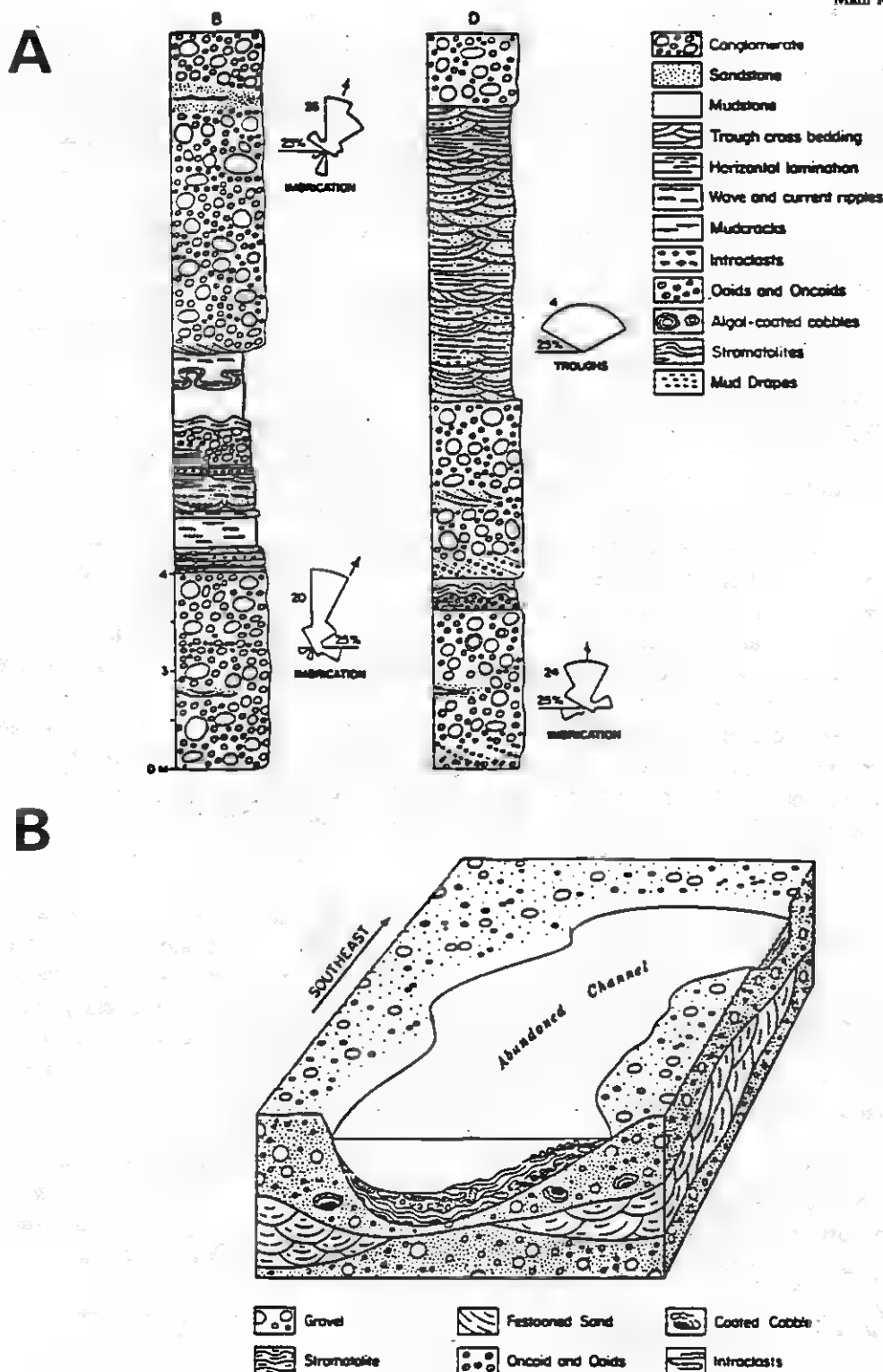


Figure 41: (a) Measured stratigraphic sections from Horseshoe Harbor (B) and Dan's Point (D) with current direction rose diagrams. (b) Schematic cartoon of the depositional environment which fostered growth of stromatolites in temporarily abandoned medial-fan stream channels (from Elmore, 1981).

- 91.6 Entrance to Fort Wilkins State Park. There is a fee to enter the state park. The entrance pass is also valid for McLain State Park, visited at Stop H6 on the McLain Leg. Upon entrance into the park, pull into the parking lot and proceed to the park store. The Fort has many excellent exhibits illustrating the mining history of the Keweenaw Peninsula.

STOP 28: Fort Wilkins State Park (native copper veins within Copper Harbor Conglomerate)

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 1843-1846 period. Just north of the park store, several pits provide evidence of early mining activity by European settlers. The Pittsburgh and Boston Mining Company operated here in the 1840's on a vein of native copper within the Copper Harbor Conglomerate, the vein was reported to be up to 0.3 m wide. This venture was not profitable.

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 vesicular basalt of the Lake Shore Traps here, and the area is well known for datolite collecting.

An occurrence of manganese minerals in a fissure accounts for the name of Manganese Lake, south of Lake Fanny Hooe (refer to Map). The manganese minerals found here were pyrolusite, manganite, braunite, and orientite. The Estivant Pine tract represents a part of the Clark Mine lands which were deeded to the C&G Company in 1942, and are now a nature preserve, containing the last virgin pine tracts in the Upper Peninsula.

Opposite Fort Wilkins on one of the Park trails that crossed US-41, is a view of the Copper Harbor Lighthouse. Near the point of the lighthouse on the shore facing the big lake, is the sight of the famous "green rock". The "green rock" is a vein seen by early voyagers and was described by Douglass Houghton; it is one of the localities that focused early interest in the Copper Country. Houghton himself may have never really understood the uniqueness of the district, as the conventional wisdom then, was that it was the surficial alteration of a sulfide ore. But Houghton promoted the district well (Krause, 1993).

Horseshoe Harbor has excellent exposures of the Copper Harbor Conglomerate and interbedded algal stromatolites can be reached via the Horseshoe Harbor Leg. Keweenaw Point, East Bluff, and other points of interest can be reached by continuing on the unmarked dirt road which goes eastward from the end of US-41 and are discussed in the Horseshoe Harbor Leg.

- 91.7 Entrance to Fort Wilkins State Park. Retrace the route back toward Copper Harbor. The Horseshoe Harbor Leg begins here.
- 93.15 The junction of M-26 and US-41. Turn left on US-41, south out of Copper Harbor.
- 94.25 Nice exposures of the Copper Harbor Conglomerate are to the left of the road as we are going up the hill.
- 94.6 Entrance to the Keweenaw Mountain Lodge and Golf Course. During the Great Depression of the 1930's, the unemployment rate in Keweenaw County was around 70 to 80%. Keweenaw

County's Board of Trustees submitted a proposal to the Civil Works Administration (C.W.A.) and became one of the first work projects within the Federal programs. Most of the present buildings were completed on the 167 acre site in 1935 with Federal funds. Revenue from operations have allowed several new cottages (after a report by J. W. Jackson). The lodge has accommodations and an excellent atmosphere for eating.

MAP 19

97.5 Lake Medora on the right side of the road.

MAP 20

100.35 The junction on the left goes to Mandan. Mandan now is only a few houses, but it had 300 residents in 1910. Continue ahead on US-41.

100.6 The road to the left 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.

100.8 On the left hand side of the road is a swamp lying east of a north-south trending esker.

100.9 A small road on the right. Pull over and park here. Proceed on foot to view the esker.

STOP 29: Mandan (Mandan esker)

The Mandan esker, featured in many geological lab exercises, is clearly visible on Map as a north-south trending topographic ridge with up to 25 m of relief from near Clear Lake. The ridge is composed of coarse Pleistocene sand and gravel, and was deposited by glacial meltwater flowing in a subglacial tunnel. The esker sediments are not exposed along the road, but can be viewed by walking along the ridge toward the south to an old railroad cut (Regis personal communication, 1992). This stop is best in the fall or spring due to the dense foliage.

MAP 21

103.4 The junction of the road to Lac La Belle. Continue ahead on US-41. The Eastside Keweenaw Peninsula Leg begins here and ends in Lake Linden.

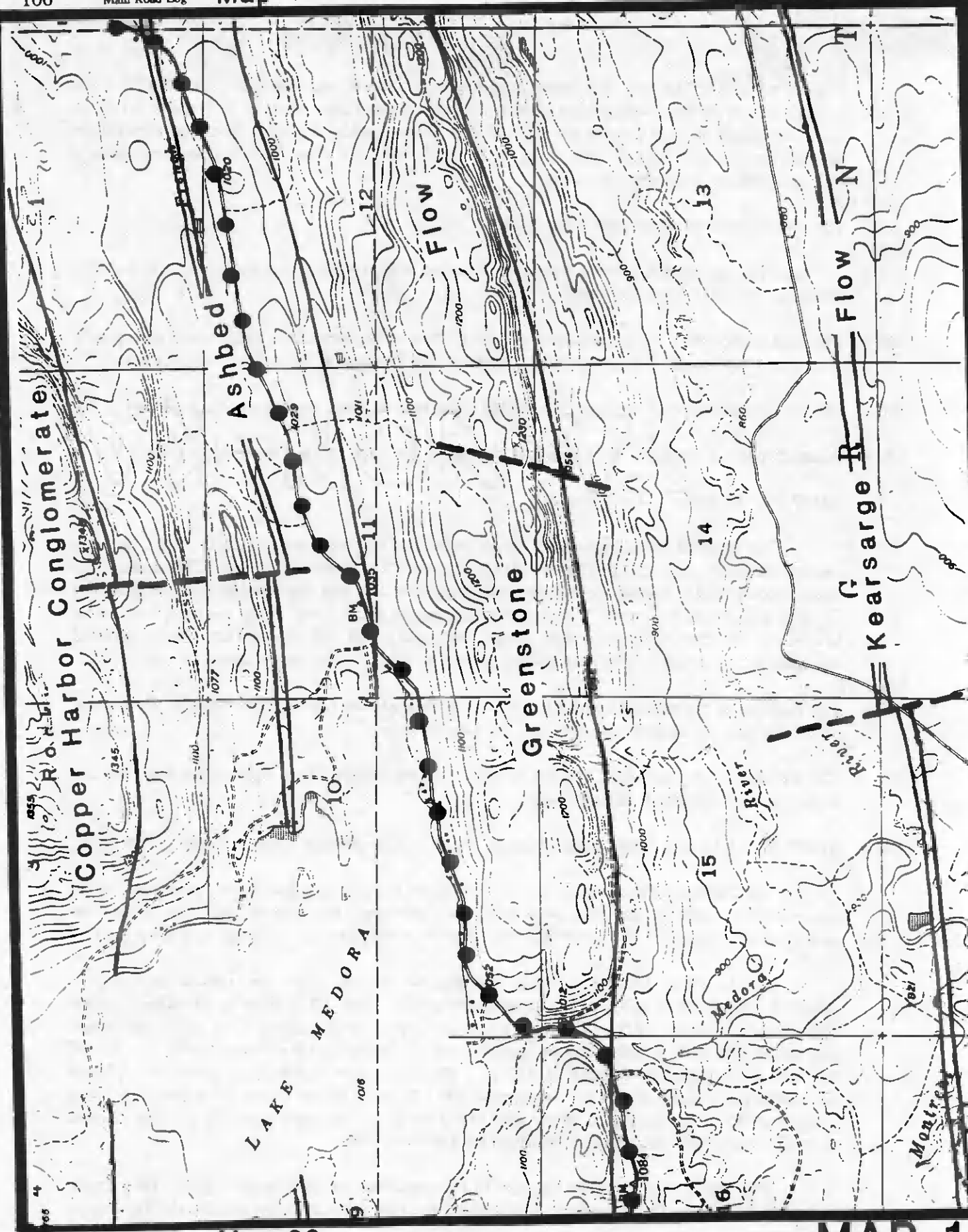
104.05 The dirt road to the right goes to Stop 30 at the Delaware Mine. Turn right on the dirt road and follow the signs to the Delaware Mine.

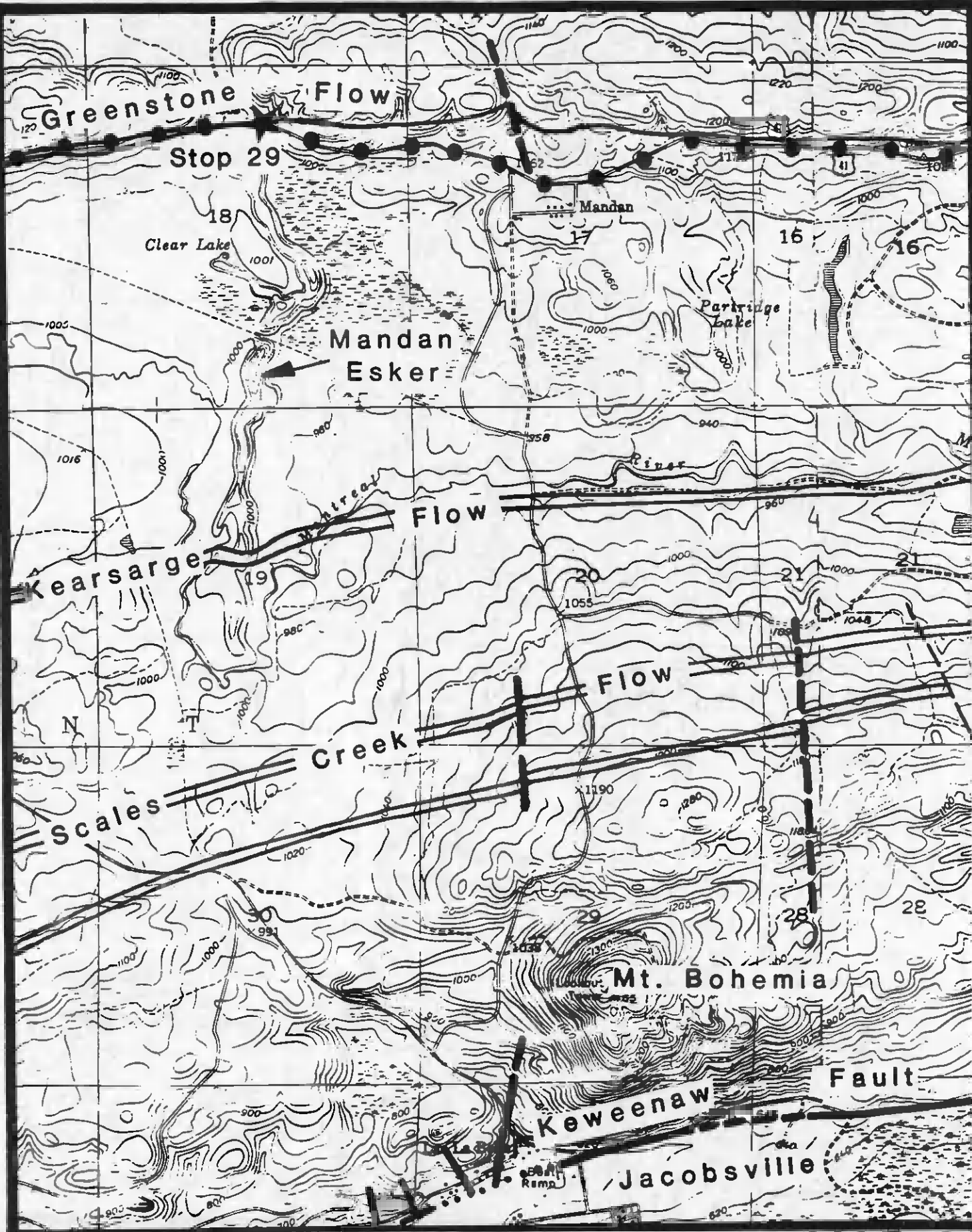
104.2 **STOP 30: Delaware Mine** (native copper deposit within Portage Lake Volcanics [PLV])

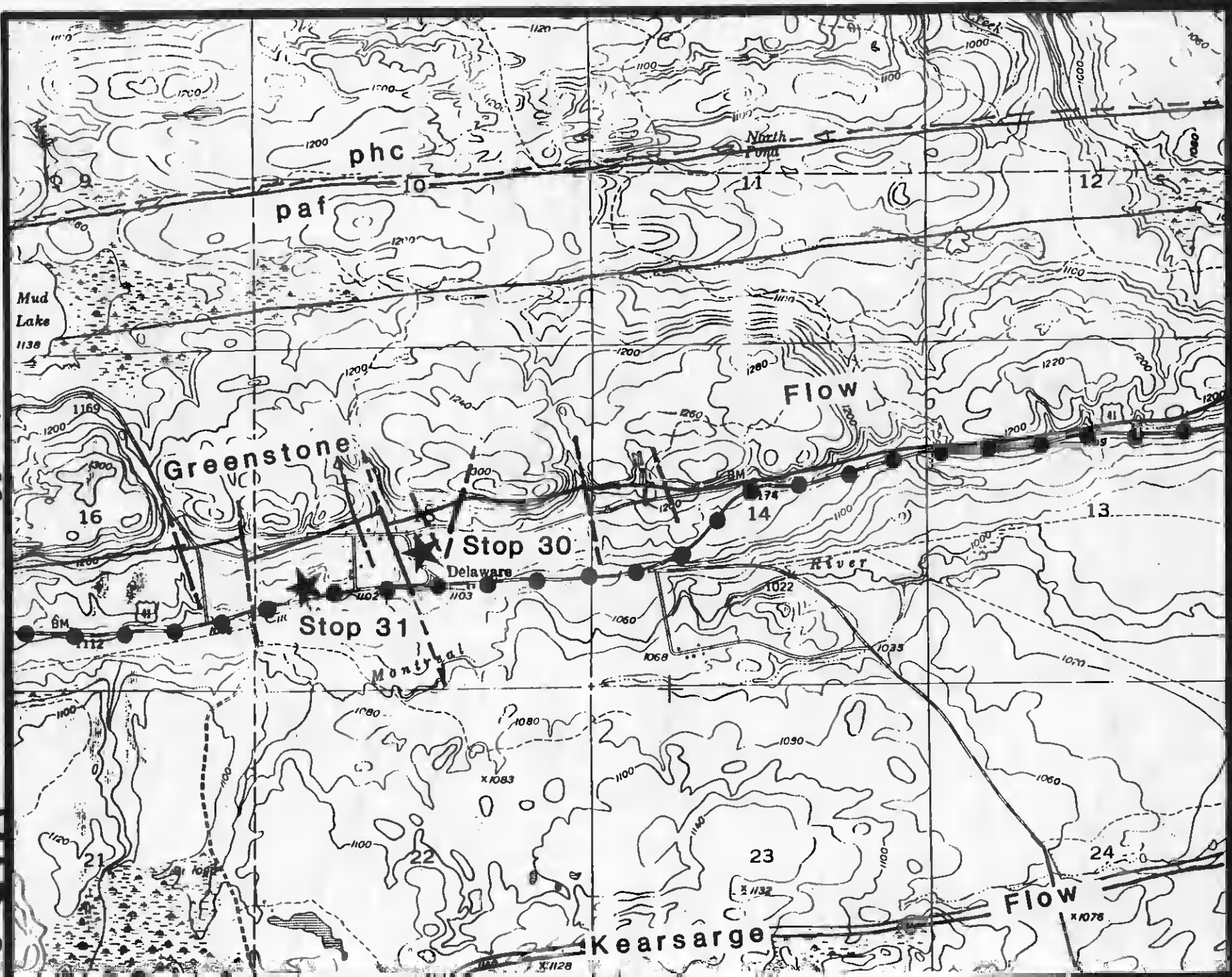
The Delaware Mine is open to tours during the summer months. At this stop, one has the opportunity to look at the rock piles from the Delaware Mine and to visit (for a fee) the underground workings. The other opportunity to visit underground workings is at Stop 8.

The Delaware Mine is a typical vein deposit situated below the Greenstone Flow. It operated from 1848 to 1887, with a total production of about 3.5 million kg of refined copper (Butler and Burbank, 1929). Overall, it was not a profitable venture. The early and major production was from a native copper-bearing vein, the Stoughtenburgh Vein, which was mined for 265 m on strike, to a depth of 330 m. The productive section was below the Allouez Conglomerate. Three shafts were opened in 1881 to mine copper from the adjacent Allouez Conglomerate. The Delaware Mine was first known as the Northwest Mine. The current accessible mine was mapped and described by Schleiss (1986).

Two thin basalt flows are exposed in two crosscuts on the first-level drift. They strike E-W and dip 25°N. The flows have fine-grained massive interiors and amygdaloidal flow tops,







Map 22

MAP 2

with amygdules predominantly filled with calcite. A weathered zone on the top of the uppermost of the two basalt flows is overlain by the Allouez Conglomerate. The Allouez is the only unit along the first-level, and currently is the only accessible level. It is 8 m thick; is composed of rounded-to-subangular clasts up to 30 cm in diameter; composed of rhyolite, granophyre, and rare basalt; and is supported by a matrix of sand. There is an interbedded lens of fine- to medium-grained red sandstone and is overlain by the Greenstone Flow, which crops out up the bluff above the mine, but is not exposed in the mine.

The principal accessible portion of the Stoughtenburgh Vein is about 35 cm wide. Here, as in all veins in the mine, calcite is the main filling. The paragenetic sequence is *minor* quartz, microcline, and muscovite; followed by minor native copper and abundant calcite; in turn, followed by minor chalcocite. In the Allouez Conglomerate, the epigenetic minerals consist of calcite with minor amounts of quartz and microcline filling the interstices between matrix and clasts, and sporadic native copper within the matrix.

The only faults in the mine are bedding plane faults, at the upper and lower contacts of the conglomerate. The fault in the hanging wall is denoted by more than 18 cm of clay fault gouge (vermiculite and smectite) with introduced calcite. The footwall bedding plane fault is denoted by a 2 to 5 cm thick layer of gouge, consisting of chlorite with lesser amounts of calcite; microcline; quartz; and native copper. The amount of displacement along these faults is unknown. In the first-level drift of the Delaware Mine there are a large number of parallel- to sub-parallel fractures, filled with calcite. The fractures, known as tension fractures, can be subdivided into a major northwest-striking set and a minor northeast-striking set.

A model for the Delaware fissure vein-conglomerate lode mineralization begins with copper bearing fluids along permeable flow tops and conglomerates. Faults and fractures produced during late compression--reverse Keweenaw fault motion--integrated the paleohydrologic system and allowed effective movement of ore fluids. The steeply dipping tension fractures (veins) were efficient pathways for fluid movement. The fluids migrated upward and laterally through these open fractures and were diverted beneath the thick, unfaulted, massive interior of the Greenstone Flow so that fluids moved laterally from the fractures into the Allouez Conglomerate. Ore minerals were deposited, probably in response to a combination of fluid mixing; cooling of the solution; and fluid wall-rock reactions.

The Delaware Mine rock pile, as with other vein deposits in the Keweenaw, is a notable locality for datolite. Also included in reports about the rock pile are these minerals: chlorastrolite, prehnite, calcite, laumontite, analcite, chlorite, epidote, native copper and native silver (Clarke, 1975; Zelenka, 1978).

- 104.35 The junction of the Delaware Mine and US-41. Left turn on US-41 and continue ahead toward Phoenix.
- 104.45 Exposures of basalts of the PLV on the right side of the road. Massive basalt on the east end of the outcrop is cut by several fracture zones trending N30°W. The orientation of these fractures is similar to those in the Delaware Mine. The fractures contain minor amounts of native copper.
- 104.8 Pull over on the right hand (north) side of the road just before the outcrops.

STOP 31: US-41 near Delaware (Portage Lake Volcanics [PLV])

The character of basalt lava flows within the PLV can be observed at this locality. The strike of the flows is about E-W here, roughly parallel to the orientation of the road, thus you are looking at a strike-parallel section. The lower half of the 5 m high outcrop face consists of vesicular basalt with a rubbly appearance. In the center of the outcrop, a large egg-shaped mass of more dense basalt is surrounded by vesicular basalt. The vesicles dominantly are filled with calcite, prehnite, and chlorite. The character of this flow top represents a pahoehoe flow with limited brecciation. This is overlain by fine-grained massive basalt with subvertical joints of the next stratigraphically higher flow. The contact between these two flows is irregular. Note that no sediment exists between these flows. The lack of sediment between flows is a common feature, and is indicative of a rapid rate of extrusion. Where sediment horizons exist, the temporal composition of the basalts often suggest the end of a cycle, and is consistent with a hiatus in volcanic activity. The flows at this locality are stratigraphically below the Greenstone Flow.

MAP 22

107.0 Ahead are cliffs of the Greenstone Flow. The road nears the basal contact of the flow.

108.3 An exposure of one of the flows beneath the Greenstone Flow.

109.1 To the right, one can see the Greenstone Ridge in the background. In the foreground is the ghost town of Central and its associated rock piles.

109.45 A junction of paved roads to the right and left. Continue ahead on US-41. The road to the left goes to Gratiot Lake and is the start of Leg E - 932 Creek. The road to the right goes toward the ghost town of Central and the Central rock 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 was settled in 1854 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 town site. Later immigrant groups to the copper mining towns included: Italian, German, Croatian, and Finnish people.

MAP 23

110.8 A junction of a road to the right. Continue ahead on US-41. The road to the right connects with Leg B - Owl Creek, at mileage 60.3.

