FIELD TRIP GUIDEBOOK FOR THE GLACIAL GEOLOGY OF THE LAURENTIAN DIVIDE AREA, ST. LOUIS AND LAKE COUNTIES, MINNESOTA

PREPARED FOR THE 39TH MIDWEST
FRIENDS OF THE PLEISTOCENE FIELD
TRIP, BIWABIK, MINNESOTA, 1992

UNIVERSITY OF MINNESOTA

MINNESOTA GEOLOGICAL SURVEY
ST. PAUL, MINNESOTA
GUIDEBOOK SERIES NO. 18
ISSN-0192-6268


Vermilion Lake
Lost Lake Swamp
Vermilion Lake Indian Reservation
Tower Soudan State Park
Bear Head Lake State Park
Bear Island State Forest
Babbitt
Giants Ridge Ski Area
Embarrass Mine
Duluth Missabe and Iron Range
Aurora
Biwabik
Hoyt Lakes
Gilbert
Eveleth
Superior National Forest
1
2
3
4
5
6
7

MINNESOTA GEOLOGICAL SURVEY
Priscilla C. Grew, Director

FIELD TRIP GUIDEBOOK 18

GLACIAL GEOLOGY OF THE LAURENTIAN DIVIDE AREA, ST. LOUIS AND LAKE COUNTIES, MINNESOTA

J.D. Lehr and Howard C. Hobbs, Leaders

PREPARED FOR THE 39TH MIDWEST
FRIENDS OF THE PLEISTOCENE FIELD
TRIP, BIWABIK, MINNESOTA, 1992

CONTENTS

MEETINGS OF THE MIDWEST FRIENDS OF THE PLEISTOCENE

1	1950	Eastern Wisconsin	S. Judson
2	1951	Southeastern Minnesota	H.E. Wright, Jr. and R.V. Ruhe
3	1952	Western Illinois And Eastern Iowa	P.R. Shaffer and W.H. Scholtes
U	1952	Southwestern Ohio	R.P. Goldthwait
U	1953	Northeastern Wisconsinan	F.T. Thwaites
U	1954	Central Minnesota	H.E. Wright, Jr. and A.F. Schneider
6	1955	Southwestern Iowa	R.V. Ruhe
U	1956	Northwestern Lower Michigan	J.H. Zumberge and others
8	1957	South-central Indiana	W.D. Thornbury and W.J. Wayne
9	1958	Eastern North Dakota	W.M. Laird and others
10	1959	Western Wisconsin	R.F. Black
11	1960	Eastern South Dakota	A.G. Agnew and others
12	1961	Eastern Alberta	C.P. Gravenor and others
13	1962	Eastern Ohio	R.P. Goldthwait
14	1963	Western Illinois	J.C. Frye and H.B. Willman
15	1964	Eastern Minnesota	H.E. Wright, Jr. and E.J. Cushing
16	1965	Northeastern Iowa	R.V. Ruhe and others
17	1966	Eastern Nebraska	E.C. Reed and others
18	1967	South-central North Dakota	L. Clayton and T.F. Freers
19	1969	Cyprus Hills, Saskatchewan and Alberta	W.O. Kupsch
20	1971	Kansas-Missouri Border	C.K. Bayne and others
21	1972	East-central Illinois	W.H. Johnson and others
22	1973	Lake Michigan Basin	E.B. Evenson and others
23	1975	Western Missouri	W.H. Allen and others
24	1976	Meade County, Kansas	C.K. Bayne and others
25	1978	Southwestern Indiana	R.V. Ruhe and C.G. Olsen
26	1979	Central Illinois	L.R. Follmer and other
27	1980	Yarmouth, Iowa	G.R. Hallberg and others
28	1981	Northeastern Lower Michigan	W.A. Burgis and D.F. Eschman
29	1982	Driftless Area, Wisconsin	J.C. Knox and others
30	1983	Wabash Valley, Indiana	N.K. Bleuer and others
31	1984	West-central Wisconsin	R.W. Baker
32	1985	North-central Illinois	R.C. Berg and others
33	1986	Northeastern Kansas	W.C. Johnson and others
34	1987	North-central Ohio	S.M. Totten and J.P. Szabo
35	1988	Southwestern Michigan	G.J. Larson and G.W. Monaghan
36	1989	Northeastern South Dakota	J.P. Gilbertson
37	1990	Southwestern Iowa	E.A. Bettis, III and others
38	1991	Mississippi Valley, Missouri and Illinois	E.R. Hajic and others
39	1992	Northeastern Minnesota	J.D. Lehr and H.C. Hobbs

GLACIAL GEOLOGY OF THE LAURENTIAN DIVIDE AREA, ST. LOUIS AND LAKE COUNTIES, MINNESOTA

by

J.D. Lehr[1] and Howard C.Hobbs[2]

[1]Minnesota Department of Natural Resources
Division of minerals
St. Paul, MN 55155

[2]Minnesota Geological Survey
2642 University Avenue
St. Paul, MN 55114

INTRODUCTION

J.D. Lehr's interest in this area began in 1984, when he began a Master's thesis at the University of Minnesota, Duluth. He mapped the Quaternary geology of the area between the eastern Mesabi range and the Vermilion moraine. Much of this area had been covered by Glacial Lake Norwood, which had been recognized by Winchell (1901), but hardly studied since.

Hobbs visited Al Friedman's field area around Isabella in the summer of 1978. Friedman's thesis was completed in 1981, and the Minnesota Geological Survey considered publishing his map of the Isabella 15-minute quadrangle, but the project languished for several years. Finally, in 1988 Hobbs put together a map and report covering the Isabella quadrangle and the 15-minute quadrangles on the east and west (Hobbs and others, 1988), which incorporated part of Stark's 1977 thesis area, and all of Fenelon's 1986 thesis area. The project was partly supported by the Minnesota DNR-minerals Division, in order to assist the DNR's drift prospecting effort.

The project began with the idea that the three maps could simply be put together with a few minor revisions for the sake of uniformity. But the match was not so simple, and Hobb's ideas about the area evolved as the project went along. The resulting product was a new synthesis of Stark's, Friedman's, Fenelon's and Hobbs' ideas.

Hobbs and Lehr have discussed the relationships between their areas for some time, in particular, ice-margin positions and correlation, and meltwater flow paths. After announcing this trip, we did fieldwork together in the summer of 1991, and worked out the main problems of correlation. We don't claim to have everything worked out, though.

The map (Plate 1) is a joint effort, but Lehr had the main responsibility for St. Louis County and Hobbs for Lake County. Parts of the areas were not field checked at all; reliability is better in areas that were mapped for theses. Ice flow paths can be inferred from the pattern of streamlined features and the orientation of moraines and Rogen moraine ridges. Meltwater flow paths are shown schematically, partly for legibility at this scale, partly because the actual boundaries of outwash are poorly known in many places.

Moraine terminology is a compromise among several systems. The Outer and Inner moraines are labeled as in Stark (1977) and Friedman (1981), but Friedman's Vermilion moraine is here labeled Isabella moraine. This moraine is correlated to the Vermilion moraine, but its orientation is different. It represents a distinct sublobe, and it is useful to be able to refer to it separately. The Allen, Wahlsten, and Big Rice moraines were named following the Minnesota Soil Atlas, Hibbing Sheet (1971). The First, Second and Third moraine terminology of Stark's (1977) is not used, because it is too local. Stark's First moraine is here called the Wampus Lake moraine, and his Third moraine is included in the Vermilion moraine. His Second moraine is not mapped as a significant moraine.

The classification of streamlined features as rock-cored and drift-cored is done in a general way, and does not imply a detailed knowledge of them. We recognized that there is a continuum between them. In areas where many small features are grouped together, the orientation is maintained, but several individual features are shown with one symbol. By convention, we mapped the crests of the streamlined features, but we do not consider the crest to be any more significant than the trough or sides.

One unifying feature of the field trip area is the Laurentian divide, which separates the Hudson Bay and Great Lakes watersheds. This divide influenced deglaciation by governing where proglacial lakes formed and where meltwater streams developed. So, in an indirect way, the Laurentian divide controlled the shape of the ice margin, ice-marginal sedimentation, and possibly the rate of deglaciation.

The purpose of this trip is not to show off a completed piece of work, but rather to share our current understanding of an area that has been little studied until recently. Some of the sediments and landforms will be unfamiliar to most Midwest Friends, and we also do not understand them completely.

ACKNOWLEDGMENTS

We would like to thank the landowners who granted us permission to enter these sites, and the staff of Giants Ridge for accommodating an unusual group of people. A special thanks to the people at the Superior National Forest and LTV Steel Mining Company. The Minnesota Geological Survey and the Department of Natural Resources co-sponsored this trip, and much of our preparation for this trip was done on "company time." Herb Wright provided greatly appreciated comments during a brief field review of the area. We appreciate the help of the MGS logistical committee: Sue Benson, Alan Knaeble, Amy Nuutinen, and Carrie Patterson. Terry Boerboom and Mark Jirsa of the MGS helped identify pebbles from the Rotasonic cores in the Toimi drumlin field.

BEDROCK GEOLOGY

The bedrock geology of the area is dominated by the Midcontinent rift system. This Middle Proterozoic rift truncates older Proterozoic and Archean rocks. The main exposed rocks of the rift system are basalt and rhyolite of the North Shore Volcanic Group and associated red interflow sediments, intruded by gabbro and anorthosite of the Duluth Complex. Lake Superior is a structural, as well as a topographic basin. The lower part of the basin is filled with red sandstone and shale. These rocks underlie Lake Superior and are not mapped in Figure 1, but are exposed on land farther to the southwest (Morey and others, 1982). Green (1982) shows more detail of the bedrock geology in the eastern part of the field trip area.

The whole package of rift-related rocks is called the Keweenawan Supergroup. Although they comprise a diverse assemblage of rocks, they give a distinct appearance to sediments in which they appear, because their color is dominantly gray, black and red. The anorthosites, troctolites and anothositic gabbros range from medium to dark gray. The basalts are generally black, but some are weathered red. The felsic differentiates, granophyre and rhyolite, are red, as are the interflow sediments and most of the post-volcanic rift sediments.

The pre-rift rocks consist mainly of metasedimentary rocks of the lower Proterozoic Animikie Basin, which rest on a highly deformed Archean basement. The rocks of the Animikie Basin are primarily slate and graywacke, underlain by quartzite and iron-formation which form the Mesabi range on the northwestern side of the basin. This range is the largest of the many iron ranges in the Lake Superior region, and the only one still mined in Minnesota.

The Archean basement in the field trip area is a granite-greenstone terrane. Granitic complexes of plutons and high-grade metamorphic rocks are separated by belts of metamorphosed volcanic and sedimentary rocks. The latter include minor iron-formations, one of which is shown on Figure 1. This iron-formation was mined, and is mentioned later in the road log. The whole sequence has been severely faulted, and intruded by mafic dikes, which strike NW-SE.

Precambrian rocks in Minnesota have developed a thick regolith of saprolite in many places. This probably represents more than one episode of weathering , inasmuch as saprolite is present under Paleozoic rocks in southern Minnesota, but we are primarily concerned with the pre-Late Cretaceous saprolite that formed over the rest of the state.

The pre-Late Cretaceous saprolite is typically clay to sandy clay, depending on the texture and mineralogy of the parent rock. Feldspars and ferromagnesian silicates are altered to clay, leaving only quartz and resistant heavy mineral grains in the sand fraction. The clay is dominantly kaolinite, typically white to pale greenish- and bluish-gray. In the Minnesota River Valley, the full range of weathering profile can be observed, from a pisolitic surface verging on bauxite, grading down to grusified rocks in which the gneissic banding is still visible.

The saprolite is commonly more than 100 feet thick in central to southwestern Minnesota, under Cretaceous rocks or thick drift, or both. Its thickness is strongly dependant on jointing and permeability of the rock; saprolite may extend several hundred feet vertically in fracture zones, and may also extend along horizontal fractures. Zones of saprolite are reported interspersed with sections of sound rock in some logs of boreholes drilled into bedrock for mineral exploration..

Northeast of a line stretching approximately from the Twin Cities to Lake of the Woods, the saprolite layer is increasingly thin and patchy. This trend is roughly the same as the drift thickness trend, and reflects increased glacial scouring. Saprolite was generally thought until recently to be absent from the Arrowhead region (the northeastern corner of the state). Recent drilling in the area has penetrated saprolite in places, generally on bedrock lows under thick drift.

By analogy with areas where the saprolite is thick and widespread, these occurrences in the Arrowhead region are probably the basal parts of "pendants" of saprolite that extended deep into the rock in areas of jointing. By further analogy, maybe the depressions in the bedrock surface in this area originated as pendants of saprolite. In fact, the bedrock surface in this area may approximate the original surface of sound bedrock at the beginning of the glacial period. We estimate that more than 100 feet of saprolite has been eroded from the Arrowhead region, but only tens of feet of sound bedrock erosion, rather than hundreds. Feininger (1971) came to similar conclusions.

REGIONAL TOPOGRAPHY

The Lake Superior basin is the largest and most prominent topographic feature of the area. It exists largely because the sandstone and shale which formerly filled it are soft, and have been scooped out by successive glaciations. The North Shore slopes rather steeply into the lake: the highest point in Minnesota, Eagle Mountain, is only 12 miles away from Lake Superior.

Most of the North Shore of the Superior basin is underlain by rocks of the North Shore Volcanic Group; they crop out or subcrop under thin Superior lobe deposits. Many outcrops have been scoured and streamlined by ice flowing out of the Superior basin (the Highland flutes of Wright, 1972).

The rest of the area can be roughly divided into areas of scoured bedrock to the north, and a variety of glacigenic landforms to the southern part of the map area (Plate 1). The boundary is roughly at the Vermilion and Wahlsten moraines. The bedrock topography south of the scoured-bedrock region is not well known. Water-well logs are sparse over much of the region. mineral-exploration borings are abundant locally, as on the Mesabi range, but sparse regionally. The bedrock surface is not flat, but whether the low areas form a network of buried valleys, like that of the Twin Cities area and southeastern Minnesota, is not known. We suggest, on the contrary, that the bedrock surface is basically a glacially scoured surface controlled by structure, jointing, and rock type. In other words, that it is much like the bedrock exposed north of the Vermilion moraine.

The Giants Range is the main exception to the general observation that scoured-bedrock features are mostly north of the Vermilion moraine. It is a bedrock ridge rising roughly 300 to 500 feet above the surrounding landscape. The highest part is less than a mile wide. The Giants Range parallels the Mesabi iron range on its north side. The Mesabi "range" is not really a positive topographic feature despite its name; it is just a step on the side of the Giants Range, only a little above the Animikie basin (Fig. 2).

The Giants Range is composed of granite and greenstone, mainly the former. Its topographic form does not correspond closely to rock type, however. Not all the range is composed of Giants Range Granite; and the lower bedrock to the north of the range is generally the same rock as the range itself. Thus, simple resistance to weathering and erosion cannot explain the form.

LOBES AND SUBLOBES

The southern boundary of the Laurentide Ice Sheet tended to be lobate, following broad lowlands, such as the Great Lakes and the Red River Valley. The lowlands have been eroded by successive glaciations in areas of relatively weak rock, and are probably much deeper now than before the first continental glaciation. North of the Great Lakes, lobes are much less pronounced. Our Canadian colleagues are largely spared the problems of lobe definition and terminology; instead, they deal directly with the domes and divides in the ice source areas.

As traditionally used in the upper Midwest, the lobe concept combines both form of the ice margin, and composition of the sediment. Sediment composition (texture, color, carbonate content, stone assemblage) tends to be similar in deposits of a given lobe throughout a glaciation, and even through several glaciations, because the ice flowed more or less the same direction over the same terrane.

The lobe concept in Minnesota ranges from highly predictive to unhelpful. At one extreme, the Superior lobe is quite a well-behaved lobe. Its deposits are generally reddish brown, only slightly calcareous (except over carbonate bedrock), and rich in volcanic clasts from the North Shore and red sandstone from the Superior basin. Its till is sandy except where it has overridden its own proglacial lake clay; it is rocky, but not as rocky as till derived only from the Canadian Shield uplands. These characteristics are widespread in late Wisconsinan deposits, and can be recognized in numerous pre-Wisconsinan deposits, mostly in the subsurface. The Superior basin is quite deep, and its northeast-southwest orientation has consistently channeled ice from the Labrador sector of the Laurentide Ice Sheet into Minnesota and western Wisconsin.

On the other hand, tills known only from the subsurface in Minnesota are more difficult to assign to lobes. Their margins are not well known, and they may not have been as lobate as their late Wisconsinan counterparts. Their suites of characteristics may not be strictly comparable to the late Wisconsinan surface tills which have been assigned to lobes.

For example, subsurface tills in north-central Minnesota are generally referred to a Winnipeg lobe (northwestern source) (Martin and others, 1989) or Rainy lobe (northeastern source). Late Wisconsinan Rainy lobe tills in the area are typically very sandy and rocky; they are only slightly calcareous, and most of their clasts are derived from the Canadian Shield. The Winnipeg lobe tills are similar to the Wadena lobe tills of Wright (1972) and Hobbs and Goebel (1982); the till texture is loamy to sandy, only moderately rocky; carbonate is common both in the clasts and the matrix. But some "Old Rainy" tills actually have more carbonate than some Winnipeg lobe tills. This lack of correspondence may be due partly to incorporation of local drift having a composition different from the local bedrock. However, in this region between the two major basins of the Red River Valley and Lake Superior there are no large deep basins to channel flow, and directions are more controlled by large-scale flow from accumulation centers. Directions should not be expected to remain the same from one glaciation to another.

In fact, in much of Minnesota, the best we can do in the subsurface is to assign tills to northwest (Keewatin) and northeast (Labradoran) provenance. Even here, there are potential problems. The Wadena drumlin field is now believed to have been deposited by an ice sheet from the northeast (Goldstein 1986; Meyer, 1986) rather than the northwest, as postulated by Wright (1962). If this is true, the drumlin till is really a Rainy lobe till which has acquired the characteristics of a Winnipeg lobe till by incorporation of older drift (Goldstein, 1986; Meyer, 1986), although some of the carbonate may have been brought directly from the Hudson Bay lowland.

In our field trip area, we have to deal with two lobes and two sublobes. A sublobe is smaller than a lobe, and its drift has enough characteristics in common with a particular lobe, that it can be considered a subset. The Superior lobe has already been described. The Rainy lobe is named for Rainy Lake and Rainy River on the International Boundary. Like the Superior lobe, its large-scale

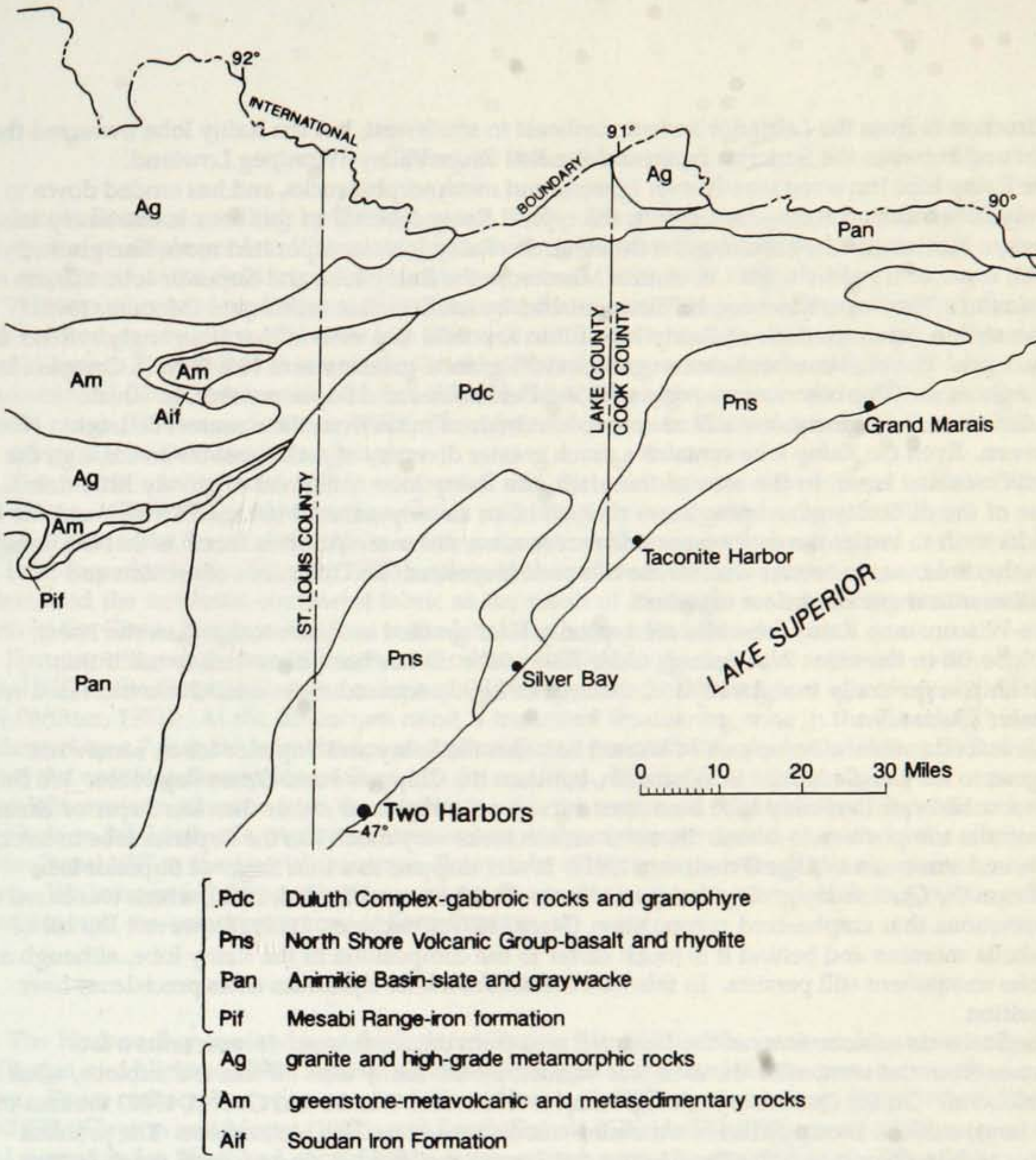


Figure 1. Bedrock geology of northeastern Minnesota; generalized from Morey and others (1982)

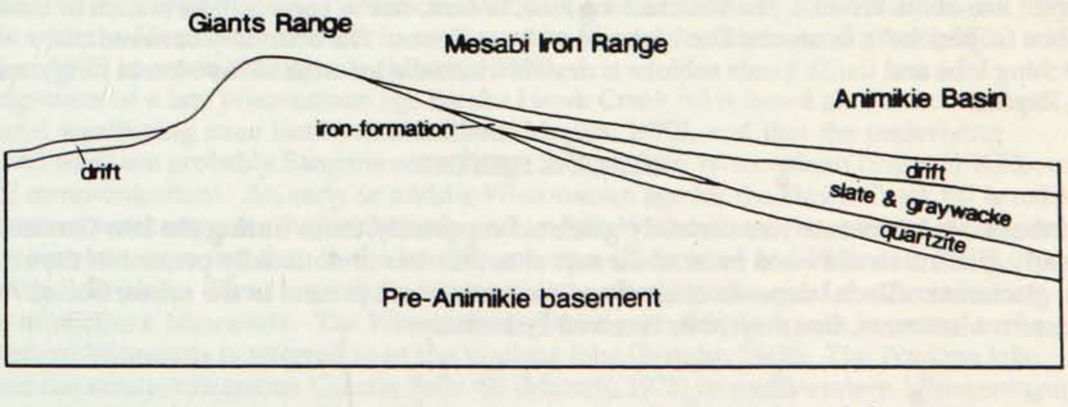


Figure 2. Generalized topographic and structural relationships, Mesabi and Giants Ranges

flow direction is from the Labrador sector, northeast to southwest, but the Rainy lobe traversed the high ground between the Superior basin and the Red River Valley-Winnipeg Lowland.

The Rainy lobe traversed mostly over igneous and metamorphic rocks, and has eroded down to relatively unweathered rock. As a result, the typical Rainy lobe till of this area is extremely sandy and rocky. Farther southwest along the flowline, the Rainy lobe incorporated more fine-grained material, some of it reddish, until in central Minnesota the Rainy lobe and Superior lobe tills are fairly similar. They can, however, be distinguished by multivariate techniques (Mooers, 1990).

One striking characteristic of Rainy lobe till in the field trip area is that it strongly reflects the local bedrock. The clast composition can go from 90% granite-greenstone to 90% Duluth Complex in only a mile or so. This contrasts strongly with the Des Moines and Superior lobes, in which characteristic rock fragments are still common, hundreds of miles from their nearest bedrock occurrence. Even the Rainy lobe contains a much greater diversity of rock types down-ice, e.g., the St. Croix moraine area. In the area of thin drift, the Rainy lobe contained relatively little debris, because of the difficulty of scraping more rock off of an already-scoured terrane. There was little if any older drift to buffer the drift composition over some distance. Another factor is that the Rainy lobe in this area was in retreat when these tills were deposited, and the zones of erosion and deposition must have been close together.

Pre-Wisconsinan Rainy lobe tills are typically finer grained and less rocky than the latest Rainy lobe till in the area. Not enough older Rainy lobe till has been described to tell if this relationship is generally true, but if it is, the area of highly-scoured rocks must have increased with successive glaciations.

The Isabella sublobe occupies a re-entrant between the Rainy and Superior lobes, somewhat analogous to the Langlade lobe in Wisconsin, between the Chippewa and Green Bay lobes. We think of it as a sublobe of the Rainy lobe because it occupies the highland rather than the Superior basin. However, its composition is mixed. Its outer section looks very much like the Superior lobe in color, texture, and stone assemblage (Friedman, 1981). It was mapped as a thin finger of Superior lobe moraine on the Quaternary geologic map of Minnesota (Hobbs and Goebel, 1982), which was based on interpretations that emphasized composition (Stark, 1977; Friedman, 1981). However, the till of the Isabella moraine and behind it is much closer to the composition of the Rainy lobe, although a red stone component still persists. In this lobe definition, the ice dynamics takes precedence over composition.

The St. Louis sublobe entered the field trip area from the southwest. It represents a late readvance from the west, after the area was vacated by the Rainy lobe. If this is a sublobe, what is it a sublobe of? On the Quaternary geologic map of Minnesota (Hobbs and Goebel, 1982) the area of the St. Louis sublobe is mapped as two moraine associations of the Des Moines lobe. The problem with this terminology is that the Des Moines and James lobes did not diverge until much farther south. Also, there is no name for the eastern bulge of Keewatin ice in north-central Minnesota, unless it, too, is called St. Louis sublobe.

Our current solution (Martin and others, 1989) is to consider the St. Louis a sublobe of the Koochiching lobe, which occupied north-central Minnesota and a slice of Ontario between Rainy Lake and Lake of the Woods. The Koochiching lobe, in turn, can be considered a branch of the Red River lobe (superlobe?), as are the Des Moines and James lobes. The boundary between the Koochiching lobe and the St. Louis sublobe is drawn where the ice crossed the Mesabi range near Grand Rapids.

GLACIAL HISTORY

Northeastern Minnesota was certainly glaciated repeatedly times during the late Cenozoic. These early glaciations removed most of the saprolite that was undoubtedly present in the area prior to glaciation. Glacial deposits older than Wisconsinan are present in the subsurface of northeastern Minnesota, but they have received little study.

Pre-Late Wisconsinan

Recent Rotasonic drilling by the Minnesota DNR - Division of minerals has revealed the presence of multiple pre-late Wisconsinan tills of both Keewatin and Labradoran provenance in the area northwest of the field trip area (Martin and others, 1988, 1989, 1991).

Winter and coworkers (Winter, 1971; Winter and others, 1973) reported several occurrences of a dark-colored, sandy, silty, till below late Wisconsinan Rainy lobe deposits in open pit mines on the Mesabi range. They called this unit the "basal till" and interpreted it to be older than late Wisconsinan. They also mentioned that this till did not look the same at all localities along the Mesabi range (Winter and others, 1973). Therefore there may be multiple pre-Wisconsinan tills in the subsurface of the Mesabi range area.

The matrix of the "basal till" is calcareous, and the predominate clay mineral is illite (Winter and others, 1973). The pebble fraction of this unit is mostly locally derived granitic and metamorphic rocks, but it also contains a few carbonate pebbles and a few rock types derived from the Lake Superior basin. Winter (1971) explained the presence of carbonate clasts, a calcareous matrix, and the northeast-southwest fabric as the result of Keewatin ice advancing northeastward south of the Giants Range, analogous to the late Wisconsinan St. Louis sublobe.

Spruce or tamarack wood (Preston and others, 1955) from glaciofluvial sediment overlying the "basal till" at the Duncan-Douglas mine near Hibbing yielded a radiocarbon age of >36,490 BP (Y-250) (Winter, 1971). At the Embarrass mine, a truncated weathering zone in the "basal till" is evidenced by a 7-foot-thick leached zone and oxidation from 10YR lower in the unit to 5YR at the top of the unit (see description of Stop 4 in the roadlog). We suggest that the "basal till" represents a pre-Wisconsinan advance from the northeast, with the carbonate eroded from Paleozoic rocks in the Hudson Bay lowlands. A northeastern source of the carbonate would account for the similarity of the "basal till" to the late Wisconsinan Rainy lobe till in texture, overall pebble content, and fabric. We interpreted the weathering zone present in this unit to be interglacial, so "counting down from the top," the weathering zone is Sangamonian.

Late Wisconsinan

The Hudson Bay lowland was deglaciated during the middle Wisconsinan, approximately 46-32 ka (Berger and Nielsen, 1990), so this is a maximum age for the late Wisconsinan Laurentide Ice Sheet. Finite radiocarbon ages on wood from Alberta (I-4878), Saskatchewan (S-96), North Dakota (W-2450) (Clayton and Moran, 1982), and South Dakota (GX-14,675) (Gilbertson, 1990) suggest that the Laurentide Ice Sheet had considerable southwestern extent by approximately 27 to 29 ka.

Hawk Creek phase. Little is known about the glacial history of Minnesota in the earliest part of the late Wisconsinan (35 to 20 ka). In Minnesota, the first late Wisconsinan advance was probably that of the Superior lobe, approximately 29 ka. This glacier advanced into southwestern Minnesota and to the base of the Coteau des Prairies in northeastern South Dakota, depositing the red, sandy Hawk Creek till (Fig. 3) (Matsch, 1972; Gilbertson, 1990). The Hawk Creek till may correlate with the Marcoux Formation in northwestern Minnesota (Moran and others, 1976) and with the "old red till" in central Minnesota (Mooers, 1988).