111.9 Another view of the ENE striking Greenstone Flow holding up the prominent ridge.

112.6 Again another excellent view of the Greenstone Flow ridge.

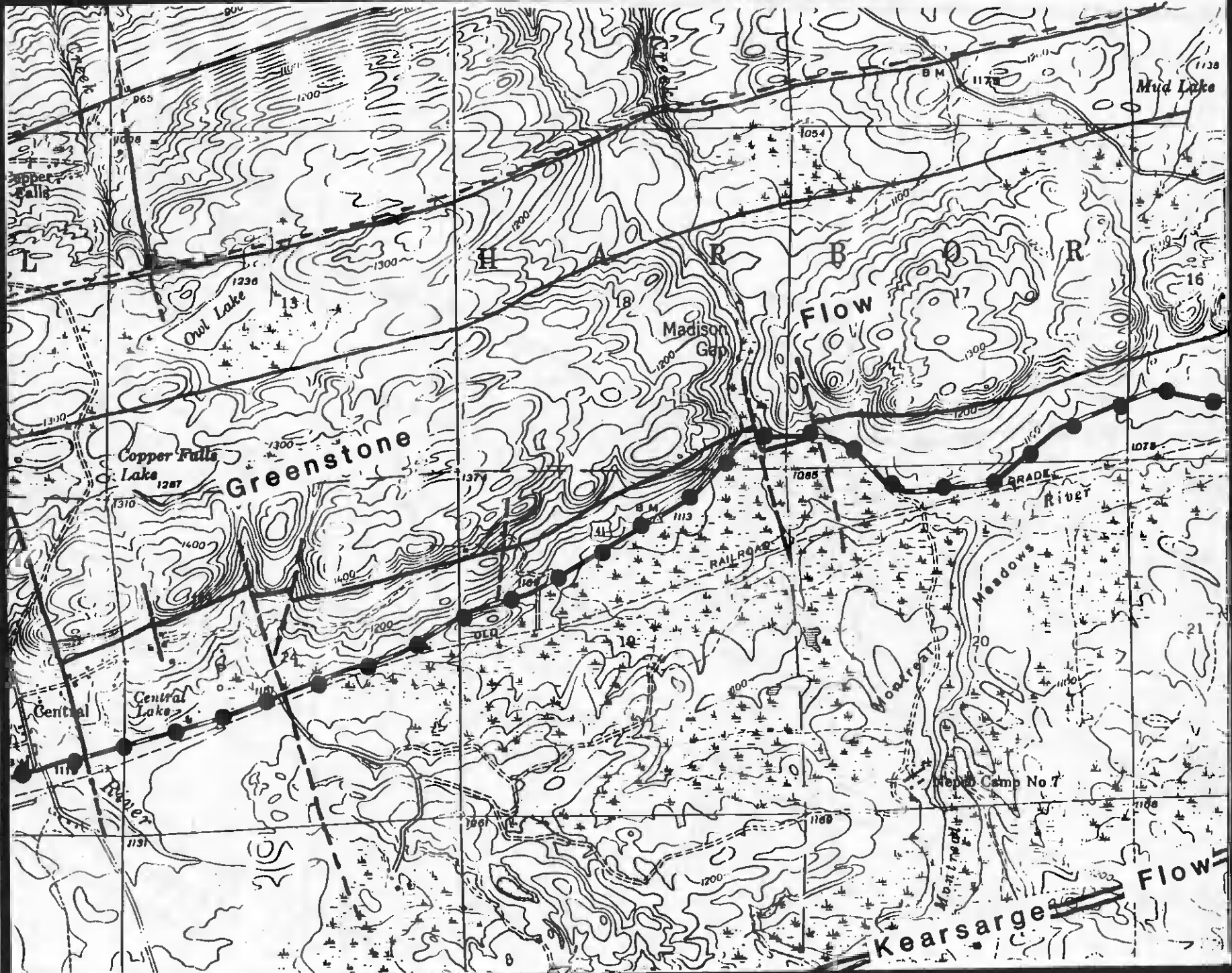
MAP 11

113.4 The junction of M-26 and US-41 at Phoenix. Continue ahead on US-41. For an alternate route to Ahmeek with two stops, go to Leg F - Five Mile Point. This leg begins near the settlement of Eagle River.

113.5 On the right is the road toward Stop 18. Continue on US-41.

Map 23

MAP 22



Map 21

Main Road Log

- 113.8 Cross the West Branch of the Eagle River.
- 114.9 The junction of US-41 and Cliff Drive. Bear left on US-41. Another excellent view of the Greenstone Flow ridge.
- 116.2 On the left is a small park and the snow "thermometer" showing the amount of snowfall in the Keweenaw Peninsula.
- 117.7 Cross Gratiot River.
- MAP 10
- 118.6 The open site on the left was a lumber mill which closed in the 1980's.
- 119.4 Entering Mohawk.
- 119.5 On the left side of the road are mine rock piles from the Mohawk Mine.
- 119.7 Turn left on 3rd Street in Mohawk and proceed past the school toward the Keweenaw County garage.
- 119.8 Park at the rock piles of the Mohawk Mine.

STOP 32: Mohawk Mine (native copper deposit within Portage Lake Volcanics [PLV])

The Kearsarge Flow top deposit was worked by the Mohawk Mine and seven other mines: Centennial, South Kearsarge, Wolverine, North Kearsarge, Ahmeek, Mohawk, and Seneca. The Mohawk Mine consisted of 6 different shafts along about 3 km of strike length of the ore body. The Mohawk was opened in 1902 with production ending in 1967 from the Kearsarge deposit. Total production of refined copper from the Kearsarge Flow top was 1026 million kg. The Kearsarge deposit is described in detail at Stop 13. The rock piles at this locality are from the No. 3 shaft. R. E. Stoiber made the following estimate of the percentages of the secondary minerals: calcite, 73%; K-feldspar (red and pink), 24%; prehnite, 1%; epidote, 1%; and quartz, trace. The Mohawk Mine is notable for the occurrence of veins containing Cu-Ni arsenides.

Return to US-41.

- 119.9 Turn left on US-41 toward Calumet.
- 120.6 The hill on the skyline with the four towers on it is Bumbletow' Hill, the location of Stop 16.
- MAP 9
- 121.3 The junction of US-41 and Cliff Drive (Cliff Drive was followed earlier in the field trip) just before Ahmeek.
- 121.6 The junction of US-41 and the road from Five Mile Point. This is the end of Leg F - Five Mile Point.
- 122.4 The road to the left goes to Copper City. This is the start of Leg G - Copper City.
- 122.5 Enter Houghton County.
- 122.55 The road to the right goes to Stops 15 and 16. Continue on US-41.

123.8 The road on the left goes to Stops 13 and 14.

124.8 Settlement of Centennial.

125.45 The junction of US-41 and M-203 on the north edge of Calumet/Laurium. This is the start of Leg H - McLain State Park, an alternate route back to Hancock. Continue ahead on US-41.

MAP 24

126.15 Turn right at the flashing light toward the center of Calumet on Red Jacket Street. After the turn on the left, is the "Welcome to Calumet" sign and a large piece of float copper. Float copper is masses of native copper plucked by glaciers from veins and lodes during the latest Pleistocene glaciation. Later, the masses of native copper were deposited with other sediments as the glaciers retreated, about 10,000 years ago. Float copper of varying sizes are still being found by farmers and during construction of buildings. On the right and ahead, are basalt block buildings that were the former headquarters of the Calumet and Hecla Consolidated Copper Company, which was the largest mining company in the Keweenaw Peninsula.

126.2 Turn right on Mine Street, going one-way toward the school and water tower. Straight ahead is the historic downtown Calumet, which is part of the Keweenaw National Historical Park. The Coppertown Museum is 0.2 miles ahead on the left, and offers an overview of the C&H Mining Company.

126.3 The Calumet school is on the left. An old stack is visible at 2:00.

126.4 The water tower is on the left. At 9:00, about 100 m beyond the tower, is an old stone building which houses 200 km of locatable drill core owned by Gordon Peterson. The fenced area at 7:00, is the location of the Red Jacket Headframe, it sits above the Calumet and Hecla Conglomerate-hosted native copper deposit--the largest single deposit in the Keweenaw Peninsula.

126.45 Just at the end of an old sandstone building, turn left on the gravel road entrance to the school parking lot. Park on the right and walk about 50 m ahead on the right to a low outcrop.

STOP 33: Calumet (glacial grooves)

Basalt of the PLV is exposed in this low, glacially smoothed outcrop. This stop provides an opportunity to observe exceptionally well-developed glacial grooves. The grooves are oriented about E-W with a crest-to-crest spacing of about 25 cm and amplitude of 3 to 5 cm. Mineralized segregation cylinders in the lava flow are resistant to the glacier, so flow direction vectors are spectacularly shown.

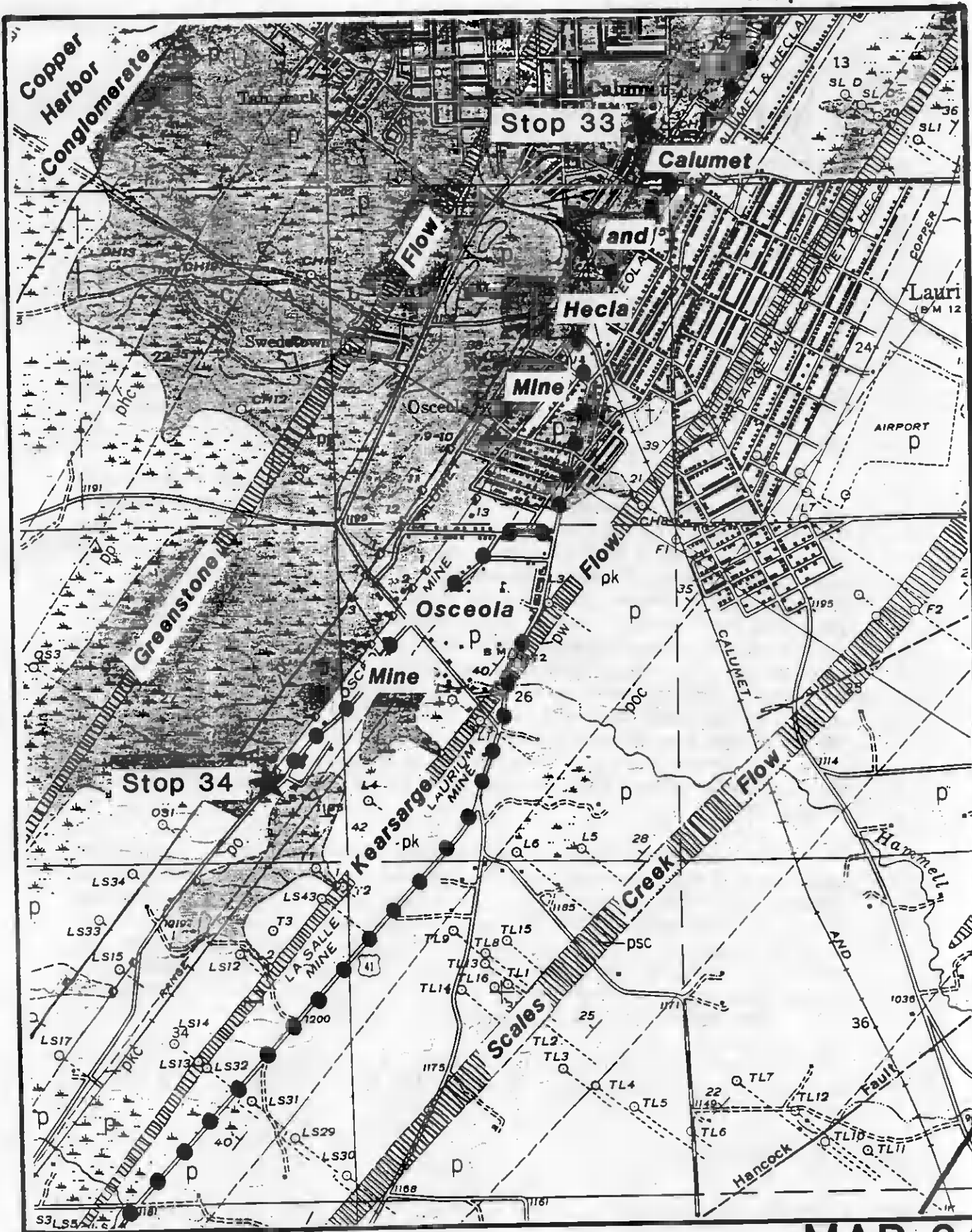
126.5 Turn around and return to Mine Street and turn left (one-way).

126.6 Stop sign. Turn right onto Church Street. The Peterson Funeral Home is on the left.

126.65 A stop sign at the junction with US-41. Turn right toward Hancock.

126.95 Flashing light again. Continue straight ahead this time.

127.9 Southern edge of Calumet. The Osceola Mine Shaft No. 13 can be seen on the right side of the road behind the Holiday gas station.



To Hancock

MAP 24

- 128.0 Turn right on Millionaire Street just beyond the Holiday gas station.
- 128.15 Turn left onto Church Street, just before the old mine headframe.
- 128.5 A four-way junction, continue straight ahead.
- 128.6 Pull over alongside the road and walk to the rock piles on the right side of the road (northwest).

STOP 34: Osceola Mine (native copper deposit within Portage Lake Volcanics [PLV])

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 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 production in the Keweenaw native copper district. The amygdaloid was developed for about four miles along strike and to a depth of 1372 m along incline (823 m vertically) (summarized from Weege and Pollack, 1971).

The Osceola Flow is ophitic basalt and varies in thickness from 11 to 64 m. 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 Mine. 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, annular fragments of vesicular lava which typically range in size from a few cm up to 30 cm in diameter. The lode ranged in thickness from 30 cm up to and sometimes greater than 18 m. 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 also minor amounts of prehnite, pumpellyite, laumontite, and analcite are found. 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. The 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 rock pile. An estimate was made by Stoiber (unpublished data) of the percentages of the secondary minerals: calcite, 59%; microcline, 29%; prehnite, 4%; epidote, 1%; quartz, 1%; and chlorite, 5%. Pumpellyite, laumontite, native copper, and the minerals listed above can be found on this rock pile. Bleaching of the basalt in the vicinity of native copper can be seen in individual specimens.

Retrace the route back to US-41. Turn right on US-41 to return to Hancock/Houghton or turn left to return to Calumet for the junction of Leg H - McLain State Park, at M-203 on the far end of Calumet.

END OF MAIN ROAD LOG

LEG A REDRIDGE

Mileage

MAP A1

- 0.0 Begin Leg A from the circular drive located on the northeast side of the Memorial Union Building on the campus of Michigan Technological University.
- 0.05 Turn left.
- 0.1 Immediately after, turn right on Townsend Drive/US-41. The Quincy Mine can be seen on the skyline ridge. Continue on US-41 through Houghton.
- 0.7 On the left is Burger King and Stop 6.
- 0.85 The stop light in Houghton.
- 1.15 Intersection, follow M-26 toward Ontonogan.
- 1.7 Turn right on Canal Road.

MAP A2

- 2.5 **Stop A1: Houghton Canal Road (Copper Harbor Conglomerate)**

Copper Harbor Conglomerate is exposed along the south side of the road. It is mostly red-brown conglomerate composed of clasts of rhyolite (~50%), granophyre (~40%), and basalt (~10%) with typical diameters of about 1 cm and maximum diameter of 40 cm. Clasts are matrix supported with occasional 45 cm thick, discontinuous lenses of clast-supported conglomerate, cemented with sparry calcite (possibly paleocaliche). Conglomerate beds on the order of 1 m thick alternate with 15 to 25 cm thick beds of very fine to coarse red-brown sandstone. Such lithologies are typical of the Copper Harbor Conglomerate, which was deposited in alluvial fans. The attitude of bedding is N20°E, 39°W. Stratigraphic position of the Copper Harbor Conglomerate is shown in Figures 2, 6, and 25.

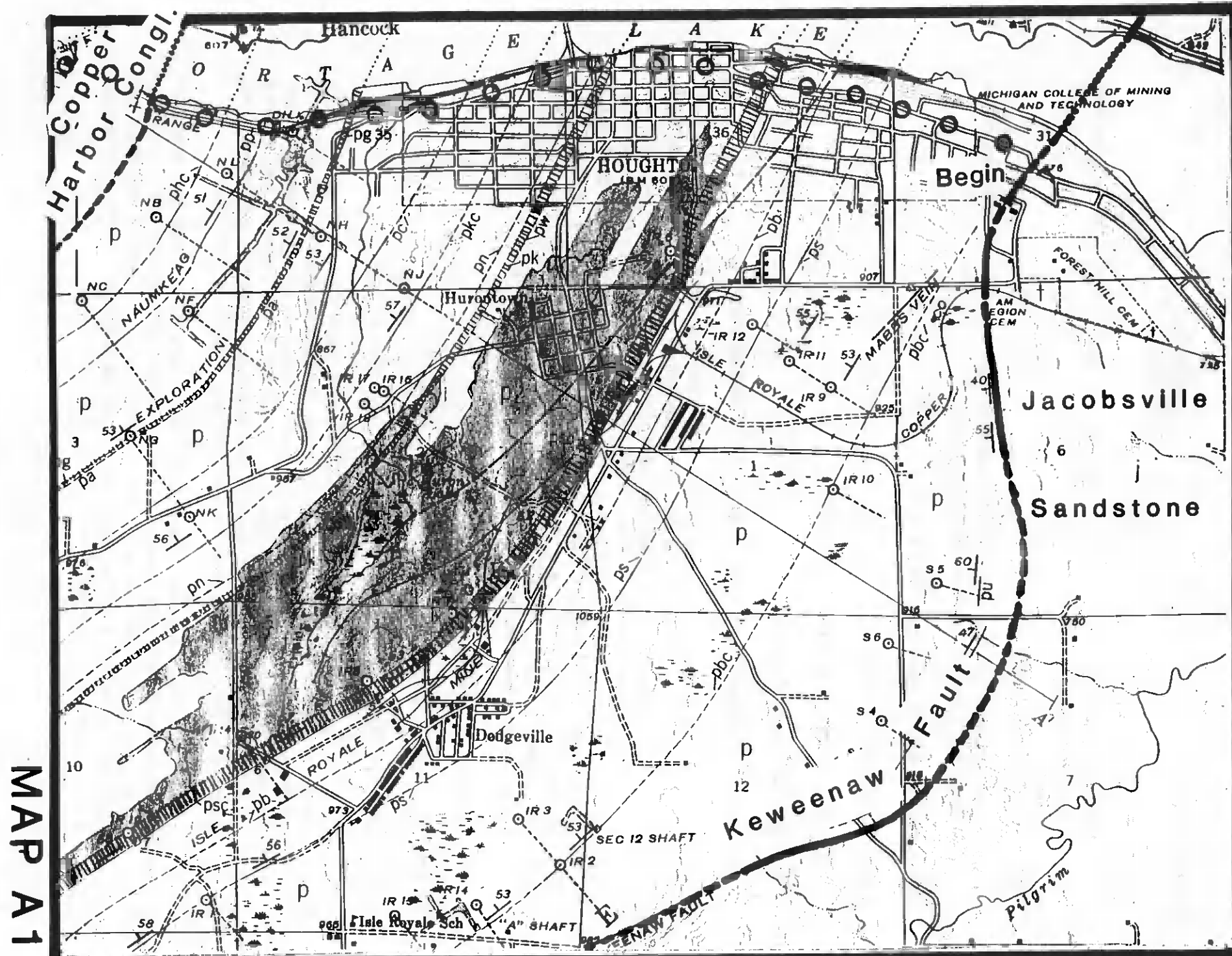
Continue on the Houghton Canal Road.

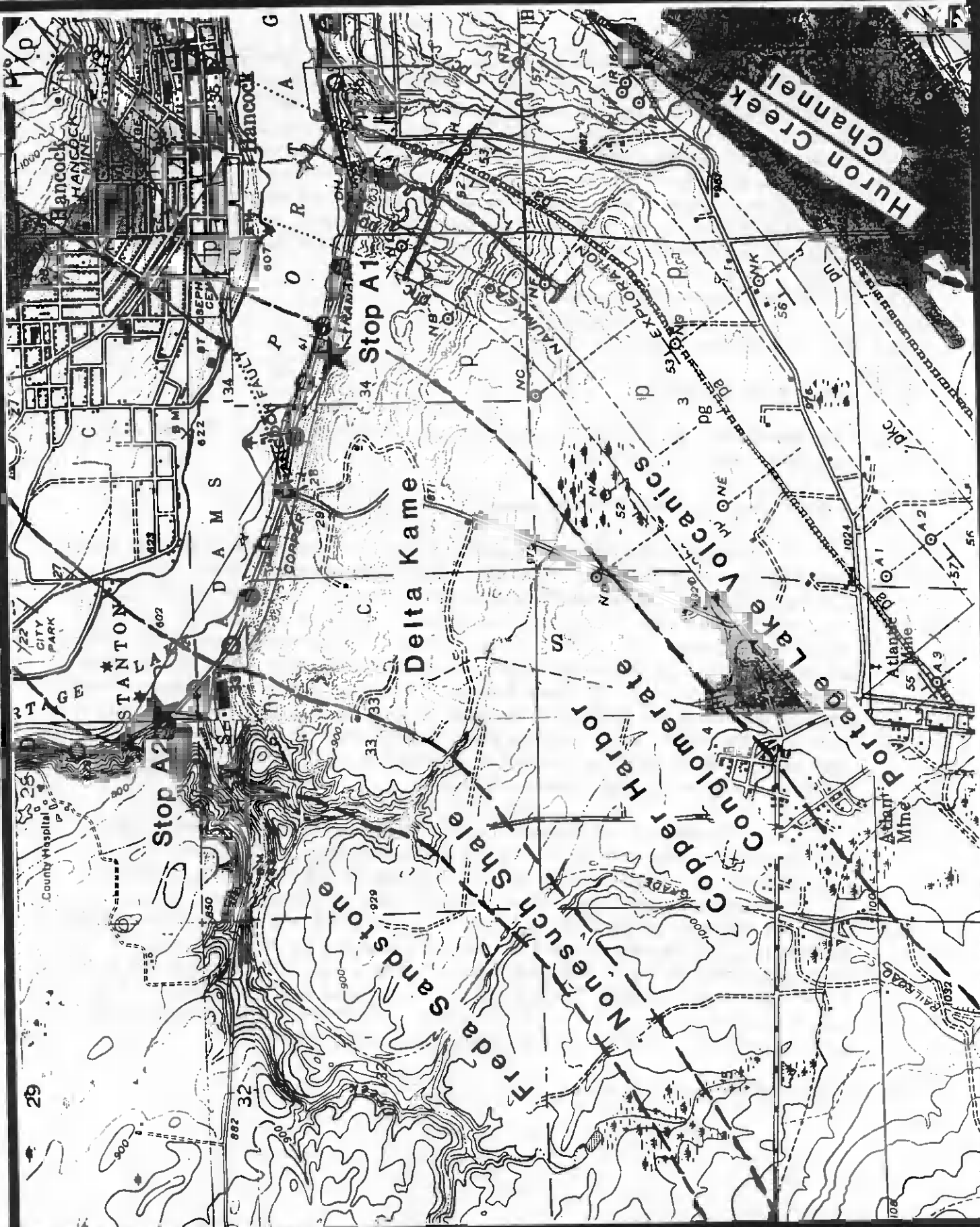
- 3.75 Pleistocene glacial fluvial sand and gravel at Cole's Creek.

Stop A2: Cole's Creek (glacial sediments)

A variable thickness of unconsolidated Pleistocene glacial sediments cover much of the bedrock of the Keweenaw Peninsula. 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 final glacial advance and stillstand over the Keweenaw Peninsula was made by the Keweenaw Bay Lobe, marked by an end moraine of the Wisconsin Stage (Fig. 15) (Warren, 1981).

The earliest recognized channel cut by drainage through the Portage Gap area, is the Huron Channel (Map). The channel is waterworn bedrock due to a southward flow of water. 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. 18.





This locality, part of a delta kame, is just west of the Huron Creek Channel. The sands and gravels in this dissected ridge 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, which suggests differing flow regimes during deposition. Poorly- to well-worked unconsolidated sands predominate, but poorly sorted cobble-to-pebble gravels are also present. The gravel lenses may be seen near the top and bottom of the exposure, and numerous cut-and-fill structures are present. Toward the left side of the cut, individual resistant bedding in the sands is visible. On the right side of the cut, contorted bedding within the sand layers is visible. This deformation is a result of post-depositional slumping of the unconsolidated sands.

MAP A3

5.85 Turn left (west) toward Redridge and Freda.

MAP A4

9.45 The road curves to the left.

MAP A5

11.55 The settlement of Redridge.

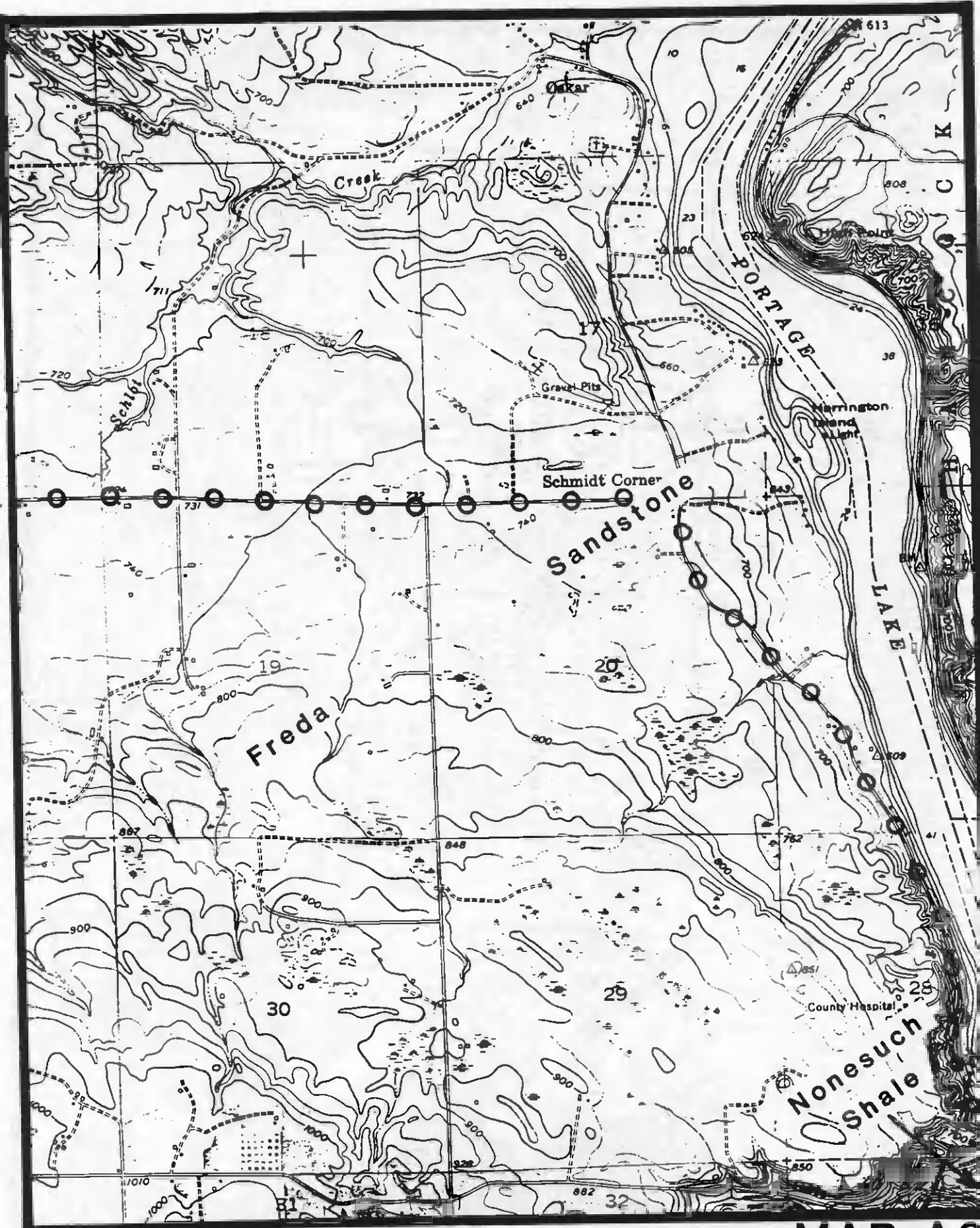
11.85 Turn right toward Lake Superior, just past the guardrail. Follow the main dirt road to Lake Superior by either foot or auto.