Assignment of a late Wisconsinan age for the Hawk Creek till is based on the fact that no interglacial weathering zone has been identified (Matsch, 1972), and that the underlying "gastropod silts" are probably Sangamonian (Stage 5) to middle Wisconsinan (Stage 3) (Gilbertson, personal communication). An early or middle Wisconsinan age for the Hawk Creek till is unlikely, because recent work suggests that in the early and middle Wisconsinan, the southwestern Laurentide Ice Sheet was less extensive than in the late Wisconsinan (Richmond and Fullerton, 1987).

Granite Falls phase. Flow later shifted to a more northerly path across the Precambrian uplands of northern Minnesota. The Wisconsinan glacier with this flow path in central and southwestern Minnesota is referred to as the Wadena lobe (Wright, 1962). The Wadena lobe deposited the sandy, calcareous Granite Falls till (Matsch, 1972) in southwestern Minnesota and northeastern South Dakota (Fig. 4) (Gilbertson, 1990) soon after the Hawk Creek phase, because no buried weathering zone has been documented in the Hawk Creek till (Matsch, 1972).

The age of the Granite Falls till has received much discussion, and remains ambiguous. Two radiocarbon ages on wood from sediment beneath the Granite Falls till are >31,000 BP (W-99) and >39,000 BP (I-4932), and one is finite at 34,000 +2800 -2450 BP (GX-1309). The infinite ages can be explained as wood eroded from the widespread, wood-bearing "gastropod silts." Wood from the "gastropod silts" has yielded several infinite radiocarbon ages, the oldest being >56,000 (QL-4151 and QL-4152).

Toronto phase. Flow continued to shift westward, because by approximately 23 ka, Keewatin ice (Des Moines lobe) had reached southwestern Minnesota and northeastern South Dakota, depositing the Toronto till (Fig. 5) (Lehr and Gilbertson, 1988). Two radiocarbon ages on wood from beneath the Toronto till and above a thick oxidized zone in northeastern South Dakota range from 22,900 ± 1000 (GX-3439) to 26,150 +3000 -2000 (GX-2864).

Alexandria phase. Upon retreat of Keewatin ice at the end of the Toronto phase, Labradoran ice receded into central Minnesota and stabilized for some time at the Alexandria moraine complex. The Superior lobe at this time was probably at the St. Croix moraine in the southern part of the present Twin Cities (Fig. 6). Both the Alexandria moraine complex and the St. Croix moraine in the Twin Cites are massive ice-stagnation complexes, which suggest a stable ice margin for possibly thousands of years. Buried ice persisted in the Alexandria moraine complex and the southern St. Croix moraine until after the 14-ka advance of the Des Moines lobe.

Hewitt phase. Renewed recession of the Wadena lobe resulted in formation of the Wadena drumlin field (Fig. 7) and deposition of the sandy, calcareous Hewitt till in north-central Minnesota. We disagree about the source of the carbonate in Wadena lobe deposits. Lehr proposes a derivation from the Paleozoic rocks of the Hudson Bay lowlands. Hobbs prefers the explanation of Meyer (1986) and Goldstein (1986) that carbonate was eroded from underlying calcareous drifts.

This chronology of an early late Wisconsinan shift of flow direction from southwest (Labradoran) to more southerly (Hudson) to southeast (Keewatin) is the same sequence displayed by the younger late Wisconsinan glacial deposits of Minnesota.

St. Croix phase. During the St. Croix phase maximum, the confluent Superior and Rainy lobes stood at the St. Croix moraine while the Wadena lobe was at the Itasca moraine (Fig. 8) (Wright, 1972). By this time, flow in the Wadena lobe had shifted to slightly west of south, while flow in the Rainy and Superior lobes was nearly straight east.

An age of greater than 20,500 ± 400 BP (I-5443) is suggested for the St. Croix phase by a radiocarbon age on basal organic sediment from a bog in the Pierz drumlin field behind the St. Croix moraine (Wright, 1972). Clayton and Moran (1982), on the other hand, suggest an age of 15 ka for the St. Croix phase, based on correlations with ice margins outside Minnesota. The Superior and Rainy lobes had certainly retreated from the St. Croix moraine by 14 ka, because outwash from the Des Moines lobe can be traced behind the St. Croix moraine (Mooers, 1988). The St. Croix phase—the time from the advance of the Superior lobe to the St. Croix moraine to the retreat of the Rainy lobe and the creation of the Toimi drumlin field (Wright, 1972)—probably spans several thousand years from >20 ka to approximately 14 ka.

As the Superior lobe receded from the St. Croix moraine, it formed the Pierz drumlin field, ice-marginal fans, and a widespread network of tunnel valleys with eskers in east-central Minnesota (Fig. 9) (Mooers, 1988). The southern part of this terrane is mantled by deposits of the Keewatin-provenance Grantsburg sublobe. As the Rainy lobe receded from the St. Croix moraine, it formed the Brainerd drumlin field and hummocky end moraines (Mooers, 1988), some of which were later mantled with deposits of the St. Louis sublobe (Hobbs and Goebel, 1982). At this time, the margin of both the Superior and Rainy lobes was south of the Laurentian divide; in other words, meltwaters were flowing directly into the Mississippi River watershed.

Continued recession of the Rainy lobe formed the Toimi drumlin field and deposited the Independence till (Wright and others, 1970). At most surface exposures in north-central and northeastern Minnesota, Rainy lobe tills are noncalcareous, although Björck (1990) reported some near-surface Rainy lobe tills in the field trip area as calcareous. Three recently described Rotasonic cores from the northeastern part of the Toimi drumlin field show that the Independence till is locally quite thick, ranging from 39 to 138 feet in thickness. Approximately the upper 30 feet of the Independence till in these cores is noncalcareous, but it is calcareous and contains carbonate pebbles at depth (Hobbs, this volume). We propose that most, if not all, Rainy lobe tills in Minnesota were originally at least slightly calcareous, but where most commonly observed in surface exposures, they are leached.

An alternative hypothesis explaining the noncalcareous nature of near-surface Rainy lobe tills in northeastern Minnesota involves large-scale ice dynamics. While the Rainy/Wadena lobe margin was in southwestern and central Minnesota, the Hudson ice divide (connecting the dome in Labrador and the Keewatin dome) was northeast of the western margin of Paleozoic rocks in the James Bay/Hudson Bay lowlands. In the earliest stages of southwestward flow, the Laurentide Ice Sheet incorporated large amounts of carbonate from a possibly frost-shattered surface. This debris was then elevated above the basal zone and transported into central and southwestern Minnesota. The development of an ice stream in Hudson Strait (Dyke and others, 1989), during recession of the Rainy/Wadena lobe, caused a southwestward shift in the Hudson ice divide (Dredge and Cowan, 1989). By the time the Rainy lobe receded through northeastern Minnesota, only Precambrian rocks were being eroded, thereby diluting any carbonate debris in the ice. In this hypothesis, the lower portion of the Independence till was deposited earlier, when the Hudson ice divide was farther northeast, and the upper part of the Independence till was deposited after the ice divide had been displaced southwest.

The precise age of the Independence till is uncertain, but an age of approximately 15 ka is suggested by two radiocarbon ages on organic sediment from bogs in low areas between Toimi drumlins. Basal radiocarbon ages of 14,690 ± 390 (W-1763) at Weber Lake and 15,850 ± 240 (I-5048) at Kylen Lake have been considered too old (Clayton and Moran, 1982), because in both cases, the dated material was lake silt. Lignite and black shale are absent from this area, but the introduction of old carbon from the calcareous Independence till has not previously been considered. The Independence till is older than 12.1 ka (Lu-2556), but probably not much younger than 15 ka.

Automba phase. The Superior lobe, being thicker and more dynamic than the Rainy lobe, flowed into an area formerly occupied by the Rainy lobe in the Mille Lacs Lake area during the Automba phase (Fig. 10) (Wright, 1972). The marginal position of the Rainy lobe at this time is uncertain, but it was probably in the area now covered by St. Louis sublobe deposits. After the Rainy lobe retreated through the Toimi drumlin field, the Superior lobe advanced to the Highland moraine on the North Shore highland, truncating the Toimi drumlins and forming the Highland flutes (Wright and Watts, 1969).

As the Rainy lobe retreated northeast of the Aitkin area, proglacial lakes developed. Lake Aitkin I occupied the low areas northeast of Aitkin and was dammed on the south by the Superior lobe at the Mille Lacs moraine (Wright, and Watts, 1969). On the west, this lake was probably blocked, in part, by ice-cored Rainy lobe end moraines, and drained into the Mississippi River near Brainerd. The exact path of this meltwater is obscured by younger deposits. Lake Upham I occupied the lowlands in the upper part of the St. Louis River watershed and was probably confluent with Lake Aitkin I (Wright, and Watts, 1969). These lakes were receiving meltwaters from both the Rainy and Superior lobes, with brown-colored sediment supplied by the Rainy lobe and red-colored sediment by the Superior lobe. Little more is known about Lakes Aitkin and Upham I because the St. Louis sublobe covered the entire lake plain, incorporating reddish silt and clay (mapped as Alborn drift on Plate 1).

After the Rainy lobe retreated northeast of the Hibbing area, where there is a three-way divide separating the Mississippi River, Hudson Bay, and Great Lakes watersheds, proglacial lakes developed north of the Giants Range in the Hudson Bay watershed. A group of approximately 75 drumlins were formed at this time between Keewatin and Buhl on the Mesabi range (Wright and Watts, 1969).

The extent to which the Giants Range controlled the marginal shape of the Rainy lobe at this time is not certain, because Rainy lobe end moraines of this age are covered by St. Louis sublobe deposits (Hobbs and Goebel, 1982). It has been suggested (Mooers, personal communication) that the approximate 90-degree junction of the Rainy lobe at the St. Croix moraine and the Wadena lobe at the Itasca moraine was caused by a diversion of flow lines by the Giants Range.

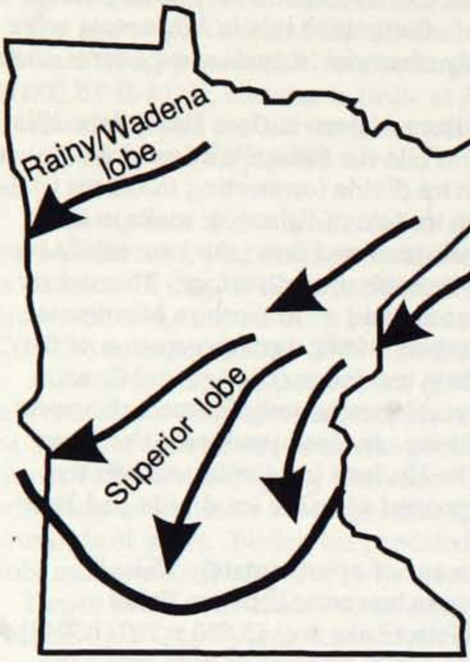


Figure 3. Hawk Creek phase

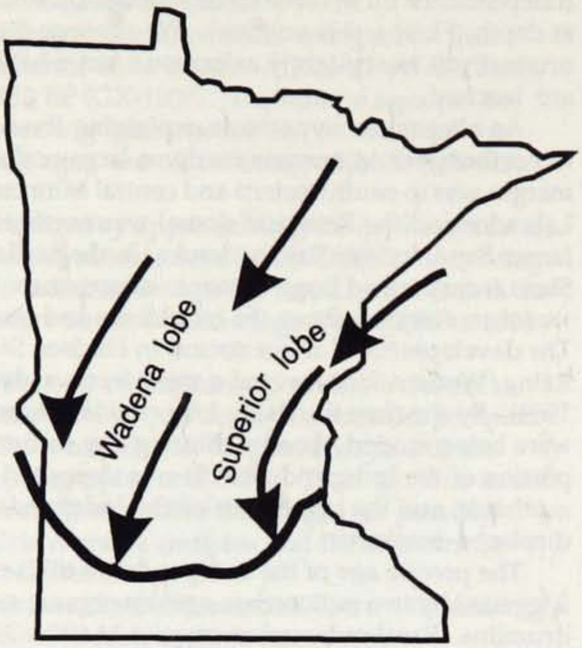


Figure 4. Granite Falls phase

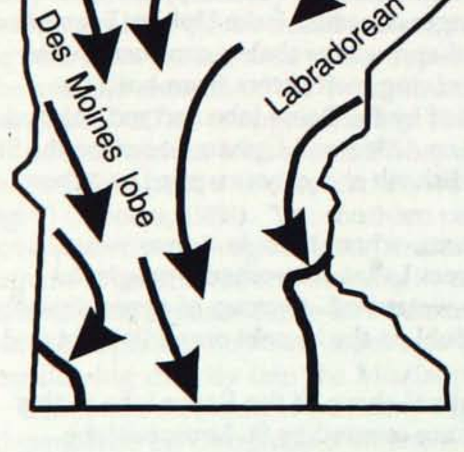


Figure 5. Toronto phase

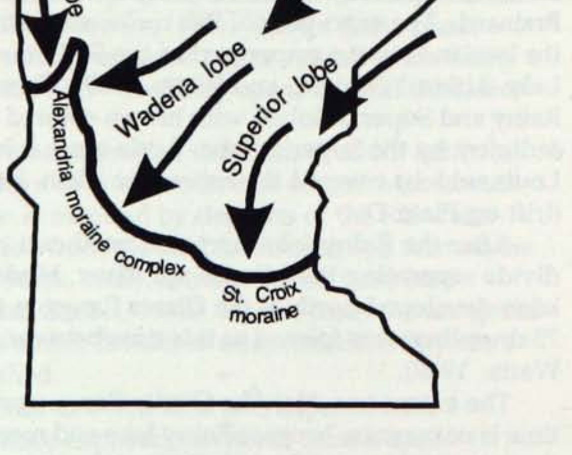


Figure 6. Alexandria phase

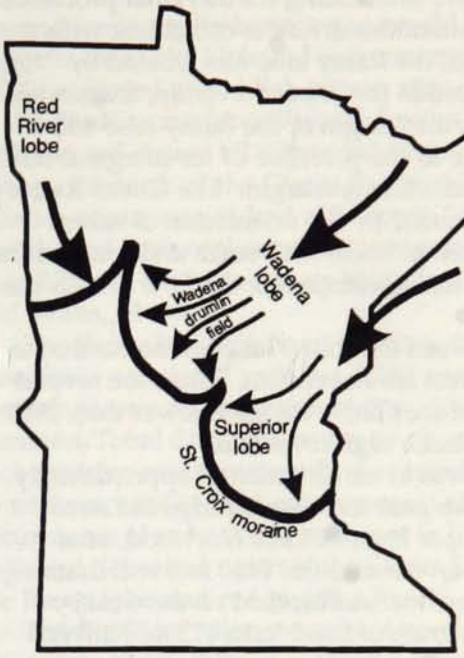


Figure 7. Hewitt phase

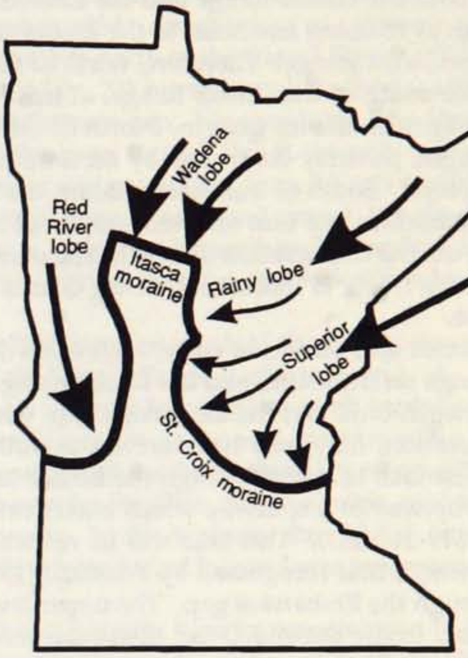


Figure 8. St. Croix phase

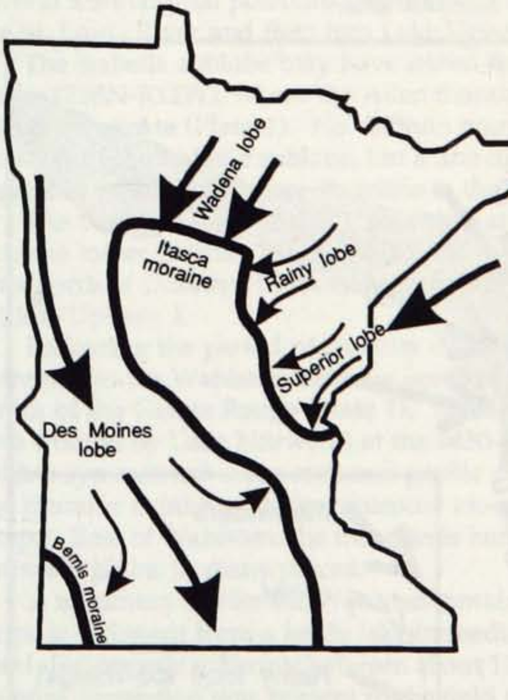


Figure 9. St. Croix phase recession

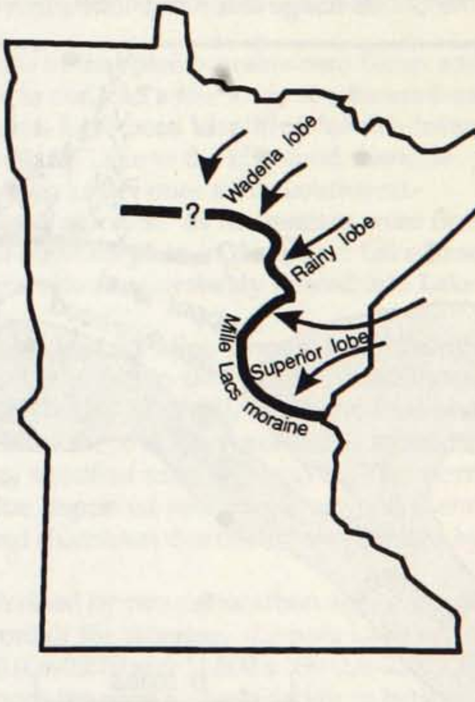


Figure 10. Automba phase

Vermilion phase. Certainly by the time the margin of the Rainy lobe retreated into the field trip area, both the Giants Range and the Laurentian divide were influencing ice-marginal processes. From north of Hibbing northeast to the Embarrass gap, the Laurentian divide is coincident with the crest of the Giants Range. Therefore, north of the Giants Range, the Rainy lobe was fronted by lakes, while south of the Giants Range, at least in the area outside the Alborn overlap, meltwaters flowed away from the ice margin. North of the Giants Range, the margin of the Rainy lobe was fairly straight, possibly controlled by accelerated ablation due to the presence of ice-marginal lakes (Lehr, in prep.). South of the Giants Range, the Rainy lobe had a lobate margin. The Giants Range and the Embarrass gap also affected subglacial drainage, evidenced by the orientation of eskers deposited during deglaciation (Plate 1). The occurrence of Rogen moraine both north and south of the Giants Range (Plate 1) indicates that the Giants Range was creating compressional flow within the Rainy lobe.

The extent and outlets of early, high lakes developed between the Rainy lobe on the north, the Giants Range on the south, and the Koochiching lobe on the west are not certain. There are several places between Buhl and the Embarrass gap, where the crest of the Giants Range is lower than 1610 feet in elevation; they may have served as outlets for these local, high-level lakes.

The first lake to drain through the Embarrass gap outlet was at an elevation of approximately 1475 feet, by way of a spillway which enters the Embarrass gap near the Giants Ridge Ski Area (T59N-R16W-24A&D). This lake will be referred to as the upper level of Lake Norwood, after Lake Norwood, first recognized by Winchell (1901) as having an elevation of 1450 feet and draining south through the Embarrass gap. The upper level of Lake Norwood was blocked on the west by high ground (more than 1470 feet above sea level) in the area south of Sand Lake (T59N-R18W). The margin of the Rainy lobe at this time was probably south of the Big Rice moraine west of the Embarrass gap, possibly crossing the Giants Range at the Embarrass gap (Fig. 11). The north-south-trending eskers south of the Big Rice moraine between Big Rice Lake and the Embarrass gap may have been deposited into the upper level of Lake Norwood at this time. As the margin of the Rainy lobe stood in the Embarrass gap, the resulting re-entrant in the ice margin focused meltwater, burying the ice margin with sand and gravel, and filling the gap. The Koochiching lobe did not have to be blocking low western outlets at this time for there to be a lake at 1475 feet in elevation between the Giants Range and Rainy lobe south of the Big Rice moraine.

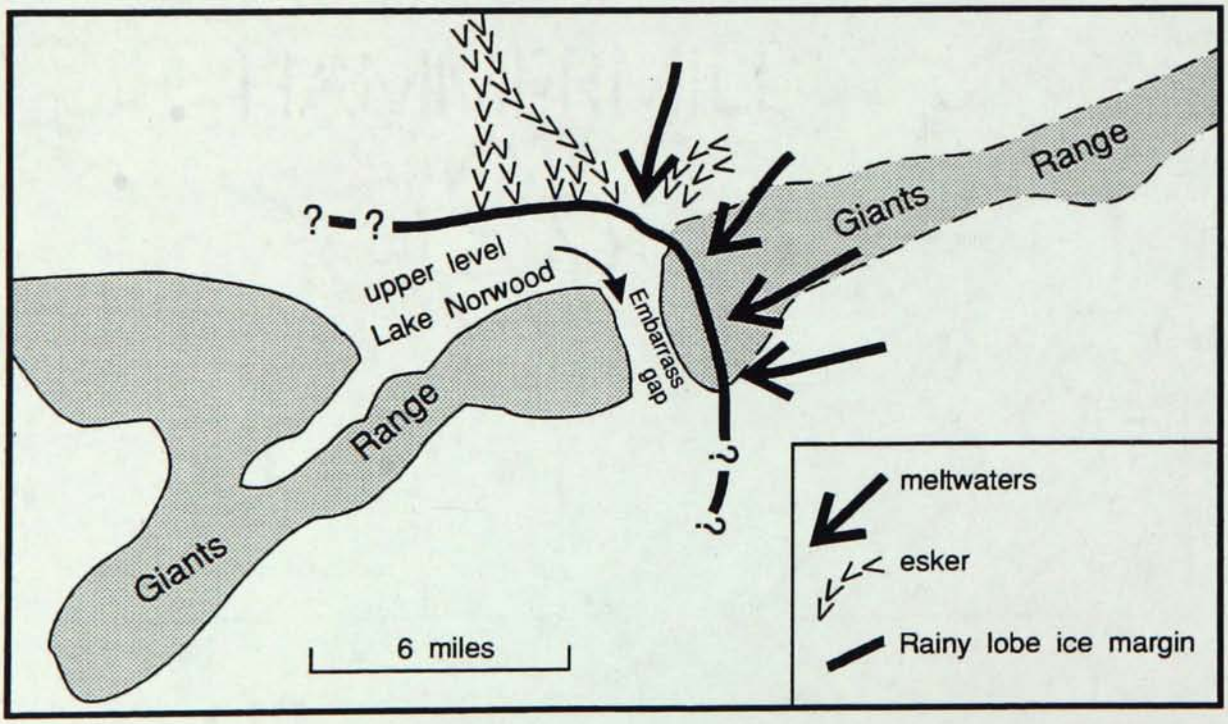


Figure 11. Rainy lobe ice margin in the Embarrass gap and development of the upper level of Lake Norwood

Lake Upham I must have been in existence south of the Giants Range at this time, or the debris-covered ice in the Embarrass gap would have easily been eroded. Another line of evidence also suggests that Lake Upham I was contemporaneous with lakes north of the Giants Range. Björck (1990) reported a "reddish-brown silty-clayey diamicton" (p. 23) overlying glaciofluvial sediments in the Big Rice moraine (Plate 1) 5 miles north of the Embarrass gap. He correlated this diamicton with the red clayey till deposited by the St. Louis sublobe, even though this is the only report of Alborn till north of the Giants Range this far east. Also, a water-well log from 0.5 mile southeast of Björck's occurrence of "red till" reports "red clay" beneath 19 feet of sand and gravel. We suggest that the red color of these sediments comes from sediment deposited by northward overflow from Lake Upham I, which was receiving red sediment-laden meltwaters from the Superior lobe (Wright and Watts, 1969).

The Rainy lobe stabilized for some time at the Big Rice moraine north of the Giants Range. This moraine is correlated with the Allen moraine south of the Giants Range (Lehr, in prep.). A readvance, or a reorientation of flow of the Rainy lobe, is inferred because the Allen moraine truncates Toimi drumlins on the south, and north of the Giants Range the east-west-trending Big Rice moraine cuts across northwest-trending Rogen moraine and northeast-trending eskers (Plate 1). A readvance (of at least minor extent) of the Rainy lobe to the Big Rice moraine helps explain the occurrences of red-colored sediment in the Big Rice moraine. In this scenario, the reddish lacustrine sediment deposited north of the Giants Range by overflow from Lake Upham I was incorporated by the Rainy lobe and redeposited locally.

The Big Rice/Allen moraine is younger than the Toimi drumlin field (approximately 14 ka) and older than 12,100 ± 150 (Lu-2556), a radiocarbon age from basal organic sediment from Heikkilla Lake (Björck, 1990), a kettle in the big Rice moraine (T60N-R12W-30). The actual age of the Big Rice moraine is probably as much as a few thousand years older than 12.1 ka. Tundra vegetation was present in the Heikkilla Lake area until approximately 10.5 ka (Björck, 1990), and therefore ice-block meltout was certainly slowed (Florin and Wright, 1969).

Tracing the Big Rice moraine through the Embarrass area to the Allen moraine south of the Giant Range is difficult. Ice-contact fans deposited into the upper level of Lake Norwood mark several ice-marginal positions. Meltwaters from the Rainy lobe at the Allen moraine flowed into the St. Louis River and then into Lake Upham I.

The Isabella sublobe may have joined the Rainy lobe at the Allen moraine near Stone and Big Lakes (T58N-R12W), where the Allen moraine appears to end and a few long, southwest-trending eskers terminate (Plate 1). No definite marginal deposits have been identified for this inferred position of the Isabella sublobe, but a line drawn from Stone Lake to the Highland moraine separates an area of shorter drumlins to the northeast from longer ones to the southwest.

The Superior lobe, at this time, stood at the Highland moraine. Its meltwaters were flowing into the lower Cloquet River and depositing the broad outwash plain in the Island Lake Reservoir area north of Duluth (Hobbs and Goebel, 1982). These meltwaters probably flowed into Lake Aitkin-Upham I.

Following the period of stability marked by the Big Rice and Allen moraines, the Rainy lobe retreated to the Wahlsten moraine north of the Giants Range and to the Wampus Lake moraine south of the Giants Range (Plate 1). West of Wahlsten (T61N-R15W-29), the Rainy lobe margin was fronted by Lake Norwood at the 1450-foot level. Here the Wahlsten moraine is a smooth ridge with a symmetrical cross-sectional profile composed of stratified sand and gravel. This portion of the moraine is inferred to be coalesced ice-contact deltas deposited into Lake Norwood (Lehr, in prep.). East of Wahlsten, the moraine is hummocky and diamicton dominated and fronted by outwash plains in many places.

A minimum age for the Wahlsten moraine is constrained by two radiocarbon ages on basal organic sediment from a kettle lake immediately in front of the moraine. Lempia Lake began receiving organic sediment between about 12,050 ± 240 (Lu-2555) and 11,500 ± 550 (Lu-2502) BP. Tundra vegetation was present in the field trip area from the time of deglaciation to between 10.5 ka (Huber, this volume) and 10 ka (Wright and Watts, 1969). The cold climatic conditions suggested by the pollen record may have enabled permafrost to persist in the area until after 12 ka. If permafrost was not present this late, the cold climate certainly inhibited meltout of buried ice (Florin and Wright, 1969). Therefore the actual age of the Wahlsten moraine must be older than 12.1 ka, possibly 13 ka.

Correlation of the Wahlsten moraine across the Giants Range to the Wampus Lake moraine is even more tenuous than the correlation of the Big Rice and Allen moraines. The eastern end of the Wahlsten moraine is covered by younger outwash from the Vermilion moraine and, the Wahlsten ice margin was in Lake Norwood at the re-entrant in the Rainy lobe north of the Giants Range. Meltwaters from the Wampus Lake moraine, south of the Giants Range, followed the Partridge River into the St. Louis River and then into Lake Upham I.

By the time the Rainy lobe stabilized at the Wahlsten moraine, the level of Lake Norwood had dropped from 1475 to 1450 feet. The lake continued to use the Embarrass gap outlet, where there are terraces at approximately 1450 feet in elevation. There is also a boulder lag on the side of the Giants Range in the Embarrass gap at approximately 1450 feet. In the area of Embarrass, there are commonly boulder concentrations at approximately 1450 feet in elevation which are interpreted to be wave-washed shorelines of Lake Norwood (Lehr, in prep.). As mentioned above, Lake Upham I must have had approximately the same level as Lake Norwood at this time, or the ice-cored Embarrass gap would have been eroded to levels below 1450 feet.

Lake Norwood at the 1450-foot level was blocked on the south by the northern slope of the Giants Range and on the north by the Rainy lobe at the Wahlsten moraine. To the west there now are areas lower than 1450 feet in elevation. Either Lake Norwood was held in by stagnant ice, or the Koochiching lobe was at least as far east as Swan Lake (near Pengilly, T56N-R22W), blocking a gap in the Giants Range lower than 1450 feet.

As the Rainy lobe retreated through the northern part of the Toimi drumlin field, outwash from the Superior lobe at the Highland moraine was deposited along the Stony River. The Stony River at this time, probably crossed the Laurentian divide in what is now a peatland southwest of Sand Lake (T59N-R11W). At some point, these meltwaters became ponded in the upper Stony River basin, because the advance of the Isabella sublobe to the Outer moraine incorporated a considerable amount of reddish silt, in addition to Superior lobe sand and gravel. The till of the Outer and Inner moraine of the Isabella sublobe is thus quite similar to till of the Superior lobe (Friedman, 1981).

The Outer moraine may be slightly younger than the Wampus Lake moraine, because it appears to truncate the Wampus Lake moraine. If the Wampus Lake moraine correlates with the Wahlsten moraine, the Outer moraine may have been deposited approximately 13 ka. The Inner moraine appears to be truncated by the Vermilion moraine, and therefore it is older than approximately 12.5 ka.

As the Isabella sublobe retreated from the Outer to the Inner moraine, lower meltwater outlets were opened to the northwest and west. Each recessional ice position is marked by a meltwater channel or a band of outwash (Hobbs and others, 1988). One of these Superior lobe valley trains can be traced through the gap between the Vermilion moraine and the Giants Range into the Babbitt area (Stark, 1977). These Superior lobe meltwaters eventually entered Lake Norwood. At the time the Isabella sublobe was at the Outer and Inner moraines, the Superior lobe was at the Highland moraine.