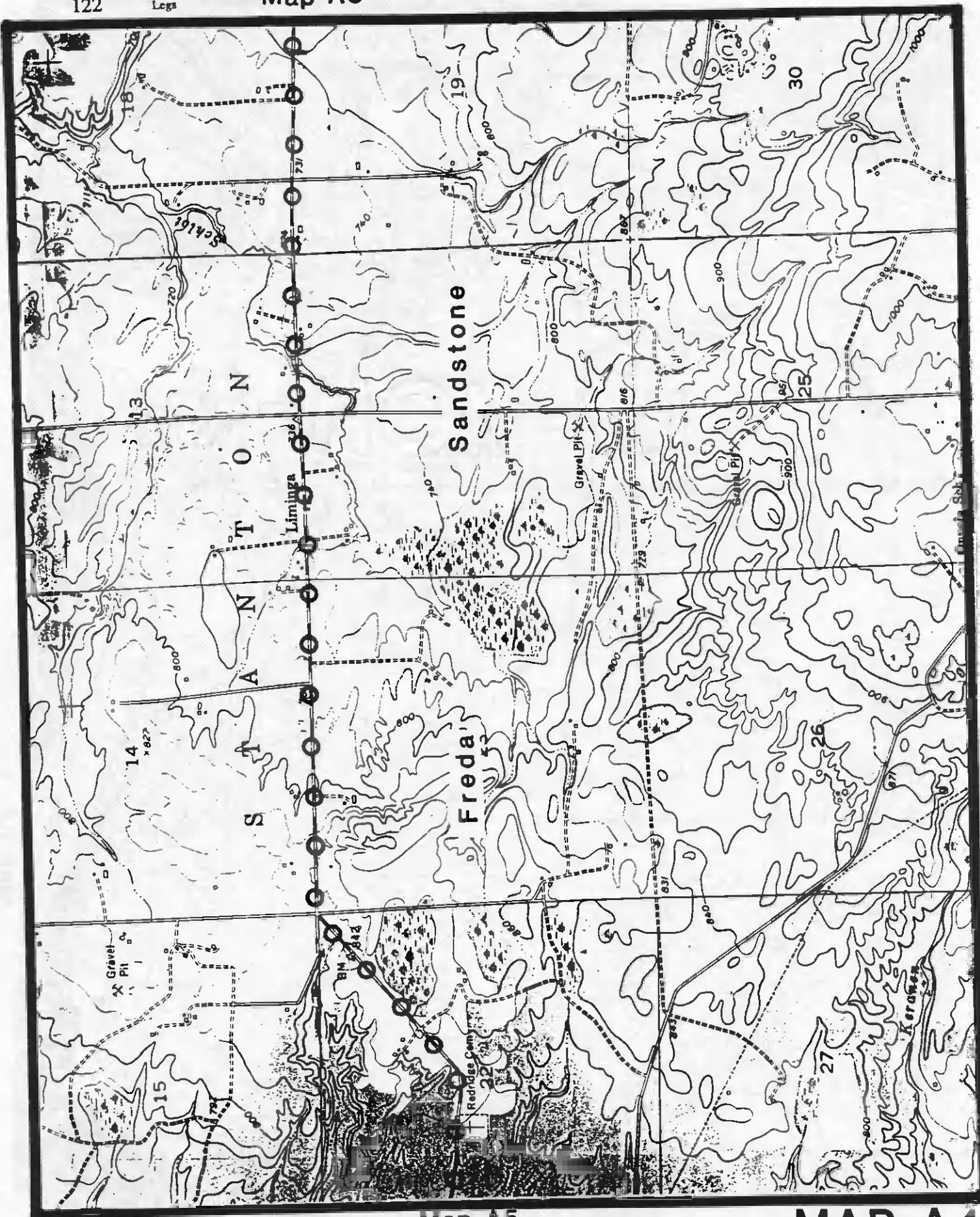
12.25 **Stop A3: Redridge Cliffs (Freda Sandstone)**

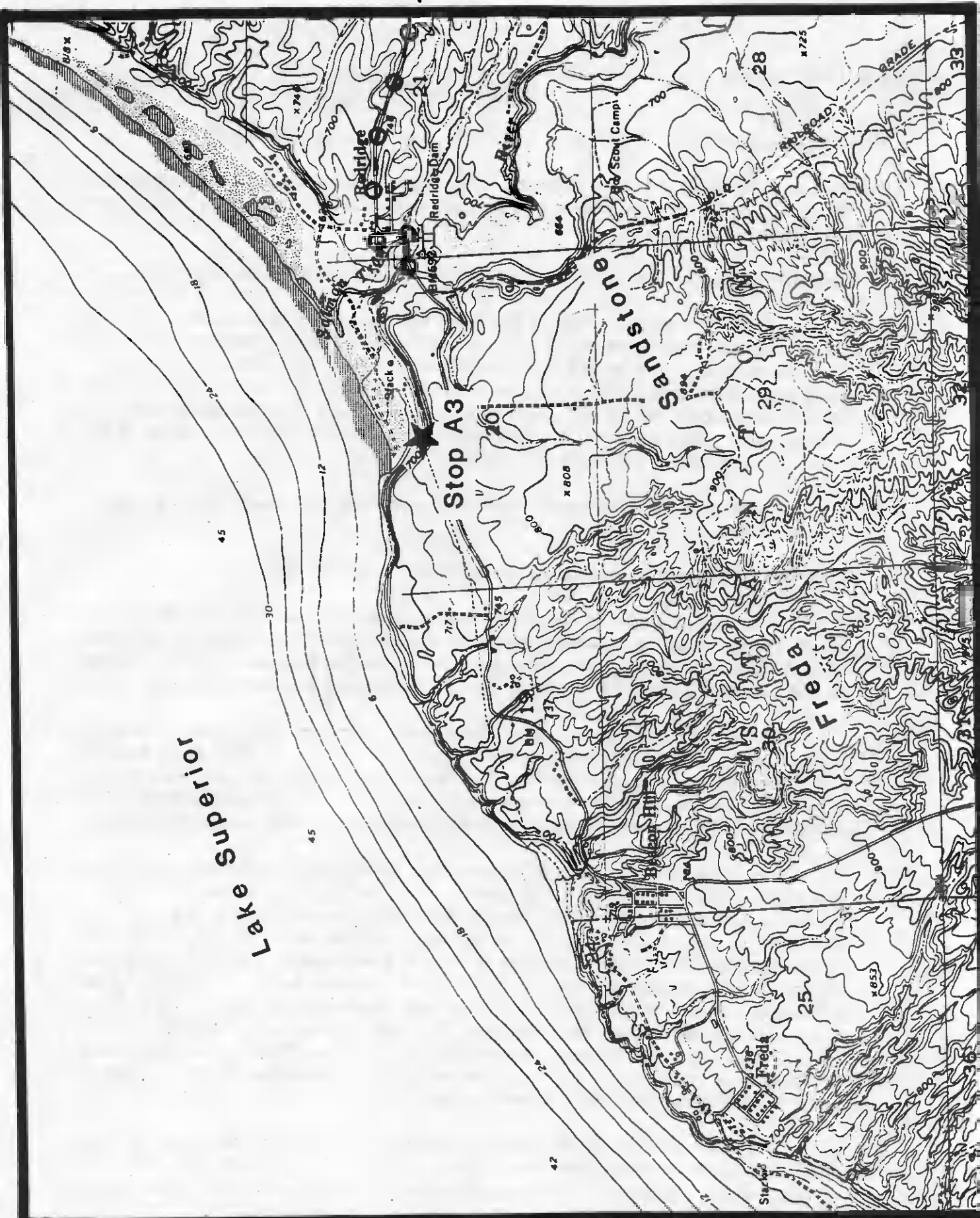
At the edge of Lake Superior, is a large area of gray-to-black "stamp" sands. The sands were produced during processing of the native copper ores shipped by train to a mill here (Redridge). The steel structure on the opposite side of the paved road at the turnoff, is an old dam which provided water for the mill. The old smoke stack is the principal ruins of the mill here. The stamp sands were deposited in Lake Superior as tailings from the mill. Since pyrite and other potential acid- producing minerals are virtually absent in the ores of the Keweenaw Peninsula, these sands do not yield acid drainage. The elemental constituents of the sands are contained in minerals that are relatively insoluble, except under acid conditions. Thus, without acid waters, the constituents are locked in place. This minimizes the environmental impact of these sands. Walk to, and along, the beach to the red-colored cliffs. During the walk, you can see sections of the stamp sands cut by wave action.

Freda Sandstone is well exposed in a 20 meter high wave-cut cliff on the shoreline of Lake Superior, and is composed of red very fine sandstone-to-siltstone. Sub-parallel to bedding, about 20 to 40 cm thick, red color alternates with 3 to 5 cm thick of gray color (reduced) without striking differences in grain size. Mica is readily visible on bedding plane surfaces. The lithologies exposed are typical of the Freda Sandstone, which was deposited in a fluvial environment. Bedding dips shallowly toward Lake Superior, about N-S strike, and 5°W dip. Prominent joints in this exposure are spaced about 2.5 m apart, striking N38°W and dipping 88°W. Irregular subvertical gray zones follow the joints. This is one of many spots along the shore of Lake Superior where canoes offer an excellent way to see the geology. If you launch here (don't go if the surf is up), paddle westward to Freda for spectacular sandstone cliffs.

End of Leg A - Retrace route to Houghton.







LEG B OWL CREEK**MAP B1**

- 0.0 At Eagle Harbor, M-26. Turn right on Garden City Road at the head of the bay.
- 1.05 There is a dirt road that goes off to the left. From this dirt road, just a few hundred meters up hill, you can begin a traverse upstream on Eliza Creek to get to the exposures of the Portage Lake Lava Flows of this region.
- 1.15 Crossing Eliza Creek. You can also begin a traverse upstream on Eliza Creek from here.

MAP B2

- 2.5 The road to the right goes downhill. If you follow this road several hundred meters, you will reach the 30-mile stamp sands; which are the tailings from the Copper Falls mining operation. From this stamp sand, you can gain access to the bottom of Owl Creek, and can begin a 2 to 3 hour traverse upstream to the bridge along this road. If you continue upstream beyond the bridge, you will reach a poor rock pile 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 mileage 2.7 just ahead.
- 2.6 Road to the left goes uphill to the rock piles of the Copper Falls Mine, which is part of Stop B1 described below.

STOP B1: Owl Creek (Portage Lake Volcanics and Copper Falls Mine)

Owl Creek is another of the streams that cuts across the upper part of the PLV. The traverse begins downstream, where the base of the Copper Harbor Conglomerate and top of the PLV interfinger. Excellent exposures of interbedded conglomerate/sandstone and lava flows along the bed and sides of Owl Creek are visible, as well as several well exposed amygdaloidal flows.

The Copper Falls Mining Company worked several fissures and the Ashbed Amygdaloid. The mine operated from 1847 to 1893, producing 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).

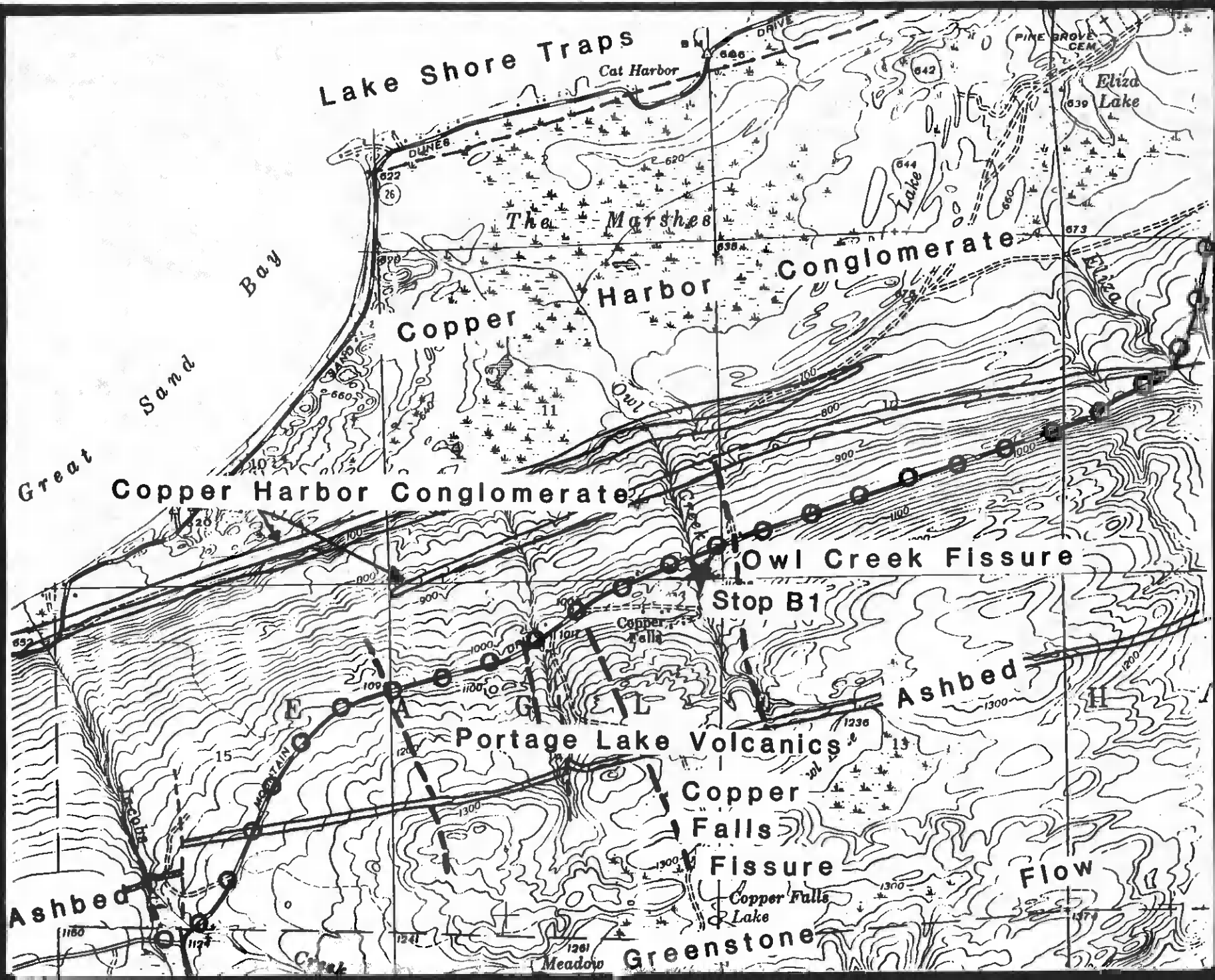
The Owl Creek vein starts near the base of the Copper Harbor Conglomerate and extends through the Portage Lake Volcanic Series, probably into the Greenstone Flow. The vein was productive only in the vicinity of the Ashbed Amygdaloid (described also at Stop 20). The Ashbed Flows are porphyritic and scoriaceous, with a notable clastic component. In some localities, pebbles and boulders of amygdaloid are set in a sandy matrix. Johnson (1985) studied the Ashbed exposed upstream of the road on Owl Creek. Here the Ashbed consists of a broken pillowed lava breccia (hyaloclastite). The hyaloclastite contains angular fragments of vesicular basalt ranging in size from ash-sized to blocks. The larger fragments often have distinct rinds, whereas smaller fragments are finely fractured, like perlite texture. This horizon is interpreted as subaqueously emplaced. It is the only documented subaqueous-emplaced volcanic horizon within the PLV of the Keweenaw Peninsula (see also Stop 20).

The mineralization of the Ashbed Amygdaloid is similar to that found in other amygdaloids in the Keweenaw Peninsula. At the Copper Falls Mine, the following are the more abundant minerals: calcite, quartz, epidote, and pumpellyite. Datolite is abundant in the Ashbed



Map B2

MAP B 1



near fissures, such as Owl Creek. Native copper was more abundant toward the top part of the deposit. Also reported in the Copper Falls area are these minerals: laumontite, prehnite, native silver, adularia, analcime, apophyllite, faujasite, natrolite, and stilbite (summarized from Butler and Burbank, 1929; Clarke, 1974b). The Copper Falls Mine is stratigraphically the highest in the Keweenaw native copper district, and is near the top of the pumpellyite zone (see Figs. 8 and 12 in the Introduction).

2.7 Cross Owl Creek.

3.0 A dirt road that slants to the left goes to the old town site 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.

3.7 On the right 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.

4.4 The junction of a dirt road on the right. Continue ahead on the paved road. From this road, a short distance to the west, there is access to Jacobs Creek, the site of the Arnold Mine, along the Ashbed Arnygdaloid. This is the end of a traverse one can make across the upper part of the PLV. It is recommended to begin the traverse at the lower end of Jacobs Creek, where it crosses M-26. This is a very tough traverse with many steep and dangerous points within it. Excellent exposures of many individual lava flows are 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 19), Owl Creek (Stop B1), and Jacobs Creek allow one to look in detail at lateral variations in the upper part of the PLV.

4.6 Cross Jacobs Creek.

END OF LEG B - Continue ahead on the paved road to reach US-41, or turn around and return to Eagle Harbor.

LEG C HORSESHOE HARBOR**MAP C1**

- 0.0 Start Leg C at the entrance to Fort Wilkins State Park, east of Copper Harbor. Continue ahead to the east (away from Copper Harbor.)
- 0.15 On the left is a trail for access to the shoreline of Copper Harbor. The basalt flows of the Lake Shore Traps are exposed along the lakeshore.

MAP C2

- 1.05 The end of the paved road. This is the end of US-41, which goes south from here all the way to the southern tip of Florida. Continue ahead on the poorly maintained gravel road. The road is easily traversed with a regular passenger car.
- 1.5 At the ridge crest.
- 1.65 On the right, a ridge of Copper Harbor Conglomerate is visible.
- 1.95 The crest of a ridge with a dirt road on the left, which goes steeply downhill. This dirt road goes to Horseshoe Harbor. It is not recommended that you drive this road with a regular passenger car. Park and proceed on foot along the dirt road toward Horseshoe Harbor.

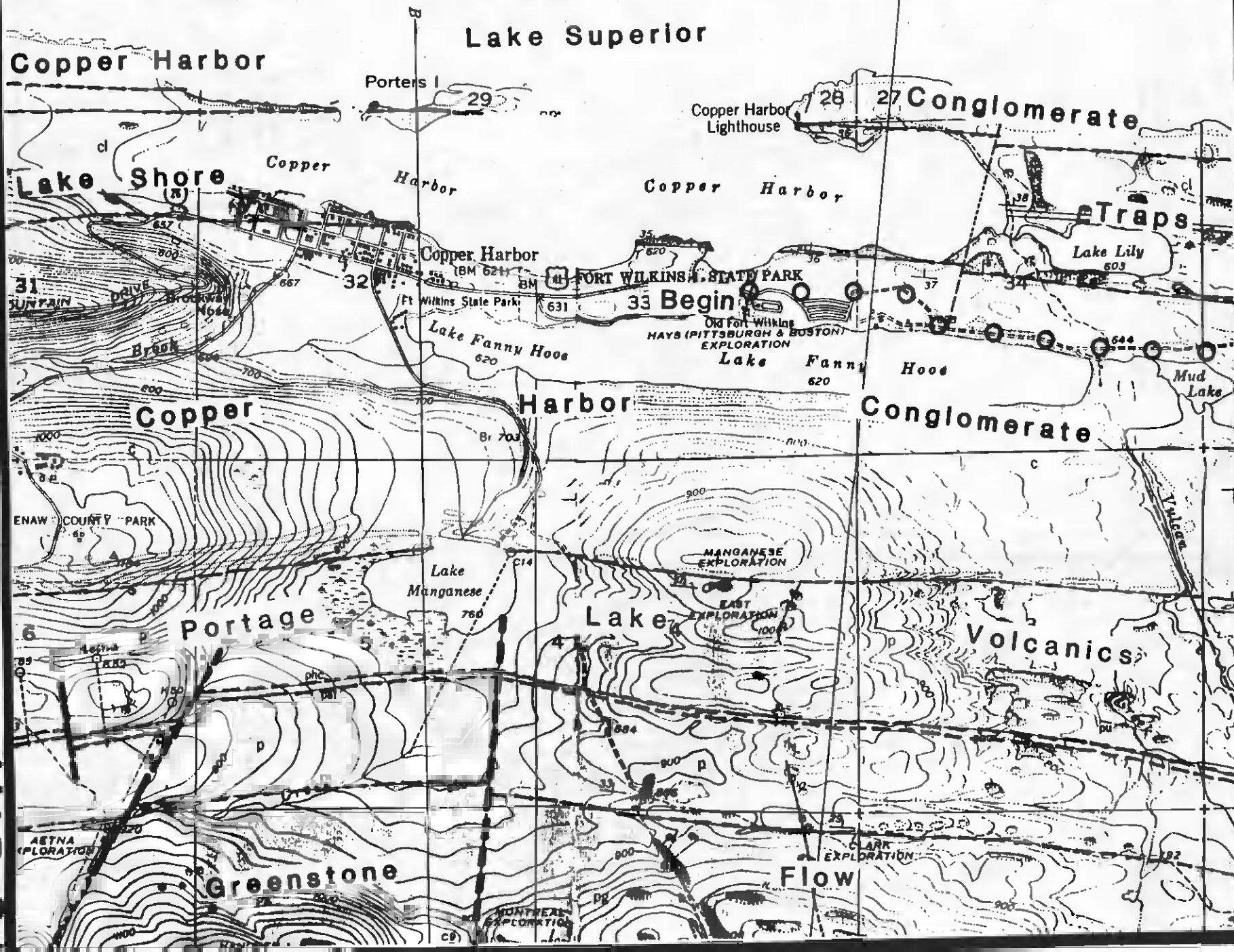
If you continue on the main road (straight ahead), you can gain access to the region around Keweenaw Point (it is private land). Of greatest geologic interest is the region around High Rock Bay, accessible by four-wheel drive vehicles. North of the end of the road, the Lake Shore Traps are exposed in a series of rocky wave-washed outcrops that allow examination of the physical/solidification features of Keweenawan lava flows.

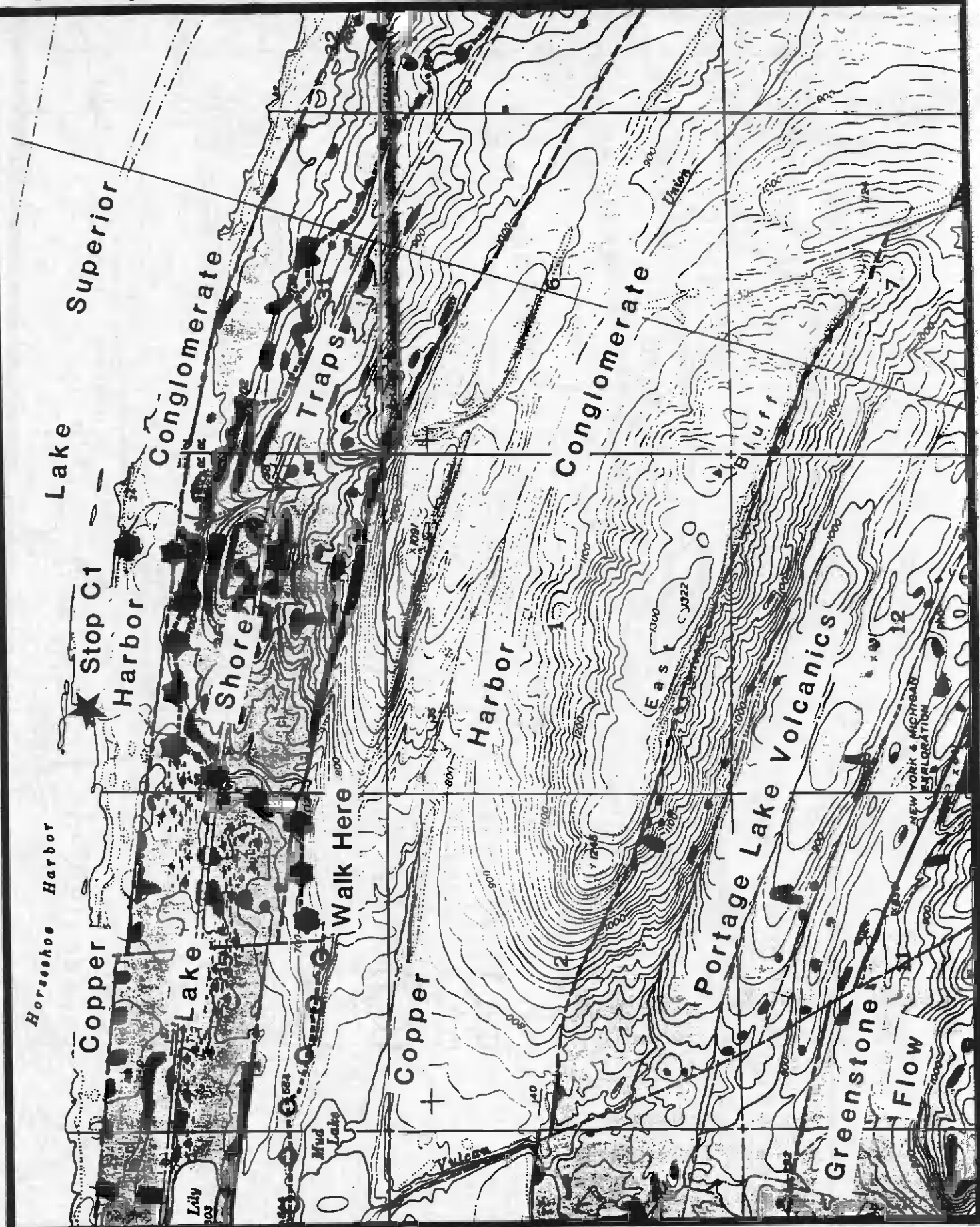
Walking Distance (A typical pace--2 steps--is about 5 ft.)

FEET

(Approximate)

- 0 The parked cars on the gravel road is at the crest of the ridge. This ridge is supported by tilted beds of Copper Harbor Conglomerate. Begin walking downhill (it is steep) on the poorly maintained dirt road.
- 1750 A glacially polished outcrop of basalts of the Lake Shore Traps.
- 2700 On the left is a ridge of basalt of the Lake Shore Traps, which are a sequence of mafic-to-intermediate lava flows within the Copper Harbor Conglomerate. The Lake Shore Traps are described more at Stop 24. Continue on the main road.
- 2850 Copper Harbor Conglomerate outcrops on the left and in the road bed. Just ahead, the basalt of the Lake Shore Traps are seen in the road bed. We are now near the upper contact of the Lake Shore Traps and conglomerates of the Copper Harbor Conglomerate.
- 3000 Lake Shore Traps basalt outcrops in the road bed.
- 4000 Lake Shore Traps basalt outcrops on the left.
- 5300 Several pullouts for autos are on the right.