The Rainy lobe probably retreated somewhat before readvancing to the Vermilion moraine. A retreat and readvance is inferred only because the Vermilion moraine is oriented northwest-southeast compared to east-west for the Wahlsten and Big Rice moraines. Alternatively, the reorientation of the ice margin at the Vermilion moraine may represent a shift to a southwestward flow direction, possibly caused by a lowering of the glacier's profile by accelerated ablation in the areas to the west where the Rainy lobe was fronted by a lake (Lehr, in prep.).

From southeast of Soudan (T62N-R15W-36D) northwestward to Nett Lake, the Rainy lobe was fronted by a lake. In this area, the Vermilion moraine is composed of sorted sand and gravel with large-scale foreset bedding. Lenses of coarse, poorly sorted gravel are interbedded with erosional lower contacts. The moraine is generally less than one-half a mile wide, has a symmetrical cross-sectional profile, and is remarkably linear. The proximal ice-contact face is fairly straight, while the distal margin is distinctly scalloped. Where the moraine is narrow, the upper surface is commonly flat and uncollapsed, with many segments 1450 to 1460 feet in elevation. The wider parts of the Vermilion moraine are pitted and generally higher than 1460 feet in elevation.

A series of coalesced ice-contact deltas is suggested by the predominance of foreset-bedded sand and gravel, a scalloped distal margin, and the presence of flat-topped segments at approximately 1460 feet in elevation in the Vermilion moraine from southeast of Soudan to Nett Lake (Lehr and Matsch, 1987). These flat-topped segments represent the water level in Lake Norwood to which the deltas were built. Sediment was transported to the ice margin primarily by subglacial streams, as evidenced by numerous sharp-crested eskers north of the moraine. Delivery of some sediment to the ice margin by supraglacial streams and mass wasting is suggested by the higher and wider hummocky portions of the Vermilion moraine.

As the Rainy lobe retreated from the Wahlsten moraine, extensive low areas were uncovered to the west. At this time, either the Koochiching lobe was at least as far east as Swan Lake (near Pengilly, T56N-R22W), or Lake Norwood drained. The early, high lake that developed in front of Keewatin ice north of the Giants Range has been referred to as Lake Koochiching, a precursor to Lake Agassiz (Hobbs, 1983).

While the Rainy lobe was at the Vermilion moraine, Lake Norwood expanded westward, merging with Lake Koochiching, apparently maintaining the 1450-foot level. Field evidence suggests that Lake Norwood was not receiving meltwaters from the Koochiching lobe at this time, because in the eastern part of the Lake Norwood basin (Babbitt-Embarrass area), no Keewatin lacustrine sediments have been identified. Several exposures were examined in the Babbitt and Embarrass areas between 1430 and 1450 feet in elevation and all show only Rainy lobe lacustrine sediment (Lehr, in prep.). One possible explanation for the lack of Keewatin lacustrine sediment in the Babbitt-Embarrass area is that currents did not distribute Keewatin meltwaters into the eastern part of the Lake Norwood basin. Furthermore, meltwater was also entering the eastern part of the Lake Norwood basin while the Rainy lobe was at the Vermilion moraine, both directly from the ice margin and as meltwater streams, and this influx of sediment-laden meltwaters may have prevented the circulation of Keewatin-derived meltwaters into the eastern part of the Lake Norwood basin.

From Soudan, eastward to the junction with the Isabella moraine, the Vermilion moraine is slightly lobate, and nearly in contact with the northeastern of the end of the Giants Range (T60N-R12W-09). In the area of Eagles Nest, Bear Head and Bear Island Lakes, the Vermilion moraine is hummocky and diamicton-dominated. Near the area where the Rainy lobe was in contact with the Giants Range, the Vermilion moraine has a gentle proximal slope, a steep distal slope, and is composed of silty, sandy till. This segment of the Vermilion moraine is interpreted to be a push moraine (Lehr and Matsch, 1987).

The age of the Vermilion moraine can be inferred only from relative dating, because no radiocarbon ages are associated with this moraine. The Vermilion phase was interpreted by Wright (1972) to be contemporaneous with the Automba phase of the Superior lobe. Because there are several Rainy lobe recessional moraines between the St. Croix and Vermilion moraines (Pleasant Lake, Stewart Lake, Outing, Sandy Lake, Big Rice, and Wahlsten moraines), it is unlikely that the Vermilion moraine correlates with the Mille Lacs moraine of the Superior lobe (Mooers, 1988). The western part of the Vermilion moraine, in the vicinity of Nett Lake, was overridden by the most extensive Koochiching lobe advance (Martin and others, 1988). This advance is correlated with the Alborn advance of the St. Louis sublobe at about 12 ka. Therefore the age of the Vermilion moraine is older, possibly 12.5 ka.

The Vermilion moraine correlates with the Isabella moraine of the Isabella sublobe. Northeast of the Isabella moraine is an area of large Rogen moraine ridges (Plate 1). By the time the Isabella sublobe stabilized at the Isabella moraine, the till being deposited was increasingly more like the Rainy lobe till in color and stone content. Even so, at the Rogen moraine site (Stop 8), the till has a red-pebble component reminiscent of Superior lobe deposits (Friedman, 1981). Certainly, much of the red color in the tills of the Outer and Inner moraines comes from Superior lobe meltwaters, but the red pebbles in Isabella sublobe tills to the northeast could have been derived from the granophyre and North Shore volcanics mapped (Green, 1982) in the Alton and Brule Lakes area immediately up-ice from the Isabella moraine.

Two large esker systems of the Superior lobe converging in the area around Dumbbell Lake form a large kame complex, marking the point where the Isabella moraine merges with the Highland moraine of the Superior lobe (Hobbs and others, 1988).

As the Rainy lobe retreated from the Vermilion moraine, Superior lobe meltwaters crossed a low area in the moraine where it is bisected by the Stony River (T60N-R11W-08C). Superior lobe outwash can be traced both behind and in front of the Vermilion moraine into the Babbitt area, suggesting that while the Rainy lobe was retreating from the area for the last time, the Superior lobe was still thick enough for its meltwaters to flow northwest of the North Shore highland and into the area north of the Mesabi range. The Superior lobe must have retreated from the Highland moraine soon after the Rainy lobe withdrew from the Vermilion moraine, because Superior lobe outwash is found only immediately north of the Vermilion moraine in the Birch Lake area. No Superior lobe outwash has been reported from the lower areas farther to the north.

According to this chronology, the Superior lobe stood at the Highland moraine from the time the Rainy lobe vacated the Toimi drumlin field, approximately 14 to 15 ka, until after the Rainy lobe retreated from the Vermilion moraine about 12.5 ka. The combination of this long period of stability and lateral flow out of the Lake Superior basin, evidenced by the Highland flutes, produced the massive Highland moraine.

With the retreat of Rainy lobe, Superior lobe, and Isabella sublobe ice approximately 12.5 ka, the field trip area was deglaciated for the first time since about 30 ka. This 17,500-year period of continuous glacial cover of Labradoran ice is at least partly responsible for the extensive areas of scoured bedrock and the general lack of older glacigenic deposits in the field trip area.

Alborn phase. In the past, it has been assumed that Keewatin ice north of the Mesabi range (Koochiching lobe) and south of the Mesabi range (St. Louis sublobe) advanced synchronously (Winter, 1971). The Keewatin Koochiching lobe may have advanced into the low areas north of the western Mesabi range as many as three times in latest Wisconsinan time (Martin and others, 1991), while the St. Louis sublobe probably advanced only once. The chronology of the Koochiching lobe is poorly constrained, because only one radiocarbon age (11,120 ± 250; Y-1782) is associated with these advances. This age is from wood detritus at the base of a core from Myrtle Lake (Stuiver, 1969) in southeastern Koochiching County (T63N-R24W). Myrtle Lake probably originated as a kettle, and thus the significance of this date is uncertain. The first advance of the Koochiching lobe may correlate with the advance of the St. Louis sublobe and with the advance of the Red River lobe to the Big Stone moraine.

The St. Louis sublobe of the Red River lobe advanced southeastward into the Lake Aitkin-Upham I basin south of the Giants Range, reaching a point only 22 miles from Lake Superior (Hobbs and Goebel, 1982). The St. Louis sublobe incorporated reddish lacustrine sediment from Lake Aitkin-Upham I and deposited the red, clayey Alborn till (Baker, 1964). It is unclear whether Lake Aitkin-Upham I had drained by this time, or whether the glacier advanced into the lake, displacing the water.

Radiocarbon ages associated with the St. Louis sublobe are in conflict. Wood fragments from peat buried in the upper part of Lake Aitkin II sediment at the main Aitkin site (Farnham and others, 1964) yielded radiocarbon ages of 11,560 ± 400 BP (W-1141) and 11,710 ± 325 BP (W-502) and provide a minimum age for Lake Aitkin-Upham II, which formed after the St. Louis sublobe advance. An age of 10,620 ± 400 (W-574) from buried peat 2 miles to the west suggests that the lake drained later, although this peat may not correlate with peat at the main Aitkin site

Two radiocarbon ages (11,330 ± 350 BP; W-827 and 11,100 ± 400 BP; W-1140) from wood enclosed in the Alborn till at the Mariska mine near Gilbert (T58N-R17W-24DC) conflict with the dates from the Aitkin site. These ages have been rejected as too young (Wright and Watts, 1969), because the Red River lobe had retreated by this time, allowing Lake Agassiz to form in the Red River Valley (Clayton and Moran, 1982). In addition to this argument, the following explanation is offered. The geologic setting at the Mariska mine appears, from examination of air photos, to be a Rainy lobe esker complex that is mantled with reddish-colored clayey till (Farnham and others, 1964). Stagnant ice persisted in the Embarrass gap area, just 10 miles northeast of the Mariska mine, until approximately 10 ka (Lu-2504, Lu-2506, Lu-2507). Therefore, the apparently young ages can be explained as dating the meltout of underlying Rainy lobe ice and burial by flow till of trees growing on the debris-covered ice.

We accept the older dates from the main Aitkin site (W-502 and W-1141), as others have (Clayton and Moran, 1982; Wright and Watts, 1969), as a minimum age for the Alborn advance. Therefore the St. Louis sublobe advance may have occurred about 12 ka (Wright and Watts, 1969) or a few hundred years earlier.

As the St. Louis sublobe stood at the Culver moraine, meltwater streams flowed south, merging with meltwater streams from the Superior lobe at the Nickerson-Thomson moraine. This demonstrates that the Alborn phase of the St. Louis sublobe was contemporaneous with the Nickerson phase of the Superior lobe (Wright and Watts, 1969).

The St. Louis sublobe probably stagnated soon after advancing. As the cleaner ice in the center of the lobe melted, Lake Aitkin-Upham II formed, held in by ice-cored moraines (Hobbs, 1983). This lake drained through a variety of outlets to the south, both directly into the Mississippi River and into the St. Croix River via several channels that pass around the Nickerson-Thomson moraine (Wright and Watts, 1969; Hobbs, 1983). Lake Aitkin-Upham II had drained by about 11.6 ka (W-502 and W-1141).

Embarrass phase. Lake Koochiching/Norwood maintained the 1450-foot level while the Koochiching lobe was at its maximum somewhere near the western St. Louis County line (Martin and others, 1988), and the St. Louis sublobe was at its maximum south of the Giants Range. Meltwaters flowed southward through the Embarrass gap and then around the eastern margin of the St. Louis sublobe into the Us-Kab-Wan-Ka, Cloquet and St. Louis Rivers, around the Superior lobe, and into the St. Croix River (Hobbs, 1983). Upon stagnation of the St. Louis sublobe, and retreat of the Koochiching lobe, the level of Lake Koochiching/Norwood dropped from 1450 to the early Mizpah level of 1430 feet (Hobbs, 1983). At Togo, in northeastern Itasca County, the highest wave-washed surfaces are at about 1430 feet (Hobbs, 1983), suggesting that this area was ice-covered when Lake Koochiching/Norwood was at the 1450 foot level. Drainage from the early Mizpah stage of Lake Koochiching crossed the Laurentian divide approximately six miles north of Giants Ridge (T60N-R15W-30, 31, 32), then flowed south through the Embarrass gap where there are terraces at approximately 1430 feet. This water must have drained into an early, high stage of Lake Upham II (Hobbs, 1983) and eventually into the Mississippi River via the St. Croix River.

With continued retreat of the Koochiching lobe and establishment of lower levels of Lake Aitkin-Upham II, the level of Lake Koochiching dropped to the later Mizpah stage of approximately 1400 feet (Hobbs, 1983). This level is marked by strandlines near Mizpah (T62N-R28W) at approximately 1400 feet and by terraces in the Embarrass gap at approximately 1400 feet. The drainage of the later Mizpah stage of Lake Koochiching followed the same path through the Embarrass gap as drainage in the early Mizpah stage, although the land in the area of the Laurentian divide (T60-R15W-30, 31, 32) is presently approximately 1425 feet. It is proposed that at least 25 feet of peat has been deposited in this area. Thick accumulations of peat are known to form near watersheds on former lake plains in other parts of northern Minnesota (Severson and others, 1980).

Cass phase. Continued recession of the Koochiching lobe uncovered the Prairie River outlet near Grand Rapids, lowering Lake Koochiching to the Gemmell stage of about 1350 feet (Clayton, 1983; Hobbs, 1983). While Lake Koochiching stood at the Gemmell level, water from Lake Climax, at the south end of the Red River lobe, entered the lake via the McIntosh channel and deposited a delta near Trail (Clayton, 1983; Hobbs, 1983). Therefore, the River Warren outlet had not yet developed. These events help define the early Cass phase of Lake Agassiz, approximately 11.6 to 11.7 ka (Fenton and others, 1983).

As Lake Koochiching dropped from the Mizpah to Gemmell level approximately 11.6 ka, significant drainage of glacial meltwaters through the Embarrass gap ceased. Final meltout of stagnant ice in the Embarrass gap is recorded by radiocarbon ages on basal organic sediment from Sabin Lake, which currently occupies the northern part of the Embarrass gap at elevations lower than any known lake drainage level. Ages of 10,230 ± 120 (Lu-2506) and 10,320 ± 170 (Lu-2507) suggest that final meltout of stagnant ice in the Embarrass gap post-dates the entire lake-drainage history of the Embarrass gap. A small lake just north of the Embarrass gap did not begin receiving organic sediment until 9.5 ka (9,510 ± 90; Lu-2504).

More rapid rates of uplift in the Lake Koochiching basin than in the Lake Climax basin resulted in a reversal of flow in the McIntosh channel, and with melting of stagnant ice in the Big Stone moraine, the River Warren outlet became established (Fenton and others, 1983; Hobbs, 1983). This lowered Lake Climax to the Herman level and Lake Koochiching to the Trail level, and the Prairie River outlet was abandoned (Hobbs, 1983). Ice recession in the area of the McIntosh channel uncovered lower ground and Lakes Climax and Koochiching merged to form Lake Agassiz at, or above the Herman level, marking the end of the Cass phase and the beginning of the Lockhart phase of Lake Agassiz (Fenton and others, 1983).

Lockhart phase. The history of Lake Koochiching outlined above occurred between the time the Rainy lobe receded from the Vermilion moraine (approximately 12.5 ka) and approximately 11.6 ka, the beginning of the Lockhart phase. During this time, the Rainy lobe was somewhere between the International Boundary and the Lake Nipigon area, blocking the eastern outlets of Lake Agassiz, possibly at the Eagle-Finlayson-Brule moraine (Teller and Thorleifson, 1983).

Moorhead phase. Approximately 11 ka, the Rainy lobe retreated north of the Lake Nipigon area (Fenton and others, 1983) and the Superior lobe may have retreated north of the Lake Superior basin (Clayton, 1983). This retreat opened outlets to Lake Superior that were lower than the River Warren outlet and initiated the fall in Lake Agassiz from the Campbell level to the Ojata level (Clayton, 1983). This event marks the end of the Lockhart phase and the beginning of the Moorhead phase of Lake Agassiz.

Emerson phase. A readvance of the Rainy lobe to the Hartman-Dog Lake moraine and of the Superior lobe to the Marks moraine approximately 9.9 ka blocked the eastern outlets, and Lake Agassiz rose again to the Campbell level and drained through the River Warren outlet (Fenton and others, 1983). This event marks the beginning of the Emerson phase of Lake Agassiz.

The Emerson phase lasted until approximately 9.5 ka, when the Rainy and Superior lobes retreated north of the Lake Nipigon area (Fenton and others, 1983). Soon after this retreat, the Rainy lobe readvanced to the Nipigon moraine, depositing till rich in Paleozoic carbonate derived from the James Bay lowlands (Zoltai, 1965; Karrow and Geddes, 1987).

ROADLOG AND STOP DESCRIPTIONS — DAY 1

Saturday, May 16, 1992

Miles

0.0 Start roadlog at Giants Ridge Ski area (St. Louis County, T59N-R15W-19C). Go north (left) at main entrance to ski area on St. Louis Co. Rd. 138 (paved road). We begin the trip in the St. Louis River watershed, the largest tributary in the western Lake Superior basin. The Laurentian divide is approximately 2 miles northwest of Giants Ridge. North of the Laurentian divide, waters drain into Hudson Bay.

0.4 Pavement ends. Driving on hummocky supraglacial sediment deposited by the Rainy lobe.

1.4 Driving on Rainy lobe ice-contact fluvial sand and gravel.

3.2 Junction with St. Louis Co. Rd 416. Continue north on St. Louis Co. Rd. 138.

5.4 Lake Norwood plain. Driving approximately on the crest of the Laurentian divide.

5.9 Stop sign. This is the point at which the water draining Lake Koochiching at the Mizpah stage (1430 to 1400 feet) crossed the Laurentian divide from the Pike River (Hudson Bay watershed) into the Embarrass River (Lake Superior watershed). Turn right (east) onto St. Louis Co. Rd. 21 (paved road).

6.0 Cross the Laurentian divide. Back in the Lake Superior watershed.

6.8 Rainy lobe subglacial till plain with Rogen moraine.

7.8 Junction with Minnesota Highway 135 (stop sign). Continue east on St. Louis Co. Rd. 21.

9.0 Enter Lake Norwood plain.

9.4 Island in Lake Norwood plain.

10.5 Town of Embarrass.

10.9 Ice-contact outwash fan deposited by the Rainy lobe into Lake Norwood.

11.6 Lake Norwood plain.

12.6 Junction with St. Louis Co. Rd. 26. Continue east on Co. Rd. 21.

13.1 Bear Creek.

14.7 Streamlined outcrops of Archean gneiss on left (north).

15.4 Rise onto former bedrock peninsula in Lake Norwood.

15.5 Outcrop of Archean gneiss on left.

15.6 Lake Norwood plain.

16.0 Camp Eight Creek.

17.8 Southward-sloping Rainy lobe outwash plain to north (left), entered Lake Norwood here.

19.0 Bedrock high.

19.6 Outcrop of Archean gneiss on left (north).

20.1 Crest of lake-modified Rainy lobe esker.

20.2 Lake Norwood plain.

21.2 Rise onto Babbitt/Benville outwash plain. This is partly Rainy lobe and partly Superior lobe in origin.

22.5 Cross the Laurentian divide. We are now in the Hudson Bay watershed.

24.5 Junction with St. Louis Co. Rd. 70, continue straight (east) on St. Louis Co. Rd. 70 into Babbitt. Driving on Babbitt/Benville outwash plain.

26.3 Steep, rocky distal slope of the Vermilion moraine on left (north). This portion of the Vermilion moraine is interpreted to be a push moraine composed of subglacial till.

26.8 Pass through a gap in the Vermilion moraine. This gap served as a pathway for Superior lobe meltwater immediately following retreat of the Rainy lobe from this portion of the Vermilion moraine. Note the gentle proximal slope of the Vermilion moraine to the right.

28.5 Low exposure of Superior-lobe fluvial sand and gravel on left (north).

28.8 Rising onto the gentle proximal slope of the Vermilion moraine (push moraine segment).

29.8 Enter the gap between the Giants Range and the Vermilion moraine. This gap served as lower (1535-foot) outlet for Lake Dunka, which was dammed on the south by the Laurentian divide and on the north by the Rainy lobe at the Vermilion moraine.

30.1 Dunka River on left (north).

30.4 Turn left (north) into LTV Steel's Dunka mine (gravel road). This is a private mining road owned by LTV Steel.

30.6 Exposure in the steep distal slope of Vermilion moraine on right (east).

31.3 Taconite train loading station on right (east).

31.9 Mining railroad crossing. Turn right (east) on mine road.

32.2 Yield sign at "T" intersection. Turn right (south) on mine road.

32.7 Stop sign at road intersection. Continue straight on center choice of roads (small fleet road).

33.4 **STOP 1:** Dunka Pit section. St. Louis County, T60N-R12W-10BCBA (Fig. 12).

THIS IS A POTENTIALLY DANGEROUS SECTION. PLEASE BE AWARE OF WHAT IS HAPPENING ABOVE YOU AT ALL TIMES. IF YOU ARE JUST CONVERSING, PLEASE STAND WELL BACK OF THE BASE OF THE SECTION.

Figure 12. STOP 1: Dunka Pit section, St. Louis County, T60N-R12W-10BCBA

This section is located on the proximal slope of the Vermilion moraine (late Wisconsinan Rainy lobe). The Vermilion moraine in this area has an asymmetrical cross-sectional profile, with a steep distal slope and a gentle proximal slope (Fig. 12). The sediment in this portion of the moraine is rocky, silty, sandy till interpreted to be subglacial in origin. This segment of the Vermilion moraine is interpreted to be a push moraine (Lehr and Matsch, 1987), as evidenced by the asymmetrical cross-sectional profile and the presence of till with a silty, sandy matrix (Andrews, 1975).

The section described below is located at approximately the midpoint along a large exposure in the southwestern part of the south pit at the Dunka mine. The lowest portion of the section appears to occupy a swale in the bedrock. This section is in the same general area from which Stark (1977) described the Dunka pit till, a dark-colored, silty, sandy, calcareous till. This unit is not visible at this time at this section, but may be within the covered portion of this section. This till probably correlates with one of Winter's (1971) "basal tills."

Another interesting point about this section is the presence of Paleozoic carbonate clasts and a calcareous matrix in the lower unit. In the past, all carbonate found in glacial deposits of northern Minnesota was inferred to have been derived from the Winnipeg lowlands to the northwest. The reasoning was that the Rainy lobe deposits of northeastern Minnesota appeared to be noncalcareous. Recent drilling and mapping has revealed that carbonate is a common constituent of Rainy lobe tills, both pre-Wisconsinan and late Wisconsinan (Martin and others, 1988, 1989, 1991; Björck, 1990; Hobbs, this volume). The carbonate was probably transported from the Hudson Bay lowlands.

Interval (feet)	Description
0 to 16	Oxidized fine to medium sand containing some boulders. Bedding is subhorizontal in places, and massive in other places. This unit is interpreted to be lacustrine sediment deposited between the retreating Rainy lobe and the moraine crest. The boulders are interpreted to have been elevated into the sand from the underlying till by tree-throw, frost, and possibly permafrost processes. Alternatively, some boulders may have been deposited from the ice margin by gravity.
16 to 26	Very rocky, loamy sand diamicton (Fig. 13), grayish brown (2.5Y 5/2). Numerous laminae of sorted sand. Few small, diffuse iron stains in the range of 10YR. Clast types dominated by granitiod pebbles, cobbles and boulders. Also some basalt, diabase (possibly locally derived hornfels), greenstone, schist and gneiss. No Paleozoic sandstone or carbonate clasts in this interval. Also no Superior lobe rock types present. This unit is interpreted to be the late Wisconsinan Rainy lobe till that comprises the push moraine segment of the Vermilion moraine (Lehr and Matsch, 1987). This unit corresponds to the "bouldery till" of Winter (1971; Winter and others, 1973).
26 to 40	Very rocky, loamy sand diamicton (Fig. 13), noncalcareous, with interbedded sorted sand. The top of this interval (26 to 29 feet) is brown (10YR 5/3) with yellowish red (5YR 4/8) mottles, which are larger and more abundant at the top of this interval. A gradational color change from brown (10YR) to light olive brown (2.5Y 5/3) occurs at approximately 29 feet. Although, at the measured section this till is noncalcareous, other portions of this interval lateral to the measured section are calcareous. This unit is interpreted to be a pre-late Wisconsinan oxidized till of northeastern provenance, possibly of supraglacial origin.
40 to 44	Interbedded silty sand, silt, and pebbly sand containing occasional cobbles and boulders, calcareous, cross-bedded. Bedding is locally collapsed. Color of this interval ranges from light yellowish brown (2.5Y 6/3) to light olive brown (2.5Y 5/4). Carbonate pebbles present. Note that this stratified sediment is texturally very similar to the tills at this section (Fig. 13). This interval is interpreted to be pre-late Wisconsinan oxidized, collapsed fluvial sediment of northeastern provenance, with the carbonate derived from the Hudson Bay lowlands.

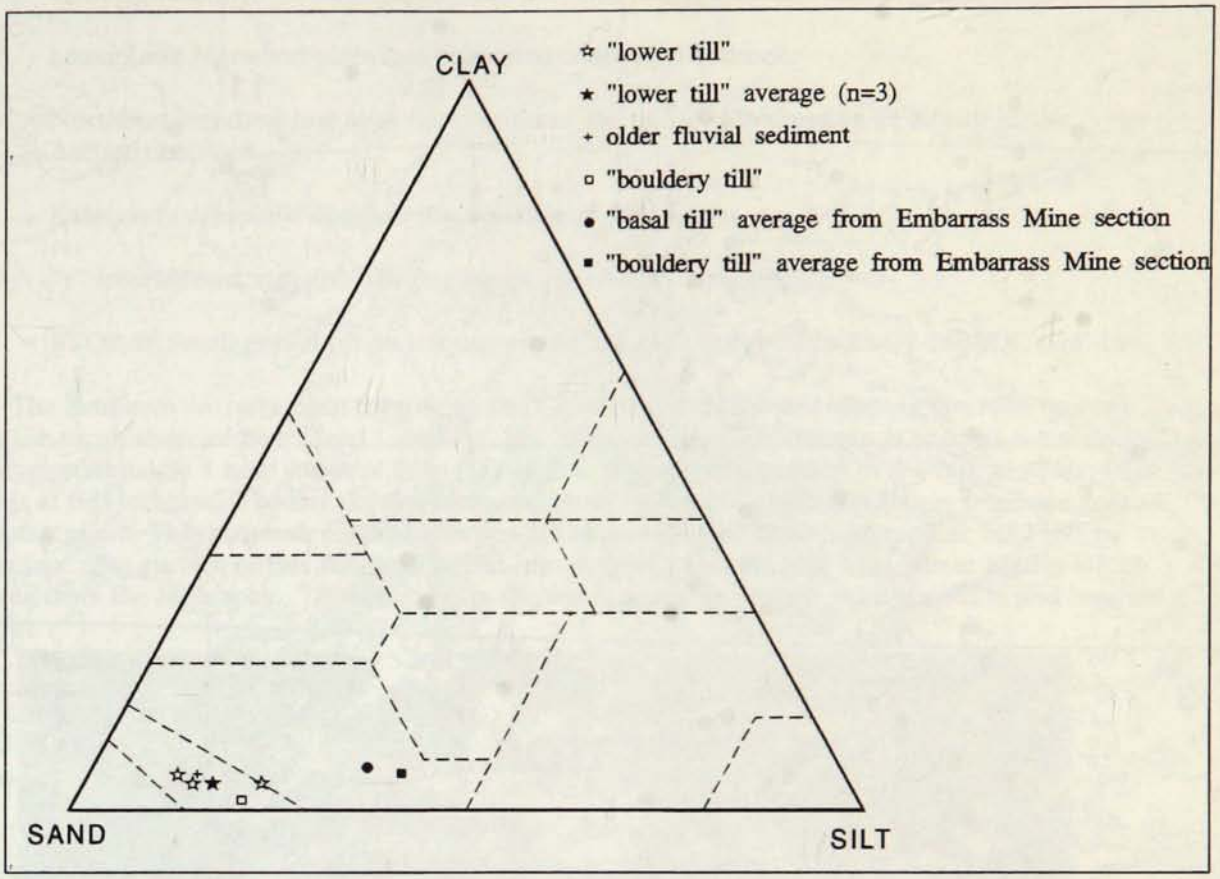


Figure 13. Matrix textures from the Dunka Pit Section

Turn around and retrace route out of Dunka mine.

34.0 mine road intersection. Follow center road.

34.1 Yield sign. Go straight, staying left at "Y."

34.5 mine road intersection. Turn left.

34.9 Junction with mine entrance road and stop sign at railroad crossing. Turn left (south).

36.3 Stop sign at mine entrance. Turn right (north) on Superior National Forest Rd. 112 (unmarked paved road). Vermilion moraine on right. Continue on St. Louis Co. Rd. 70 around Babbitt.

42.1 Junction with St. Louis Co. Rd. 21 (paved road). Proceed straight (west) on Co. Rd. 21. Driving on the Babbitt/Benville outwash plain.

44.1 Cross the Laurentian divide. We are now in the Lake Superior watershed.

Figure 14. STOP 2: St. Louis County, T61N-R14W-26BBDC. Numbers refer to largest clast present (inches)—mean of 50 values at each locality

49.6 Turn right (north) on St. Louis Co. Rd. 360, also called Pulkinen Road (gravel road).

50.0 Leave Lake Norwood plain and enter area of scoured bedrock.

50.3 Northeast-trending low area interpreted to the surficial expression of a fault in the Archean bedrock.

51.4 Enter outwash plain distal to the fan-shaped landform.

52.5 "Y" intersection, stay left. Beginning of fan-shaped landform.

54.2 **STOP 2**: Small gravel pit on left (west). St. Louis County, T61N-R14W-26BBDC (Fig. 14).

The landform we have been driving on for 1.7 miles is a southward-sloping fan with its apex near the south shore of Bear Head Lake (Fig. 15). Superimposed on this fan is another fan with its apex approximately 1 mile south of Bear Head Lake. The highest portion of the fan, at about 1600 feet, is at this location. The fan slopes southward from 1600 feet to 1500 feet where it merges into an outwash plain. This outwash plain terminates at the shoreline of Lake Norwood at 1450 feet in elevation. The surface of this fan is collapsed into a series of ridges and long, linear kettles which radiate from the high apex. The sediment in the fan is primarily sandy, pebbly, cobble and boulder gravel.