Map C1

MAP C2

5375 The major trail to Horseshoe Harbor is on the left. Follow that trail downhill.

Reset Distances

- 0 At the dirt road and the trail to Horseshoe Harbor, going downhill.
- 60 Horseshoe Harbor sign. Horseshoe Harbor is a part of the Michigan Chapter of The Nature Conservancy. Please do not collect rocks.
- 450 Copper Harbor Conglomerate outcrops in the path.
- 1350 At Horseshoe Harbor beach. Proceed left (north) toward the rock ridges along the Lake Superior shoreline. Follow the prominent ridge to the left (west). It is recommended to walk along the lowland just landward of the ridge (south). Stop C1 is at the far west end of this ridge, where there are excellent exposures of stromatolites.

Stop C1: Horseshoe Harbor (Copper Harbor Conglomerate)

PLEASE DO NOT REMOVE ROCKS

The Copper Harbor Conglomerate at the east end on Horseshoe Harbor is composed of red clast-supported conglomerate with a 5 m thick bed of shale, sandstone, conglomerate, and stromatolite (Fig. 41). The conglomerate is composed of pebble-to-cobble, well-rounded clasts dominated by rhyolite and corresponds to conglomerate facies as described by Elmore (1984). These conglomerates are interpreted as an alluvial fan deposit shed toward the center of the rift. The stromatolites are associated with conglomerate, trough cross-stratified sandstone, and conglomerate-mudstone (Elmore, 1983). The stromatolites, *Collenia undosa* species (Cornwall, 1955), are intermittently found from here to Dan's Point (Stop 27). Elmore (1983) describes the various forms of stromatolites, including laterally linked bedded, oncolites, and poorly developed mats. The typical stromatolite is a hemispheroid, about 15 cm thick and up to 40 cm in diameter, and is often draped over cobbles. Contorted stromatolites may be due to soft sediment deformation during compaction. Ooids, oncolites, and intra clast limestone (stromatolite and oolite fragments) occur within stromatolites. The stromatolites are cryptalgal deposits in abandoned stream channels (Fig. 41).

Horseshoe Harbor is worth the time to visit for its beautiful scenery alone. The exposures of stromatolites are the best of the Keweenaw Peninsula.

END OF LEG C - Return to the vehicles and proceed back to Copper Harbor.

LEG D EAST SIDE OF THE KEWEENAW PENINSULA**MAP D1**

0.0 The junction of the road to Lac La Belle. Turn left and go down hill toward Mt. Bohemia.

MAP D2

3.5 On the left side of the road is a large outcrop of amygdaloidal basalt of the PLV. These exposures are flows in the lower part of the formation, below the Scales Creek Flow.

3.9 A dirt road turning off the main road to the left. This is STOP D1 at Mt. Bohemia. It is about a one half mile walk up this road to the summit of Mt. Bohemia; the road is a four-wheel drive vehicle road.

STOP D1: Mount Bohemia (diorite stock within the Portage Lake Volcanics [PLV])

Walk the road to the summit of Mount Bohemia. The road crosses flows of the PLV. The diorite and granophyre intrusive complex crops out to the southeast of the summit. Intrusive stocks are not common in the Keweenaw Peninsula, most occur in the lower part of the PLV and are rhyolitic in composition. Mount Bohemia is the only occurrence of a diorite stock in the Keweenaw Peninsula.

An intrusive stock of diorite and granophyre crops out on the south slope of Mount Bohemia (Map D1). The majority of the Mount Bohemia stock is an altered, massive, medium- to coarse-grained, miarolitic diorite. The pre-alteration mineral assemblage consists of 45 to 50% sodic plagioclase, 30 to 50% mafic minerals (augite and hornblende), and up to 3% quartz (Sikkila, 1984). Magnetite is found throughout the stock, and in small areas exceeds 15%. Apatite and sphene are also present in trace amounts. The southeast portion of the stock consists of quartz diorite with approximately 60% sodic plagioclase, 30% quartz, 7% biotite, and 3% quartz. The central core is a fine- to coarse-grained, miarolitic granophyre. The major constituents of the granophyre are sodic plagioclase, 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, chalcopyrite, and chalcocite (Cornwall, 1954).

The diorite and granophyre at Mt. Bohemia intrude basaltic lava flows of the lower part of the PLV. 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 chalcopyrite and bornite with a gangue of calcite, chlorite, and quartz (Juillard, 1965).

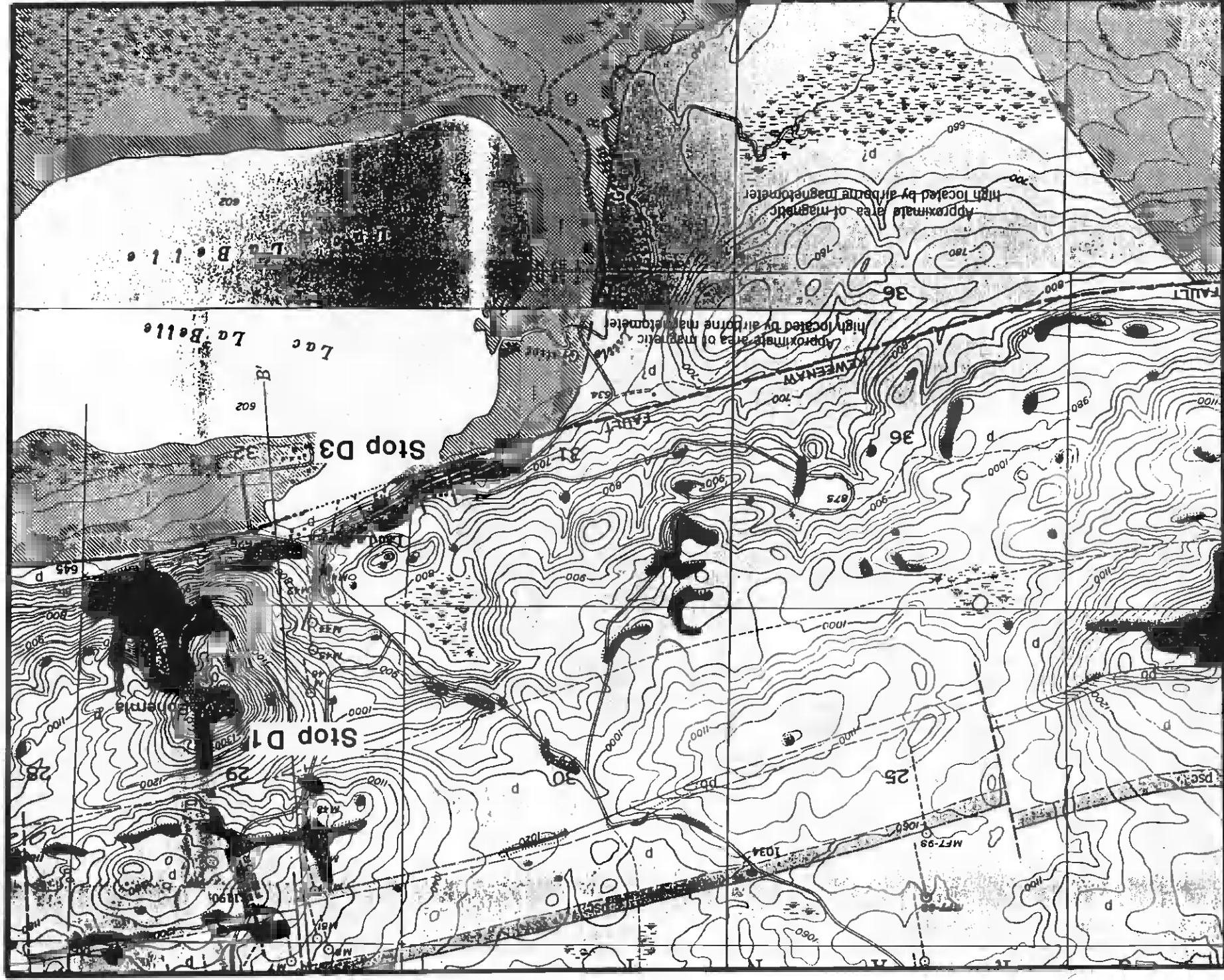
The stock has been moderately-to-strongly altered. Secondary potassium feldspar is observable throughout the stock. Hand specimens have the misleading appearance of syenite, because of the potassium feldspar and secondary fine-grained hematite after magnetite. Alteration products include serpentine (after mafics), epidote (after plagioclase and mafics), calcite (after plagioclase), actinolite (after pyroxene), sericite (after plagioclase), and chlorite (after mafics). Sikkila (1984) reports a correlation between alteration and the cross-cutting Lac La Belle Fissure, indicating a preferential channeling of hydrothermal fluids. Secondary geochemical variations in the stock also tend to correlate with respect to the fissure. The grade of alteration of the Mount Bohemia stock is higher than the surrounding PLV. Actinolite has not been observed within the PLV. Both the grade and character of alteration may have been the result of a local hydrothermal system related to the stock itself, rather than to the regional hydrothermal system, which produced



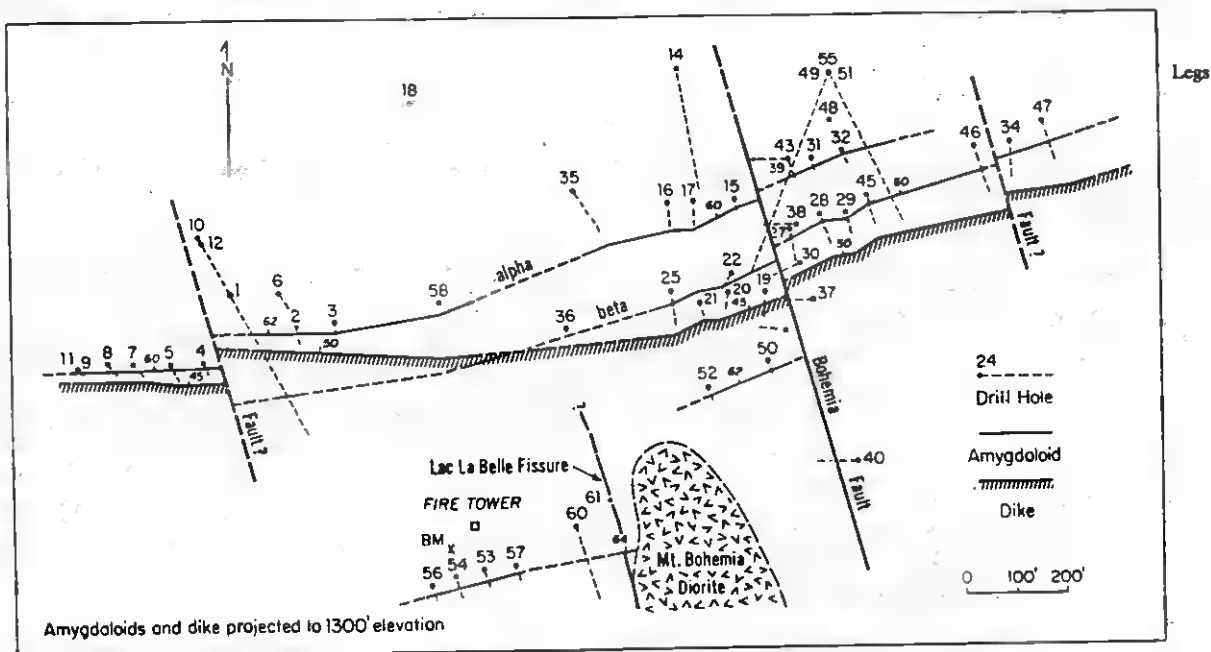
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(1 cm = 1689.6 m or 3/8" = 1 mile)

MAP D1



A



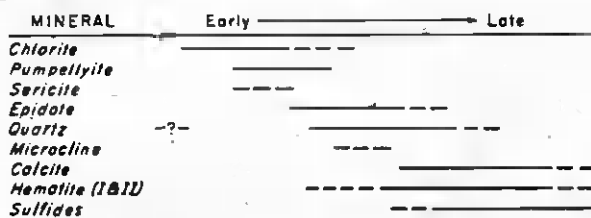
B

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

Nonpyrogenic Minerals in the Dikes

C



D

MINERAL	Pyrogenic	Deuteric	Hydrothermal	Supergene
<i>Magnetite</i>	---	---	---	---
<i>Hematite I</i>	---	---	---	---
<i>Pyrite</i>	---	---	---	---
<i>Chalcopyrite</i>	---	---	---	---
<i>Galena</i>	---	---	---	---
<i>Sphalerite</i>	---	---	---	---
<i>Pink bornite</i>	---	---	---	---
<i>Purple bornite</i>	---	---	---	---
<i>Digenite</i>	---	---	---	---
<i>Djarite</i>	---	---	---	---
<i>Chalcocite</i>	---	---	---	---
<i>Hematite II</i>	---	---	---	---
<i>Covellite</i>	---	---	---	---

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

Figure D1: Geologic map showing andesitic dikes near Mount Bohemia and occurrence and paragenesis of secondary and opaque minerals in the dikes (from Robertson, 1975).

the native copper deposits. Mount Bohemia stock a bears resemblance to a porphyry copper system.

Andesitic dikes are found in the vicinity of Mt. Bohemia (Fig. 35a), and average about 5 m in thickness. The dikes intrude flows of the PLV. 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, and native copper is the dominant ore mineral of the Keweenaw Peninsula. A variety of secondary and opaque minerals are found in the dikes and flow tops (Fig. D1). Copper sulfides are paragenetically late. The copper and sulfur in this occurrence is believed to be of direct magmatic origin. The atypical copper sulfide mineralized flow tops and dikes also may have been related to the magma source that produced the Mount Bohemia stock and andesite dikes, rather than the regional hydrothermal system (Robertson, 1975).

- 4.3 At the turnoff to Mt. Bohemia. Go straight ahead (south) toward Lac La Belle, down hill.
- 4.7 A junction of roads at Lac La Belle. Turn right (west) along the shore of Lac La Belle. For the stop at Bete Grise, turn left and continue until the Bete Grise sand beach.

To Bete Grise, turn left. (See Map D1, there is no mileage logged to Bete Grise and back)

Stop D2: Bete Grise (white sand beach from Jacobsville Sandstone)

The white sand beach is derived from Jacobsville Sandstone and is typical of beaches on the east side of the Keweenaw Peninsula, whereas on the west side, the beaches are often of pebbles from the Copper Harbor Conglomerate. Black sand beaches on the Keweenaw Peninsula are crushed mine rock derived from milling of native copper ores.

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. A canoe or small boat is a good way to visit these areas. Also to the east, are several of the rhyolite bodies which are chiefly found in the lower part of the PLV. Three tenths of a mile north of Bete Grise, a four-wheel drive road continues east of the paved road to Smith's Fisheries. The road intersects the Bare Hill Rhyolite body, which is 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, ash flow tuffs, and a rhyolite dome--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, an extrusive rhyolite dome with prominent flow banding and block and ash flow deposits on its flanks. Mt. Houghton is best approached from the Mandan Road (Map 20). See Stop D4 (this leg), for more on rhyolites.

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

Return to the junction at Lac La Belle.

MAP D2

- 5.1 Behind, is an excellent view of Mount Bohemia described at Stop D1.
- 5.2 Pull over to the right at Haven Park.

Stop D3: Haven Park (Portage Lake Volcanics [PLV] near the Keweenaw Fault)

The exposures at the waterfalls provide an excellent view of the PLV adjacent to the Keweenaw Fault. At this locality, the Keweenaw Fault is oriented subparallel to the slope face (and the road), and is less than 100 m to the south (toward Lac La Belle) of the exposures at the waterfalls. In addition, in this general area several faults cut the PLV nearly perpendicular to the Keweenaw Fault. Basalt at the base of the falls is overlain by conglomerate, and in turn, overlain by basalt. The conglomerate is unnamed (Cornwall, 1954) and is an interflow sedimentary horizon within the PLV. Conglomerate beds are common at, or near, the exposed base of the PLV close to the Keweenaw Fault. The rocks of the PLV here, and elsewhere adjacent to the Keweenaw Fault, are typically quite fractured and altered. The basalt is cut by closely spaced fractures that trend subparallel and perpendicular to probable bedding (subparallel to the Keweenaw Fault) that yield 1 to 2 cm rectangular pieces of basalt. The rock is quite altered, with a lot of veinlets up to 1 cm wide, and a dominant orientation subparallel to the Keweenaw Fault. Secondary minerals include laumontite, calcite, chlorite, and hematite. The grade of regional alteration varies systematically within the PLV (see Fig. in Introduction), with the highest grades lower in the PLV. Paragenetically late lower grade assemblages are superimposed on higher grades where sufficient porosity and permeability still exists, such as at this stop. The alteration minerals here, and at other locations near the Keweenaw Fault, are characterized by low grade and late minerals such as laumontite. Some localities have abundant higher grade assemblages near the fault, with clear superimposed lower grade assemblages. This suggests that the Keweenaw Fault was a long-lived conduit of hydrothermal fluids.

Continue west on the paved road.

- 5.3 Highly fractured and altered basalt of the PLV is exposed on the right side of the road.
- 5.85 River Side Park at Little Gratiot River. This locality, and the remaining localities on this leg, are south and east of the Keweenaw Fault, with the principal bedrock being Jacobsville Sandstone. The Jacobsville Sandstone is the typical rock unit juxtaposed against the PLV by the Keweenaw Fault.

However, 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. D2). These basalts may represent the lowest stratigraphic horizons exposed in the PLV. The area has been studied by geological and geophysical methods by DeGraff (1976), whose model for the development of this unusual feature is shown graphically in Fig. 36. It is yet another example of the deformation along the high-angle reverse Keweenaw Fault. 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 the PLV was defined by a 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 PLV, have normal magnetic polarity.

MAP D1

- 7.4 End of Lac La Belle.

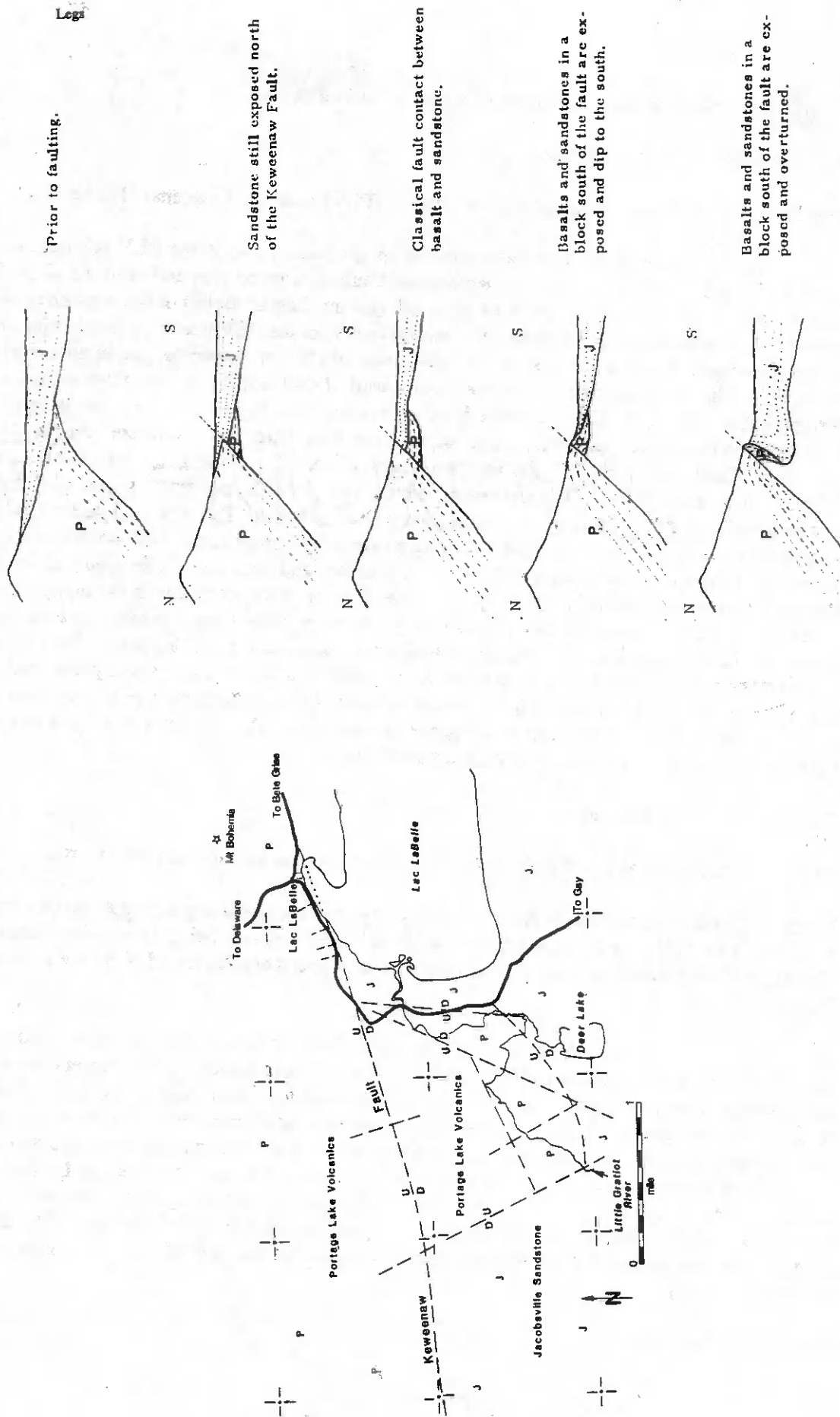


Figure D2: Geologic sketch map of part of the Keweenaw Fault in the vicinity of Deer Lake, where the Portage Lake Volcanics are found south of the Keweenaw Fault. At right, schematic cross sections show stages in the development of the Keweenaw Fault at Deer Lake as envisioned by DeGraff (1976). P = PLV, J = Jacobsville.

9.4 Behind, is a view of Mount Bohemia.

10.5 Along the shore of Lake Superior,

11.7 At South Point.

Stop D4: South Point (view of the tip of the Keweenaw Peninsula)

South Point, being on the southern end of Bete Grise Bay, provides an excellent view of the tip of the Keweenaw Peninsula--visible on the far right (northeast) (Fig. D3).

At 1:00, facing perpendicular to the shoreline, is Fish Cove Knob, a rhyolite intrusive body into the base of the PLV (Bornhorst, 1975). The rhyolites at Fish Cove Knob contain sparse phenocrysts of feldspar and quartz.

At 12:00, is a light-colored bare rock bluff which is part of the Bare Hill Rhyolite. Bare Hill consists of several sills of rhyolite, containing sparse phenocrysts of feldspar and quartz (Cornwall, 1954).

At 10:00, facing perpendicular to the shoreline, is Mount Houghton, a rhyolite dome complex within the lower section of the PLV. Rhyolite at Mount Houghton is aphyric with well-developed flow foliation. Several beds of conglomerate, interclated with basalts of the PLV, are detritus shed off the rhyolite dome.

The Keweenaw Fault follows the Lake Superior shoreline from south of Mount Houghton to Keweenaw Point.

Rhyolite intrusive and extrusive rocks occur stratigraphically below the Bohemia Conglomerate (Fig. D3). The Bohemia Conglomerate is stratigraphically in the lower part of the PLV. The older Keweenawan North Shore Volcanic Group contains frequent rhyolites, similar to the proportion found in the lower PLV (Green, 1982). Nicholson (1992) proposed Iceland as a modern volcanological analog for rhyolites within the Midcontinent rift system. Within-rift central volcanic complexes in Iceland are localized accumulations of basalts-to-rhyolites, surrounded by basalts erupted from fissures (Walker, 1966). The distal part of these central volcanoes may be a good model for rhyolites within the PLV.

12.7 Point Isabelle is on the left.

13.0 Good exposures of Jacobsville Sandstone on the shoreline extend from here to the roadside pullover. The Jacobsville Sandstone yields excellent light-colored sand beaches.

13.3 The roadside pullover is on the left.

15.1 Excellent low exposures of Jacobsville Sandstone are on the left.

STOP D5: Eastern Keweenaw Peninsula (Jacobsville Sandstone)

Jacobsville Sandstone is well exposed along the Lake Superior shore at this location. The character of the Jacobsville Sandstone illustrated here is typical of many exposures elsewhere. Here, the medium- to coarse-grained sandstones are red-colored with characteristic circular white

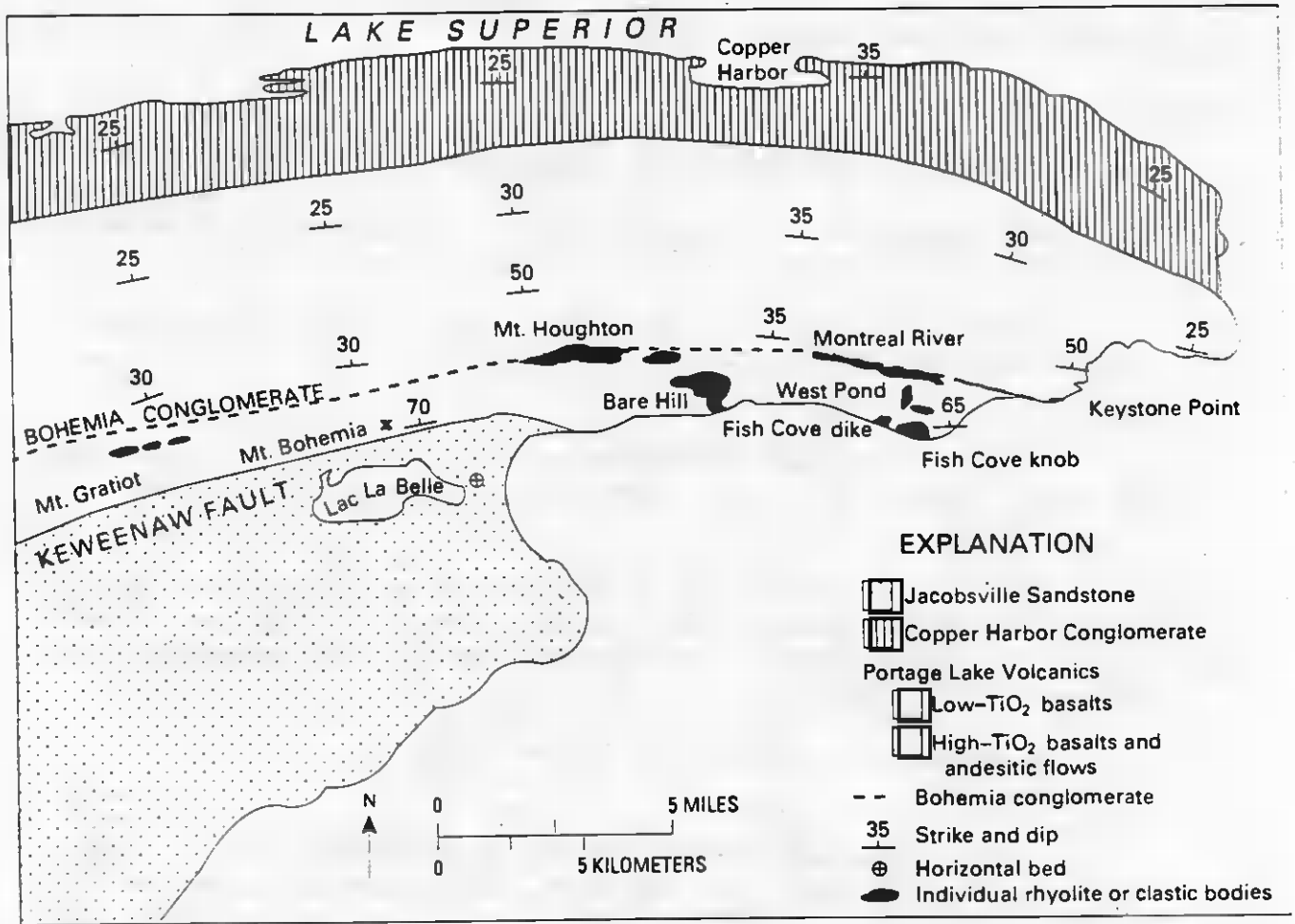


Figure D3: Geologic map showing the location of rhyolites on the eastern tip of the Keweenaw Peninsula (from Nicholson, 1992).

reduction spots up to about 2.5 cm in diameter. Well developed white reduced zones of variable thickness are subparallel to bedding. Some zones within the sandstones show cross-bedding and others contain mud chips. For a further description of the Jacobsville Sandstone, refer to Stop 10.