Figure 15. Aerial photograph of jökulhlaup-deposited fan. See Plate 1 for half-tone reproduction of this photograph

The gravel pit exposes approximately 10 feet of sandy, pebbly, bouldery cobble-gravel, poorly sorted, apparently unbedded. The cobble and boulder fraction is approximately 90% locally derived Giants Range granite, and approximately 10% greenstone, schist and gneiss. The pebble fraction is similar, but contains more greenstone, schist, gneiss and some basalt. The cobbles and boulders are primarily subrounded to rounded; the pebbles are angular to subrounded.

This gravel is overlain by 6 to 24 inches of yellowish-brown (10YR 5/4) fine sandy silt, pebbly in places. Silt similar to this occurs throughout the uplands of the field trip area. This sandy silt is interpreted to be loess, and the coarser sand and pebbles to be derived from the underlying sediment by permafrost/frost processes and tree-tip. The source of the wind-blown sediment was probably outwash plains and recently drained lake basins to the south and west of this area.

The fan is interpreted to have formed by possibly two or more jökulhlaups from the Rainy lobe at the Vermilion moraine (Lehr and Matsch, 1987). Meltwaters from these jökulhlaups flowed across outwash plains south of the fan and eventually into Lake Norwood. Subglacial water burst through a debris/ice dam at the slight re-entrant in the Rainy lobe in the vicinity of Bear Head Lake. The initial, high discharge flow scoured a proglacial stagnant ice surface into a series of long, linear channels, separated by clean-ice "interfluves." As flow waned, poorly sorted, sandy, cobble and boulder gravel was rapidly deposited in these channels. The modern topography is the result of a reversal of topography, with the ridges representing former channels, and the linear kettles representing the clean-ice "interfluves."

In an attempt to determine if there is any decrease in grain size toward the margins of the fan, Lehr measured 50 of the largest clasts at each of 15 localities across the fan; the averages of are shown in Figure 14. A crude decrease in maximum grain size is present from approximately 15 inches in the north to 12 to 13 inches in the central part of the fan to approximately 8 inches near the margin of the fan (Lehr and Matsch, 1987).

Proceed south on gravel road and return to St. Louis Co. Rd. 21.

58.7 Junction with St. Louis Co. Rd. 21 (paved road). Turn right (west).

63.1 Junction with St. Louis Co. Rd. 26 (paved). Turn right (west).

63.7 Leave Lake Norwood plain. Driving on hummocky supraglacial sediment and ice-contact sand and gravel.

66.3 Large graded-over gravel pit.

67.2 Cross the Laurentian divide. We are now in the Hudson Bay watershed.

68.2 Enter outwash plain heading at Wahlsten moraine (Rainy lobe).

69.5 Junction with Minnesota Highway 135 (paved road). Stop sign. Turn right (north).

69.8 Cross Wahlsten moraine, which is not very distinct here, because from approximately this point westward, the Rainy lobe was fronted by Lake Norwood (1450 feet). Traveling on bedrock-dominated terrain mantled by thin Rainy lobe sediment.

72.6 West Two River

74.7 Junction with Minnesota Highway 1 and 169 (paved road). Turn right (east) into Tower.

76.0 Headframe of the inactive Soudan mine ahead.

77.5 Vermilion moraine cored by bedrock in this area. Driving through bedrock-dominated landscape.

84.1 Intersection with St. Louis Co. Rd. 128, also called Bearhead State Park Road. Turn right (south).

88.3 Enter Bear Head Lake State Park.

90.1 Proximal slope of Vermilion moraine.

90.2 Turn left on road into group camp area. Driving on the Vermilion moraine, which is about half a mile wide and is hummocky.

90.8 Group camp area—**LUNCH STOP.** The area where we will be having lunch is near the point where the jökulhlaups that deposited the coarse outwash fan to the south emanated from the Rainy lobe.

Turn around and return to St. Louis Co. Rd. 128.

91.5 Intersection with Co. Rd. 128, also called Bear Head Lake State Park Road. Stop sign, turn right (north).

97.5 Intersection with Minnesota Highway 1 and 169 (paved road). Stop sign. Turn left (west).

103.5 Proximal slope of Vermilion moraine.

106.4 Town of Tower.

106.9 Intersection with Minnesota Highway 135. Continue straight on Minnesota Highway 1 and 169. Outcrops of the Archean Lake Vermilion Formation are common the next few miles.

111.2 Junction with St. Louis Co. Rd. 77, also called Angus Rd. (Paved road). Turn right (north).

111.8 Pike River. Note outcrop of graywacke (Lake Vermilion Formation) on left.

115.1 Distal slope of the Vermilion moraine.

115.2 Junction with St. Louis Co. Rd. 414, also called Everett Bay Rd. (paved road). Turn right (east).

115.3 Turn right onto gravel pit access road. **STOP 3**: Gravel pit in Vermilion moraine. St. Louis County, T62N-R16W-22BCDC (Fig. 16).

In this area, the Vermilion moraine is approximately 1/4 to 1/2 mile wide, has a symmetrical cross-sectional profile, and is not collapsed. The proximal slope of the moraine is fairly straight, but the distal slope is distinctly scalloped (Fig. 16). The maximum elevation of the moraine in this area is 1460 feet. In a few areas to the west, the Vermilion moraine is somewhat wider and higher (approximately 1500 feet) and collapsed. The entire Vermilion moraine from southwest of Soudan northwestward to at least Nett Lake is composed of stratified sand and gravel (Lehr, in prep.)

The western portion of this gravel pit consists of interbedded sand, sandy silt, and pebbly coarse sand, with lenses of sandy pebble gravel. Bedding in this section consists chiefly of large-scale foreset beds dipping south, but the upper part of the section is flat bedded. The eastern part of the pit exposes sand, ranging from silty fine sand to medium sand, with interbedded pebbly sand. The bedding in this area is highly convoluted, due to loading and dewatering.

These sediments are interpreted to have been deposited by subglacial streams as they entered Lake Norwood/Koochiching at the 1450-foot level. The foreset and topset beds suggest deltaic sedimentation, and the scalloped, flat-topped segments of the moraine represent coalesced ice-

Figure 16. STOP 3: Gravel pit in Vermilion moraine. St. Louis County, T62N-R16W-22BCDC

contact deltas constructed to the 1450-foot level of Lake Norwood/Koochiching. The higher and broader, collapsed portions of the Vermilion moraine to the northwest represent debris above the level of the lake by gravity and supraglacial streams deposited burying blocks of stagnant ice. North of the ice-contact proximal slope are numerous eskers which are remnants of the conduits that brought meltwater and sediment to the ice margin.

Sharpe and Cowan (1990) have reported on "Rainy lobe" moraines marginal to Lake Agassiz in northwestern Ontario that seem to be the same in shape and composition as the Vermilion moraine from southeast of Soudan to Nett Lake. They explained them as having been deposited by outbursts of subglacial water, possibly triggered by a drop in lake level or lifting of a marginal ice dam. In their scenario, moraines such as these are deposited rapidly and do not represent periods of ice-margin stability.

The origin of these types of moraines in Minnesota is probably quite similar to that of the sorted sand and gravel moraines of northwestern Ontario (Zoltai, 1965; Sharpe and Cowan, 1990) and the Salpausselkä moraines in Finland (Fyfe, 1990)

Turn around to go west on St. Louis Co. Rd. 414.

115.4 Junction with St. Louis Co. Rd. 77 (paved). Stop sign. Turn left (south).

119.4 Junction with Minnesota Highway 1 and 169. Stop sign. Turn left (east).

123.7 Junction with Minnesota Highway 135 (paved). Turn right (south).

128.8 Junction with St. Louis Co. Rd. 26. Continue straight (south) on Minnesota Highway 135. Driving on a small outwash plain graded to the Wahlsten moraine.

129.4 Driving on Rainy lobe subglacial till plain with Rogen moraine and eskers.

132.3 Enter Lake Norwood plain.

133.5 Rainy lobe esker.

133.8 Rainy lobe subglacial till plain with Rogen moraine.

134.4 Cross the Laurentian divide. We are now in the Lake Superior watershed.

134.7 Intersection with St. Louis Co. Rd. 21 (Four Corners). Continue straight on Minnesota Highway 135.

135.5 Enter Lake Norwood plain.

137.3 Embarrass River.

138.3 Exit Lake Norwood plain. Begin ascent of Giants Range.

139.7 Crest of Giants Range.

145.1 Northern margin of Alborn till (St. Louis sublobe).

145.7 Junction with St. Louis Co. Rds. 100 and 110. Turn right (west) remaining on Minnesota Highway 135.

146.4 Turn right onto highway approach. **STOP 4**: Embarrass mine section. St. Louis County, T58N-R15W-05 (Fig. 17).

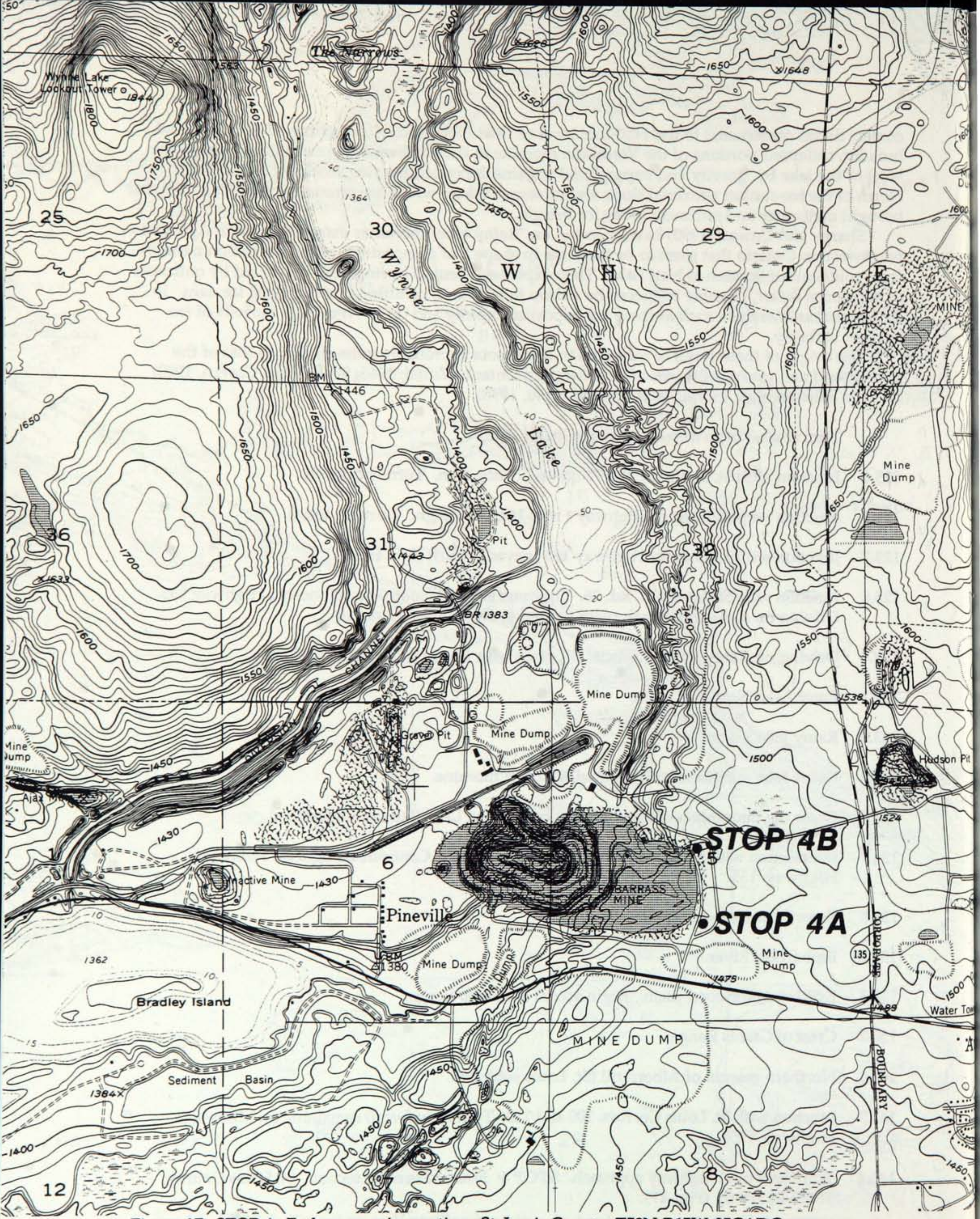


Figure 17. STOP 4: Embarrass mine section. St. Louis County, T58N-R15W-05CADC

The now inactive Embarrass mine produced 18.6 million tons of hematite ore from 1944 to 1964. It is now managed as a trout lake and has a public boat access. Three tills are exposed at this section.

From highway approach, walk north over berm. Continue north on old mine-access road and cross second berm. Exposure on right (Location A on Fig. 17, T58N-R15W-05CADC).

Depth (feet)	Description
0 to 15	Clayey diamicton, brown (7.5YR 5/4). Leached to approximately 7 feet, calcareous below 7 feet. Abundant clasts of phyllite (Virginia Formation), some granite, rare clasts of Paleozoic carbonate and rhyolite, no Cretaceous shale visible. This unit is the late Wisconsinan Alborn till deposited by the St. Louis sublobe south of the Giants Range after retreat of the Rainy lobe approximately 12 ka. The red clay was incorporated as the ice advanced into Lake Aitkin-Upham I, which was receiving red-clay laden meltwaters from the Superior lobe (Wright and Watts, 1969).

Proceed north down old mine-access road to water level. The section described below is in the northeastern part of the Embarrass mine (Location B on Fig. 17, T58N-R15W-05BDDC). Two tills are present.

Depth (feet)	Description
0 to 16	Pebbly sand, slightly silty, slightly cobbly and bouldery, poorly to very poorly sorted. Some contorted bedding present.
16 to 66	Sandy loam diamicton (Fig. 18), not extremely stony, contains laminae of sorted sand, grayish brown (2.5Y 5/2), massive to faintly stratified, fairly loose consistency. This is the late Wisconsinan Rainy lobe till, the "bouldery till" of Winter (1971; Winter and others, 1973).
66 to 85	Sandy loam diamicton, brown to dark yellowish brown (7.5YR to 10YR 4/4), leached from 66 to 70 feet, calcareous from 70 to 85 feet. Blocky structure, with individual blocks apparently cemented with iron oxide. Harder to excavate than the unit above. In general, this till is less rocky than the "bouldery till." Common rock types include: greenstone, granite, gneiss, Algoman iron-formation, also some limestone and graywacke. Fabrics measured by Winter (1971) (Fig. 19) show a fairly strong NE-SW orientation. Winter (1971; Winter and others, 1973) called this unit the "basal till."

Another section of the "basal till" was measured just west of the section described above. The weathering profile here appears to be better preserved.

Height above lake (feet)	Description
24 to 20	Sandy loam diamicton, reddish brown (5YR 4/4), jointed, leached.
20 to 16.5	Sandy loam diamicton, brown to dark brown (7.5YR 4/3), jointed, with reddish material coating joint surfaces, leached.
16.5 to 10	Sandy loam diamicton, brown to dark brown (7.5YR 4/3), calcareous.
10 to 8	Sandy loam diamicton, brown to dark brown (10YR 4/3), calcareous.
8 to 0	Section is mostly covered, probably same unit to water level. In 1985, J.D. observed well-sorted sand below this unit, in places.

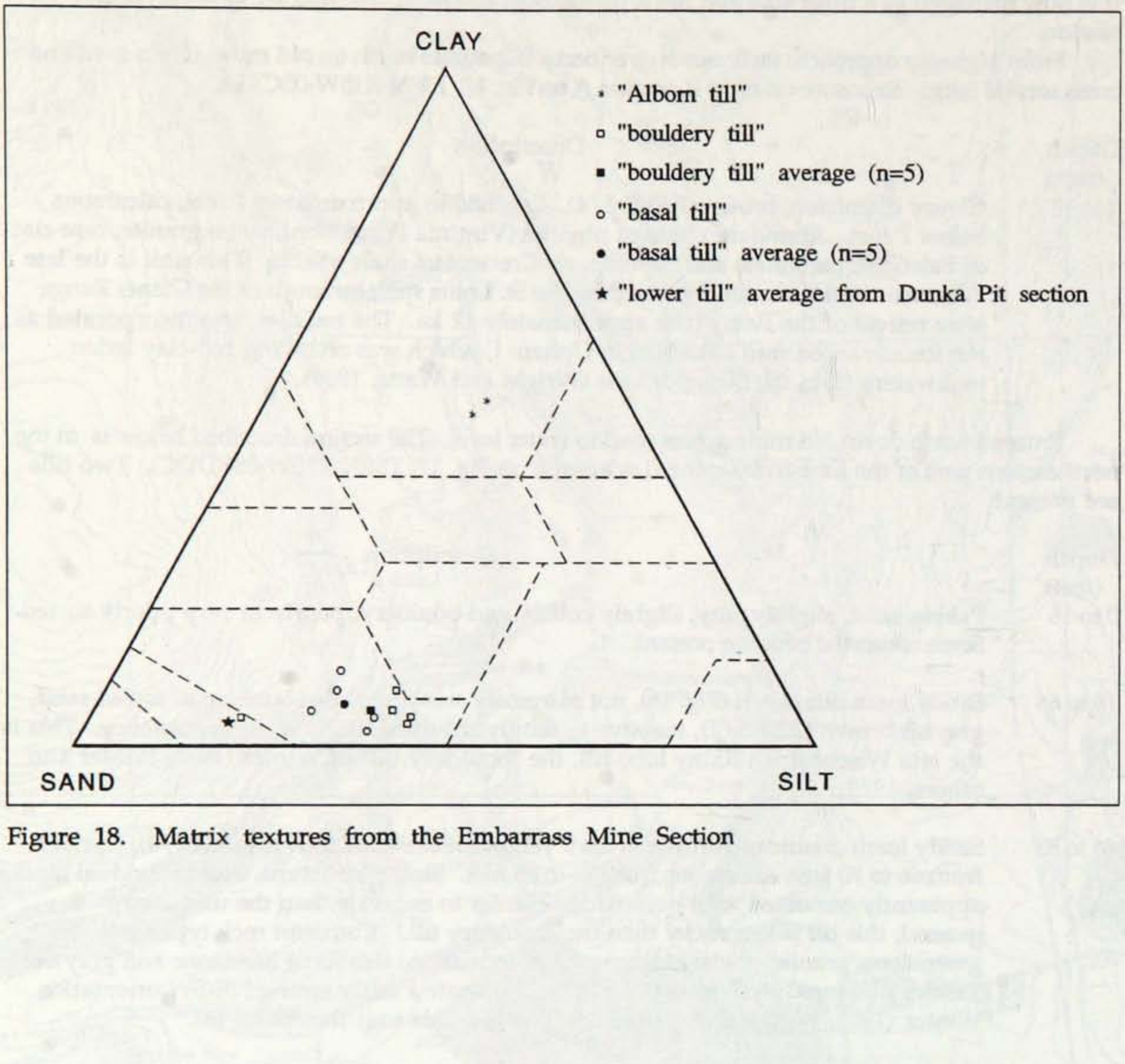


Figure 18. Matrix textures from the Embarrass Mine Section

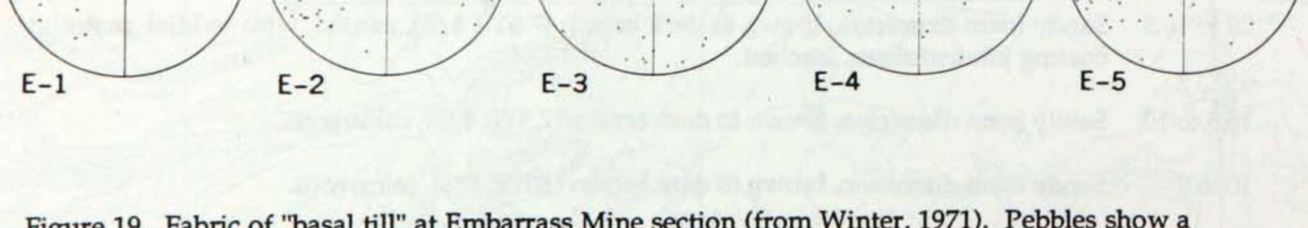


Figure 19. Fabric of "basal till" at Embarrass Mine section (from Winter, 1971). Pebbles show a general northeast-southwest orientation of long axes

Winter (1971) interpreted the "basal till" to have been deposited by a Keewatin glacier flowing east-northeast along the south flank of the Giants Range. However, the texture, fabric and overall stone content are nearly identical to the late Wisconsinan Rainy lobe tills, and we therefore interpret this unit to be a pre-Wisconsinan till of northeastern provenance, with the carbonate derived from the Hudson Bay lowland. This unit probably does not correlate with the older till at the Dunka Pit.

It is interesting that here the "bouldery till" is siltier and slightly more clayey than the "bouldery till" at the Dunka Pit (Fig. 18) and in the areas immediately north of here (Lehr, in prep.). At the Embarrass mine section both the "basal" and "bouldery tills" have similar textures, as do both tills at the Dunka Pit section (Fig. 18). This similarity implies that local conditions, either bedrock source or proglacial lakes, were controlling till texture.

Turn around and continue west on Minnesota Highway 135.

148.2 Junction with St. Louis Co. Rd. 138 (paved road). Turn right (north). Enter the Embarrass gap. Driving on terrace at 1430 feet correlated with the Mizpah stage of Lake Koochiching. Giants Range on left.

151.8 Giants Ridge Ski Area. **STOP 5**: Observation deck near top of ski runs. St. Louis County, T59N-R16W-25AA (Fig. 20).

At this stop we intend to discuss two topics: (1) the origin of the Giants Range, the Embarrass gap, and bedrock-dominated landscapes on the Canadian Shield in general; and (2) the role of the Embarrass gap in the drainage of proglacial lakes north of the Giants Range.

The Giants Range is a prominent bedrock ridge extending from the south shore of Birch Lake near Babbitt, southwestward to the Nashwauk and Keewatin area. The Giants Range and areas immediately north are underlain by the Archean Giants Range Granite and small areas of Archean supracrustal rocks. South of the Giants Range are the relatively flat-lying rocks of the Animikie Group (Fig. 2). The northeastern end of the Giants Range coincides with the eastern end of the Biwabik Iron Formation (Fig. 21) (Green, 1982). The topographic prominence of the Giants Range diminishes southwestward where the Biwabik Iron Formation changes from magnetite facies to carbonate facies (G.B. Morey, personal communication).

At the Embarrass mine, at the south end of the Embarrass gap, the entire thickness of Biwabik Iron Formation hosted a soft, hematite ore deposit (Fig. 22). There are various theories for the formation of these "natural ores," but a credible theory invokes weathering of silicate iron-formation to a variety of ferric iron oxides, by ground water. At the Embarrass mine, this chemical weathering was concentrated along a fault (Fig. 22).

We believe that the presence of magnetite iron-formation played a role in the formation of the Giants Range. The Precambrian bedrock of Minnesota has been subjected to at least two periods of intense chemical weathering, a pre-Late Cambrian episode (Morey, 1972b) and a late Cretaceous (Parham, 1970) to possibly Tertiary episode. The Giants Range Granite would have been easily weathered, resulting in a thick saprolite. The silicate iron-formation, on the other hand, would not have weathered as deeply (Fig. 23).

The first late Cenozoic glacial advances would have easily eroded the thick saprolite north of the Mesabi range, and some of the weathered iron-formation. The present-day Giants Range was protected from deep chemical weathering by a cap of silicate iron-formation. The Embarrass gap originated because there was no protective cap of silicate iron-formation, and it had been entirely weathered to "natural ore" (Fig. 22). Therefore, Embarrass gap is probably a late Tertiary to early Pleistocene feature.

In parts of northeastern Minnesota where bedrock is near the surface, the modern topography is clearly related to bedrock type and structure. For example, iron-formation and volcanic rocks form higher areas, and granitic and sedimentary rocks form lows. The Duluth Complex, in general, is quite high in elevation, but within this area, the felsic differentiates form some of the highest hills in the state. Several faults in northeastern Minnesota have distinct topographic expression.

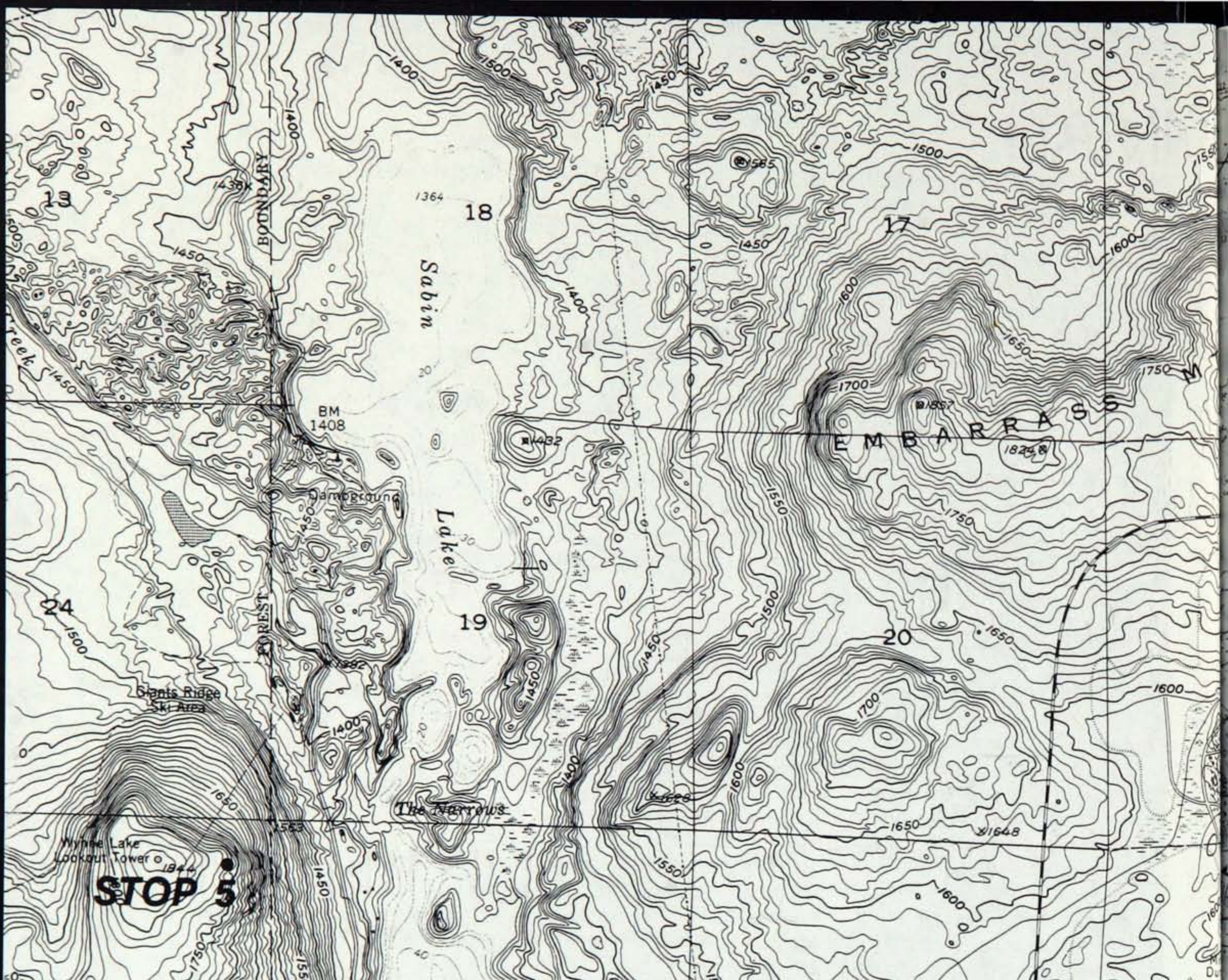


Figure 20. STOP 5: Observation deck near top of Giants Ridge Ski Area. St. Louis County, T59N-R16W-25AA

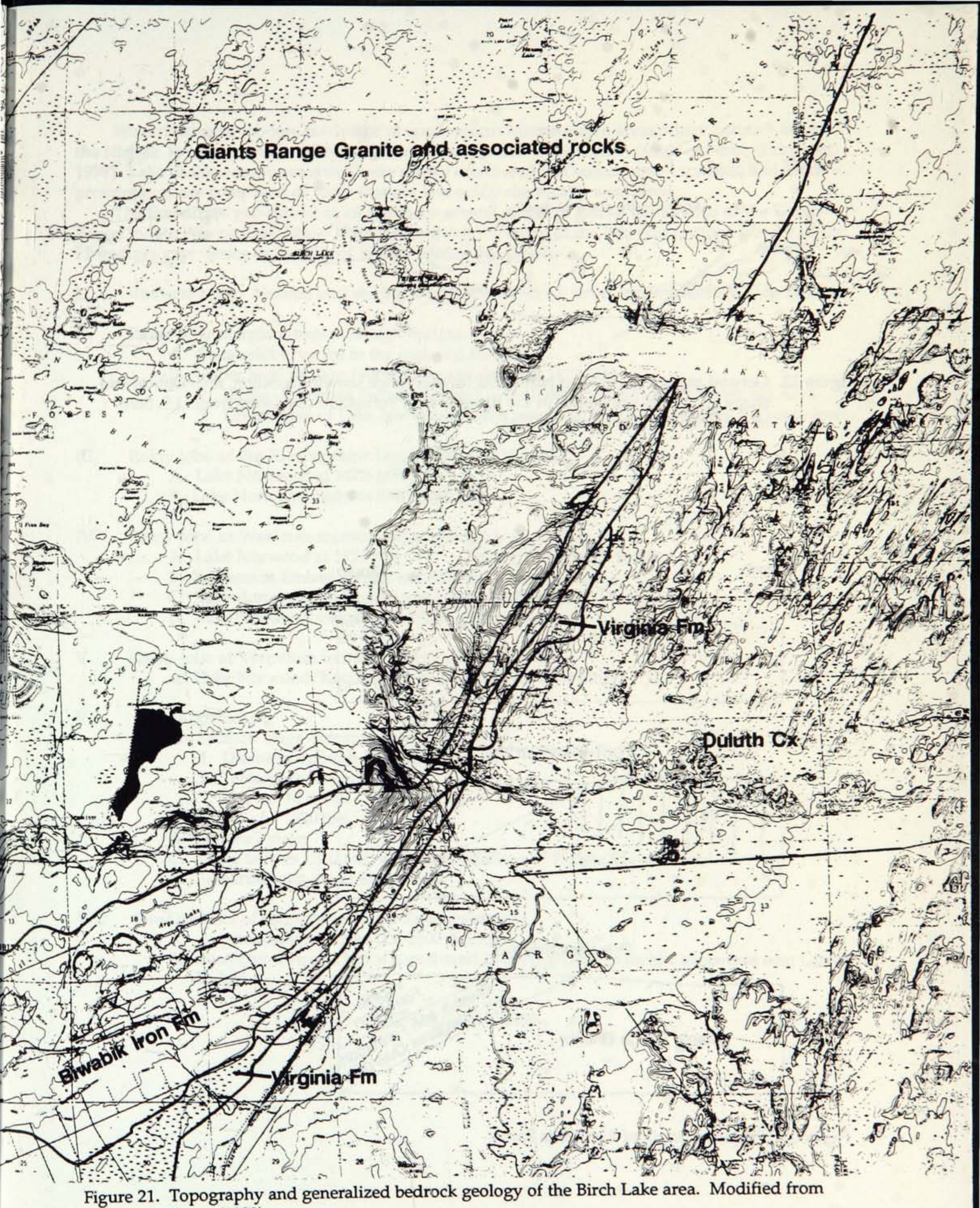


Figure 21. Topography and generalized bedrock geology of the Birch Lake area. Modified from Green (1982)

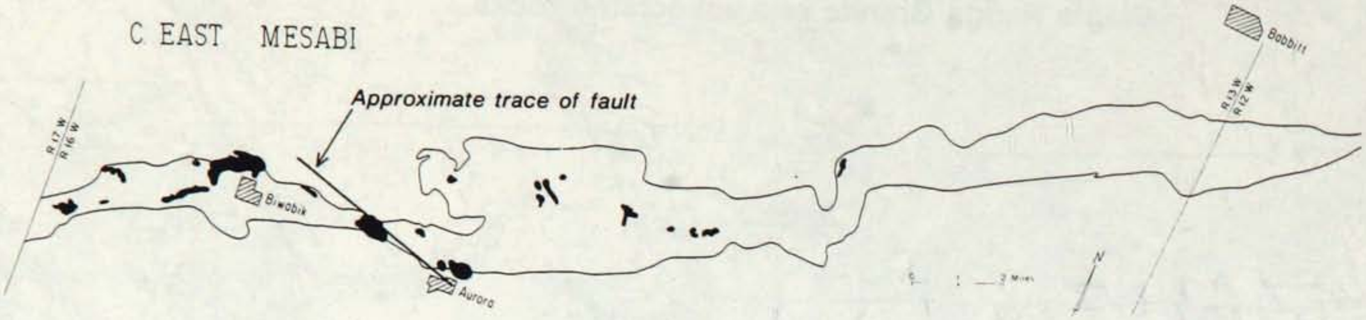


Figure 22. General map of the eastern part of the Mesabi range showing location, distribution and shape of natural ore bodies in the Biwabik Iron Formation (modified from U.S. Steel map of 1956). From Morey (1972a)

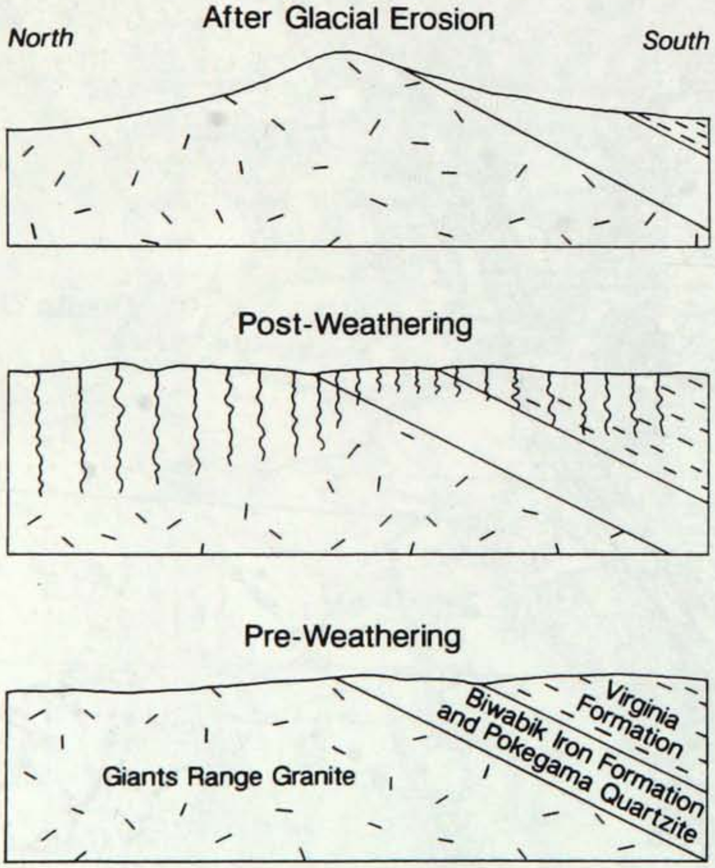


Figure 23. Proposed origin of the Giants Range

We envision the modern landscape of northeastern Minnesota, in areas where bedrock is near the surface, to correspond roughly to the top of unweathered bedrock in preglacial time (Feininger, 1971). Lake basins occupy areas that were deeply weathered and subsequently scoured, and most prominences are composed of rocks that are less easily chemically weathered.

The Embarrass gap served as an outlet for several stages of glacial lakes north of the Giants Range in late Wisconsinan time. The following is a summary of the late Wisconsinan history of the Embarrass gap. Refer to the glacial history section for details.

I. Embarrass gap "cleaned out" during late Wisconsinan ice cover (approximately 30 to 14 ka)

II. Rainy lobe margin retreats through the gap
    A. Outwash buries ice in the gap, and fills it
    B. Upper level of Lake Norwood approximately 1475 feet
        1. Meltwater enters the gap through a spillway north of Giants Ridge Ski Area
        2. Upper level of Lake Norwood drains into Lake Upham I at nearly the same level

III. Rainy lobe at Big Rice moraine (approximately 13.5 ka)
    A. Lake Norwood at 1470-1450 feet
    B. Lake Norwood outlet is Embarrass gap

IV. Rainy lobe at Wahlsten moraine (approximately 13 ka)
    A. Lake Norwood at 1450 feet
    B. Terraces in Embarrass gap at 1450 feet
    C. Lake drains via Embarrass gap into Lake Upham I
    D. Lake Norwood merges with Lake Koochiching

V. Rainy lobe at Vermilion moraine (approximately 12.5 ka)
    A. Lake Norwood/Koochiching at 1450 feet, for how long?

VI. Lake Koochiching
    A. Mizpah stage (approximately 12 ka?)
        1. Drainage through Embarrass gap
        2. Terraces in Embarrass gap
            a. 1430 feet
            b. 1400 feet
    B. Gemmell stage
    C. Level falls to 1350 feet with establishment of Prairie River outlet
    D. Embarrass gap outlet abandoned

VII. Final meltout of stagnant ice in the Embarrass gap
    A. Approximately 10.3 ka (Lu-2507 & 2506)
    B. Diamicton flows on top of sorted sand in the gap (seen in former exposures near Giants Ridge)

END OF DAY ONE

ROADLOG AND STOP DESCRIPTIONS — DAY 2

Sunday, May 17, 1992

0.0 Start from Giants Ridge Ski Area (St. Louis County, T59N-R15W-19C). Turn left (north) at entrance to ski area on St. Louis Co. Rd. 138 (paved road). Retrace the first day's route to the junction of St. Louis Co. Rds. 70 and 21, west of Babbitt.

24.5 Junction with St. Louis Co. Rd. 70. Continue straight (east) on Co. Rd. 70.

26.0 Babbitt outwash plain. Vermilion moraine visible to left. Note large boulders on steep distal slope. Giants Range ahead and to right. Road bends around Babbitt, a town without a main street.

26.8 Pass through Vermilion moraine. Note gentle proximal slope (on left).

28.5 Turn left on Mattilla Road (paved road).

29.1 Turn right on unmarked dirt road. (Mattilla Road turns to gravel at this intersection).

29.2 **STOP 6**: Mattilla's gravel pit. St. Louis County, T61N-R12W-33 (Fig. 24).

The pit exposes 15 to 20 feet of pebbly sand in most places, capped by about a foot of sandy, pebbly silt. A deeper part of the pit exposes about 8 feet of dark, medium to coarse sand under the pebbly sand. The pebbly sand is fairly clean and well-sorted, mostly flat-bedded. A few silt beds are present. The pebbles are mostly fine to medium. The lower sand is cross bedded and moderately well sorted. Much of the black color is due to magnetite grains.

We interpret the upper silt as a thin loess cap, much mixed with sand and gravel from below. Thin loess of this sort is quite common in the area, though it is rarely mentioned in the literature.

The main pebble types are as follows: gabbro, various kinds of granite, red rhyolite and granophyre, basalt and graywacke. Agates are rare; carbonate and red sandstone are absent. The larger pebbles are dominated by granite and gabbro. Red pebbles (rhyolite, red basalt, and granophyre) are most common among the smaller pebbles (<1.5 inches).

This pebble assemblage clearly belongs to the Superior lobe, although it is more a North Shore assemblage than a center-of-lake assemblage. Presence of Superior lobe outwash here, behind the Vermilion moraine, shows that the Superior lobe was still extensive, and thick enough, to send outwash this far west, even after the Rainy lobe had retreated from the Vermilion moraine. On the other hand, the ice could not have withdrawn very far to the north, or the meltwater would have bypassed this area, and deposited sand and gravel in the basin of Birch Lake. In fact, the southern beach, and a nearby island, are composed of this same outwash, but it has not been identified farther north.

Tracing the flow path from here to the source in the Superior lobe is tricky, and the exact path and timing of the flow are uncertain. The plain of Glacial Lake Dunka is floored by a similar red sand and gravel, which seems to have entered through obscure channels east of the lake, after the lake drained. The most likely exit is through the gap in the Vermilion moraine now occupied by the Dunka River. The modern Dunka River flows north into Birch Lake, but the meltwater path must have been diverted west by ice in the Birch Lake basin. Otherwise, Birch Lake would have been filled up with outwash.

After flowing behind the Vermilion moraine for a few miles, this meltwater stream crossed the moraine again and built at least part of the outwash plain under the town of Babbitt (the town of no longer exists where it is shown on the base map — it was moved onto the outwash plain in the 1950s). The meltwater continued southwest, flowing into glacial Lake Norwood, where it presumably dropped its load of sand and gravel as a delta. The finer sand spread out over the bottom. The further course of the meltwater is hard to trace, because most of its distinctive sediment

Figure 24. STOP 6: Mattilla's gravel pit. St. Louis County, T61N-R12W-33CCDD

had dropped out, but some enigmatic red clay beds in glacial lake sediment may have been derived from this source.

Retrace route out of gravel pit.

29.4 Turn left on Mattilla Road.

30.0 Turn left on St. Louis Co. Rd. 70 (paved road).

30.3 Enter Superior National Forest. Road (unmarked) is now called Forest Road 112.

30.8 Crest of Vermilion moraine.

31.2 Passing between distal slope of moraine on left, and end of Giants Range on right. Dunka River on left.

32.0 Cross railroad tracks from Dunka pit.

32.7 Junction with Forest Road. Continue straight.

33.0 Road forks. Follow left fork (Forest Road 424), the new alignment of the Tomahawk Road. This new road is not shown on your map of the Superior National Forest.

33.7 Gravel pit (active) to left, developed in outwash in front of the Vermilion moraine (but contains red Keweenawan rocks).

34.1 Forest Road 424A joins from north. Continue straight on 424.

34.6 Climb onto distal face of the Vermilion moraine. Note abundant boulders. Travel more or less on crest of moraine for 1.5 miles.

36.0 Descend into Glacial Lake Dunka plain.

36.4 Rise onto bedrock-dominated hills.

36.7 Junction with Forest Road 1131 on right. Go straight on 424.

36.8 Streamlined outcrop of Duluth Complex.

37.3 Junction with Forest Road 178. Continue straight on Forest Road 424. Cross the Stony River. Now traveling on outwash gravel. Vermilion moraine intermittently visible to left.

38.1 New gravel pit. Gravel and boulders predominantly Duluth Complex.

39.2 Gravel pit on left, backfield with mega-boulders of Duluth Complex.

39.7 Cross Vermilion moraine, indistinct in this area. Moraine now to right (south).

40.8 Road curves right and cuts through Vermilion moraine. Beyond Vermilion moraine travel over collapsed outwash.

41.9 **STOP 7**: Tomahawk Road gravel pit. Lake County, T60N-R11W-01DBCD (Fig. 25).

Figure 25. STOP 7: Tomahawk Road gravel pit. Lake County, T60N-R11W-01DBCD

This pit exposes about 25 feet of sand and gravel, capped by thin, slightly pebbly silt loam. We interpret the sand and gravel as outwash derived from the nearby Vermilion moraine; the pebbly silt is loess.

The silt is oxidized to brown (7.5YR 4/4, moist); most of it has been scraped off, along with the topsoil. The upper few feet of the outwash is also oxidized brown (generally 10YR), but the bulk of the deposit is dark gray or dark grayish brown (2.5 Y 4/2). Some silt from the loess has filtered down into the upper part of the gravel.

The outwash is crudely flat bedded, and only moderately sorted. Although mostly sand and gravel, it includes thin beds of fine sand and silt, and occasional cobbles and boulders. This outwash is highly collapsed in this area, but no collapse features are visible in this pit, and the top of the pit is a flat depositional surface. All of these characteristics, combined with proximity to the moraine, indicate a short distance of transport.

The dominant rock type here is anorthositic gabbro, derived from the Duluth Complex, which is the local bedrock. This is also the dominant rock type in the till of this area. Contrast this assemblage with the one at Dunka Pit, just west of the Duluth Complex. This type of rock weathers very easily. Notice that the olivine crystals are weathered and iron-stained throughout most of the deposit, except at the bottom of the pit.

Turn around in gravel pit and turn left (east) on Forest Road 424, traveling through hummocky moraine composed largely of coarse, collapsed fluvial sediment.

43.1 Junction with State Highway 1 (paved road). Turn left (north) and pass through Vermilion moraine again.

44.0 Descend proximal side of Vermilion moraine.

44.6 Turn right (east) on Forest Road 173 (gravel road). This is also called the Tomahawk Road.

45.3 Forest Road 386 joins on right. Go straight on Forest Road 173.

47.7 Forest Road 1456 joins on right. Continue straight on Forest Road 173.

48.5 Forest Road 387 joins on left. Continue straight on Forest Road 173.

48.6 Cut through esker.

48.9 Cross Snake River.

50.4 Cross Snake Creek.

50.8 Forest Road 381 joins on left, which goes to the Snake River and Little Isabella River entry points to the BWCAW.

51.5 Little Isabella River.

53.4 Junction with Forest Road 377; 173 turns to the south. Continue straight on Forest Road 377.

53.9 Cross Inga Creek.

56.9 Cross Mitawan Creek.

57.0 Junction with Forest Road 373 (Northwest Road) (number written on back of stop sign). Turn right (south) on Forest Road 373.

60.5 Forest Road 173 joins on the right. Continue straight. This road is now Forest Road 173, but it is still called Northwest Road.

61.1 Road climbs up onto a Rogen moraine ridge and continues on top for 0.6 miles.

61.7 End of Rogen moraine ridge.

61.9 Camp Creek.

62.3 Stop sign. Forest Road 369 goes straight. Turn sharp to the left (northeast) on Forest Road 173. Esker visible on left after turn.

63.0 Arrowhead Creek.

65.1 Intersection with old railroad grade, unnumbered. Turn right.

65.2 "Y" in road. Keep right.

65.4 Railroad grade joins on left. Continue straight. Road is good, despite the sign "not maintained for public vehicle use."

66.6 **STOP 8:** Rogen moraine cut. Lake County, T60N-R8W-11ADA (Fig. 26).

This stop is an old railroad cut. The logging railroad has long been abandoned, but there are still some fairly good exposures where it cut through ridges of Rogen moraine here. As you can see from the map, the ridges trend NW-SE in this area, separated by strips of swamp. In some of these low strips, meltwater from the Superior lobe flowed, either after the ice had melted out, or parallel to the front as it was melting back. This site is close to the northeast edge of this area of Rogen moraine.

The cut is about 16 feet high. Only part of this is now well exposed (although the exposure is pretty good, considering how old the cut is). Texture of the till is rocky sandy loam to loamy sand. The only texture sample taken showed sand 69%, silt 29%, and clay 2% of the fraction less than 2 mm. Of the total sample 26% was coarser than 2 mm, but that figure is low for the cut as a whole, because large rocks obviously were avoided. Can this be considered a diamicton, even though it lacks clay?

The upper part of the cut is oxidized to brown (7.5YR, 4/4, moist), but most of the cut is dark grayish brown (10YR, 4/2, moist). Even the unoxidized part is not totally unweathered; a few of the gabbro pebbles are crumbly. The deposit is noncalcareous. However, the calcareous till in the Toimi drumlin field is leached to about 30 feet, and so lack of fizz in this cut is not conclusive. There is no loess at the top of this cut. This area is miles away from any extensive outwash deposits, and was probably not exposed until they were stabilized.

The till here is compact and hard to dig. This property suggests a subglacial environment of deposition. There are no structures to suggest mode of formation of Rogen moraine—the till is uniform, unjointed, and possesses no obvious fabric. However, the excavation at the time of the field trip may show things that we could not see when we described the cut for this field guide.

The deposit contains many large boulders, generally subangular to subrounded. Almost all the largest boulders are Duluth Complex, which is the local bedrock. Clast composition is best seen on a washed till surface. Smaller clasts (cobbles and pebbles) include Duluth Complex, but also basalt, rhyolite, granophyre, and gray metasedimentary rocks. This composition is fairly typical of the Isabella sublobe where it is behind the Isabella moraine. The till of both Outer moraine and Inner moraine is finer grained, contains more clay, and is much richer in Superior lobe rocks than the till at this site (Friedman, 1981).

The difference is ascribed to incorporation of Superior lobe outwash and lake sediment into the outer parts of the sublobe in the re-entrant between the Superior and Rainy lobes (Fenelon, 1986).

Figure 26. STOP 8: Rogen moraine cut. Lake County, T60N-R8W-11ADA

Where did this incorporation take place? Partly, this question becomes: how far back did the ice margin retreat before readvancing to the Outer moraine? Probably not more than 10 miles, that is, not back to where we are at this stop. The Isabella sublobe could not have retreated beyond the end of the Highland moraine, because this moraine formed between the ice-filled Superior basin and the ice-free North Shore highland. Where the Highland moraine ends, presumably ice of the Isabella sublobe existed at the same time as ice of the Superior lobe. Another line of evidence is the rock assemblage in this area. Most of the rocks here are local, or can be traced back along the flow lines to areas of outcrop. Gabbro, anorthosite, and granophyre come from the Duluth Complex, and the metasediments come from a sliver of the Animikie Group rocks between the Duluth Complex and the International Boundary. The basalt and rhyolite come from the North Shore Volcanic Group and indicate some component of the Superior lobe. However, the pebble assemblage of the till in the Toimi drumlin field (Hobbs, this volume) includes the same rocks. Perhaps these can be considered as typical of this flow path.

Continue southwest on old railroad grade, driving parallel to the direction of ice flow, and perpendicular to the Rogen moraine ridges.

68.9 Stop Sign at Kelly Landing. Turn left (south) on Forest Road 369.

69.1 Junction with Forest Road 176. Continue straight on Forest Road 369.

69.6 Cross Arrowhead Creek.

70.9 Cross Trappers Creek.

71.9 Turn right on unmarked road to gravel pit.

72.0 Turn right just past gate.

72.1 **STOP 9**: Eighteen Lake Gravel Pit. Lake County, T60N-R8W-34CAC (Fig. 27).

This pit exposes two sections. The east side is dug into a kame which is part of the Isabella moraine; the west side exposes outwash of the Superior lobe in a channel just behind, and parallel to the moraine. The kame is composed of about 35 feet of sand, silt, gravel, and boulders, capped by a few feet of rocky silt. The outwash is coarse gravel capped by very thin silt.

The kame cut contains a variety of sediments: fine to medium gravel, sand, and sandy silt. Boulders large and small are scattered more or less at random. The deposit contains a few clean, well-sorted beds, but in general, the sorting is only moderate. Bedding appears to be almost radial, sloping away from the center, roughly approximating the land slope. The cap of rocky unbedded silt is interpreted as loess and loess-derived colluvium. It is about 2 feet thick on top, and thickens to 3 feet on the right bank. Color is dark yellowish brown (10YR 4/4, moist).

The outwash is crudely flat bedded, and only moderately sorted. It is more uniform than the kame deposit, and contains a smaller range of clast sizes; there are no silt beds, or large boulders. Rock types include basalt and porphyry of the North Shore Volcanic Group, gabbroic rocks of the Duluth Complex, and metasediments. Red rock, including granophyre and abundant rhyolite, is common in all size fractions. By contrast, the boulders in the kame complex are almost all Duluth Complex, although some of them are red granophyre. The gravel fraction of both deposits contains a similar composition.

The contrasting clast assemblage of the two deposits, combined with geomorphology and gross sedimentology, provides a key to the geologic history of the area. The kame deposit is ice-contact, associated with the Isabella moraine of the Isabella sublobe. We attribute the Superior-like composition of the Isabella sublobe to incorporation of Superior lobe outwash and glacial lake sediment into debris similar to the till of the last stop (Stop 8). Therefore, Superior lobe indicators chiefly occur in the finer size fractions.

Figure 27. STOP 9: Eighteen Lake gravel pit. Lake County, T60N-R8W-34 CAC

The outwash, by contrast, came directly from the Superior lobe, though it must include some material eroded from Isabella sublobe deposits along the way. The outwash could not have been deposited until active ice from the Isabella sublobe had withdrawn from the immediate area, but the ice front must have been just to the northeast while this meltwater stream was flowing. Otherwise, the flow would have gone northeast to lower ground.

The thinner eolian cap on the outwash than on the kame suggests that dust was falling on the stabilized kame while the meltwater stream was still flowing. In fact, much of the dust must have blown off outwash surfaces similar to this one.

Turn around in gravel pit and retrace route back to Forest Road 369.

72.2 Turn left on unmarked road.

72.3 Junction with Forest Road 369. Turn right (south).

72.5 Start up proximal slope of Isabella moraine.

73.1 Descend distal slope of Isabella moraine into ice-marginal channel and outwash plain.

73.5 Junction with Forest Road 172 (Wanless Rd.). Turn right (west) on Forest Road 172.

73.8 Little Isabella River. This was a major path for outwash from the Superior lobe past the front of the Isabella sublobe.

74.3 Junction with Minnesota Highway 1 (paved road). Turn left (south) on Highway 1. Travelling over outwash derived from the Highland moraine of the Superior lobe.

77.4 Rise onto distal slope of the Highland moraine. The surface is hummocky, composed of thick supraglacial drift.

78.9 Junction with Snake Trail (Forest Road 102) on right. Continue straight.

80.5 Intersection of General Grade Forest Road. Continue straight on Highway 1. This is roughly the proximal side of the Highland moraine. Ahead, the landscape is dominated by bedrock landforms, though still covered by till.

82.3 Railroad crossing just past Murphy City. Taconite pellets from LTV's Hoyt Lakes plant are transported to a Lake Superior port on these tracks.

83.3 (approx). We are traveling through the Highland flutes, streamlined bedrock knobs mantled with till. The knobs were shaped by ice spreading out of the Lake Superior basin from southeast to northwest. From ground level, these hills are hardly distinguishable from hummocks of the Highland moraine.

87.3 Huge boulder in yard on left. Erratic or local?

89.3 Finland city limit.

89.8 Junction with County Road 7 (Cramer Rd). Continue straight on Minnesota Highway 1.

90.1 Cross West Branch Baptism River.

91.7 Junction with Lake Co. Rd. 4 on right. Just past this point we descend steeply into the Superior basin. Lake Superior soon becomes visible in distance.

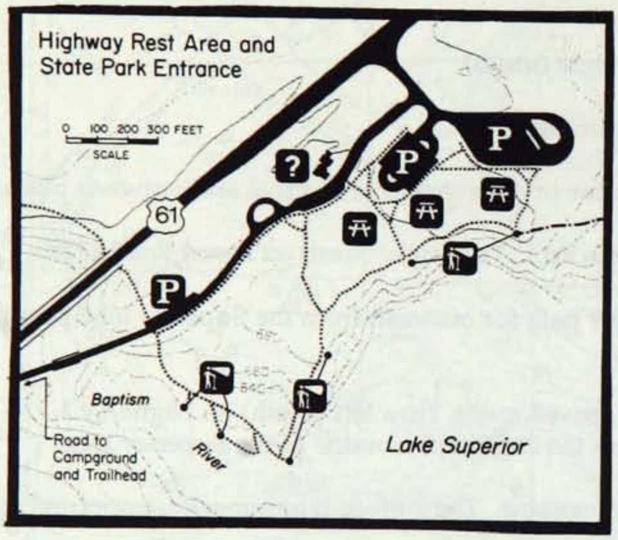
93.2 Cross the Baptism River.

95.5 Begin final steep descent to Lake Superior. Note rhyolite outcrops on right side of road.

96.0 Illgen City. End Minnesota Highway 1; turn right on Minnesota Highway 61.

96.1 Rhyolite exposed in cuts on both sides of road.

96.6 Turn left at the entrance to Tettegouche State Park. Proceed into rest area parking lot. **LUNCH STOP.**



96.8 Leave parking lot and turn left on Highway 61.

97.0 Cross the Baptism River.

98.3 Cross Palisade Creek.

98.4 Entrance road to Palisade Head on left.

99.1 Rhyolite outcrop on right.

99.8 Turn right on Rieder Memorial Drive. Proceed past the site, around the cemetery at the end of the road, then follow the road back down the hill and park just before Highway 61.

100.7 **STOP 10**: Williams Creek section. Lake County, T56N-R7W-29ADD (Fig. 28).

Descend into valley of Williams Creek under the powerline on the southwest side of the road. Proceed up stream. Stop 10 is on the left (west).

This cut exposes about 15 feet of Superior lobe till. The texture of the deposit is quite diverse; textures range from clay and clay loam to loam and silt loam (Fig. 29). All samples were pebbly, except the silt loam, which also is interpreted as till, because it is hard, unbedded, and poorly sorted. Most of it is hard, rocky loam, shot through with narrowly spaced joints. The lower half of the cut is unoxidized dark reddish gray (5YR 4/2, moist); the upper half is oxidized to reddish brown (5YR 4/4, moist). It is slightly to moderately calcareous, though carbonate pebbles were not seen.

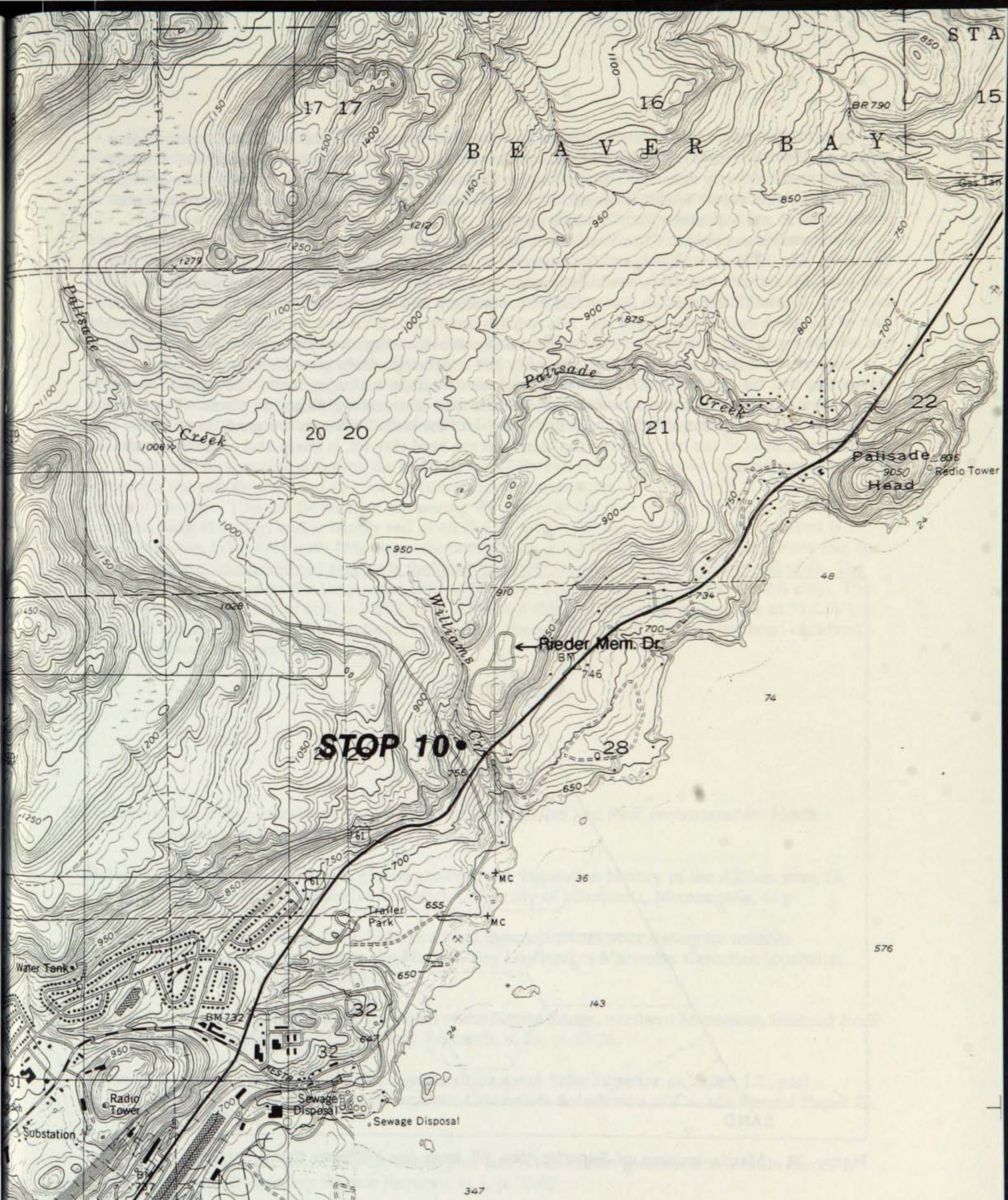


Figure 28. STOP 10: Williams Creek section. Lake County, T56N-R7W-29ADD

Basalt is the most common rock, followed by rhyolite. Granite and red sandstone are much less common. There is a trace of Archean iron-formation and Keweenawan interflow sediments. Duluth Complex rocks are very rare. This assemblage is typical of the Superior lobe, but is a "side-of-the lobe" assemblage, rich in North Shore rocks. Flow paths down the center of the Superior basin are much richer in red sandstone than this assemblage.

Clayey till is exposed in three bands in this section. The lowest is exposed near the creek bed on the south side. It is unoxidized, and is associated with the non-pebbly silt loam till. A band of soft clay loam till about 2 feet thick stretches across the south cut, approximately midway up the exposure. It is oxidized reddish brown (2.5YR 5/4, moist), and slightly calcareous. The upper most part of the south cut is hard clayey till. It is reddish brown also (5YR 4/4, moist), but not as red as the soft clayey till. It is moderately calcareous, and contains stringers of pink secondary carbonate.