- 17.5 Burnette Park is on the left. It has lakeshore exposures of Jacobsville Sandstone with a sand beach. Well-developed cross bedding is visible in the sandstone exposed here. On a clear day the Huron Mountains are visible across the Keweenaw Bay.
 - 18.3 Outcrops of Jacobsville Sandstone along the Keweenaw Bay/Lake Superior shoreline.
 - 19.0 The road to the right goes to Betsy. Continue ahead.
 - 23.6 Hermit Bay is on the right.
 - 25.2 Cross the Tobacco River at its mouth with Lake Superior. The Huron Mountains are visible across Keweenaw Bay on a clear day. The black sand beach is a result of longshore drift of the basalt mine tailings dumped into Lake Superior from 1902 to 1932.
 - 25.9 Road access to the Gay Stamp Sands. Continue on the paved road.
- MAP D3
- 26.0 The Gay smokestack is on the left.

Stop D6: Gay (stamp sands)

Walk toward the stack and Lake Superior. This vantage point provides an excellent view of Lake Superior and Keweenaw Bay. On a clear day, the Huron Mountains are clearly visible on the horizon across Keweenaw Bay. The Huron Mountains consist of a core of Archean granitoid rocks, unconformably overlain by Early Proterozoic deformed and metamorphosed sedimentary rocks. Keweenaw Bay however, is underlain by Jacobsville Sandstone with Early Proterozoic metasedimentary rocks cropping out on the opposite shore of Keweenaw Bay (Stop I1). The nearly flat-lying Jacobsville Sandstone extends from the Keweenaw Fault contact with the PLV, about 8 km N/NW, to the opposite side of Keweenaw Bay, about 35 km. The Jacobsville Sandstone fills a rift-flanking basin.

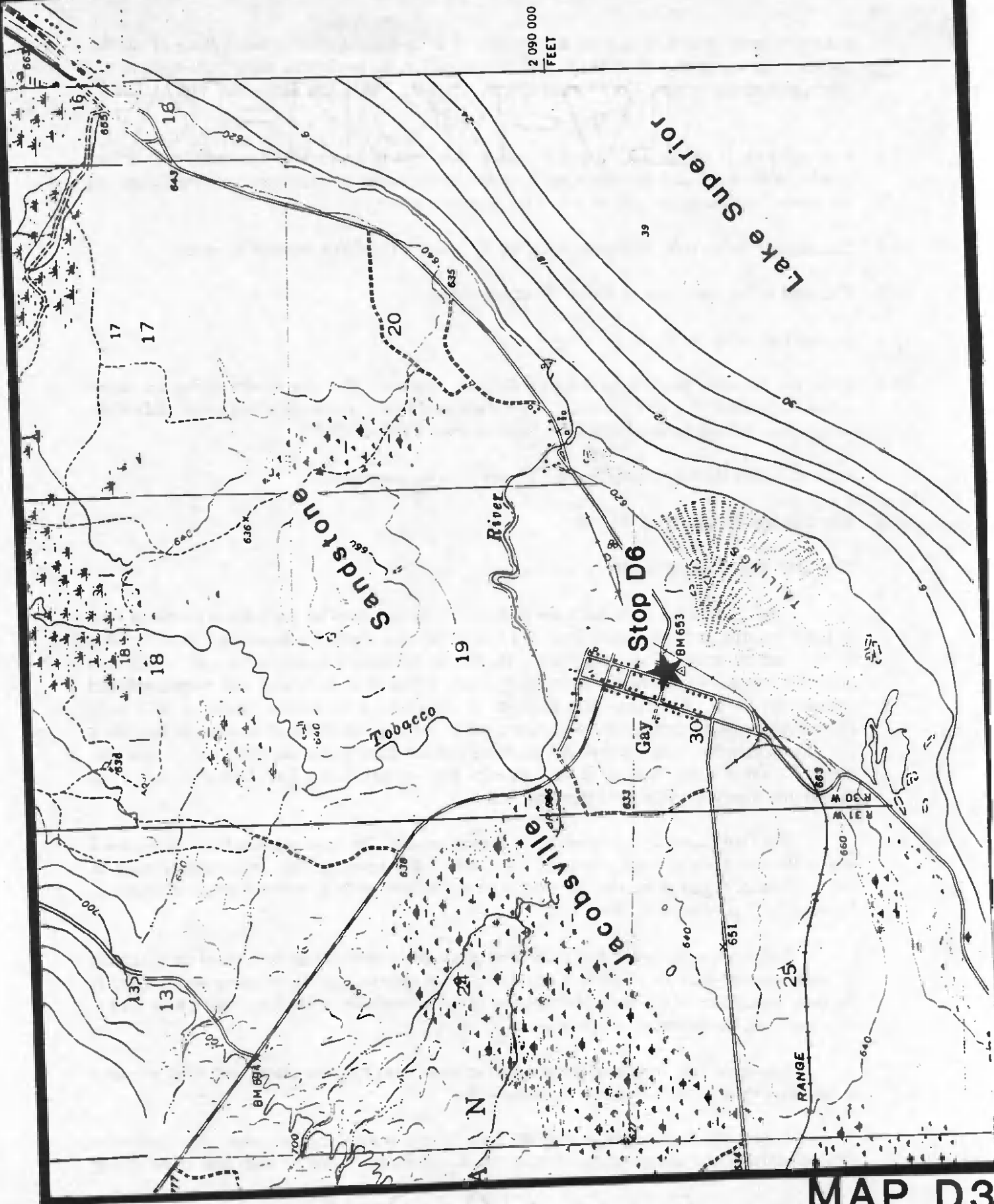
The Gay Stamp Sands are visible in the foreground. The sands accrued from the Mohawk and Wolverine Mills as tons of crushed rock were milled to extract the copper they contained. The twin mills began processing in 1902, with the Wolverine Mill working until 1922 and the Mohawk Mill running until 1932.

Both companies began their processing plants in the town of Gay because of the proximity of water-covered areas in which they could dispose of their tailings. Lumbering was previously the main occupation of the town, also because of the accessibility to the Bay, which they used to float their logs to the larger shipping areas.

Conveyor belts were used to transport the sands away from the plants, and water was used to transport them even further into Keweenaw Bay.

Access can be obtained at mileage 25.9. If you walk along the beach, you can see an erosion scarp of the stamp sands. Within the accumulation, stratified beds and cross cutting

2 090 000
FEET



layers--as the slurry found new directions in its progress toward Keweenaw Bay--are evident.

NOTE: When approaching the edge of the sands facing the bay, do not go too close to the edge because the cliff face could give way.

Erosion of the shoreline and a right lateral longshore current caused the toe of the fan to be dispersed south toward Traverse Point and beyond. Accumulations at Traverse Point are the cause of the tombolo that connects the island to the mainland now. At that point, some of the sands were diverted into the middle of Keweenaw Bay, but the majority of the sand was kept along the shore by wave refraction, to be deposited further south.

Continue ahead.

26.1 Take a left turn in Gay on Main Street.

26.3 Leave Gay with a sharp right turn.

MAP D1

30.0 The road to the left goes to Big Traverse Bay (about 1.5 miles).

30.8 The road bends right, then left.

35.0 Gently rolling farm land.

36.4 The view ahead is of a topographic slope that follows the trace of the Keweenaw Fault. At the top of the slope, the PLV are exposed. The slope face to here is underlain by Jacobsville Sandstone. The road goes downhill into the Traprock Valley.

36.7 Turn left at the stop sign toward Lake Linden.

37.6 The slope related to the Keweenaw Fault is again visible on the right.

38.1 At the stop sign, turn right toward Lake Linden, and immediately cross the Traprock River near the mouth with Portage Lake. Left, the road goes to Jacobsville via Dreamland.

38.6 Gregory Street is on the left, which goes to the Natural Wall in the main road log at mileage 37.4.

38.7 The junction of 9th Street with M-26 in Lake Linden. Turn left on M-26 to return to Houghton, or right to go to Calumet/Laurium.

END OF LEG D

LEG E 932 CREEK**MAP E1**

- 0.0 Start Leg E at the junction of US-41 and Gratiot Lake Road. North of US-41 is the Central Mine. Proceed on the paved Gratiot Lake Road, immediately after the junction on the left, there are stamp sands from the Central Mine. The copper content of the sands restricts plant growth.
- 1.3 The road traverses nearly perpendicular to strike, and goes downsection across the PLV.
- 2.65 The entrance to an abandoned Calumet Air Force Station is on the left. Continue ahead with slow, gradual descent.

MAP E2

- 4.1 Gratiot Lake is visible ahead. It is on the south side of the Keweenaw Fault and underlain by flat-lying Jacobsville Sandstone bedrock. We are on the tilted lava flows of the PLV.
- 4.25 Pull over to the side of the road. Walk along the road toward an A-frame building. The slope ahead along the paved road is the topographic expression of the Keweenaw Fault.

Walking Distance (A typical pace--2 steps--is about 5 feet.)

Feet

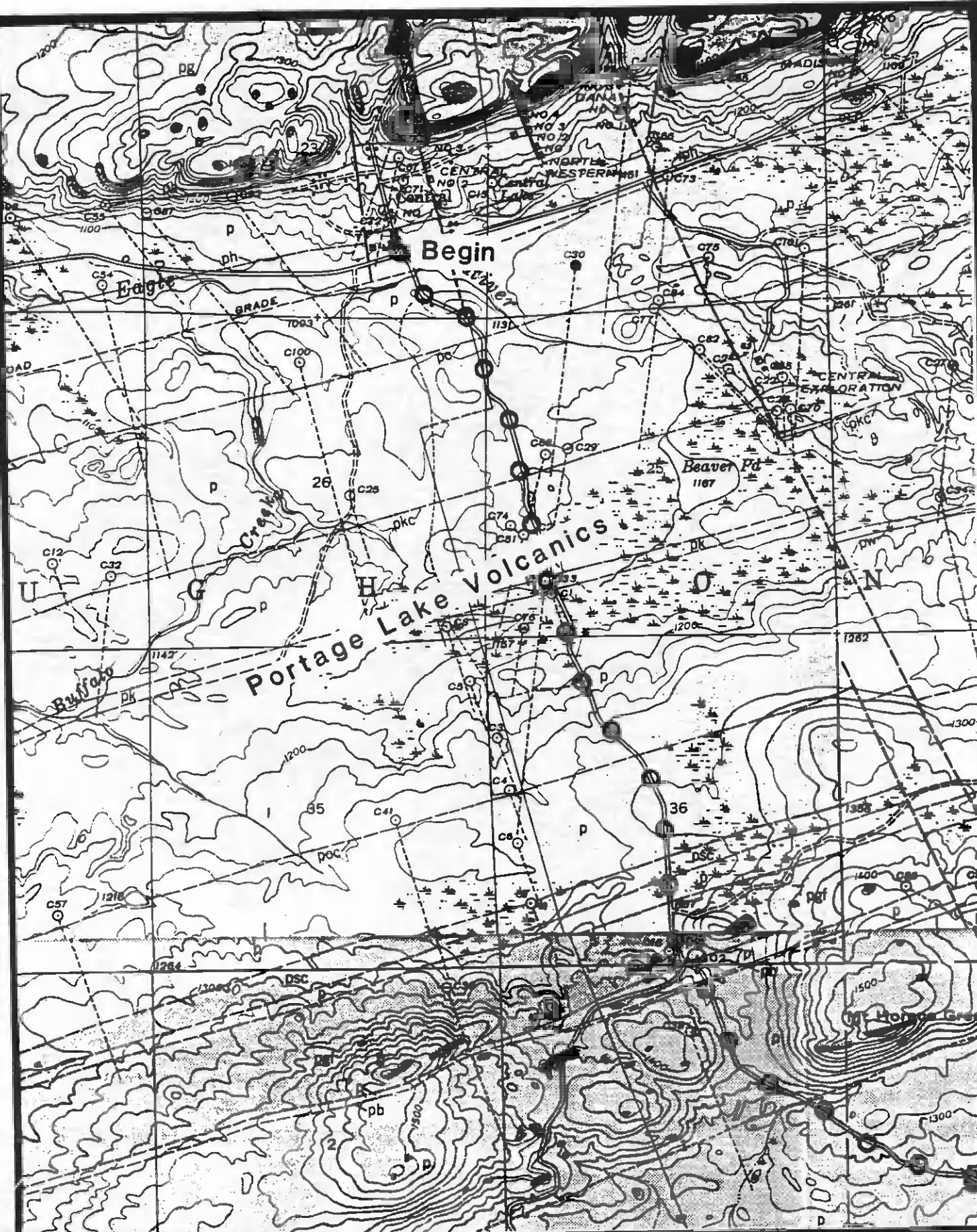
(Approximate)

- 0 Junction of the paved road and the dirt road is to the east.
- 180 A-Frame building. Bear right (N70°E) along the now forested road.
- 280 Now you are going downhill.
- 880 Continue N50°E over a berm on an abandoned road.
- 1000 Outcrops are on the right.
- 1150 The outcrops on the right are the first part of Stop E1. Proceed ahead another 25 ft. to 932 Creek and go upstream slightly to some outcrops adjacent to the Keweenaw Fault.

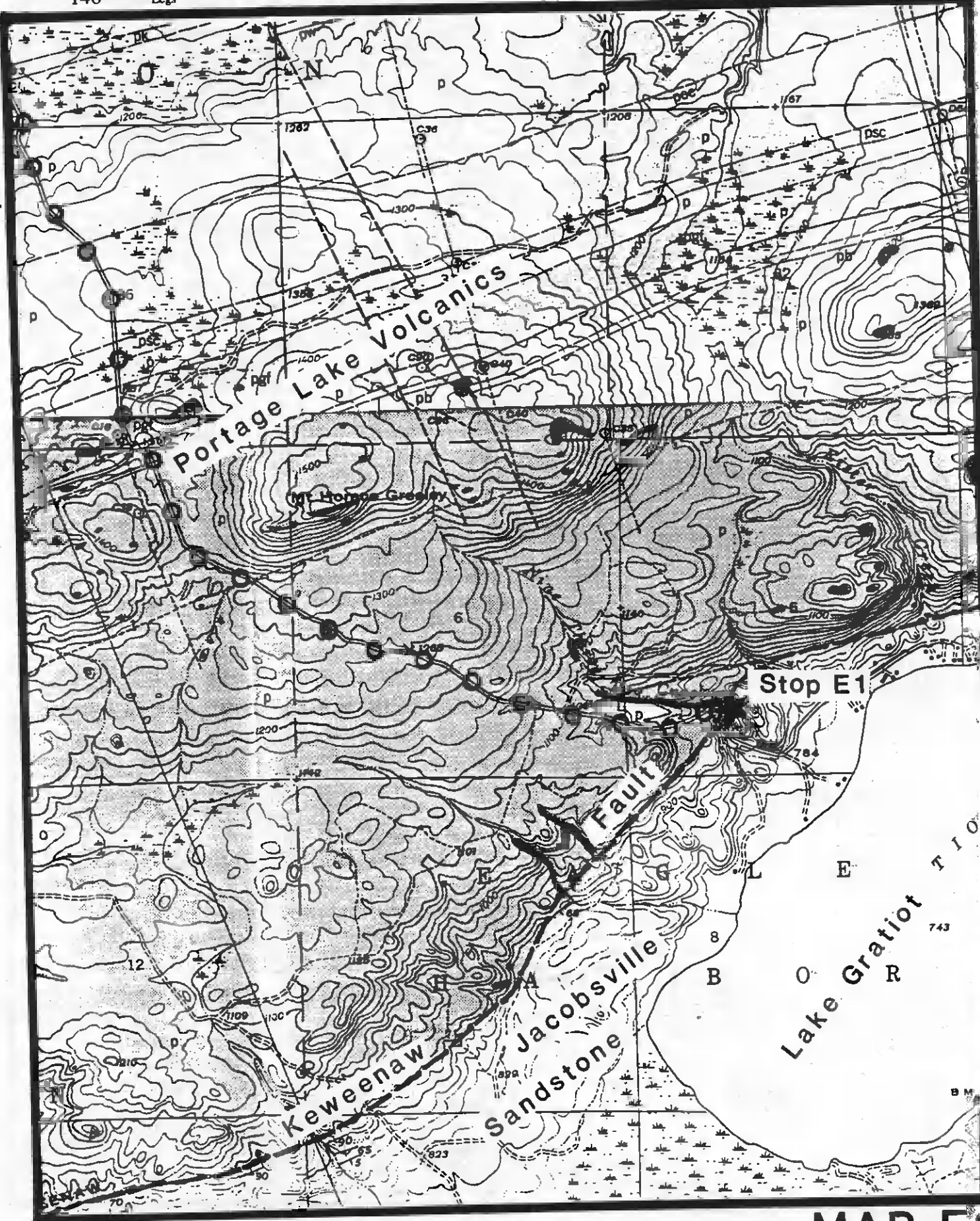
Stop E1: 932 Creek (Keweenaw Fault)

The outcrops on the right side of the road consists of altered and fractured basalts of the PLV intruded by a plug of basaltic andesite (Table E1). The fine-grained texture suggest that this plug was shallowly emplaced. The basaltic andesite plug is highly altered and contains disseminated chalcocite.

This locality is at the base of the PLV, near the Keweenaw Fault. Rhyolite extrusive and intrusive rocks, and mafic-to-intermediate intrusive rocks are much more common in the stratigraphically lower part of the PLV (Fig. E1). The mafic-to-intermediate intrusive rocks are known to contain copper sulfides (Broderick and others, 1946), (Fig. E1). Deposits discovered to date (there are 7) contain 0.1 to 4.5 million tons of ore, with 2.5 to 3.0% Cu as chalcocite in vienlets; amygdules; and disseminations (Woodruff and others, 1994). Most of the sulfur in the basalts of the PLV was lost by degassing during subaerial eruptions. Mineralizing fluids generated from within the PLV should be low in sulfur. Woodruff and others (1994) suggest that the little



Map E1



MAP E

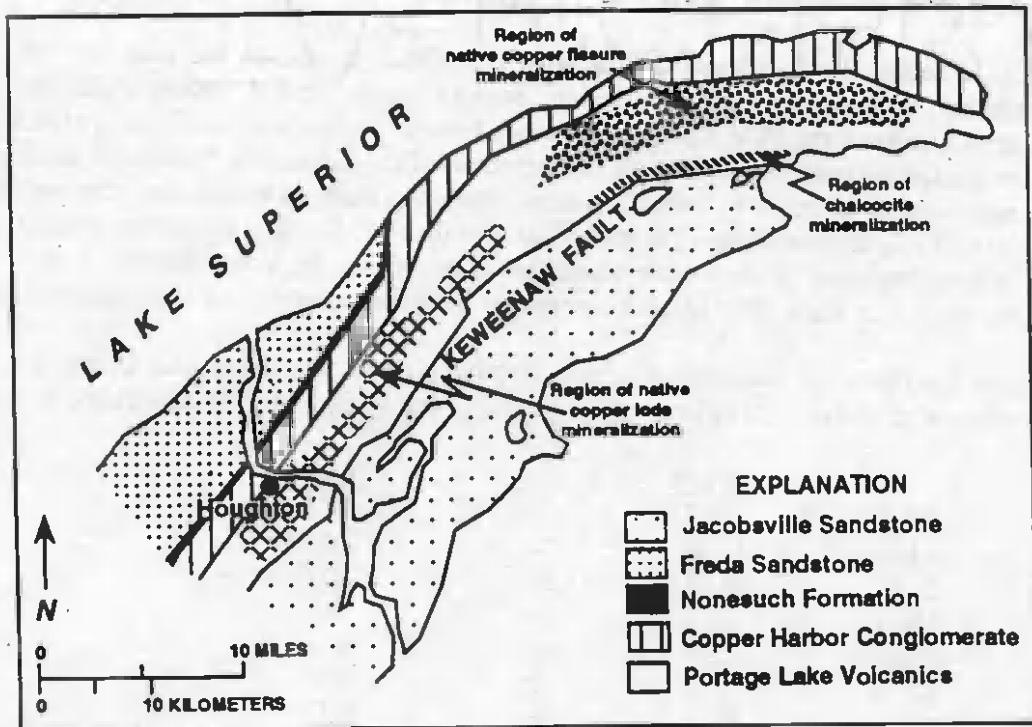


Figure E1: Location of the region of chalcocite mineralization in context with the geology of the Keweenaw Peninsula (from Woodruff and others, 1994).

available sulfur was stripped from mineralizing fluids by progressive oxidation during chalcocite deposition, but dissolved copper remained in residual fluids, allowing for deposition of native copper. The relationship between the chalcocite and native copper is uncertain.

Jacobsville Sandstone is exposed in 932 Creek just below the road. A short distance upstream, the beds in the Jacobsville Sandstone are nearly vertical, making highly fractured and altered basalts of the PLV visible in the creek bottom. The Keweenaw Fault (a reverse fault), is poorly exposed here, just as it is elsewhere. Beds of the Jacobsville Sandstone are dragged into a near-vertical position by reverse motion along the fault. Downstream, the attitude of the Jacobsville Sandstone shallows to the typical, less than 10° dip. The Keweenaw Fault was initially a graben-bounding normal fault along the edge of the Midcontinent rift system. During compression, at about 1060 Ma, the Keweenaw Fault was inverted into a high-angle reverse fault.

Table E1: Chemical composition of the intrusive plug on 932 Creek near Gratiot Lake. It is a median of 3 analyses. The low total is probably due to H₂O. Unpublished data of Bornhorst.

	<u>WT %</u>		<u>PPM</u>
SiO ₂	53.61	Cr	42
Al ₂ O ₃	14.48	Ni	14
Fe ₂ O ₃	8.69	Rb	30
MgO	2.93	Sc	20
CaO	8.54	Sr	65
Na ₂ O	4.71	Zn	145
K ₂ O	0.77	Zr	351
TiO ₂	1.30		
P ₂ O ₅	0.54		
MnO	0.13		
CuS	0.32		
	96.02		

END OF LEG E - RETRACE ROUTE BACK TO CARS AND TO US-41.

LEG F FIVE MILE POINT

MAP F1

- 0.0 Just west of Eagle River, start Leg F on the paved road to Five Mile Point. Make a left turn on the road to Five Mile Point.
- 0.5 On the right side of the road for some distance, there are sand dunes from a past high stand of the Lake Nipissing Stage of the Lake Superior basin. Ahead the road bends left.
- 0.8 Ahead, a view of Five Mile Point.
- 1.5 An excellent view of Lake Superior at 3:00, with sand dunes along the road.
- 1.8 Cross the Silver River. Sand dunes continue alongside the road.
- 2.2 Pull over on the right side of the road into the roadside park.

Stop F1: W.C. Verde Roadside Park (Copper Harbor Conglomerate)

The road is at the level of sand dunes from the Lake Nipissing Stage of the Lake Superior basin. The unconsolidated Holocene sands rest unconformably on Precambrian Copper Harbor Conglomerate exposed at the lake shore here. At the Lake Superior shoreline, one can observe the Copper Harbor Conglomerate, which continues both ways from here along the shoreline for about 0.5 km west and 2.5 km east. It interfingers with, and overlies, the PLV (Fig. 6), and at this point, it is composed of pebble-to-cobble conglomerate with interclated red sandstone. The Copper Harbor Conglomerate is in the subsurface under Lake Superior and crops out again on Isle Royale (Fig. 2).