How many tills are exposed here? Probably just one, but possibly two. At least the lower clayey tills and the silt loam till appear to be inclusions within the sandy loam. They don't form distinct layers that go all the way across the cut, and their contacts are diffuse in places. The upper and lower contacts of the soft clayey till are sharp, but the lateral contacts are gradational. The uppermost contact in the cut, between the loam and the hard clay till, is sharp and extends across the whole exposure.

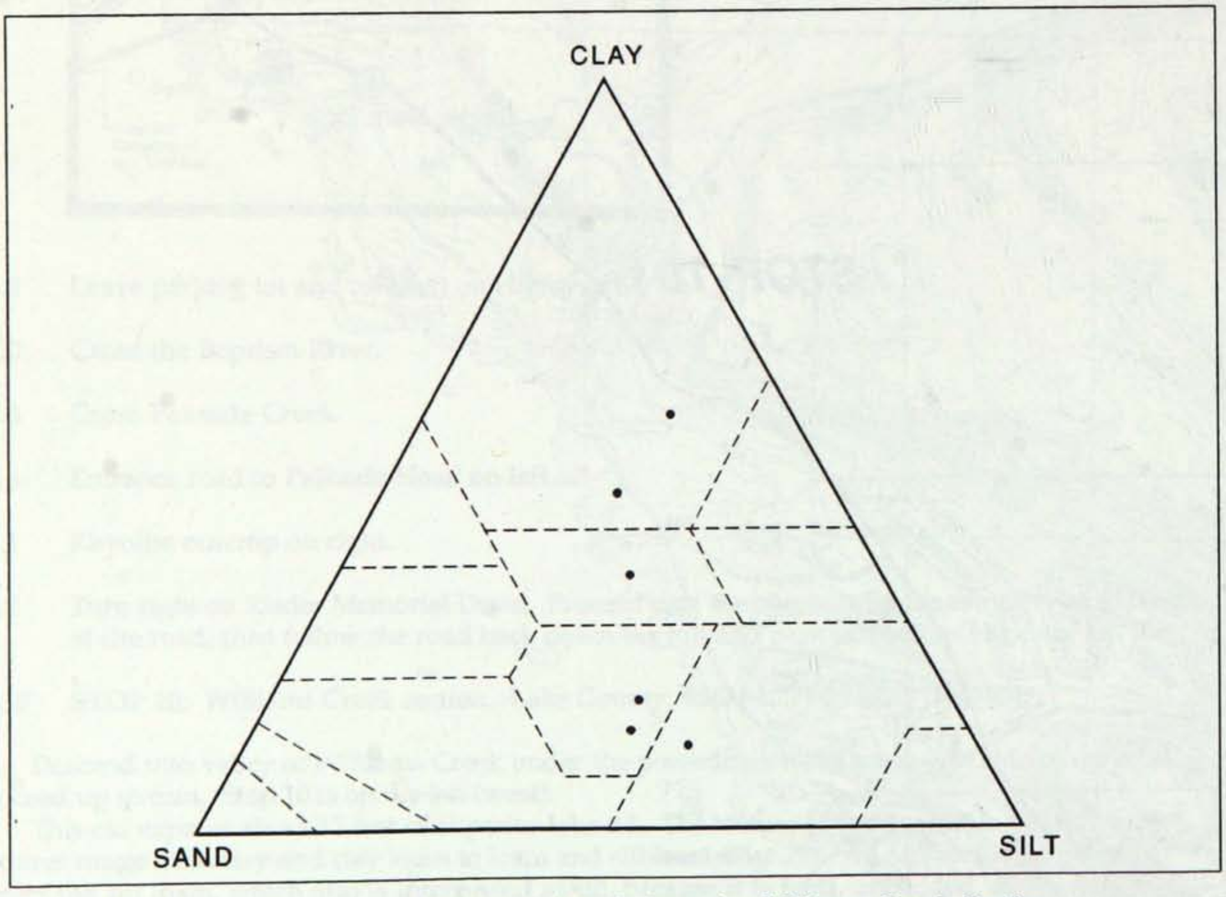


Figure 29. Matrix textures of Superior lobe till from the Williams Creek Section

Whence comes the variation in texture? The rocky loam at this site is fairly typical of the Superior lobe in general, except not as sandy. The matrix is composed in large part of ground-up red sandstone, siltstone and shale. Many of the rocks were eroded from the North Shore Volcanic Group. A certain component was derived from the Canadian Shield up-ice from Lake Superior.

Within or near the Superior basin, however, the uppermost till is commonly silty, or clayey, and stone-poor. Some, though not all, of the areas mapped in the Cloquet moraine association and Nickerson moraine association are covered by till of this type (Hobbs and Goebel, 1982). Wright (1972) attributed the fine texture of these tills as due to incorporation of silt and clay by the Superior lobe as it readvanced over its own proglacial lake sediments. This certainly seems reasonable for this site.

We suggest that the lower inclusions of fine-grained till at this site are just inclusions within the main till not completely digested. The upper clay till may be an inclusion, or it may be a separate till deposited by one of the late readvances of the Superior lobe, perhaps the Marquette advance. It is worth noting that this spot is only 200 feet above the modern level of Lake Superior, and would have been continuously under ice from the first advance of the Superior lobe until almost the final retreat.

One final observation concerns the main carrier of the red color in Superior lobe deposits. Although the pebble and sand fraction certainly contains many red clasts, the bulk of the red is in the clay fraction. This can be seen by comparing the colors to the clay content. The silt loam till contains only 11% clay, and is hardly red at all (7.5YR 4/2). The loam till, where unoxidized is reddish-brown (5YR 4/4) with 13% clay; where oxidized, it is 5YR 4/2 with 17% clay. Note that for a given texture, an unoxidized sample is the same hue (5YR) but lower chroma (2 instead of 4). The upper clay loam till is on the same color chip as the loam till, but appears redder, at 34% clay. The soft clayey till, however, at 45% is 2.5YR 4/4. Although this has the same color name as 5YR 4/4 (reddish brown), the 2.5YR hue is distinctly redder. These same relationships have been observed in many places, in Superior lobe deposits.

END OF FIELD TRIP

REFERENCES

Andrews, J.T., 1975, Glacial systems: An approach to glaciers and their environments: North Scituate, Massachusetts, Duxbury Press, 191 p.

Baker, R.G., 1964, Late-Wisconsin glacial geology and vegetation history of the Alborn area, St. Louis County, Minnesota [M.S. thesis]: University of Minnesota, Minneapolis, 44 p.

Berger, G.W., and Nielsen, E., 1990, Evidence from thermoluminescence dating for middle Wisconsinan deglaciation in the Hudson Bay Lowland of Manitoba: Canadian Journal of Earth Sciences, v. 28, p. 240-249.

Björck, S., 1990, Late Wisconsin history north of the Giants Range, northern Minnesota, inferred from complex stratigraphy: Quaternary Research, v. 33, p. 18-36.

Clayton, L., 1983, Chronology of Lake Agassiz drainage to Lake Superior, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, p. 291-308.

Clayton, L., and Moran, S.R., 1982, Chronology of late Wisconsinan glaciation in middle North America: Quaternary Science Reviews, v. 1, p. 55-82.

Dredge, L.A., and Cowan, W.R., 1989, Quaternary geology of the southwestern Canadian Shield, *in* Fulton, R.J., ed., Quaternary geology of Canada and Greenland: Ottawa, Geological Survey of Canada, p. 214-249.

Dyke, A.S., Vincent, J.-S., Andrews, J.T., Dredge, L.A., and Cowan, W.R., 1989, The Laurentide Ice Sheet and an introduction to the Quaternary geology of the Canadian Shield, *in* Fulton, R.J., ed., Quaternary geology of Canada and Greenland: Ottawa, Geological Survey of Canada, p. 178-189.

Farnham, R.S., McAndrews, J.H., and Wright, H.E., Jr., 1964, A late Wisconsin buried soil near Aitkin, Minnesota, and its paleobotanical setting: American Journal of Science, v. 262, p. 393-412.

Feininger, T., 1971, Chemical weathering and glacial erosion of crystalline rocks and the origin of till: U.S. Geological Survey Professional Paper 750-C, p. 65-81.

Fenelon, J. M., 1986, Glacial geology of the Cramer quadrangle, northeastern Minnesota [M.S. thesis]: University of Wisconsin, Milwaukee, 76 p.

Fenton, M.M., Moran, S.R., Teller, J.T., and Clayton, L., 1983, Quaternary stratigraphy and history in the southern part of the Lake Agassiz basin, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz, Geological Association of Canada Special Paper 26, p. 49-74.

Florin, M.B., and Wright, H.E., Jr., 1969, Diatom evidence for the persistence of stagnant glacial ice in Minnesota: Geological Society of America Bulletin, v. 80, p. 695-704.

Friedman, A.L., 1981, Surficial geology of the Isabella quadrangle, northeastern Minnesota [M.S. thesis]: University of Minnesota, Minneapolis, 66 p.

Fyfe, G.J., 1990, The effect of water depth on ice-proximal glaciolacustrine sedimentation: Salpausselkä I, southern Finland: Boreas, v. 19, p. 147-164.

Gilbertson, J.P., 1990, Quaternary geology along the eastern flank of the Coteau des Prairies, Grant County, South Dakota [M.S. thesis]: University of Minnesota, Duluth, 108 p.

Goldstein, B.S., 1986, Stratigraphy, sedimentology and late Quaternary history of the Wadena drumlin region, central Minnesota [PhD thesis]: University of Minnesota, Minneapolis, 216 p.

Green, J.C., 1982, Geologic map of Minnesota: Two Harbors sheet, bedrock geology: Minnesota Geological Survey, scale 1:250,000.

Hobbs, H.C., 1983, Drainage relationships of early glacial Lakes Aitkin and Upham and early Lake Agassiz in northeastern Minnesota, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, p. 245-259.

Hobbs, H.C., and Goebel, J.E., 1982, Geologic map of Minnesota, Quaternary geology: Minnesota Geological Survey Map S-1, scale 1:500,000.

Hobbs, H.C., Friedman, A.L., Fenelon, J.M., and Stark, J.R., 1988, Surficial geologic map of the Greenwood Lake, Isabella and Cramer quadrangles, Minnesota: Minnesota Geological Survey Open File Report 88-2, scale 1:62,500, 9 p. text.

Karrow, P.F., and Geddes, R.S., 1987, Drift carbonate on the Canadian Shield: Canadian Journal of Earth Sciences, v. 24, p. 365-369.

Lehr, J.D., and Gilbertson, J.P., 1988, Revised Pleistocene stratigraphy of the upper Big Sioux River basin, northeastern South Dakota: American Quaternary Association Program and Abstracts of the 10th Biennial Meeting, p. 130.

Lehr, J.D., and Matsch, C.L., 1987, The late Wisconsinan Vermilion moraine in northeastern Minnesota: An ice-marginal complex of multiple origin [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 4, p. 231.

Martin, D.P., Dahl, D.A., Cartwright, D.F., and Meyer, G.N., 1991, Regional survey of buried glacial drift, saprolite, and Precambrian bedrock in Lake of the Woods County, Minnesota: Minnesota: Minnesota Department of Natural Resources, Division of minerals Report 280, 75 p.

Martin, D.P., Meyer, G.N., Cartwright, D.F., Lawler, T.L., Pastika, T.J., Jirsa, M.A., Boerboom, T.J., and Streitz, A.R., 1989, Regional geochemical survey of glacial drift samples over Archean granite-greenstone terrane in the Effie area, northeastern Minnesota: Minnesota Department of Natural Resources, Division of minerals Report 263, v. I, 59 p., v. II, 323 p.

Martin, D.P., Meyer, G.N., Lawler, T.L., Chandler, V.W., and Malmquist, K.L., 1988, Regional survey of buried glacial drift geochemistry over Archean terrane in northern Minnesota: Minnesota Department of Natural Resources, Division of minerals Report 252, v. I, 73 p., v. II, 386 p.

Matsch, C.L., 1972, Quaternary geology of southwestern Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 548-560.

Meyer, G.N., 1986, Subsurface till stratigraphy of the Todd County area, central Minnesota: Minnesota Geological Survey Report of Investigations 34, 40 p.

Mooers, H.D., 1988, Quaternary history and ice dynamics of the late Wisconsin Rainy and Superior lobes, central Minnesota [PhD thesis]: University of Minnesota, Minneapolis, 200 p.

_____1990, Discriminating textually similar tills in central Minnesota by graphical and multivariate techniques: Quaternary Research, v. 34, p. 133-147.

Moran, S.R., and others, 1976, Quaternary stratigraphy and history of North Dakota, southern Manitoba, and northwestern Minnesota, *in* Mahanney, W., ed., Quaternary stratigraphy and history of North America: Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, p. 131-158.

Morey, G. B., 1972a, Mesabi Range, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 204-217.

_____1972b, Pre-Mt. Simon regolith, *in* Sims, P.K., and Morey, G.B., (eds.), Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 506-508.

Morey, G.B., Sims, P.K., Cannon, W.F., Mudrey, M.G., Jr., and Southwick, D.L., 1982, Geologic map of the Lake Superior region: Minnesota, Wisconsin and northern Michigan: Minnesota Geological Survey State Map S-13, scale 1:1,000,000.

Parham, W.E., 1970, Clay mineralogy and geology of Minnesota's kaolin clays: Minnesota Geological Survey Special Publication Series SP-10, 142 p.

Preston, R.S., Person, E., and Deevey, E.S., Jr., 1955, Yale natural radiocarbon measurements II: Science, v. 122, p. 954-960.

Richmond, G.M., and Fullerton, D.S., 1987, Summation of Quaternary glaciations in the United States of America: Quaternary Science Reviews, v. 5, p. 183-196.

Severson, L.S., Mooers, H.D., and Malterer, T.J., 1980, Inventory of peat resources, Koochiching County, Minnesota: Minnesota Department of Natural Resources, Division of minerals, 95 p.

Sharpe, D. R., and Cowan, W. R., 1990, Moraine formation in northwestern Ontario: product of subglacial fluvial and glaciolacustrine sedimentation: Canadian Journal of Earth Sciences, v. 27, p. 1478-1486.

Stark, J.R., 1977, Surficial geology and groundwater geology of the Babbitt-Kawishiwi area, northeastern Minnesota, with planning implications [M.S. thesis]: University of Wisconsin, Madison, 104 p.

Stuiver, M., 1969, Yale natural radiocarbon measurements IX: Radiocarbon, v. 11, no. 2, p. 545-658.

Teller, J.T., and Thorleifson, L.H., 1983, The Lake Agassiz-Lake Superior connection, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, p. 261-290.

University of Minnesota Agricultural Experiment Station, 1971, Minnesota soil atlas: Hibbing sheet: University of Minnesota Miscellaneous Report 110-1971, scale 1:250,000, text 47 p.

Winchell, N.H., 1901, Glacial lakes of Minnesota: Geological Society of America Bulletin, v. 12, p. 109-128.

Winter, T.C., 1971, Sequence of glaciation in the Mesabi-Vermilion iron range area, northeastern Minnesota: U.S. Geological Survey Professional Paper 750-C, p. 82-88.

Winter, T.C., Cotter, R.D., and Young, H.L., 1973, Petrography and stratigraphy of glacial drift, Mesabi-Vermilion iron range area, northeastern Minnesota: U.S. Geological Survey Bulletin 1331-C, 41 p.

Wright, H.E., Jr., 1962, Role of the Wadena lobe in the Wisconsin glaciation of Minnesota: Geological Society of America Bulletin, v. 73, p. 73-99.

_____1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 515-547.

Wright, H.E., Jr., and Watts, W.A., 1969, Glacial and vegetational history of northeastern Minnesota: Minnesota Geological Survey Special Publication Series SP-11, 59 p.

Wright, H.E., Jr., Mattson, L.A., and Thomas, J.A., 1970, Geology of the Cloquet quadrangle, Carlton County, Minnesota: Minnesota Geological Survey Geologic Map Series GM-3, scale 1:24,000; 30 p. text.

Zoltai, S.C., 1965, Glacial features of the Quetico-Nipigon area, Ontario: Canadian Journal of Earth Sciences, v. 2, p. 247-269.

AN OVERVIEW OF THE VEGETATIONAL HISTORY OF THE ARROWHEAD REGION, NORTHEASTERN MINNESOTA

by

James K. Huber,
Archaeometry Laboratory
University of Minnesota, Duluth

INTRODUCTION

Numerous palynological studies have been undertaken in Minnesota. The first detailed pollen study in northeastern Minnesota was by Fries (1962) at Weber Lake. Landmark studies assimilated available data into a comprehensive regional pollen stratigraphy for the state for the late glacial and early Holocene (Cushing, 1967) and for a vegetational history for northeastern Minnesota (Wright and Watts, 1969). Subsequent comparisons have been done by various authors (Birks, 1976, 1981; Craig, 1972; Huber, 1987; Huber and Hill, 1987) relating their sites to the defined vegetational sequence. Despite continued palynological investigations, a regional reappraisal of the pollen data available has not yet been undertaken. This paper presents a synopsis of two pollen sequences and a brief overview of the vegetational history of the Arrowhead region using the framework established by Cushing (1967). The Arrowhead region is defined here as Carlton, St. Louis, Lake, and Cook counties (Figure 1).

The Arrowhead region (Fig. 1) is located in the transitional conifer-hardwood forest between the deciduous forest to the south and the boreal forest to the north. This area lies within the Lake Forest region of Weaver and Clements (1938), the hemlock-white pine-northern hardwoods region of Braun (1950), and the Great Lakes-St. Lawrence forest region of Rowe (1959). The Arrowhead vegetation comprises a mosaic of conifers and deciduous broadleaf trees interspersed with wet prairies, marshes, conifer bogs and swamps, and open muskeg.

TWO POLLEN SEQUENCES FROM THE ARROWHEAD REGION

The two pollen sequences presented here have been previously described by Huber (1987, 1988, 1990, 1992a, 1992b, in press). Big Rice Lake is located approximately 65 miles northwest of Duluth and 15 miles north of Virginia, Minnesota, in the western part of the Arrowhead region. Wild rice (*Zizania aquatica*) grows abundantly over most of Big Rice Lake. The lake has a maximum depth of 1.4 m and an average depth of 1 m. An archaeological site has been excavated on the northern shore of Big Rice Lake.

Cloquet Lake, the headwaters of the Cloquet River, located approximately 56 miles north of Duluth, Minnesota in the eastern part of the Arrowhead region. Cloquet Lake has a maximum depth of approximately 2 m and a mean depth of 1.5 m. An archaeological site has also been excavated on the southeastern shore of Cloquet Lake.

Both lakes were cored near their centers using a modified Livingstone piston sampler. A 525-cm core was recovered from Big Rice Lake; below 270 cm there is too little pollen to count. At Cloquet Lake, a 438-cm core was recovered.

Big Rice Lake

The pollen diagram is divided into seven pollen-assemblage zones, based on the relative percentages of various taxa within the pollen sum and the numerical zonation procedure of Gordon and Birks (1972, 1974). The pollen sum consists of trees, shrubs, and herbs (including vascular cryptogams) and was greater than 400 grains. The pollen zones, from oldest to youngest, are numbered 1-7 (Fig. 2).

In Zone 1, NAP (nonarboreal pollen) values are greater than 40%. Sedge (Cyperaceae), wormwood (*Artemisia*), and ragweed (*Ambrosia*-type) are the prominent NAP types found at Big Rice Lake. Spruce (*Picea*) is the dominant AP (arboreal pollen) type; birch (*Betula*) is also important. A large interval ^{14}C date for most of Zone 1 (255-272 cm) is 12,040 +540 -570 B.P.

Cyperaceae is prominent in Zone 2, but declining . *Betula* and *Picea* are the most abundant AP types and *Salix* is more common than in Zone 1. The top of this zone is dated at approximately 9,500 B.P.

Two subzones are recognized in Zone 3. This zone is characterized by high percentages of *Picea* and pine (*Pinus*), with *Picea* reaching its greatest abundance (35%) in subzone 3A. Subzone 3B is marked by a maximum of fir (*Abies*). Deciduous trees, such as oak (*Quercus*) and elm (*Ulmus*) also become more abundant. This zone is dated from approximately 9,500 to 8,300 B.P.

Zone 4 is dominated by *Pinus*. Most of the identifiable pine grains in this zone are jack pine/red pine (*Pinus banksiana* /*P. resinosa*-type). Many of the pine grains are represented by wings of broken grains and are not identified below the level of genus. *Betula* and alder (*Alnus*) increase as *Picea* and *Abies* decrease. *Quercus* and *Ulmus* continue consistently throughout Zone 4 at slightly lower values than in Zone 3. Gramineae and *Ambrosia*-type pollen both increase in Zone 4 while *Artemisia* remains fairly constant at about 15% (Figure 2). Zone 4 covers a period from approximately 8,300 to 6,800 B.P.

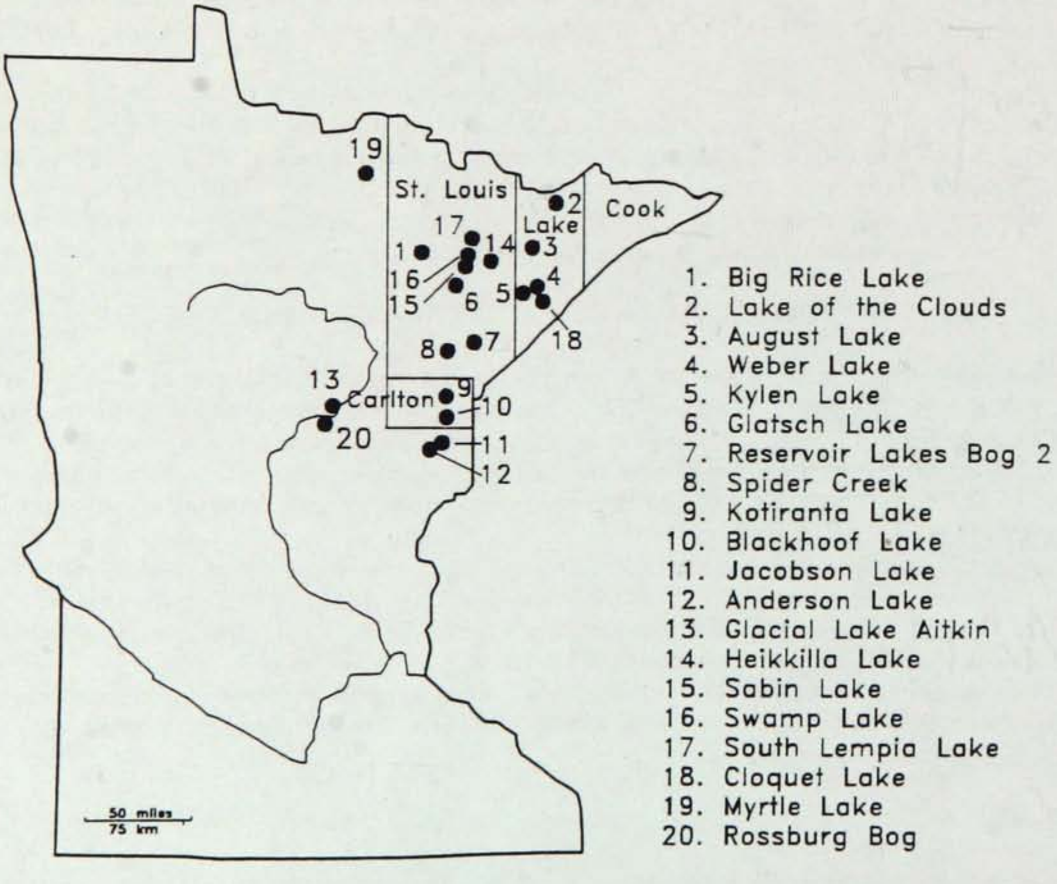


Figure 1. Locations of pollen studies in the Arrowhead Region and adjacent areas mentioned in the text.

Quercus reaches its maximum (8%), *Ulmus* increases slightly, and *Artemisia* and *Ambrosia* decline in Zone 5. There is also a shift from red/jack pine to white pine (*Pinus strobus*) in this zone at approximately 6,800 B.P. Birch, alder, and grass remain stable throughout this zone.

Zone 6 is characterized by a dramatic increase in Gramineae pollen. Gramineae pollen increases abruptly from 5% at the top of Zone 5 to 46% at the bottom of Zone 6. The increase in Gramineae is attributed to an expansion of wild rice (*Zizania aquatica*) in the lake. There is no date from the core on the increase in Gramineae; however, a wood date from a ricing jig of the Laurel period containing wild rice is 1,670 ± 45 B.P. (Rapp and others, 1990).

In Zone 7, *Ambrosia* shows a small increase (Fig. 2) that may be the result of deforestation in the area and the advent of pioneer settlement about 1890. Percentage values of *Ambrosia*-type pollen in this zone are almost twice as great without Gramineae as part of the pollen sum. Although not shown, *Ambrosia* concentration values jump from approximately 3,000 grains/cc in Zone 6 to 20,000 grains/cc in Zone 7.

Cloquet Lake

Pollen counts from Cloquet Lake are also based on a pollen sum of trees, shrubs, and herbs (including vascular cryptogams) and are greater than 400 grains. The same criteria were used to delineate the pollen-assemblage zones at Cloquet Lake, except that the 1985 version of the numerical zonation procedure of Gordon and Birks (1985) was used. The pollen diagram from Cloquet Lake (Fig. 3) is divided into five pollen-assemblage zones numbered CL-1 to CL-5, from oldest to youngest.

Zone CL-1 is characterized by NAP greater than 50%. The prominent NAP types found at Cloquet Lake are Cyperaceae, *Ambrosia*-type, *Artemisia*, and Gramineae. *Picea*, *Salix*, and cedar (Cupressaceae) are the most abundant AP types.

Picea reaches its maximum abundance (47%) in Zone CL-2. *Pinus banksiana/resinosa*, which occurs only in trace amounts in Zone CL-1, becomes the dominant taxon by the top of Zone CL-2. Cyperaceae is still prominent, but declining.

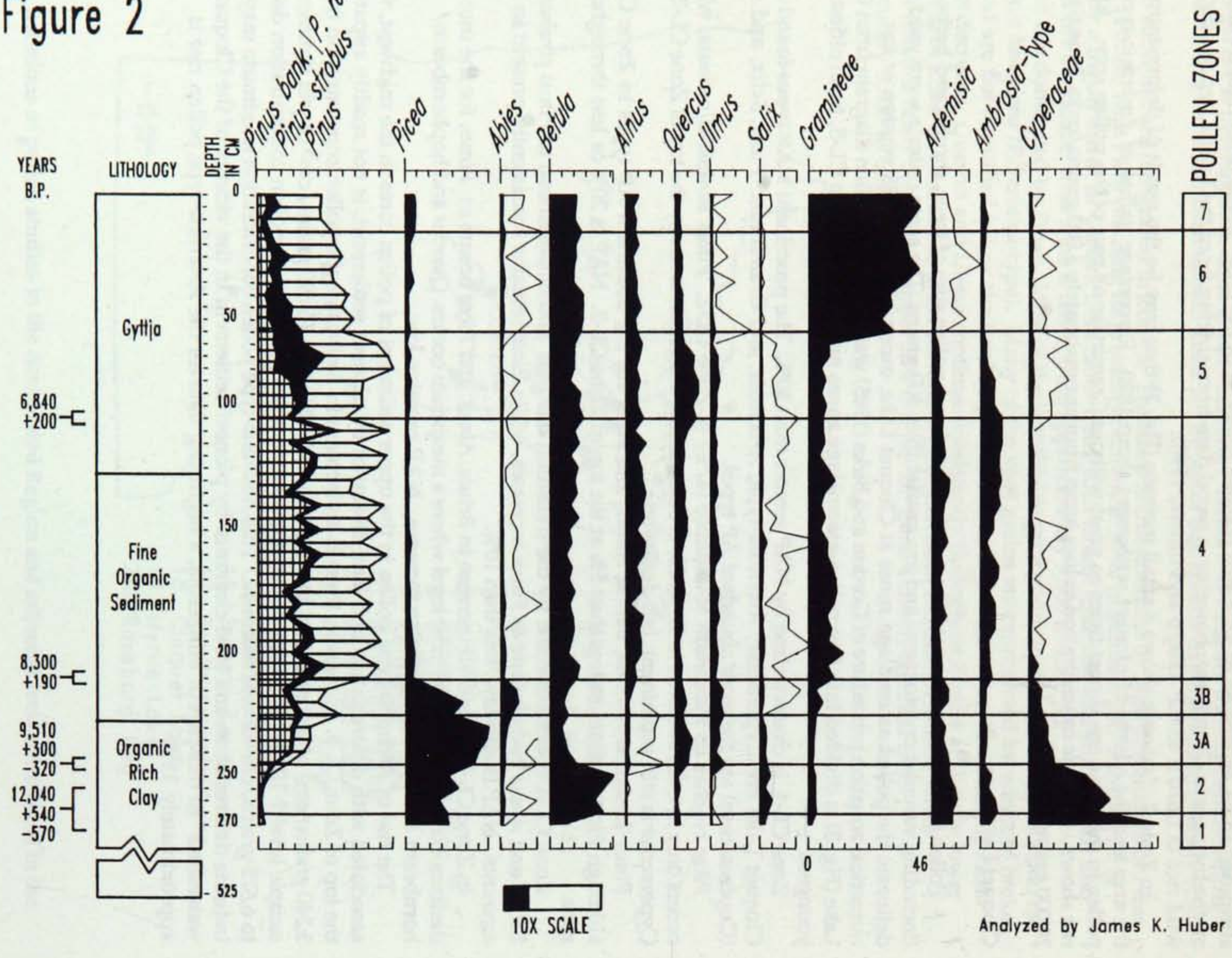
Pinus banksiana/resinosa, *Betula*, *Alnus*, and *Picea* are the dominant AP types in Zone CL-3, although *Picea* declines to less than 5% at the top of Zone CL-3. NAP is 20% or less throughout this zone.

Zone CL-4 is characterized by the transition of *Pinus banksiana/resinosa* to *Pinus strobus*. *Betula* and *Alnus* both decline as *Pinus* increases, while *Picea* remains consistently present in low amounts. NAP is also low, less than 10%.

In Zone CL-5, an overall increase in *Betula*, *Alnus*, and *Picea* occurs as *Pinus*, for the most part, declines except in the uppermost level where a maximum occurs. *Quercus* and hophornbeam/hornbeam (*Ostrya/Carpinus*) also increase. NAP remains low.

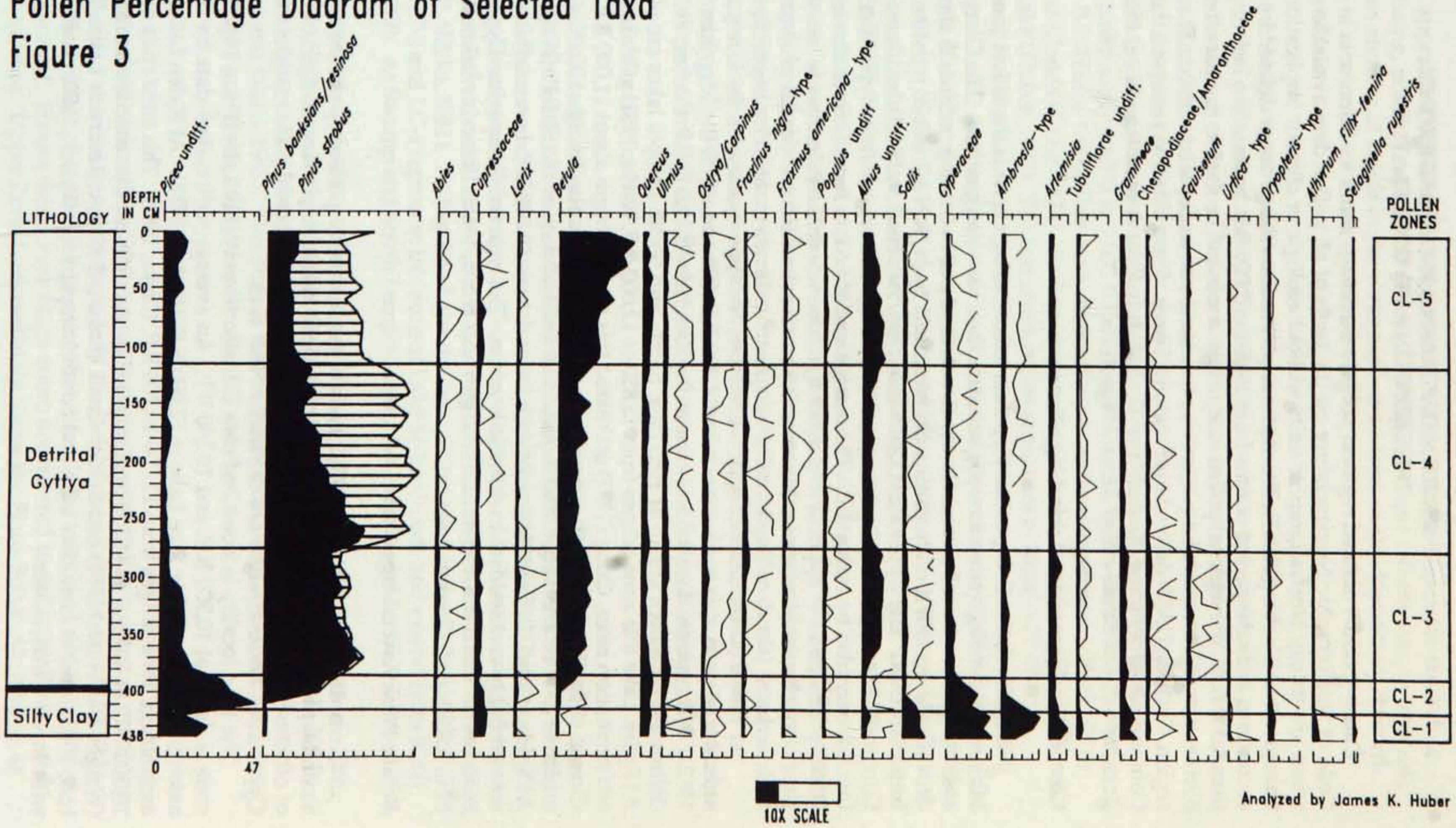
The rise of *Ambrosia*-type pollen in the upper sediment of pollen cores in the midwest, which is associated with deforestation and land clearance by pioneer settlement, is not readily apparent at the top of Zone CL-5. However, there is an increase in *Ambrosia*-type pollen concentration from 3,340 grains/cm^3 of wet sediment in sample level 19-20 cm to 16,690 grains/cm^3 of wet sediment in sample level 9-10 cm. In the uppermost level (0-1 cm) *Ambrosia*-type pollen concentration decreases to 6,675 grains/cm^3 of wet sediment. This *Ambrosia*-type pollen concentration maximum may indicate deforestation and land clearance by pioneer settlement in the vicinity of the Cloquet Lake watershed. In this part of Minnesota, a beginning date for the *Ambrosia*-type pollen rise is approximately 1890.

BIG RICE LAKE, ST. LOUIS COUNTY, MINNESOTA
Pollen Percentage Diagram of Selected Taxa
Figure 2



Analyzed by James K. Huber

CLOQUET LAKE, LAKE COUNTY, MINNESOTA
Pollen Percentage Diagram of Selected Taxa
Figure 3



Analyzed by James K. Huber

REGIONAL POLLEN ASSEMBLAGE ZONES: DESCRIPTION AND CORRELATION

Cushing (1967) defined regional pollen assemblage zones for Minnesota in accordance with the Code of Stratigraphic Nomenclature on the basis of all pollen data available at that time. The zones are strictly biostratigraphic units without ecologic or climatic implications and may be time-transgressive (Cushing, 1967). The regional pollen assemblage zones defined by Cushing (1967) encompass only the period of time from 15,000 to 8,000 B.P. because of a lack of pollen data younger than 8,000 B.P. The regional pollen assemblage zones can be used to compare local pollen sequences in northeastern Minnesota and place them in a temporal and spatial context. For the Arrowhead region, Cushing (1967) defined four regional zones. From oldest to youngest, they are the Compositae-Cyperaceae Assemblage Zone, *Betula-Picea* Assemblage Zone, *Picea-Pinus* Assemblage Zone, and *Pinus-Betula-Alnus* Assemblage Zone.

Compositae-Cyperaceae Assemblage Zone

As defined, the Compositae-Cyperaceae assemblage zone is the oldest zone in northeastern Minnesota, although some investigators use their own designations. The Compositae-Cyperaceae assemblage zone usually occurs as the first unit of pollen-bearing sediments above Wisconsin glacial drift (Cushing, 1967). This zone is characterized by high NAP values (greater than 40%). Important NAP are Cyperaceae, *Ambrosia*-type, *Artemisia*, other Tubuliflorae (subfamily of the Compositae family), and Gramineae. Two other NAP types, *Urtica*-type (nettle) and Ericaceae (heath), may also be important. The most abundant AP is *Picea*; *Salix* is also important. Cushing (1967) positioned the upper boundary of this zone where NAP declines to less than 50%. At several sites in northeast Minnesota this zone is associated with macrofossils of *Dryas integrifolia* (dryas), *Salix herbacea* (shrub willow), and other plants indicative of tundra vegetation (Cushing, 1967).

At Weber Lake, Lake County, Minnesota, the type locality for the Compositae-Cyperaceae assemblage zone, this zone dates from 14,700 B.P. (Wright, 1972) to older than 10,500 B.P. (Fries, 1962). A composite date for this zone at Big Rice Lake is 12,040 B.P. (Huber, 1988). Equivalent zones delineated by Bjorck (1990) at Heikkilla, Sabin, and South Lempia lakes are older than 11,500 B.P. At Kylen Lake this zone ranges from 15,850 to 12,000 B.P. (Birks, 1981). On the basis of sedimentation rates, Craig (1972) estimated this zone to begin about 11,000 B.P. at Lake of the Clouds. The Compositae-Cyperaceae assemblage zone is also found at Kotiranta Lake with a midzone date of 13,500 B.P. and a questionable basal date of 16,150 B.P. (Wright and Watts, 1969). At Spider Creek, Baker (1965) rejected a basal date of 22,000 B.P. because the radiocarbon sample was probably contaminated with dead carbon. The regional Compositae-Cyperaceae assemblage zone is also found at Glatsch Lake (Wright and Watts, 1969), Reservoir Lakes Bog 2 (Huber and Hill, 1987), and Cloquet Lake.

Betula-Picea Assemblage Zone

According to Cushing (1967), *Betula* is the dominant pollen type in the *Betula-Picea* assemblage zone; the next most frequent is *Picea*; also of importance is *Salix* (more than 3%). Pollen of other trees and shrubs is found at less than 5%. Nonarboreal pollen ranges from 20-40%. Cyperaceae and *Artemisia* are the major NAP taxa.

The type locality is Zone 2 of core C:1, also from Weber Lake (Fries, 1962). At Weber Lake this zone is dated at 10,500 B.P. and 10,200 B.P. An average radiocarbon date for the entire *Betula-Picea* assemblage zone at Big Rice Lake is 12,000 B.P. (Huber, 1988). At Kylen Lake, the *Betula-Picea* assemblage zone ranges from 12,000-10,700 B.P. (Birks, 1981). This zone ends at approximately 10,300 B.P. at Lake of the Clouds (Craig, 1972). As defined, this zone is also found at Glatsch Lake (Wright and Watts, 1969) and Spider Creek (Baker, 1965). At Reservoir Lakes Bog 2 (Huber and Hill, 1987), and at Heikkilla Lake and South Lempia Lake (Bjorck, 1990) similar zones occur, but with lower *Picea* values.

At Cloquet Lake, approximately 12 miles southeast of Weber Lake, evidence for the *Betula-Picea* assemblage is missing, possibly as a result of the sampling technique (10-cm sample interval), or possibly reflecting an absence of *Betula* in the watershed or a hiatus in the depositional record.

Picea-Pinus Assemblage Zone

The *Picea-Pinus* assemblage zone was defined as follows by Cushing (1967): *Picea* and *Pinus* combined exceed 50% of total pollen; they are the most abundant pollen types; and each is greater than 10%. Diploxylon *Pinus* is greater than 50%, *Larix* (tamarack) is greater than 1%, *Alnus* less than 3%, and NAP less than 20%. *Betula, Quercus, Fraxinus nigra*-type, and *Abies* are other important components, as well as *Ulmus* at greater than 3%.

The type locality for the *Picea-Pinus* assemblage zone is Zone 3, core C:1 from Weber Lake which ranges from approximately 10,000 to 9,000 B.P. (Fries, 1962). At Kylen Lake the age of this zone is 10,700 to 9,250 B.P. (Birks, 1981). This zone covers the period from approximately 10,300 to 9,200 B.P. at Lake of the Clouds (Craig, 1972). Radiocarbon dates place this zone between 9,500 and 8,300 B.P. at Big Rice Lake (Huber, 1987). The combined pollen sequences of Bjorck (1990) from Heikkilla, Sabin, Swamp, and South Lempia Lakes indicates that this zone dates between 10,600 and 9,200 B.P. At Glatsch Lake, the *Picea* peak has been dated at approximately 9,750 B.P. (Wright and Watts, 1969). This zone also occurs in cores from August Lake (Wonson-Liukkonen and Huber, 1987), Blackhoof Lake (Cushing, 1967), and Kotiranta Lake (Wright and Watts, 1969).

Zone CL-2 at Cloquet Lake and Zone 3 at Reservoir Lakes Bog 2 (Huber and Hill, 1987) approximate Cushing's (1967) *Picea-Pinus* assemblage zone; however, they do not meet all the criteria. *Picea* and *Pinus* combined do not exceed 50% of the total in all samples, and at Reservoir Lakes Bog 2, *Pinus* does not always exceed 10%. Even though these zones do not fit all of Cushing's (1967) criteria, the zones are probably equivalent and the differences may be the result of local variation in either the pollen assemblage or the taxa included within the pollen sum.

The *Picea-Pinus* assemblage zone is found near the Arrowhead region at Anderson Lake, Jacobson Lake, and Rossburg Bog (Wright and Watts, 1969). At Glacial Lake Aitkin (Farnham and others, 1964), the *Picea-Pinus* assemblage zone occurs in the lower part of Zone 3 (Cushing, 1967).

Pinus-Betula-Alnus Assemblage Zone

In the *Pinus-Betula-Alnus* regional pollen assemblage zone, *Pinus* is the dominant pollen type, *Betula* is relatively important with values greater than 10%, and *Alnus* is greater than 5%. *Abies* occurs at 1% or more and *Quercus* and *Ulmus* are less than 5%; NAP is less than 15% (Cushing, 1967).

The type locality for the regional *Pinus-Betula-Alnus* assemblage zone is Zone 4, core C:1 from Weber Lake, which dates from about 9,000 to 7,000 B.P. (Fries, 1962). At Kylen Lake this zone dates from 9,250 to 8,400 B.P. (Birks, 1981). At Big Rice Lake the base of this zone is dated at 8,300 B.P. (Huber, 1987). Zones LC-3 and LC-4 represent this zone at Lake of the Clouds and extend from 9,200 to 6,500 B.P. (Craig, 1972). At Swamp and South Lempia Lakes, this zone begins at 9,200 B.P. (Bjorck, 1990).

At Cloquet Lake, Zone CL-3 represents the regional *Pinus-Betula-Alnus* assemblage zone. The *Pinus-Betula-Alnus* assemblage zone is also found at Reservoir Lakes Bog 2 (Huber and Hill, 1987), August Lake (Wonson-Liukkonen and Huber, 1987), Glatsch Lake (Wright and Watts, 1969), and Kotiranta Lake (Wright and Watts, 1969). This zone is also found at Rossburg Bog, Anderson Lake, and Jacobson Lake (Wright and Watts, 1969) near the Arrowhead region.

Other Assemblage Zones

Cushing (1967) did not establish regional pollen assemblage zones for pollen sequences occurring above the *Pinus-Betula-Alnus* assemblage zone because of the lack of data younger than 8,000 B.P. However, at least two biostratigraphic assemblage zones can usually be identified above the *Pinus-Betula-Alnus* assemblage zone. Herein these assemblage zones are referred to as Upper Zone 1 and Upper Zone 2 for convenience. Upper Zone 1, immediately above the *Pinus-Betula-Alnus* zone, is characterized by high *Pinus* values of greater than 50% and prominence of *Betula* and *Alnus*. An assemblage zone of this type is found at Lake of the Clouds (Craig, 1972), Big Rice Lake (Huber, 1987), August Lake (Wonson-Liukkonen and Huber, 1987), and Cloquet Lake. As a result of the high number of undifferentiated pine grains, this zone is not apparent at Reservoir Lakes Bog 2 (Huber and Hill, 1987). This type of zone is also found south of the Arrowhead region at Jacobson Lake (Wright and Watts, 1969).

The rise in white pine has been dated at approximately 7,200 B.P. at Jacobson Lake (Wright and Watts, 1969) south of the Arrowhead region. Within the Arrowhead region, the white pine rise has been dated at about 6,850 B.P. at Big Rice Lake (Huber, 1990) and about 7,000 B.P. at Lake of the Clouds (Craig, 1972). At Myrtle Lake, outside the northwest part of the Arrowhead region, the white pine rise occurred sometime before 6,000 B.P. (Janssen, 1968).

Upper Zone 2 is characterized by an increase in *Picea* and *Pinus*, *Betula*, and *Alnus* are still important. Zones equivalent to an Upper Zone 2 have been delineated at August Lake (Wonson-Liukkonen and Huber, 1987), Big Rice Lake (Huber, 1987), Lake of the Clouds (Craig, 1972), Weber Lake (Fries, 1962), Kotiranta Lake (Wright and Watts, 1969) and Cloquet Lake.

A third zone commonly occurs in the Arrowhead region. This is an acme or peak zone characterized by the rise of *Ambrosia*-type pollen in the upper sediment of pollen cores in the midwest, and is associated with deforestation and land clearance by pioneer settlement (Wright, 1971). In the Arrowhead region of Minnesota, a beginning date for the *Ambrosia*-type pollen rise is approximately 1890 (Maher, 1977).

The *Ambrosia*-type pollen rise is not readily apparent at the top of Zone CL-5 at Cloquet Lake or in Zone 7 at Big Rice Lake. However, there is a general increase in *Ambrosia*-type pollen concentration in the uppermost samples in the cores from both sites. The *Ambrosia*-type pollen concentration maxima probably reflect the *Ambrosia*-type pollen rise resulting from deforestation and land clearance by pioneer settlement in the vicinity of the lakes' watersheds. An *Ambrosia*-type pollen rise is found at August Lake (Wonson-Liukkonen and Huber, 1987) and Reservoir Lakes Bog 2 (Huber and Hill, 1987). The *Ambrosia*-type pollen rise is apparent at Weber Lake (Fries, 1962) and south of the Arrowhead region at Jacobson Lake (Wright and Watts, 1969).

INTERPRETATIONS

Based on the pollen stratigraphy found in the Arrowhead region a vegetational and climatic history can be inferred, although in some cases there are no close modern analogs. According to the interpretations of Cushing (1967), the Compositae Cyperaceae Assemblage Zone represents a subarctic tundra of treeless or nearly treeless open vegetation of herbs and shrubs; the *Betula-Picea* Assemblage Zone indicates a shrub parkland; the *Picea-Pinus* Assemblage Zone represents a conifer or conifer-hardwood forest; and the *Pinus-Betula-Alnus* Assemblage Zone indicates a mixed conifer-hardwood forest. On the basis of pollen sequences investigated in the Arrowhead region, the author interprets Upper Zone 1 as representing a continuation of the mixed conifer-hardwood forest in which red and/or jack pine is being replaced by white pine. In Upper Zone 2, an increase in abundance of hardwoods in the mixed conifer-hardwood forest is suggested by the pollen stratigraphy found in the Arrowhead region.

Expansion of the Prairie Peninsula during the mid-Holocene is most evident in the Arrowhead region in the Big Rice Lake pollen sequence. Zones 4 and 5 at Big Rice Lake show an increase in deciduous trees and prairie-type plants. It is unlikely that the prairie migrated far enough east to reach Big Rice Lake; however, the eastward prairie migration is reflected by the regional pollen deposition in the lake basin.

SUMMARY AND CONCLUSIONS

Following glacial retreat in the Arrowhead region, a tundra environment was established in deglaciated areas by 14,700 years ago. By approximately 12,000 B.P., tundra was being replaced by a shrub parkland in the southern part of the region. The shrub parkland reached the northern area by about 10,500 B.P. By 8,300 B.P. the Arrowhead region was covered by a conifer or conifer-hardwood forest. As succession and plant migration continued, the forest became a mixed conifer-hardwood forest dominated by jack and/or red pine. White pine migrated into the region by approximately 7,000 years ago and began to replace the jack and/or red pine. By about 6,000 B.P., white pine had reached the northwest part of the region. Around 3,000 B.P., there was a change in the relative amounts of several of the arboreal taxa in the forest, as spruce became more abundant. An increase in *Ambrosia*-type pollen occurred about 1890 with the advent of pioneer settlement and logging.

It is evident from this brief overview that much work is needed to understand the complex vegetational history of the Arrowhead region. With more radiocarbon-dated, close-interval pollen investigations, the regional pollen assemblage zones will be refined as their characteristics are more completely understood.

REFERENCES CITED

Baker, R.G., 1965, Late-glacial pollen and plant macrofossils from Spider Creek, southern St. Louis County, Minnesota: Geological Society of America Bulletin, v. 45, p. 645-665.

Birks, H.J.B., 1976, Late-Wisconsinan vegetational history at Wolf Creek, central Minnesota: Ecological Monographs, v. 46, p. 395-429.

_____1981, Late-Wisconsin vegetational and climatic history at Kylen Lake, northeastern Minnesota: Quaternary Research, v. 16, p. 322-355.

Bjorck, S., 1990, Late Wisconsin history north of Giants Range, northern Minnesota, inferred from complex stratigraphy: Quaternary Research, v. 33, p. 18-36.

Braun, E.L., 1950, Deciduous forests of eastern North America: Philadelphia, The Blakiston Company, 596 p.

Craig, A.J., 1972, Pollen influx to laminated sediments: A pollen diagram from northeastern Minnesota: Ecology, v. 53, p. 46-57.

Cushing, E.J., 1967, Late-Wisconsin pollen stratigraphy and the glacial sequence in Minnesota, *in* Cushing, E.J., and Wright, H.E., Jr., eds., Quaternary paleoecology: New Haven, Yale University Press, p. 59-88.

Farnham, R.S., McAndrews, J.H., and Wright, H.E., Jr., 1964, A late Wisconsin buried soil near Aitkin, Minnesota and its paleobotanical setting: American Journal of Science, v. 262, p. 393-412.

Fries, M., 1962, Pollen profiles of late Pleistocene and recent sediments from Weber Lake, Minnesota: Ecology, v. 43, p. 295-308.

Gordon, A.D., and Birks, H.J.B., 1972, Numerical methods in Quaternary paleoecology, I. Zonation of pollen diagrams: New Phytologist, v. 71, p. 961-979.

Gordon, A.D., and Birks, H.J.B., 1974, Numerical methods in Quaternary paleoecology, II. Comparison of pollen diagrams: New Phytologist, v. 73, p. 221-249.

Gordon, A.D., and Birks, H.J.B., 1985, Numerical methods in Quaternary pollen analysis: London, Academic Press, 317 p.

Huber, J.K., 1987, A vegetational reconstruction from Big Rice Lake, St. Louis County, Minnesota: Current Research in the Pleistocene, v. 4, p. 91-93.

_____ 1988, Use of green algae abundances for augmenting palynological interpretation: Current Research in the Pleistocene, v. 5, p. 48-50.

_____1990, A pollen and nonsiliceous algae record from Big Rice Lake, St. Louis County, Minnesota [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 5, p. 14.

_____1992a, Results of a paleoecological study of Cloquet Lake, Lake County, Minnesota: Duluth, Archaeometry Laboratory, University of Minnesota-Duluth. Report submitted to the Superior National Forest, Cultural Resource Management Division, Duluth, Minnesota, 23 p.

_____ 1992b, A late and postglacial vegetational and lake nutrient history from Lake County, northeast Minnesota [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 4, p. 22.

_____ in press, Preliminary analysis of a late glacial pollen record from Cloquet Lake, Lake County, Minnesota, USA: Current Research in the Pleistocene, v. 8.

Huber, J.K., and Hill, C.L., 1987, A pollen sequence associated with Paleoindian presence in northeastern Minnesota: Current Research in the Pleistocene, v. 4, p. 89-91.

Janssen, C.R., 1968, Myrtle Lake: a late- and post-glacial pollen diagram from northern Minnesota: Canadian Journal of Botany, v. 46, p. 1397-1410.

Maher, L.J., Jr., 1977, Palynological studies in the western arm of Lake Superior: Quaternary Research, v. 7, p. 14-44.

Rapp, G, Jr., Allert, J.D., and Peters, G., 1990, The origins of copper in three northern Minnesota sites: Pauly, River Point, and Big Rice, *in* Gibbon, G.E., ed., The woodland tradition in the western Great Lakes: Papers presented to Elden Johnson: Minneapolis, University of Minnesota Publications in Anthropology Number 4, p. 233-238.

Rowe, J.S., 1959, Forest regions of Canada: Canadian Department of Northern Affairs and Natural Resources, Forestry Branch Bulletin 123, 71 p.

Weaver, J.E., and Clements, F.E., 1938, Plant ecology (second edition): New York, McGraw-Hill Book Company, 601 p.

Wonson-Liukkonen, B., and Huber, J.K., 1987, A paleoecological reconstruction from August Lake, Lake County, Minnesota: Current Research in the Pleistocene, v. 4, p. 98-100.

Wright, H.E., Jr., 1971, Late Quaternary vegetational history of North America, *in* Turekian, K.K., ed., The late Cenozoic glacial ages: New Haven, Yale Press, p. 425-464.

_____1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A Centennial Volume: Minnesota Geological Survey, University of Minnesota, St. Paul, p. 515-547.

Wright, H.E., Jr., and Watts, W.A., 1969, with contributions by Jelgersma, S., Waddington, J.C.B., Ogawa, J., and Winter, T.C., 1969, Glacial and vegetational history of northeastern Minnesota: Minnesota Geological Survey Special Publication Series SP-11, 59 p.

DESCRIPTION OF ROTASONIC CORE FROM THE TOIMI DRUMLIN FIELD AREA, NORTHEASTERN MINNESOTA

by

Howard C. Hobbs
Minnesota Geological Survey
St. Paul, Minnesota, 55114

INTRODUCTION

Rotasonic drilling is a relatively new technique for drilling core. The core barrel is rotated and vibrated at the same time, enabling relatively easy penetration of hard, rocky tills and even bedrock. After the core barrel is advanced a certain distance, the casing is vibrated down around the core barrel, which is then pulled up. The core sample is then vibrated out into a plastic sleeve.

This system can produce a continuous core of the whole drift sequence, although some disturbances do occur. Water-saturated sediment may flow during coring; sometimes part of the sample, especially sand, will fall out of the core barrel back into the hole; the footage of core is not always the same as the depth advanced. Still, Rotasonic core is superior to auger and split-spoon sampling in many applications, particularly in rocky drift, because the Rotasonic core bit will drill right through most rocks.

Rotasonic drilling through drift is normally done "dry" without added water, because "wet" drilling will wash out the sample. Bedrock drilling is normally done wet, because rock tends to powder and fracture when drilled dry.

The missing 172-185 feet and disturbed 185-205 feet intervals in CDC-33 are the result of mistaking boulders for bedrock. This is an easy mistake in this area, where the drift commonly contains large boulders.

Central Duluth Complex Drilling

The cores described here (see Plate 1 for locations) were taken as part of the central Duluth Complex mapping and stratigraphic study, supervised by James D. Miller, Jr., of the Minnesota Geological Survey. Study of the overburden is only an incidental part of this project. Most holes were drilled by rotary methods through the overburden into the upper part of the bedrock. The rock was then cored by standard wire-line methods.

Because a Rotasonic rig was used to speed up the overburden drilling, the opportunity arose to obtain continuous drift core in selected holes. Wet drilling is faster and cheaper, but a few holes were drilled dry, at extra cost, to permit recovery of drift core.

Three cores to bedrock are only a beginning, but two striking conclusions can be drawn already: The surface till, named the Independence Till by Wright and others (1970), and total drift thickness are much greater in the Toimi drumlin field than in the scoured bedrock area only a few tens of miles north. These northeastern source drifts are at least slightly calcareous. This had never been noted before because the surface leached zone is so thick.

ROTASONIC CORE DESCRIPTIONS

On the left of the core log, magnetic susceptibility of the material is shown in centimeters-gram-seconds x 10^{-3}. On the right of the core log, gravel is graphed as percentage of total sample and sand-silt-clay are shown as ratios of the <2-mm fraction. The real proportion of gravel and larger rocks in the core is greater than shown, because large pebbles were avoided for texture samples. Clay is very low in most samples, but never zero in these cores. Probably much of the clay fraction is composed of mechanically ground particles, rather than clay minerals.

The P symbols on the core log represent the center of sampling intervals that were wet-sieved in order to identify the pebbles. The pebble samples were larger than the texture samples, and were spread over a vertical interval of a foot or two to avoid using up all the core at any depth. On the left of the core log magnetic susceptibility of the material is shown in centimeters-gram-seconds x 10^{-3}. It was measured with a bridge, through the plastic sleeve on the core. Each data point represents the mean of two readings at different times. Few of the paired readings were identical, and most were significantly different. This difference is attributed to two factors: The bridge builds up error and has to be zeroed periodically. A reading before it is zeroed will generally be higher than one right after. Also, the material is highly anisotropic, and so a slightly different reading site may give a much different reading.

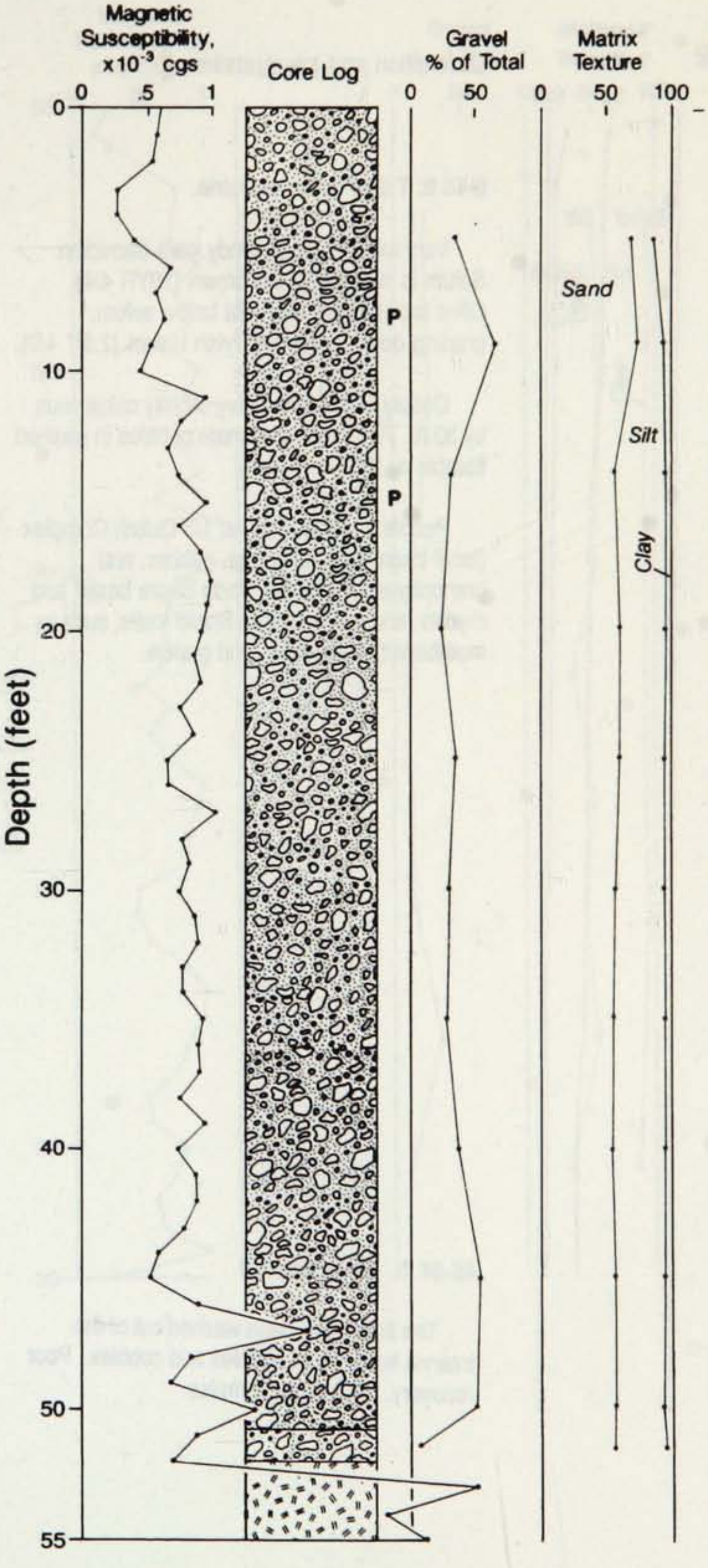
The depths of most of these readings must be considered nominal, rather than actual. Recovery of the core was less than 100%, and so for example, 4 feet of core may represent 5 feet of depth. In that case, 5 readings would be taken nominally 1 foot apart, but actually 0.8 foot apart. For these reasons, the curves should be considered approximate, and only limited conclusions drawn from them.