MAP F2

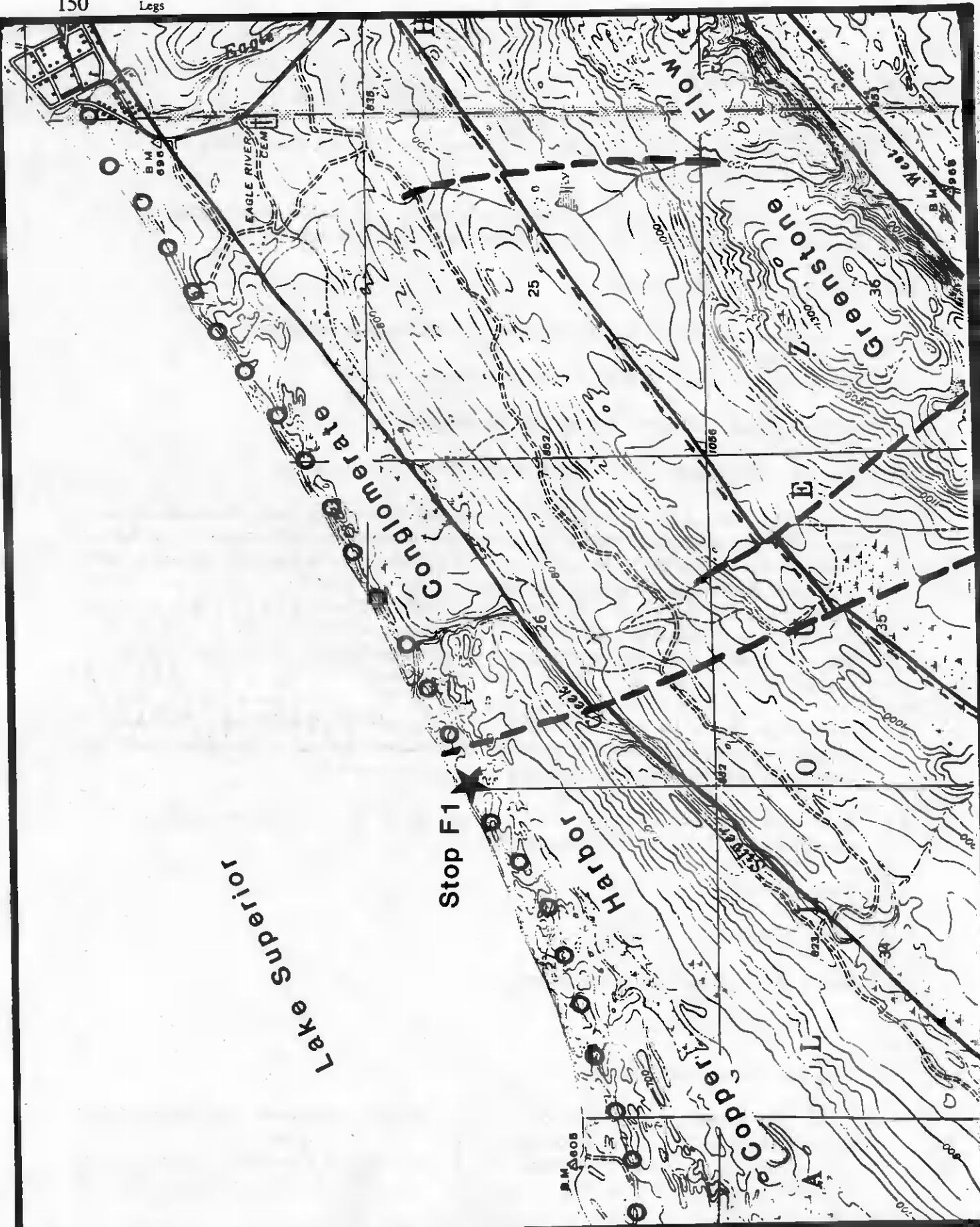
- 3.8 On the right side of the road is a turn-off to the Five Mile Point lighthouse. You *must* get permission to enter this area. In the front yard of the lighthouse, is a thin lava flow of the Lake Shore Traps with the Copper Harbor Conglomerate above and below it.
- 4.1 Seven Mile Point beach turn-off on the right side of the road. Along this beach are many exposures of the Copper Harbor Conglomerate.

MAP F3

- 9.5 Cross the Gratiot River.
- 10.45 Ahmeek Cemetary is on the left.
- 10.55 Turn right at the south end of the cemetary.
- 10.65 Pull over to the right.

Stop F2: Allouez Gap (kettles)

This locality is just northeast of the Allouez Gap, the lowest bedrock gap between the tip of the Keweenaw Peninsula and Portage Lake (Fig. 17). This gap lead to a concentration of outwash from the retreating Wisconsin glacier. A fan of outwash extends northwest to the level of glacial Lake Nipissing (Fig. 36). Northwest of the gap, the outwash is pitted and channeled



Map F2

MAP F1

Lake Superior

Fivemile Point

SAND HILL L.H.

Lake Shore Traps

Sevenmile Point

Conglomerate

Conglomerate

Harbor

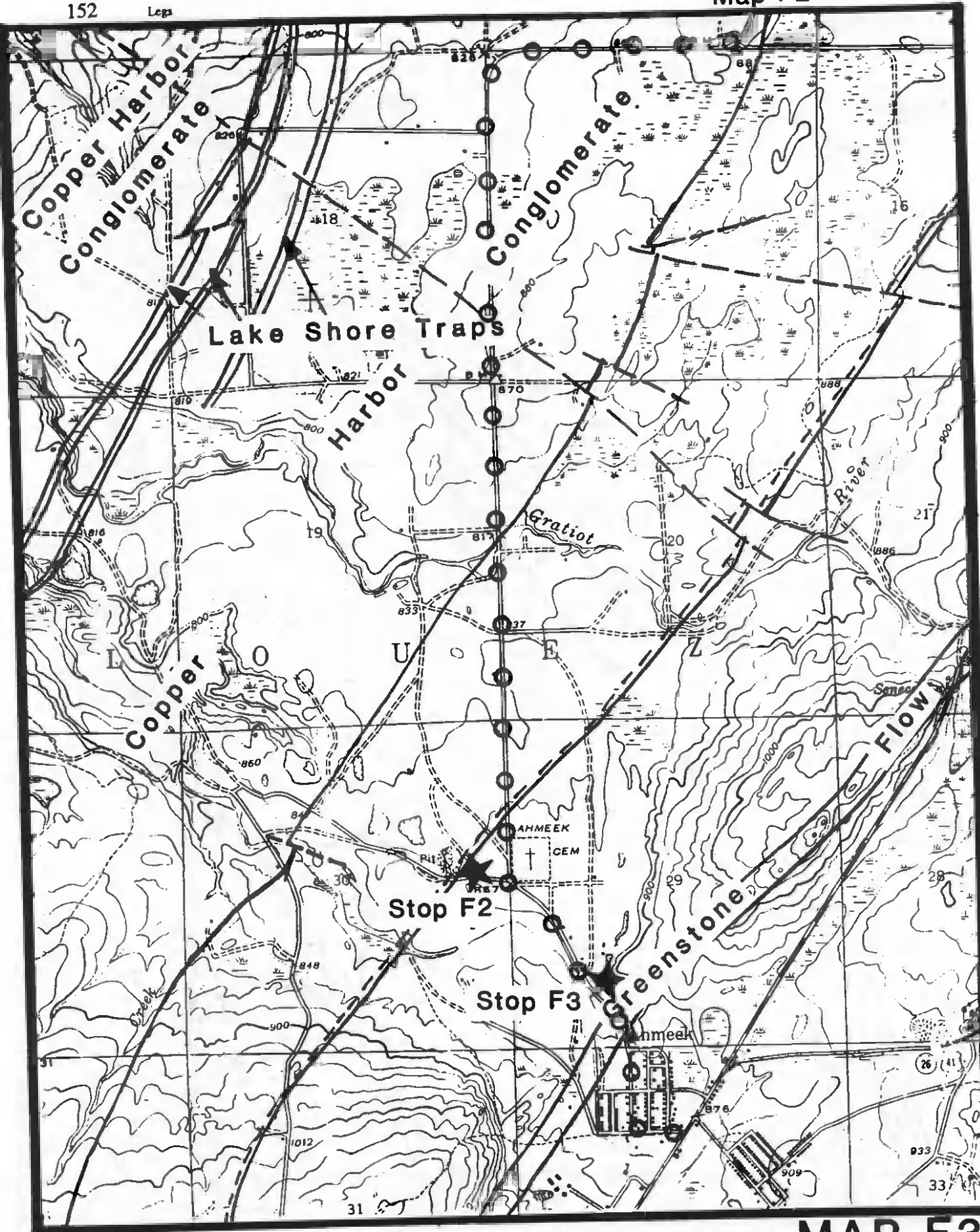
Copper

Portage Lake Volcanics

Map F3

MAP F2





with 14 kettles along a northwest trend (Regis, 1993) (Fig. 36). On the left, at the 867 foot elevation, is a shallow depression representative of a kettle. Ahead, a few tenths of a mile on the right, are more depressions. The best kettle is at the 816 foot elevation. It is to the northwest near the edge of MAP F3 and has a diameter of 100 m and a depth of about 25 m (Regis, 1993). Ahead 0.1 miles on the right, is the former Calumet landfill in a kettle.

10.75 Turn right on the paved road toward Ahmeek.

11.25 Outcrops of basalt are on the left side of the road.

Stop F3: North of Ahmeek (Portage Lake Volcanics [PLV])

A thin basalt flow of the PLV, just above the Greenstone Flow, forms an outcrop which displays 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 colonnade/entablature jointing pattern described in the 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.

11.5 At the stop sign, go straight ahead.

11.6 Another stop sign. Turn left, and after one block, turn right.

12.8 Turn right, and immediately following, is a stop sign in front of a church. Join US-41 by turning right. Directly ahead at about 11:00, is the Kingston Mine; a shallow mine that worked the Kingston Conglomerate.

This mine is said to be the only significant native- copper deposit in the region that was not discovered and worked initially by the Copper Culture Indians. Calumet and Hecla, Inc. discovered it via diamond drilling by Randy Weege in 1962 and is described by Weege and others (1972). Production from 1965 to 1974, totalled 900,000 kg of copper from about 90,000 tonnes of ore.

The original lava surface on which an interflow conglomerate was deposited, had numerous primary irregularities. As this surface rotated slowly through the horizontal during filling of the rift basin, some of the depressions on the surface formed shallow ponds and drainages for low velocity streams, in which fine-grained sediments were deposited. Only after further rotation of the surface were stream gradients sufficient to transport coarser gravels, and to deposit them as prograding sheets. The deposition of the sediment was sufficiently slow, and the climate sufficiently warm and moist, so that calcium carbonate accumulated in the sediment in horizontal zones, as caliche.

The Kingston Mine is located in one of these interflow conglomerates; a bed 0.3 to 30 m thick, and traceable for 100 km along strike. Depressions on the footwall lava surface, exposed in the mine, have fillings of reddish shale and siltstone, which measure as much as 15 m in thickness and 30 to 100 m in diameter. This unit is overlain by about 10 to 15 m of massive to faintly bedded, distinctly cross-bedded, and graded-bedded conglomerate and minor sandstone. Where the original lava surface was topographically higher, the conglomerate rests directly on a basalt footwall.

In comparison with other conglomerates within the PLV, the Kingston Conglomerate shows several unusual characteristics. For example, the clasts are composed almost entirely of a single lithology: dark red to reddish-brown quartz and feldspar porphyritic rhyolite. Also, the clasts have a high angularity and small average size (about 8 mm), with the largest pebbles being about 10 cm in size. The matrix, generally 40 to 60% of the sediment by volume, consists of fine-grained quartz, feldspar, chlorite, martite, specular hematite, and caliche-derived calcite cement (Kalliokoski, 1986). Where the calcite content is low, the cement is quartz.

Fluvial planar- and cross-beds are shown by variations in grain size and color, and in the abundance of matrix, composed of dark chlorite and calcite cement. Parts of the conglomerate that are poorly bedded and contain little matrix (~20% matrix) appear to have dis-aggregated *in situ*. In some large samples, calcite and dark chlorite occur in different parts of beds. Calcite (as caliche) may have precipitated along zones with larger clasts; less matrix; and probable greater horizontal transmissivity, but not in zones with abundant clay (chlorite) in which permeability might have been less. The source of the conglomerate was a proximal, southerly located upland with friable, unweathered quartz-feldspar porphyritic rhyolite from which the sediment was water-transported with minimal abrasion and sorting.

Mining was done on four levels along two segments of the Kingston Conglomerate, with 1000 m in total length (Fig. 34). Native copper is co-extensive with an irregularly distributed, fine-grained hematite pigmentation and kaolinite alteration. A hematite pigmentation in feldspar phenocrysts produced the reddish color in the conglomerate. In places, the rock has lost its red color due to the hydrothermal leaching of iron. The mineralization decreases gradually along strike, where the conglomerate thins or contains epidote.

Native copper occurs within the conglomerate as generally continuous zones of mineable thicknesses and grades along the footwall (43% of the mined copper) and hanging wall (33%); normally, minor mineralization (~10%) occurs along the central portions of the conglomerate. Weege and others (1972) describes several empirical relationships between ore distribution and conglomerate lithology. One important ore control is considered to be the thickness of the conglomerate: there is little or no ore where the thickness is less than 10 m. Another possibility that represents a control over permeability: where the base of the conglomerate is "muddy"--as in a basal depression--ore may be absent along this basal zone, but it may occur nearby at higher stratigraphic levels in the conglomerate.

Permeability of the host conglomerate is the fundamental control on the distribution of native copper. The Kingston deposit is bisected by the Allouez Gap Fault (Fig. 34). The conglomerate is well mineralized in the fault zone itself. At the southwest end of the mine, the conglomerate thins and ore grade is the best in the mine. The thinned conglomerate could have provided an excellent barrier to ore fluid movement, if mineralizing solutions moved parallel to strike rather than simply up-dip (Weege and others, 1972). These data are consistent with the Allouez Gap Fault as a principal pathway for ore fluid, moving outward from the fault into the conglomerate.

END OF LEG F

LEG G COPPER CITY

MAP G1

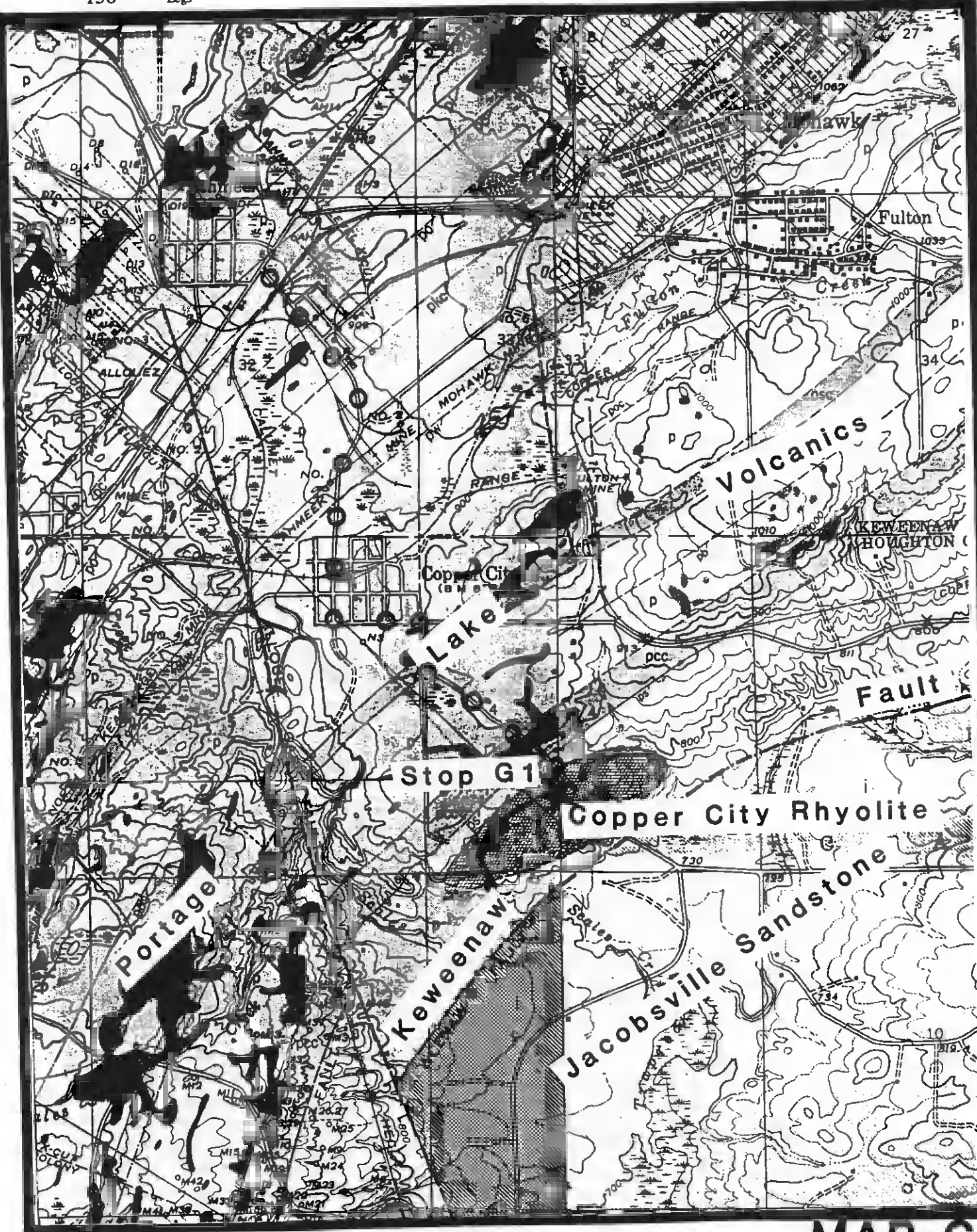
- 0.0 Start at the junction of US-41 and the paved road to Copper City in Allouez. This is 0.1 mile northeast of the Houghton and Keweenaw County line, just inside Keweenaw County.
- 0.65 Enter Copper City.
- 0.8 Ahmeek Street, on the left, goes toward the Kingston Mine, continue straight ahead.
- 0.85 At the stop sign, continue straight ahead.
- 1.05 A sharp bend in the road to the right.
- 1.15 At the junction, continue straight ahead toward Lake Linden. The road to the left goes to Gay.
- 1.25 A sharp bend in road to the left.
- 1.7 Going downhill. At the skyline, the low, smooth terrane (underlain by relatively flat-lying Jacobsville Sandstone) is visible. We are driving on the tilted basalts of the PLV.
- 1.75 A road sign on the right.
- 1.8 An open field on the right.
- 1.9 A dirt path on the right. Park and walk to Stop G1.

STOP G1: Copper City Rhyolite (Portage Lake Volcanics [PLV])

Walk along the dirt road/path parallel to the tree line, about 70 m, then walk about 170 m toward the tree line (N45°W). Small low-lying scattered outcrops and float rhyolite occur here, and can be found elsewhere further west within the tree covered area.

The Copper City rhyolite is poorly exposed throughout the body. The rhyolite is white on weathered surfaces and red-brown on fresh broken surfaces, it is fine-grained with abundant phenocrysts of quartz. Since exposures are of poor quality, it is not known whether this body of rhyolite is intrusive or extrusive, although the published geologic map shows contacts as cross-cutting; making the body more likely intrusive (subvolcanic) (Davidson and others, 1955). Stratigraphically, this body is within the lower part of the PLV exposed on the Keweenaw Peninsula, and below the Bohemia Conglomerate (Fig.). Bodies of rhyolite are much more common in the lower stratigraphic section of the PLV, although still volumetrically minor. Just downhill from here, the PLV are truncated by the Keweenaw Fault.

Recently, Nicholson (1992), as summarized below, has recognized two chemical types of rhyolite in the Keweenaw Peninsula: Types I and II (Table G1). Type I rhyolites contain between 71 to 76 weight percent SiO_2 (generally less than 75 weight percent SiO_2), and fall near the border between peraluminous and metaluminous, with less than 2 % normative corundum. The peraluminous character of some Type I rhyolites may be due to alteration. Type II rhyolites have greater than 75 weight percent SiO_2 , and are slightly peraluminous. High contents of Th and Rb distinguish Type II rhyolites from Type I. The rhyolites of the PLV are part of a bimodal basalt-



rhyolite association, typical of extensional tectonic settings such as the Midcontinent rift system. Type I rhyolites of the PLV are similar to moderate-silica rhyolites from other areas, such as Iceland, with bimodal basalt-rhyolite association. Type II rhyolites of the PLV are similar to a select subset of high-silica rhyolites, termed topaz rhyolites. Topaz rhyolites are notable for enriched lithophile elements, sometimes to economic levels. The Copper City rhyolite is the only recognized Type II rhyolite within the PLV, the other rhyolites are all Type I. Overall, the setting of basalt and rhyolite in the PLV is comparable to Iceland (Nicholson, 1992).

Table G1. Chemical Types of Rhyolites within the PLV (from Nicholson, 1992).

Major oxides:	Type I N=31	Type II N=4
SiO ₂	73.84	75.74
TiO ₂	0.12	0.05
Al ₂ O ₃	13.65	13.28
Fe ₂ O ₃	0.66	0.44
FeO	1.32	0.87
MnO	0.03	0.04
MgO	0.23	0.14
CaO	0.25	1.38
Na ₂ O	3.23	2.48
K ₂ O	6.64	5.60
P ₂ O ₅	0.03	0.02
Total	100.00	100.04
Trace elements:		
Nb	41	51
Rb	112	465
Sr	55	28
Zr	240	144
Y	56	74
La	30.3	12.0
Sm	6.57	6.9
Yb	5.55	7.68
Hf	7.53	6.3
Ta	2.91	4.9
Th	15.09	63.0

End of Leg G - Retrace route to US-41.

LEG H McLAIN STATE PARK**MAP H1**

- 0 The junction of US-41/M-26 and M-203, at the edge of Calumet. Turn right on M-203.
- 0.55 The Village Limit of Calumet. Continue straight ahead.
- 1.0 Turn right just west of an open playing field (on the right side, after the turn.)
- 1.1 Turn right.
- 1.2 Turn left just before a red sandstone block building. On the left is the concrete capped Red Jacket Mine.
- 1.3 At a sand and gravel pit.

Stop H1: Red Jacket (glacial sand and gravel)

The Pleistocene sands and gravels at this locality are interpreted as deposited in perforation kames and crevasse fillings. The deposits show both cross-bedding and channeling, due to the glacial-fluvial sediments being deposited in perforations and crevasses in the ice. These deposits, and the esker to the north of here (Fig. H1, location B), are characteristic of the glacial ice margin (summarized from Regis, 1993).

Retrace route and return to M-203.

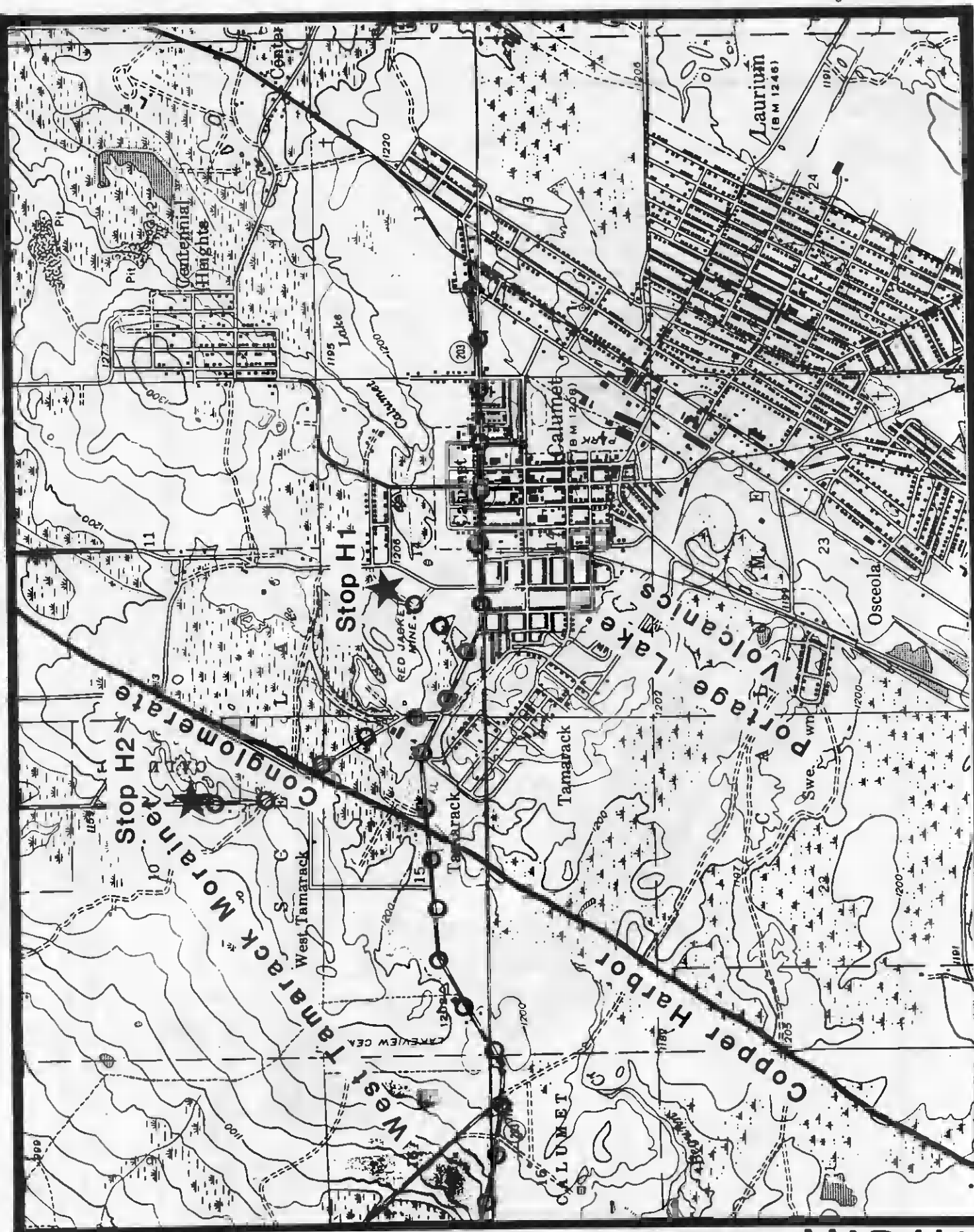
- 1.6 At the junction of M-203, turn right--away from Calumet.
- 1.95 Turn right, onto Tamarack Waterworks Road.
- 2.25 The road bends left.
- 2.45 At the crest of the West Tamarack Moraine, the view of Lake Superior on the horizon is excellent.
- 2.5 Pull over to the right.

Stop H2: West Tamarack (glacial gravels)

The West Tamarack Moraine is composed of cobbles-to-boulders in a sand matrix. This moraine extends for about 10 km, with a width of about 1.5 km in the south, several 100 m in the north (Fig. H1), and a thickness of around 20 m. The north-south trending West Tamarack Moraine has a gentler west slope, which is interpreted by Hughes (1963) as indicating underwater deposition, except at the extreme north end (summarized from Regis, 1993).

Retrace route and return to M-203.

- 3.05 Turn right on M-203.
- 4.0 Lakeview Cemetery is on the right.



Map H2

MAP H1

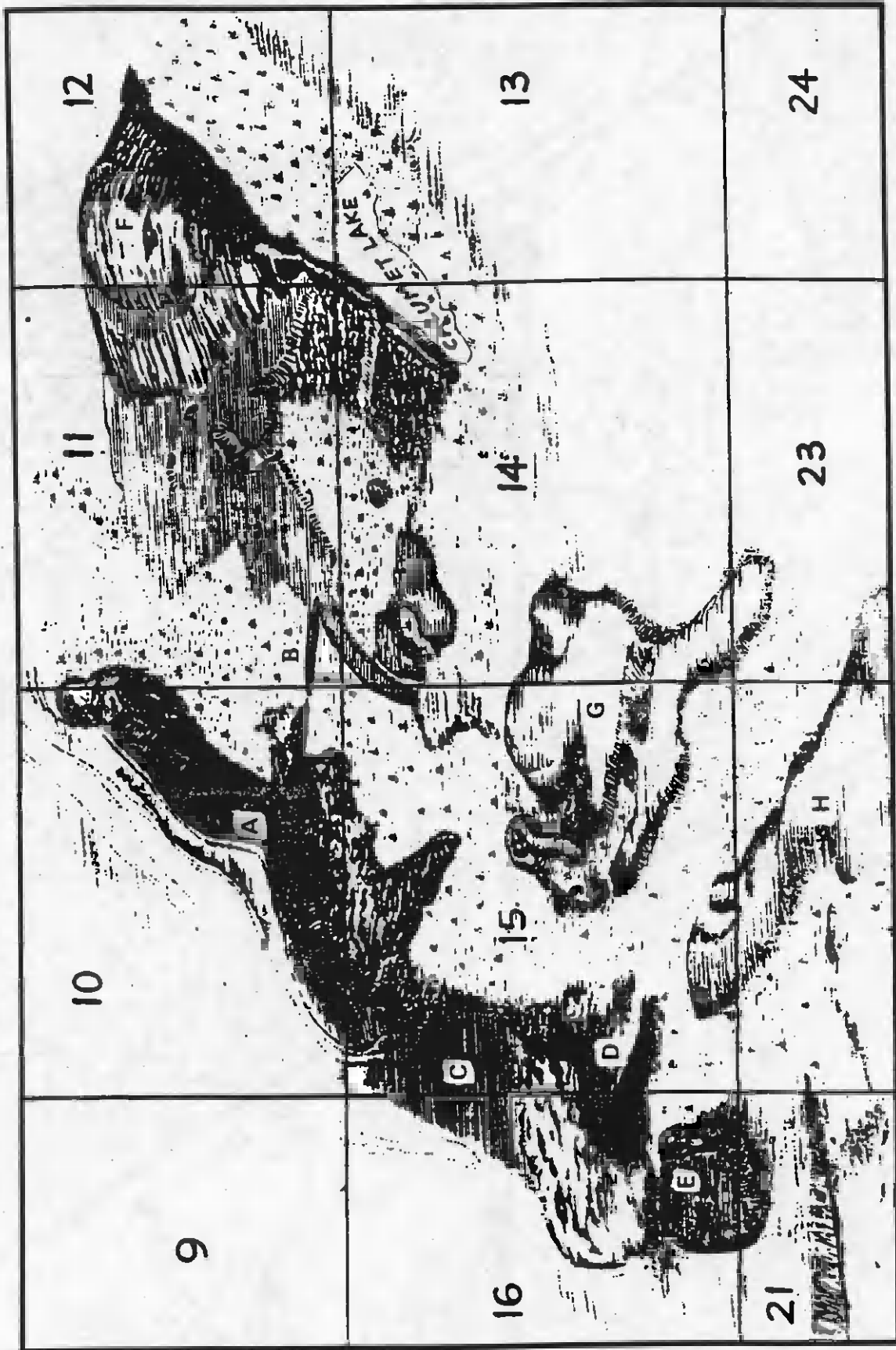


Figure H1: Physiographic and glacial features west of Calumet (from Hughes, 1963). A. West Tamarack moraine, subaerial portion; B. esker; C. sand plain; D. boulder ridge; E. delta kame; F. Centennial hill; G. Tamarack hill; H. Swedetown hill.

4.3 The junction at the road to the Calumet Waterworks Park. Continue on M-203.
MAP H2

6.0 Turn left onto Cloverland Road. The road goes uphill.

6.35 Pull over, alongside the road.

Stop H3: Cloverland Road (Washburn Stage beach ridges)

This stop is at the elevation of the Washburn Stage of the Lake Superior basin (Table 2). Here, one can view a pair of NE-SW trending beach ridges about 1.5 m high in the open field. The two ridges are only about 1 m apart and their associated sediment is well sorted medium sand. The elevation at this glacial lake stage varied between 1040 to 1051 ft, which is about 440 ft above the present-day elevation of Lake Superior. The Washburn Stage has the most traceable features, next to the Nipissing Stage (summarized from Regis, 1993).

Return to M-203.

6.7 Turn left onto M-203.

9.2 The road to the right is Lakeshore Drive, which goes to the Calumet Township Waterworks Park. The road to the left is Salo Road, which goes to the Bear Lake Rhyolite and Stop H4. The Bear Lake Rhyolite cuts the Freda Sandstone bedrock, and 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). The mileage to H4 is not logged, but just follow the directions given in the stop description, H4.

Continue on M-203 toward Stop H5.

Stop H4: Lake Annie (glacial lake baymouth bar)

Directions to Lake Annie Stop (not logged): Turn left onto Salo Road and continue due south for 1.0 miles from the turnoff, where the road bends sharp right (west). At about 1.5 miles, turn left (south). Continue straight ahead (south) and at about 4.35 miles there is a "Y" in the road, stay right. On the left, at about 5.3 miles, is a sand and gravel pit, MAP H4.

The Pleistocene glacial sediments at this stop represent a baymouth bar, related to either the Shoreline V or Washburn glacial lake stage (Table 2). This ridge is composed of sand with little gravel. Near the east edge of the pit, the sand is capped by till (summarized from Regis, 1993).

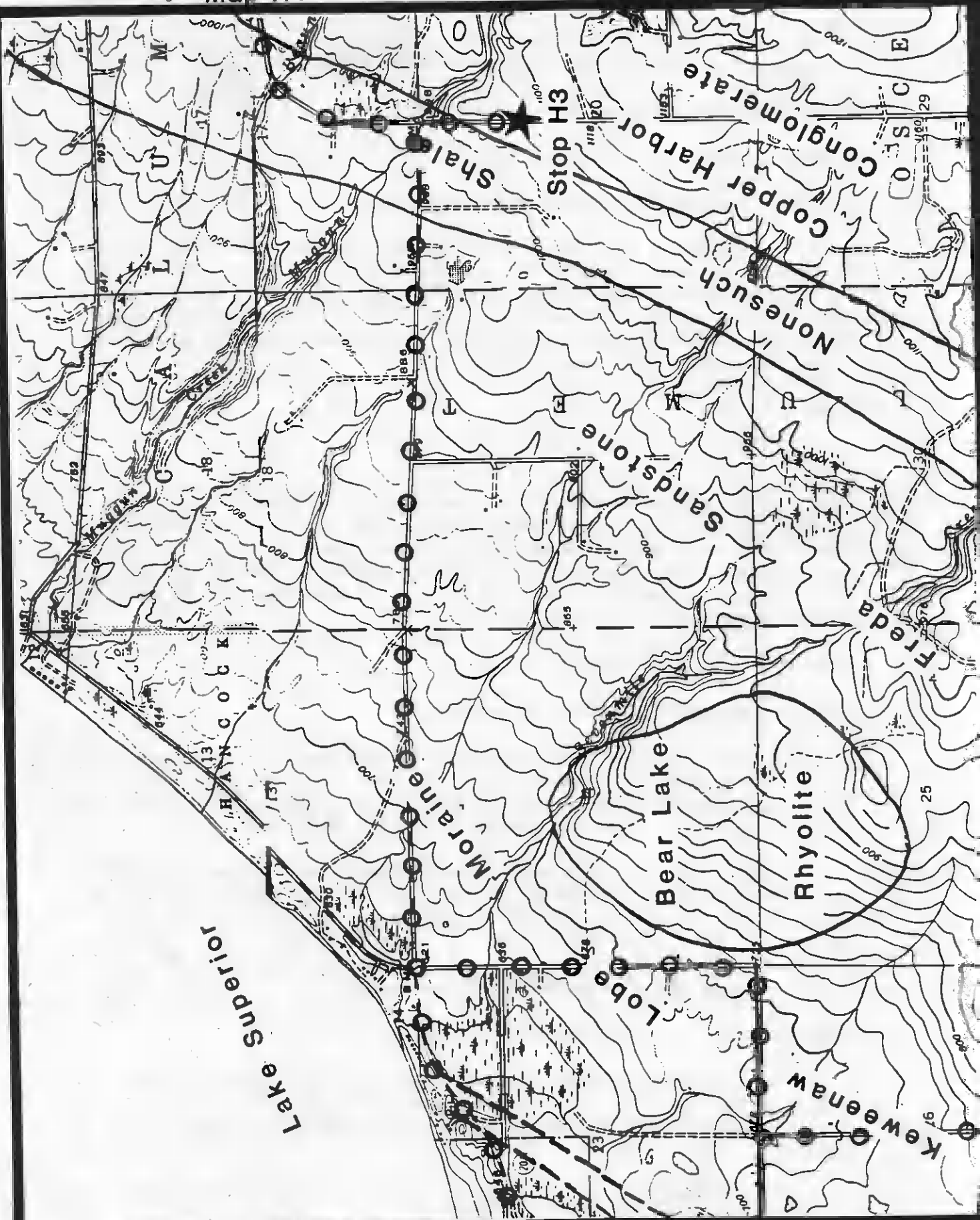
MAP H3

9.9 Sand ridges on the right, at the east end of McLain State Park.

Stop H5: Sand Ridges M-203 (Nipissing beach ridges)

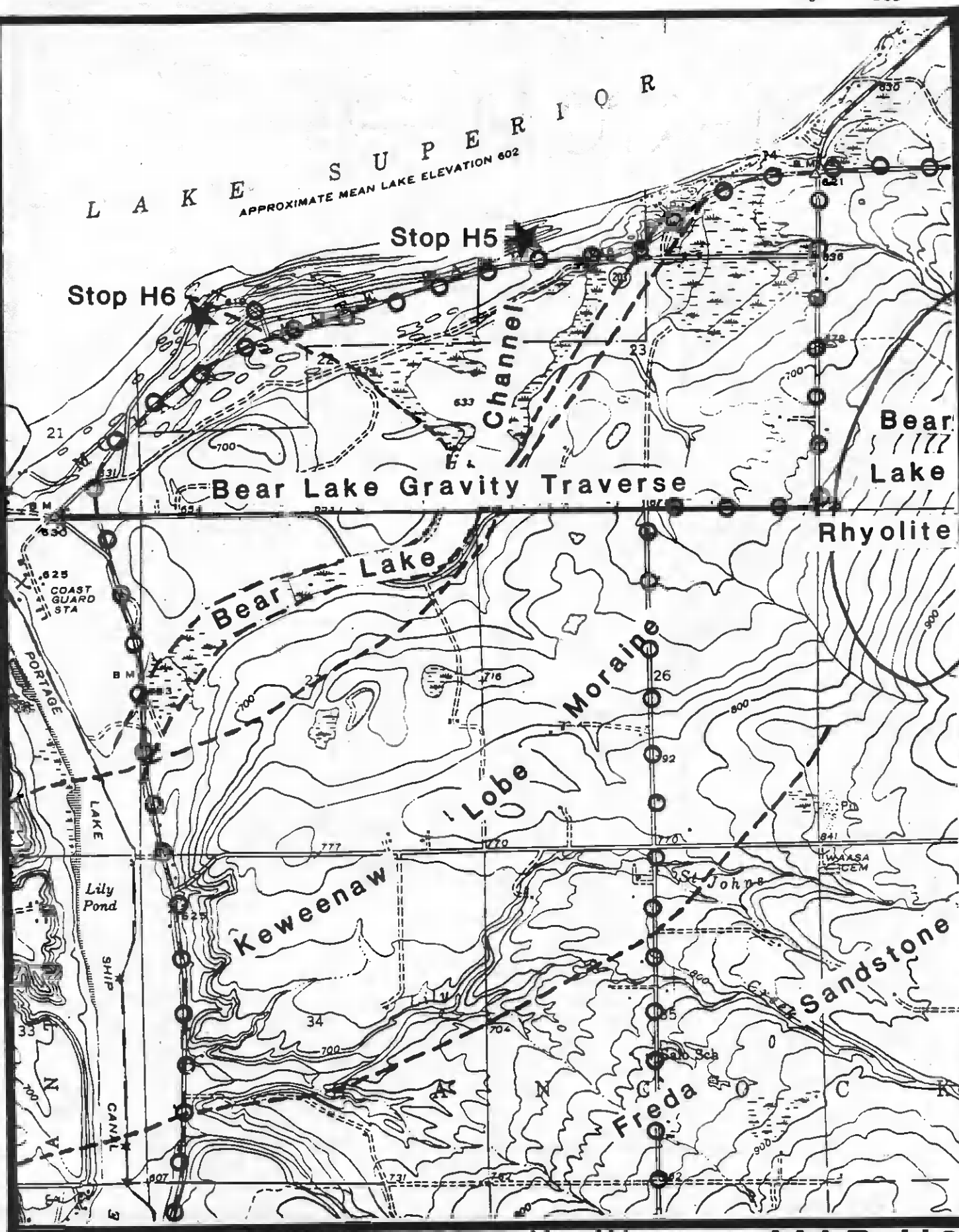
These subaqueous beach sand ridges are related to Glacial Lake Nipissing, which was about 10 m above the current level of Lake Superior—approximately 4,000 to 5,000 years ago. The Nipissing Stage features are usually close to those of Lake Superior, but sometimes are more prominent.

The north end of Portage Lake opened into two channels during the Nipissing stage, one



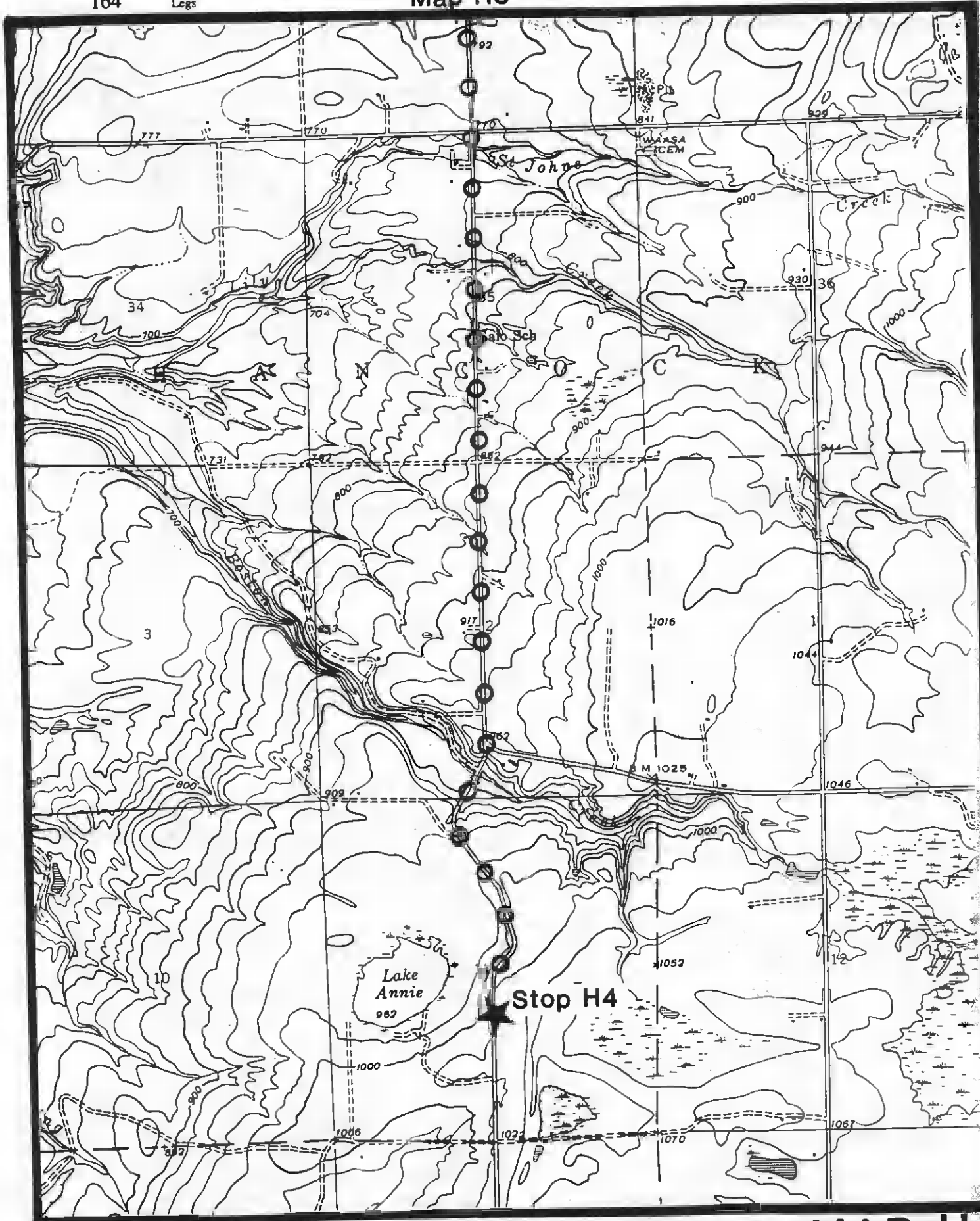
Map H3

MAP H1



Map H4

MAP H3



was the current channel, the other was the Bear Lake Channel. The two were separated by an island. Sand closed off both channels (the current-day channel was dredged by the Army Corps of Engineers for ship traffic), and eventually filled in the Bear Lake channel described below (summarized from Regis, 1993).

- 10.1 Bear Lake is on the left side of the road. Cross on top of the filled glacial Bear Lake channel.

The Bear Lake Channel (Map H3) represents a deep bedrock valley, and is an extension of the Keweenaw Waterway. The Waterway was dredged to the west of McLain Park because the distance was less, but also because the Bear Lake Channel is a much more profound feature, with more than 600 ft to bedrock. The definition of this, and similar bedrock valleys, is shown by gravity data. One such traverse, plotted on the map, is displayed as Figure H2.

- 11.0 Turn right at the entrance to McLain State Park and the other edge of the Bear Lake Channel. Camping facilities are located here.

You can park on the side of M-203 opposite to the entrance and walk into the park, or pay the vehicle fee at the entrance (the same park sticker is valid for Stop 28). Enter the park and stop at the main open area. Walk toward Lake Superior and the children's play equipment.

Stop H6: McLain State Park (Freda Sandstone)

Freda Sandstone is exposed along the shore of Lake Superior, depending upon the level of the lake. Blocks and slabs of Freda Sandstone can be found along the beach however, regardless of the lake level. It consists of red colored interbedded fine sandstone and siltstone, and the red color is interrupted by white reduced zones and spots. The Freda Sandstone was the last rift-filling clastic sediment, and was deposited in a fluvial environment.

- 11.8 Continue on M-203. The road to the right is to the Coast Guard Station; the road to the left is the Bear Lake Road, the location of gravity traverse.

- 12.8 The 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 (Fig. 16). The regional distribution of this moraine is plotted in Figure 15. The positions of lobes as they retreated at the end of the Wisconsin period are shown in Figure 14.

MAP H5

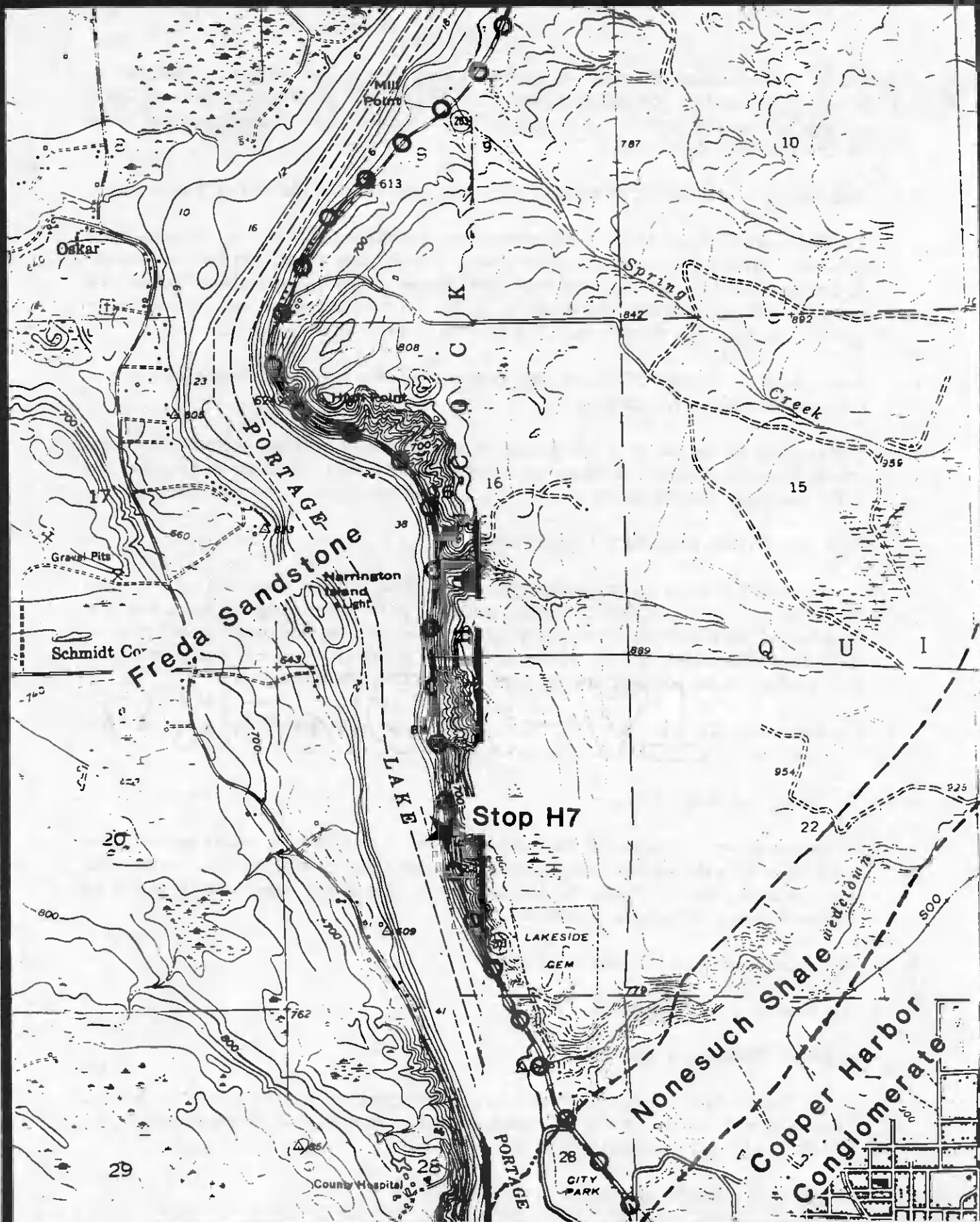
- 16.1 High Point Road, continue ahead on M-203.

- 17.85 Exposures on a vertical road cut.

Stop H7: Till along M-203 (till)

The 5 m high vertical face exposes a matrix-supported sediment: diamict. It is a hard and compact till with cobbles set in a fine matrix. Carbonate cement causes the hard character, and is likely an older till (summarized by Regis, 1993).

- 17.95 A high cut of glaciofluvial sediment on the left.



MAP H5

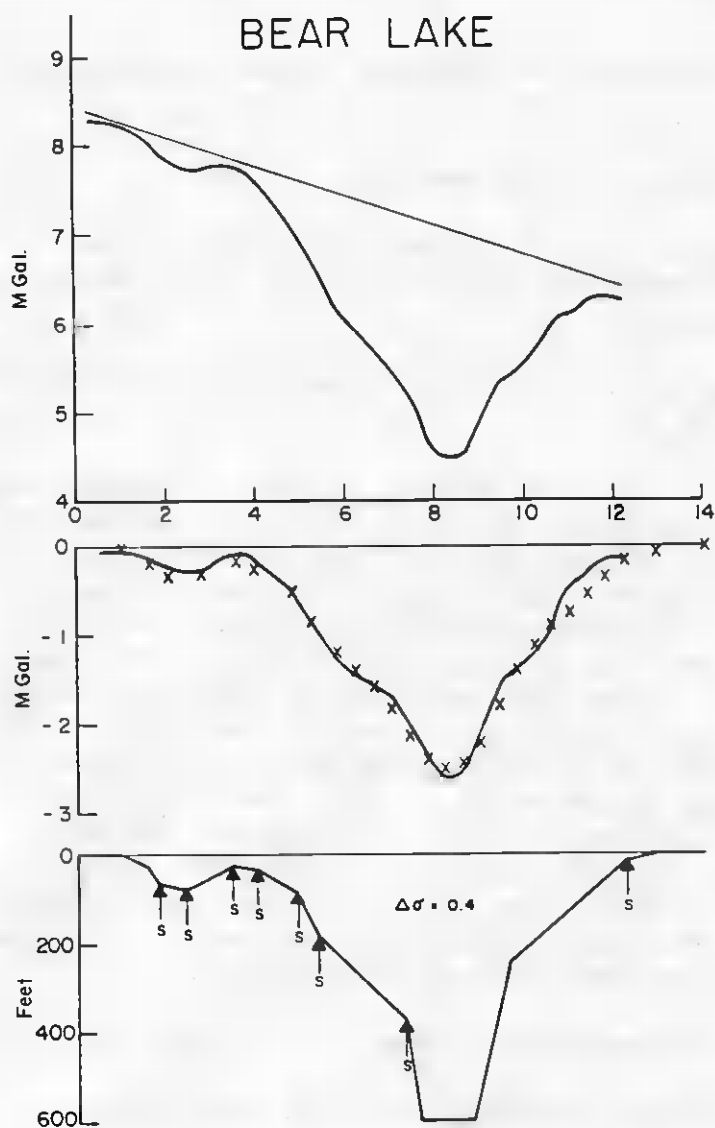


Figure H2: Results of gravity measurements across the Bear Lake traverse plotted in Map H3 (from Warren, 1981). At the top is the Bouguer anomaly with regional trend. In the middle diagram, the regional trend is subtracted to get the solid line which is compared with the modelled topography (X's). The bottom diagram is the model of the valley and the density difference of the bedrock (Freda Sandstone) and the valley fill.

18.6 Hancock City limit.

MAP H6

18.7 Cross Swedetown Creek. To the northeast along Swedetown Creek are exposures of Freda Sandstone.

19.05 Hancock Campground is on the right (Stop H8), and Superior Sand and Gravel is on the left (Stop H9).

STOP H8: Hancock Campground (Nonesuch Shale)

Follow the paved road to the boat launch. Tell the attendant you are going to look at rocks. On the shore of Portage Lake, the Nonesuch Shale is exposed. An abandoned quarry is located NE of the boat launch.

The Nonesuch is stratigraphically between the Copper Harbor Conglomerate and Freda Sandstone (Fig. 5).