All of the tills in these test holes are strikingly magnetic, compared with tills derived mostly from sedimentary rock. This is attributed to incorporation of magnetite from the Duluth Complex and other magnetite-rich rocks of the area. The upper 5 feet of CDC-33 and CDC-40 are somewhat less magnetic than the lower part, probably due to near-surface weathering. This effect is not seen in CDC-23.

REFERENCE CITED

Wright, H.E., Jr., Mattson, L.A., and Thomas, J.A., 1970, Geology of the Cloquet quadrangle, Carlton County, Minnesota: Minnesota Geological Survey Geologic Map Series GM-3, scale 1:24,000; 30 p. text.

CDC-40 — IA4341



Description and Interpretation

0-51 ft. Independence till

Very rocky gravelly sandy loam diamicton. Upper 5 ft. dark yellowish brown (10YR 3/6, 4/6) grades to dark grayish brown (2.5Y 4/2) by 15 ft. and remains the same to 51 ft.

Deeply leached, but audibly calcareous by 22 ft., visibly calcareous by 30 ft.. Rest of interval is slightly to moderately calcareous.

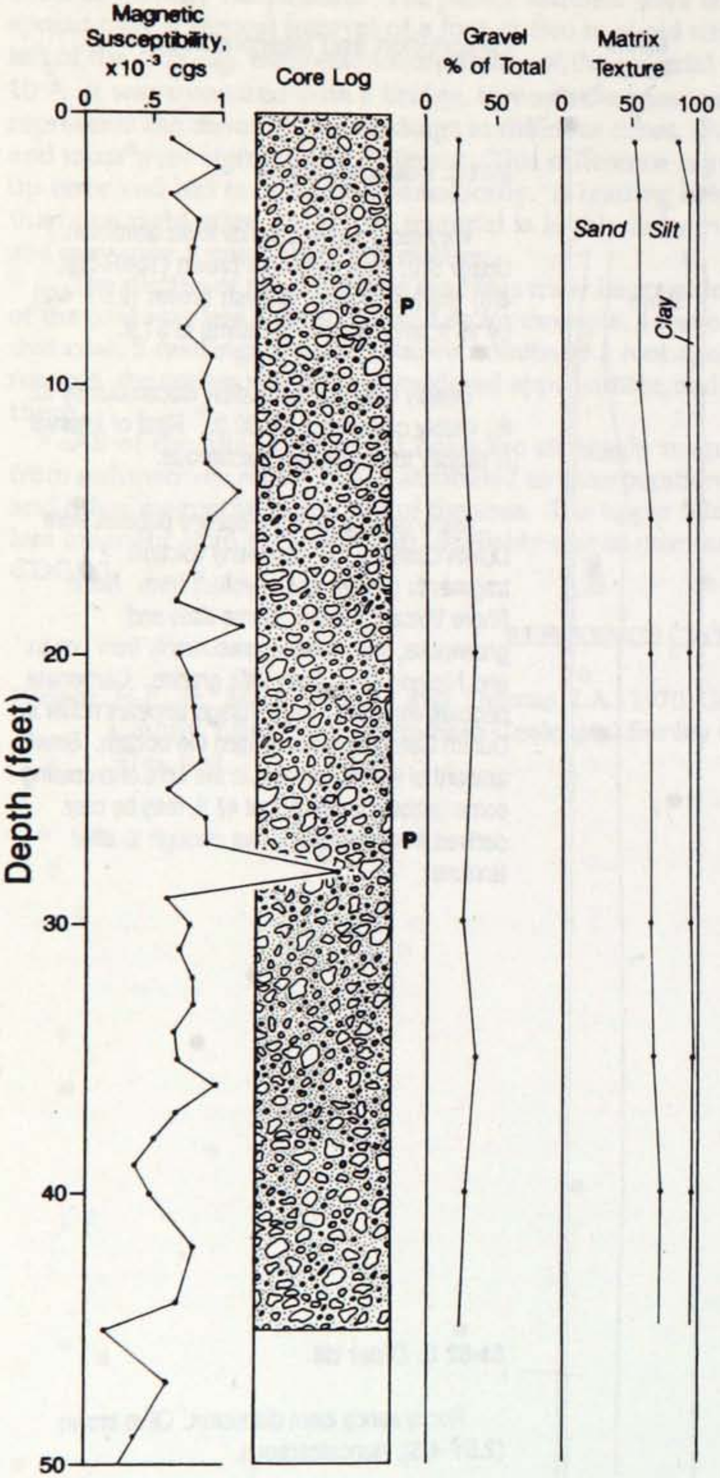
Many gabbro and granophyre pebbles from Duluth Complex, but also many volcanic fragments (basalt and rhyolite) from North Shore Volcanic Group. Some slate and graywacke, and diabase, presumably from Logan and Nipigon sills. Very little granite. Carbonate pebbles very rare. Assemblage appears richer in Duluth Complex rocks toward the bottom. Small amount of whitish powder in the core and coating some pebbles below about 41 ft. may be clay derived from saprolite. Not enough to alter texture.

51-52 ft. Older till

Rocky sandy loam diamicton. Olive brown (2.5Y 4/3), noncalcareous.

52-55 ft. Bedrock; laminated ferrogabbro

CDC-23 — IA5577



Description and Interpretation

0-45 ft. Till of Outer moraine

Very rocky gravelly sandy loam diamicton. Solum is dark yellowish brown (10YR 4/4). Olive brown (2.5Y 4/3) just below solum, grading down to dark grayish brown (2.5Y 4/2).

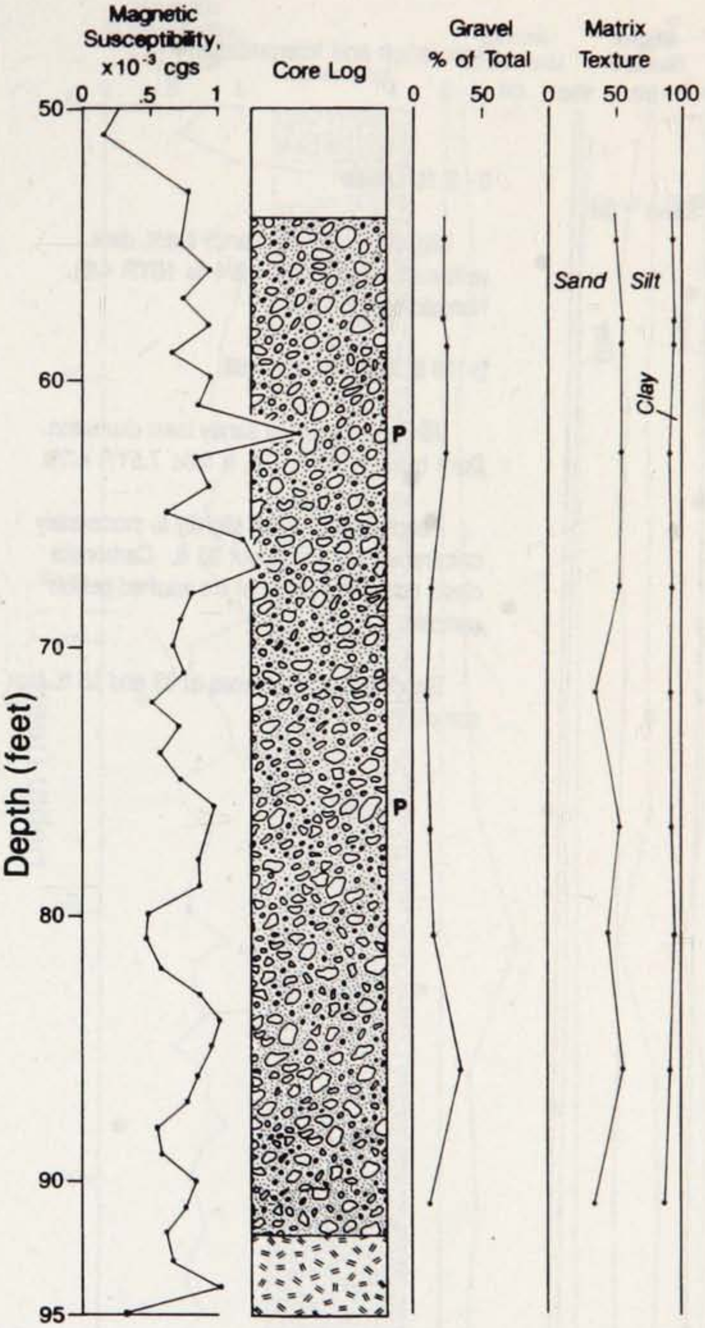
Deeply leached, but very slightly calcareous by 30 ft. Two small carbonate pebbles in washed sample at 27 ft.

Pebble fraction is about 1/3 Duluth Complex (local bedrock) anorthosite, gabbro, and granophyre. About 1/3 North Shore basalt and rhyolite, and 1/3 Canadian Shield rocks, such as metabasalt, graywacke, and granite.

45-54 ft. Disturbed till

The fines have been washed out of this interval leaving just pebbles and cobbles. Poor recovery. No texture samples.

CDC-23 — IA5577 Continued



Description and Interpretation

54 ft. - 93 ft. Independence till

Very rocky gravelly sandy loam diamicton, including some loam and silt loam. Dark grayish brown (10YR 4/2 and 2.5Y 4/2) to brown (10YR 4/3).

Slightly calcareous throughout. No carbonate pebbles seen.

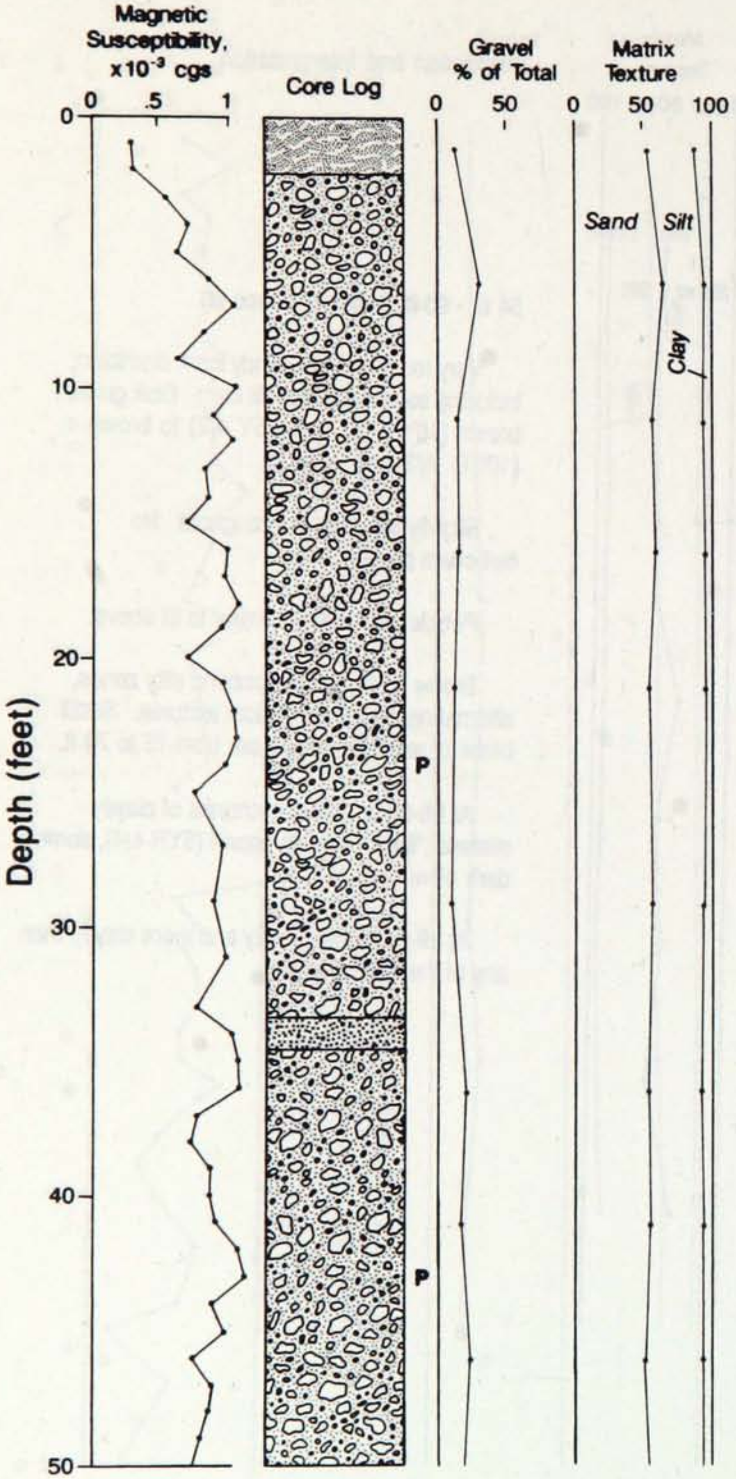
Pebble assemblage similar to till above.

Below 70 ft., the till contains silty zones, alternating with more typical textures. Small blebs of reddish sandy loam from 75 to 79 ft.

At 86-89 ft. contains chunks of clayey material, some reddish brown (5YR 4/4), some dark olive gray (5Y 3/2).

At 89-92 ft. less rocky and more clayey than any of the overlying till.

CDC-33 — IA4417



Description and Interpretation

0 - 2 ft. Loess

Slightly pebbly fine sandy loam, dark yellowish brown (10YR 3/4 to 10YR 4/6). Noncalcareous.

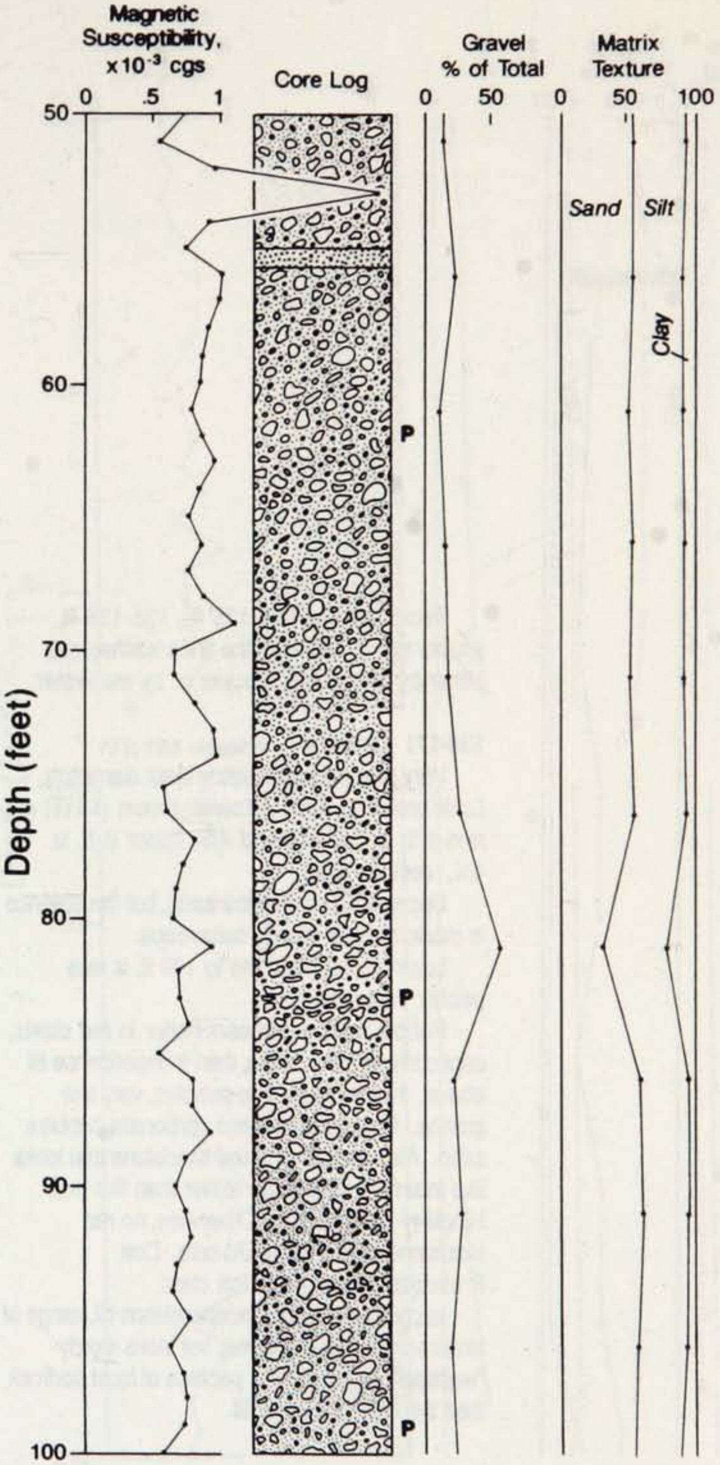
2-138 ft. Independence till

Very rocky gravelly sandy loam diamicton. Dark brown (10YR 4/3, a little 7.5YR 4/3).

Deeply leached, but slightly to moderately calcareous starting about 33 ft. Carbonate clasts not seen in most of the washed pebble samples.

Sand and gravel lenses at 33 and 55 ft. (not sampled).

CDC-33 — IA4417 Continued



Description and Interpretation

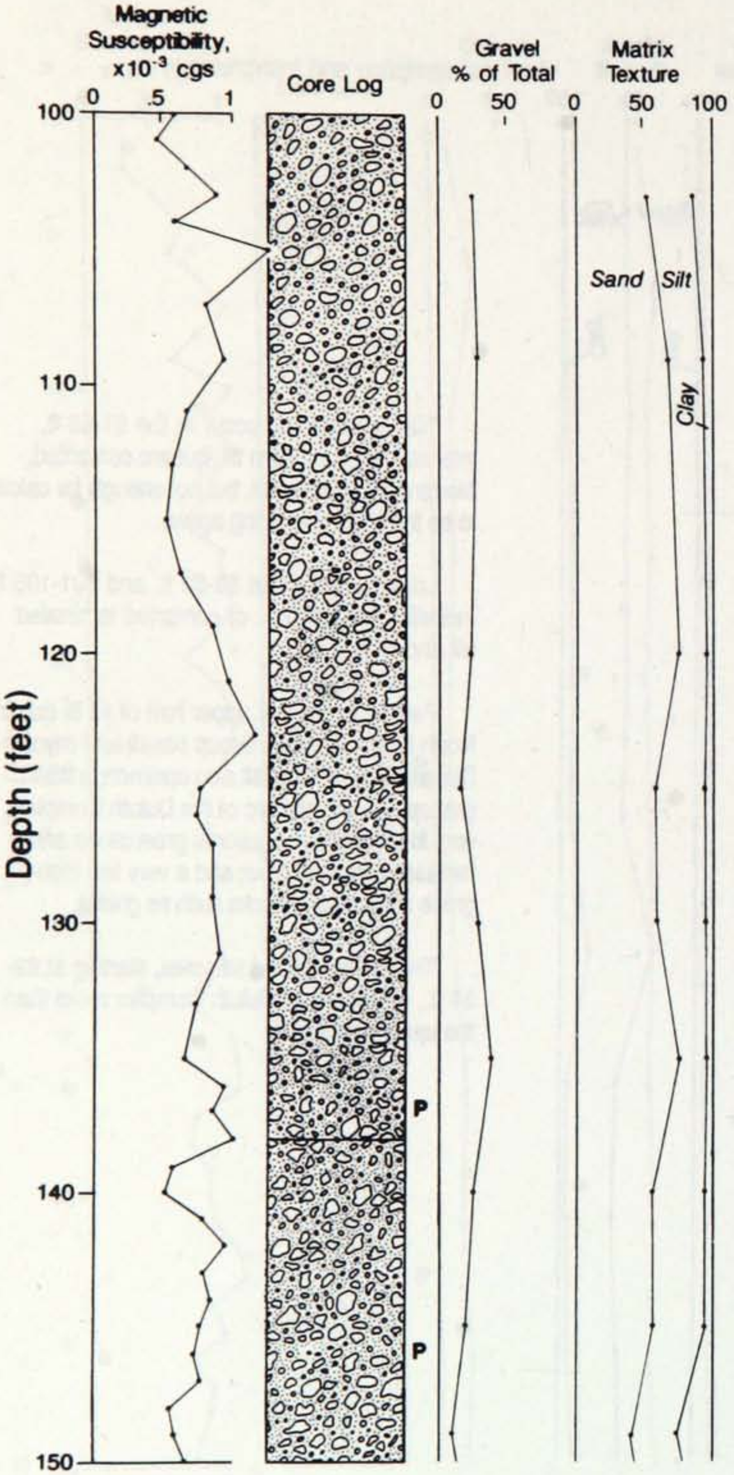
"Till concretions" occur in the 61-63 ft. interval. They look like till, but are cemented. Moderately calcareous, but not enough for calcite to be the main cementing agent.

Loamy intervals at 80-82 ft. and 101-105 ft. Inclusions at 80-82 ft. of contorted laminated silt and clay.

Pebble fraction of upper half of till is rich in North Shore Volcanic Group basalt and rhyolite. Diabase and metabasalt also common; a little granophyre and gabbro of the Duluth Complex; very little granite, occasional greenstone and metasedimentary rocks; and a very few high-grade metamorphic rocks such as gneiss.

The lower washed samples, starting at 82-84 ft., contain more Duluth Complex rocks than the upper samples.

CDC-33 — IA4417 Continued



Two intervals, 110-125 ft., 135-138 ft., appear to have some of the fines washed out, either by the drilling process or by meltwater.

138-171 Older till

Very rocky gravelly sandy loam diamicton. Dark brown to dark yellowish-brown (10YR 4/4 and 4/3; 7.5YR 4/4 and 4/3; upper 8 ft. is 4/4, rest is 4/3)

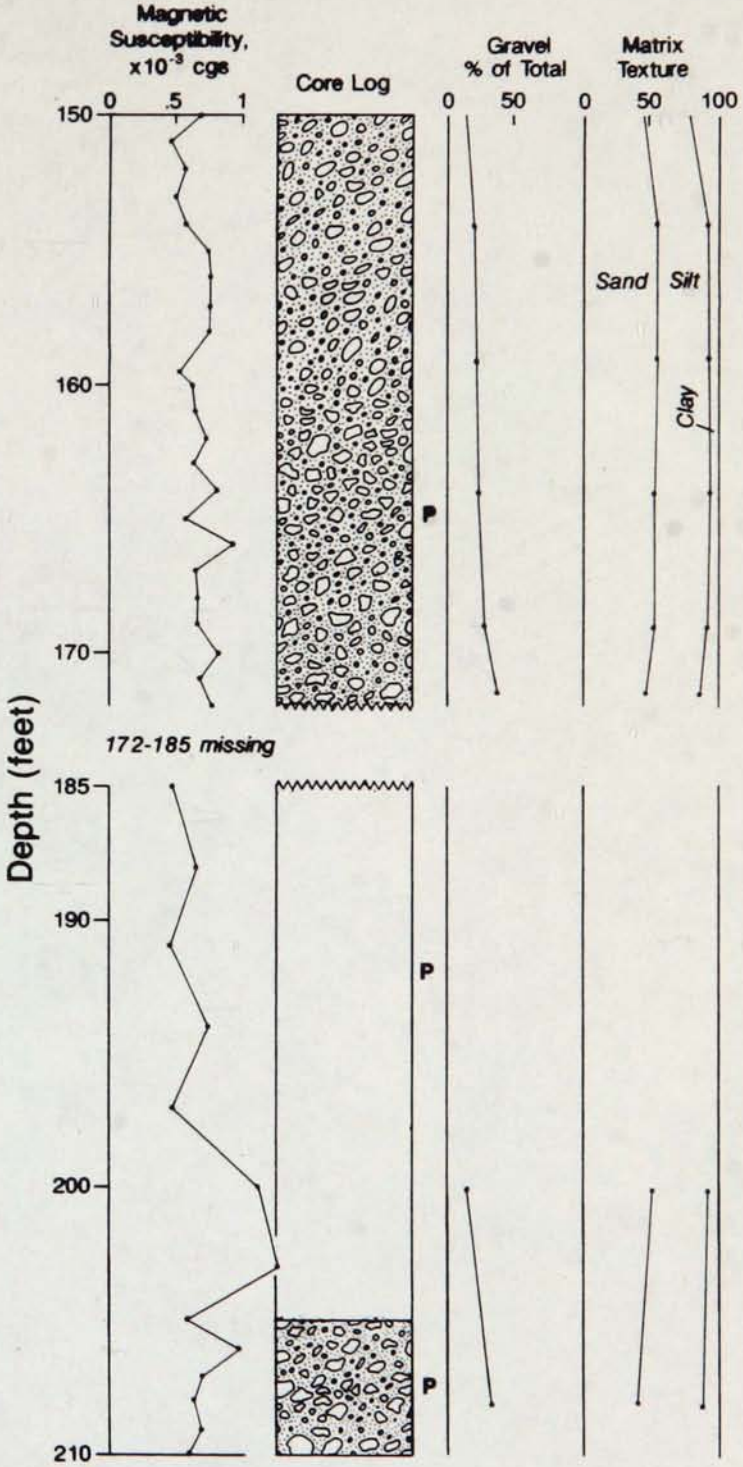
Upper 4 ft. is noncalcareous, but the balance is moderately to slightly calcareous.

Loamy zone from 148 to 149 ft. is less pebbly than rest.

Pebble fraction appears richer in red clasts, especially volcanic rocks, than Independence till above. Not many gabbro pebbles, very few granite. One chert and two carbonate pebbles seen. Also one piece of red sandstone that looks like interflow sandstone rather than like Hinckley-Fond du Lac. Otherwise, no red sandstone seen in any CDC core. One Proterozoic iron-formation clast.

In comparison with Independence till, range of textures virtually the same, but lacks sandy "washed" zones. Fewer pebbles of local bedrock than the Independence till.

CDC-33 — IA4417 Continued



Description and Interpretation

171.5 - 172 ft. Soil (?) zone

Black (2.5GY 2/1) pebbly loam mixed with till. Slightly to very slightly calcareous. Outside of core oxidized to dark olive gray (5Y 3/2). Texture sample is mostly black loam, mixed with some till from above.

172-185 ft. Missing interval

This interval was wire-line cored, in the belief that it was rock. The drift sample was not recovered.

185-205 ft. Disturbed interval

Wash from wet-based Rotasonic drilling and wire-line core from above which fell back into the hole. Texture sample from this interval comes from material that appears to be unwashed. Depths of both the texture and the pebble samples are nominal.

Washed part of sample is extremely gravelly and sandy. Pebble fraction is similar to the pebbles in the Independence till, but includes a higher proportion of Duluth Complex gabbro and granophyre.

Unwashed core is rocky gravelly sandy loam to loam diamicton. Brown (10YR 5/3), calcareous.

205-210 ft. Older till, probably the same till as at 171 ft.

Rocky gravelly loam diamicton. Brown (10YR 4/3) to dark grayish brown (2.5Y 4/2). More calcareous than till of CDC-23, CDC-40, or any other till in this core. Probably same as till in disturbed samples above.

Pebble fraction looks like that from the disturbed interval.

Lowest part of this interval includes many cored cobbles and boulders of layered gabbro, the same as underlying bedrock. May actually be in-place bedrock, broken along horizontal fractures. Rock is unweathered; there is no in-place saprolite.

IRON LAKE
Gabbro Lake
Pietro Lake
Kawishiwi Lake
South Wilder Lake
Arrow Lake
Baskatong
Gull Lake
Bald Eagle Lake
Quadga Lake
Pelt Lake
Rice Lake
Isabella Lake
Fernie Lake
Omaday Lake
SUPERIOR
Isabella
Sawmill
Forest Center
Perent L
Bogberry Lake
25
John L
Bay Lake
Brush Lake
Island River
Small
Sumpet L
Heart Lake
Harris Lake
August Lake
Snake
Little Isabella
Inga Creek
Edward Lake
Dumbbell River
1570
1650
Baird Lake
Sphagnum L
Rabbit Lake
Section 29 Lake
Warehouse
Sawbill Landing
Silver Island Lake
1644
Beaver Hut L
JACK PINE MINE
Tower
Little Bear L
Helen L
Sylvania L
Denley Lake
7
Shamrock L
Jack L
Plum Lake
Dunnigan Lake
Surprise L
Lema Lake
Inga Lake
8
Wye Lake
Stony River
Swallow L
Dragon Lake
Cat L
Kitigan L
FOREST
1600
Slate Lake
Two Deer L
Gander L
West Chub Lake
East Chub Lake
Pike Lake
Planted Lake
Resort
Wanless Lake
1840
Harriet Lake
Pitcha L
Campers Lake
Wadop L
Flat Horn L
Lake Gegoka
1900
2000
Tower
Wampus Lake
13
Dunnigan
1920
Eighteen Lake
9
Reuskin L
Ely
R 11 W
R 10 W
R 9 W
R 8 W
R 7 W
15
McDougal Lakes
Stony Lake
Isabella
Delay L
Dumbbell L
Scott Lake
Fools Lake
Round Island Lake
Hoist Lake
Bonga L
Snowshoe Lake
Greenwood R
Tower
2080
Twobey L
DULUTH MISSABE AND IRON RANGE
Lobo Lake
Stony River
1950
2000
Thunderb
Sand Lake
1980
Cougar Lake
Osier Lake
Ridgepole L
16
1750
1915
Rota Lake
Balsam Lake
Greenwood Lake
1950
Murphy City
Beaver Lake
Spruce Lake
1773
18
ABANDONED
1750
MOUNT WEBBER
Tower
Source L
Sonju Lake
Quarry
W Br
Baptism
Doyle Lake
Lookout Lake
Egge Lake
Upland Lake
Whyte
U.S. Air Force Radar Station
Crest Lake
Quarry
1935
Katherine Lake
Cloquet Lake
Fry Lake
1500
E Br Baptism River
1900
Camp
1858
Lillian Lake
Baptism R
Leskinen Lake
Murphy Creek
Quarry
1866
East Branch
Nicado Lake
rocky
1650
Sullivan Creek
Murphy Lake
1750
Beaver River
Lax Lake
Tettegouche L
Cloquet River
Langley River
15
Lake Lapler
Beaver River
1000
clay
Palisade Head
Radio tower
Marble Lake
MINING RAILROAD
1250
20
Kane Lake
AND IRON RANGE
clay
Clark Lake
Beaver Islands