The Nonesuch crops out around the margin of the quarry and lakeshore 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, 1956a). The attitude of bedding is about N30°E, 25°W. As a whole, the Nonesuch Shale consists primarily of siltstone and shale, with subordinate amounts of sandstone, deposited in a lacustrine environment. 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 % rock fragments and 60 to 70 % mineral grains. The rock fragments are mostly volcanic with a 2:1 ratio of mafic-to-silicic + intermediate composition (Daniels, 1982). The Nonesuch Shale at Hancock Campground is some 60 km northeast of the thicker section near White Pine, and likely represents lacustrine-to-fluvial facies (Elmore and others, 1989). The dip of the underlying Copper Harbor Conglomerate at Stop A1 is 39°W and overlying Freda Sandstone at the Lake Superior shoreline at Stop A3 is 5°W. This shallowing of dip up-section is typical of the rift-filling strata, and is mostly due to syn-depositional down warping of the rift-filling strata.

Stop H9: Superior Sand and Gravel (glaciofluvial sediments)

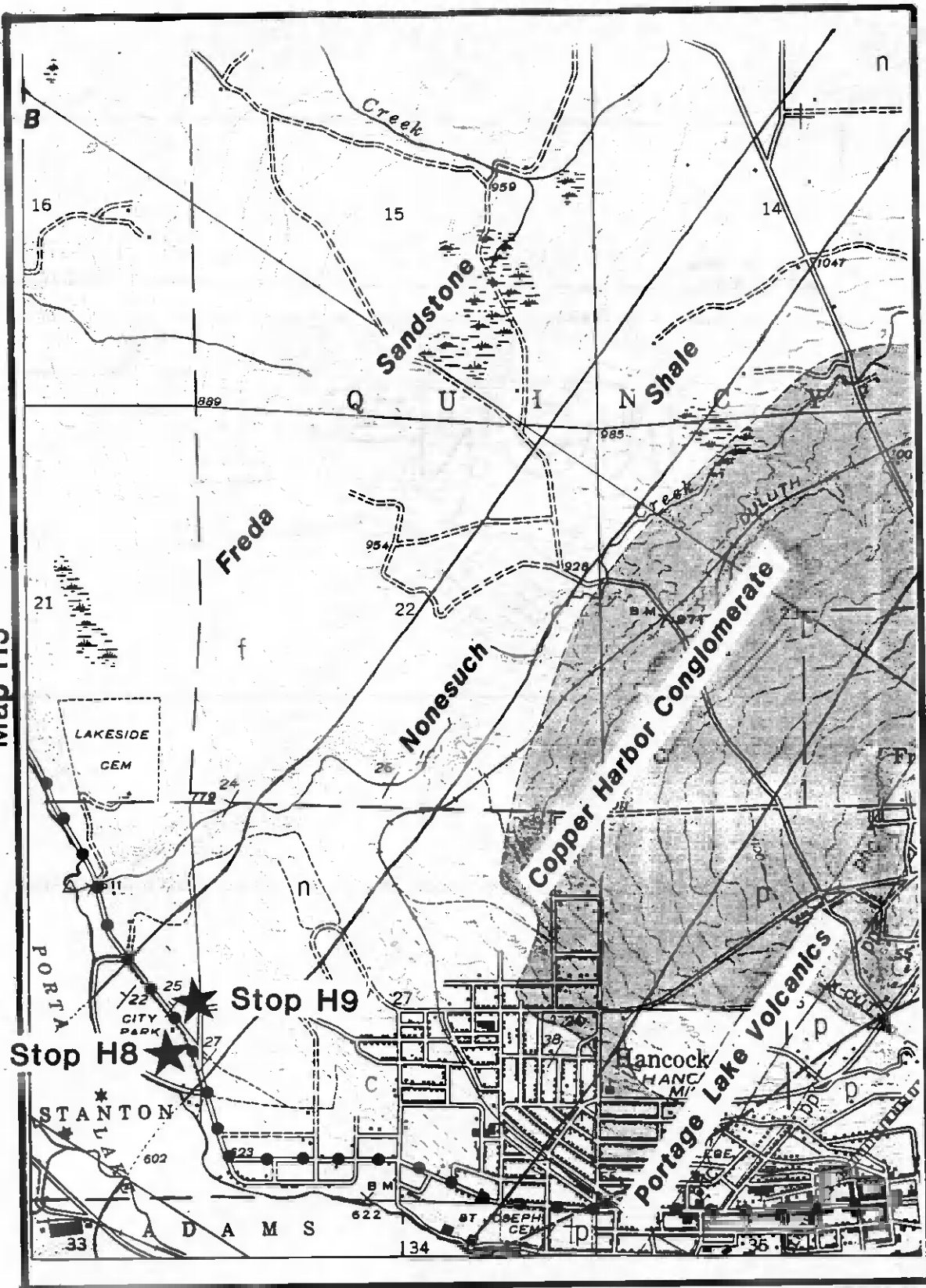
YOU MUST GET PERMISSION TO ENTER THIS LOCATION.

Sand and gravel terraces occur all along the Portage Gap, but most are less than 1.5 km long, and are related to ice margin features. The Fairground Terrace, being mined here, consists of three zones (Fig. H3 and H4). Massive lacustrine sand is overlain (in channels) by a poorly sorted gravel with a pinkish color. The pink color is the result of a significant amount of silt and clay. Some till is included in the poorly sorted gravel. At the top, the coarse, purplish gravels lack the pinkish color, and was likely deposited in a deltaic environment. The Michigan Tech Terrace formed at the same time.

The glaciofluvial sediments formed during the last glacial retreat, about 8,000 years ago. Glacial ice was abutted against the Keweenaw Fault slope from the east for a protracted period of time, with a tongue of ice in the Portage Gap. The post-Duluth glacial lake drained eastward through the Gap (summarized from Regis, 1993).

END OF LEG H - CONTINUE ON M-203 INTO HANCOCK.

Map H5



MAP H6

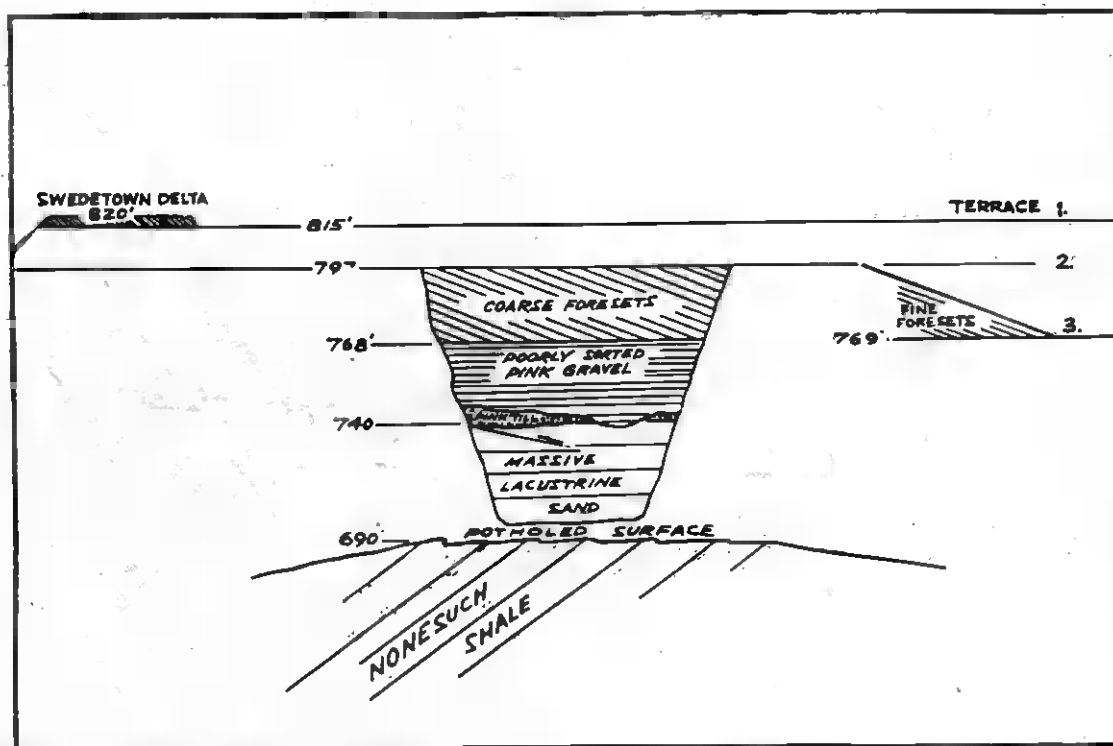


Figure H3: Geologic section through the Hancock "Fairground" terrace glacial deposit (from Hughes, 1963).

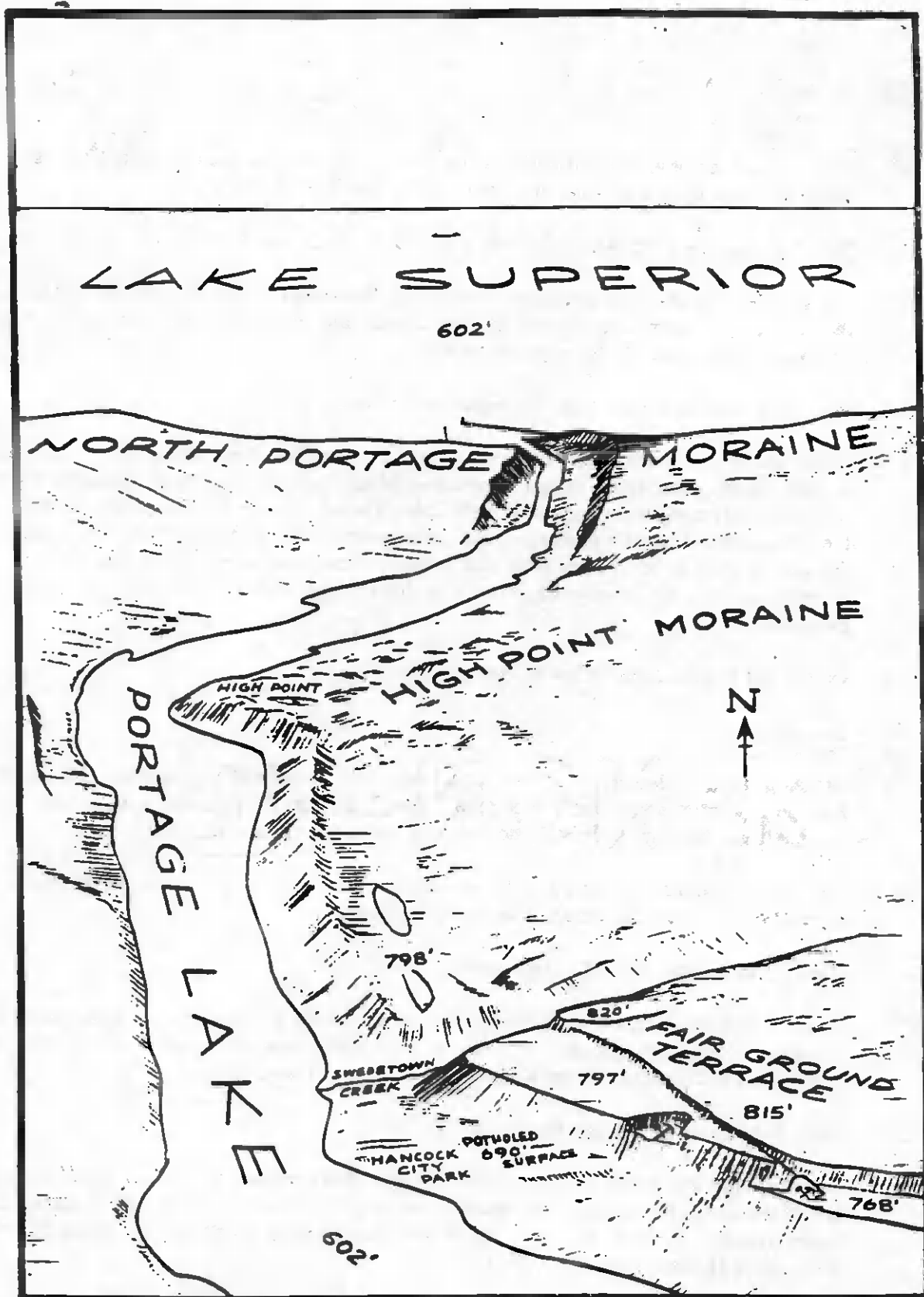


Figure H4: Physiography and glacial features of the northern part of Portage Lake (from Hughes, 1963).

LEG I L'ANSE**MAP I1**

- 0.0 Begin at the Memorial Union Building on the campus of Michigan Technological University. The campus is built on glacial sediments underlain by the PLV (see MAP 1).
- 0.1 Turn left (east) onto US-41. NOTE: Stay on US-41 all the way to Stop I1.
- 0.6 The middle of Wadsworth Dormitory overlies the Keweenaw Fault. As you follow US-41 past the dorm, the underlying bedrock is now Jacobsville Sandstone, and will continue to be Jacobsville Sandstone all the way to Stop #1.
- 0.7 East entrance/access road to the Michigan Tech campus.
- 1.2 On the left is a view of Isle Royale Sands and the Portage Waterway. The dark-colored sands are crushed basalt. The native copper mineralized basalt flow top lodes were processed by stamp mills primarily along the margin of Portage Lake, Torch Lake, and Lake Superior. In those days, the waste crushed basalt was dumped into the adjacent water. Fortunately, the native copper ore deposits of the Keweenaw Peninsula contain little, if any, acid-generating sulfide minerals--such as pyrite--so that the actual rock waste is as inert in the surface environment as natural rock exposures.
- 2.7 On the left is an excellent view of Portage Lake.
- 6.8 Enter Chassel.
- 9.0 Crossing the Sturgeon River and its associated sloughs. The Sturgeon River discharges into Portage Lake, forming a bird's foot delta. The sloughs are an excellent wildlife area where a diverse list of birds nest. It is a recommended canoe launching spot.
- 12.7 The rolling terrane here is glacially carved from the underlying Jacobsville Sandstone, and veneered with a variable thickness of glacial sediment.
- 15.6 Viewing Keweenaw Bay of Lake Superior.
- 20.5 Grover Dillman, Baraga Cliff, Roadside Pullover is on the left toward Keweenaw Bay of Lake Superior. Behind the fenced in area is a 21 m high exposure of Jacobsville Sandstone. These exposures can be seen from the Keweenaw Bay shoreline in L'Anse.
- 21.8 Enter Keweenaw Bay Indian Reservation.
- 22.3 An excellent view across Keweenaw Bay. At the 10:00 position is a good view of the western end of the Huron Mountains. This area consists of an Archean core composed of granitoid rocks unconformably overlain by early Proterozoic sedimentary rocks of the Marquette Range Supergroup (Klasner and others, 1991).
- 24.3 A good view of L'Anse across Keweenaw Bay. The black sand beaches are made of the same crushed basalt mine rock as the Isle Royale Sands near Houghton. The bedrock here, Jacobsville Sandstone, yields white sand beaches.

MAP 12

26.8 Entering Baraga.

27.3 The junction of US-41 and M-35; stay on US-41. At the 10:00 position is a view across Keweenaw Bay with L'Anse Red Rocks cliff exposures (Stop 11) in the background.

28.7 Baraga State Park.

29.1 The head of Keweenaw Bay.

29.4 L'Anse Red Rocks are visible straight ahead.

30.1 Pull over to the side of the road--being careful of traffic. It is recommended that you turn around and pull over on this end (the downhill end, near Lake Superior) of the guardrail on the pebble beach. Walk along the Keweenaw Bay shoreline toward the tree line (there is a path) to begin Stop #1, which is the unconformity between the early Proterozoic Michigamme Formation of the Marquette Range Supergroup (cleaved slate) and the Jacobsville Sandstone. After viewing the lower part, you may either climb the steep bank to the highway, or retrace the path and emerge onto the highway by the cars, where you can cross the street and proceed to walk along the cliff exposures of the Jacobsville Sandstone.
BE EXTRA CAREFUL OF TRAFFIC!!

Stop 11: L'Anse Red Rocks (Jacobsville Sandstone)

In the Lake Superior syncline portion of the Midcontinent rift zone, the Jacobsville Sandstone is a thick (+900 m) redbed sequence of fluvial sandstones; conglomerates; siltstones; and shales, completely devoid of lava flows and cross cutting dykes. On the north and south sides of Lake Superior, the formation occurs as inward-dipping, fault-bounded depositional wedges. These are separated by regional reverse faults from the strata that are more axial on the inner side of the basin, the PLV, and the Oronto and Bayfield Groups of similar red sandstones.

The sandstone lithology consists of arkose, subarkose, quartz, sub-lithic arenite, and quartzite. Locally, there are well developed massive sandstone-shale sequences representing point bar-overbank facies, and in drill cores, there are several hundreds of meters of upward fining beds, 5 to 30 cm thick, which is characteristic of fluvial, possibly braided, stream deposits. The cement varies from authigenic clay to calcite and zeolite. Conglomerates with clasts of Lower Proterozoic and Archean lithologies, are locally abundant and laterally extensive, particularly west and east of Lake Gogebic. In places, there are also clasts derived from Keweenawan volcanic rocks.

Jacobsville sedimentation was preceded by volcanic quiescence; cratonic stability; and weathering, so that chemically resistant debris such as quartz and iron-formation became concentrated in the source areas. Erosion was initiated by late Keweenawan warping, perhaps accompanied by movement along the Keweenaw Fault. Vigorous marginal fluvial systems developed on the south side from uplands dominated by ridges of iron-formation. The resistant debris was deposited in alluvial fans. Later sediments were also derived from a Keweenawan age basaltic and felsic volcanic terrane. On burial, the sandstone underwent low-grade alteration so that the present matrix mineralogy changes from microcline-plagioclase-kaolinite-montmorillonite near the surface, to microcline-montmorillonite-illite (chlorite) at depth.

At the top of the cliff is a locally fabricated sheet copper statue of Bishop Fredric Baraga

(1797-1868); a Roman Catholic priest born in Yugoslavia, who worked among the Indians and early white settlers.

The 20 m section, divided into lower (below the highway on the shoreline) and upper parts (above highway), shows many of the characteristics of this fluvial redbed formation. The sandstone rests on Lower Proterozoic Michigamme Formation Slate which displays a reddish discoloration along joints, possibly denoting pre-Jacobsville weathering. At the inner edge of the slate outcrop, under the overhang, there are parallel striations on the surface of the slate. These striations were interpreted by Murry (1955) as having been produced by pre-Jacobsville glaciation, and by Kalliokoski (1982), as produced by a more recent lakeward sliding of the Jacobsville Sandstone on top of the regionally inclined slate surface (Fig. 11).

At the base of the Jacobsville, the wide variety of clasts in the polymictic framework conglomerate resemble lithologies in igneous, sedimentary, and metamorphic Archean and Lower Proterozoic rocks that outcrop some tens of kilometers to the south and southwest. Note the abundance of pebbles of vein quartz and iron-formation. The sandstone immediately above the conglomerate display foresets and troughs.

The upper part of the Jacobsville section, above the level of the highway, consists predominantly of fine- to medium-grained reddish brown-to-tan feldspathic-to-sublithic quartz sandstone, with minor red silty shale (east, left). The sandstone ranges from well-bedded to massive. Some beds are up to 1 m thick and show conspicuous foresets overlain by planar beds and thin, continuous layers of quartz pebble lag conglomerate. Some surfaces are current ripple marked. A convoluted sandstone bed above a planar bedding surface suggests that sedimentation was on a slope.

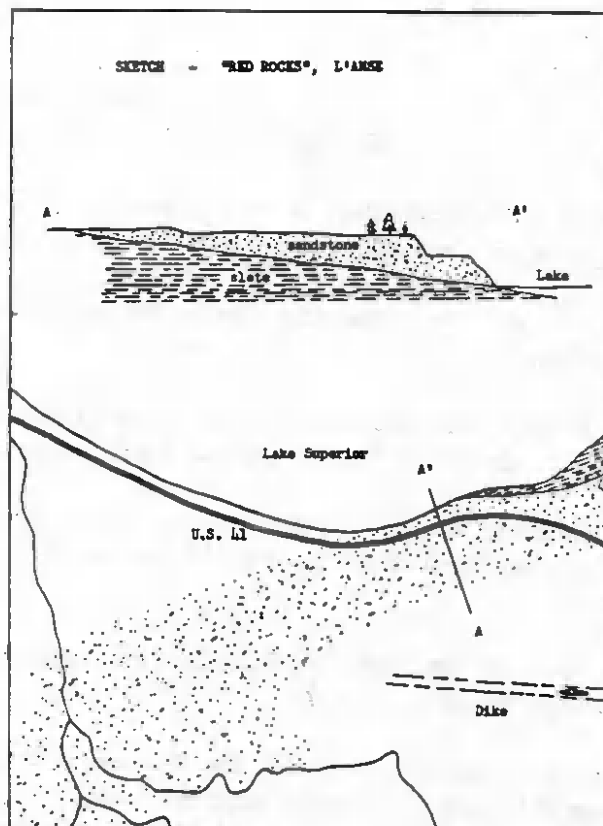
END OF LEG I - RETRACE ROUTE TO HOUGHTON

A

SKETCH - "RED ROCKS", L'ANSE

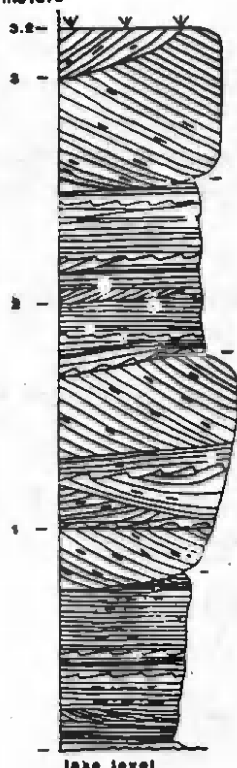
Legs

177



B

meters



S.S.; mottled red-brown; fine-grained; well-sorted; large-scale trough crossbedding; sandstone intraclasts.

S.S.; red; very fine-grained; well-sorted; thinly-planar-bedded; some small-scale cross-bedding; somewhat lenticular; asymmetric ripples common; interval drapes concave-up bedding surface of underlying interval.

S.S.; mottled red-brown; fine-grained; well-sorted; large-scale trough crossbedding; minor planar bedding; asymmetric ripples both up and down contained within interval; sandstone intraclasts; channelized lower contact.

slt.-very fine S.S.; red; thickly laminated to thinly planar-bedded; some small-scale crossbedding and cut-and-fill; asymmetric ripples; becomes shaly in upper 10 cm.

Figure 11: (a) Geologic sketch map and cross-section of L'Anse redrocks (from 1962 Michigan College of Mining and Technology, NSF Summer Conference guidebook). Sandstone is equivalent to the Jacobsville Sandstone, slate is equivalent to the Early Proterozoic Michigamme Formation, the contact is an angular unconformity. (b) Stratigraphic section of the Jacobsville Sandstone at L'Anse Redrocks (from Able, 1985).

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**Figure 1A:
Route and Stop Map**

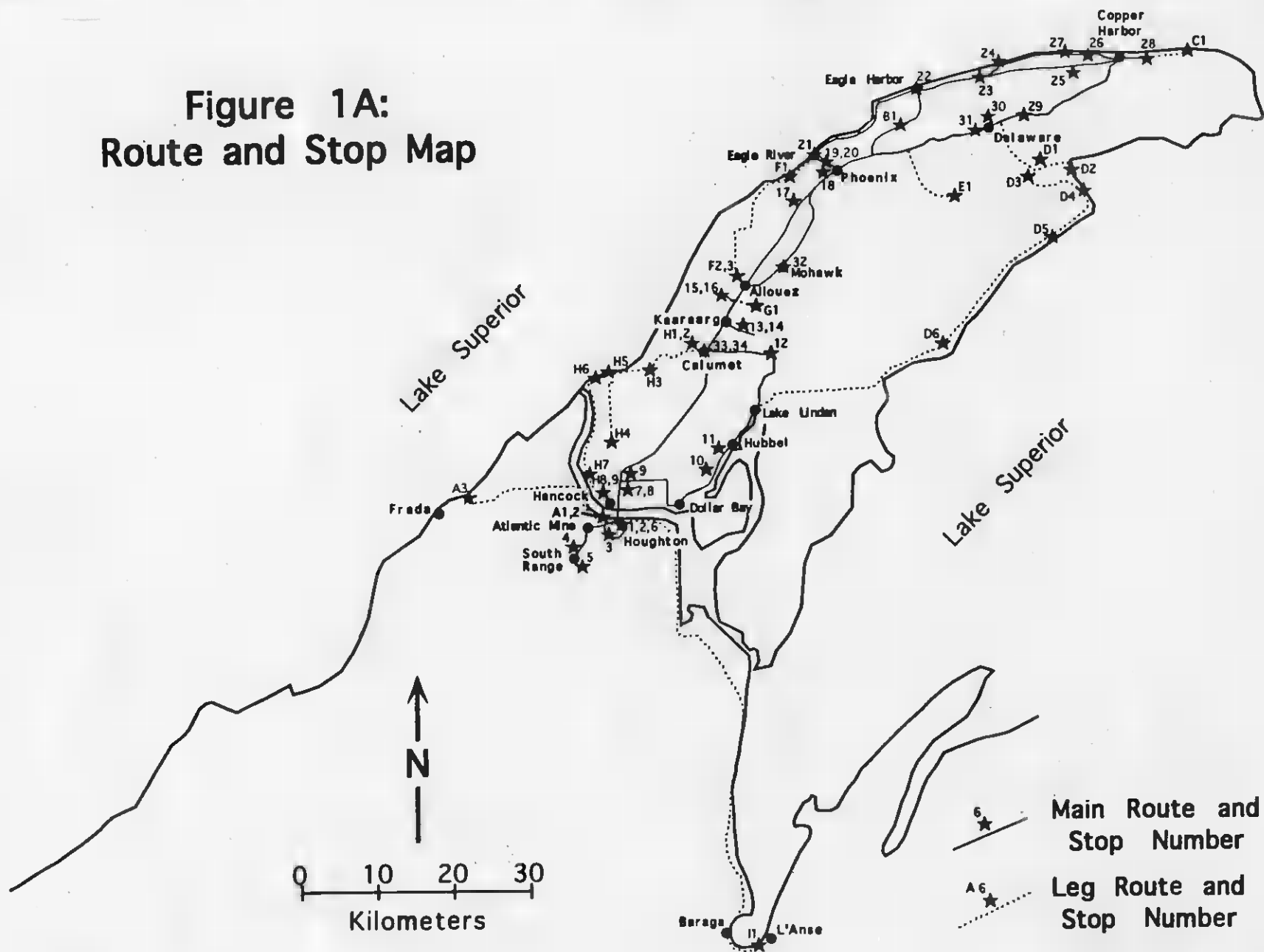


Figure 1B:
Index of 1:24,000 Scale Maps

