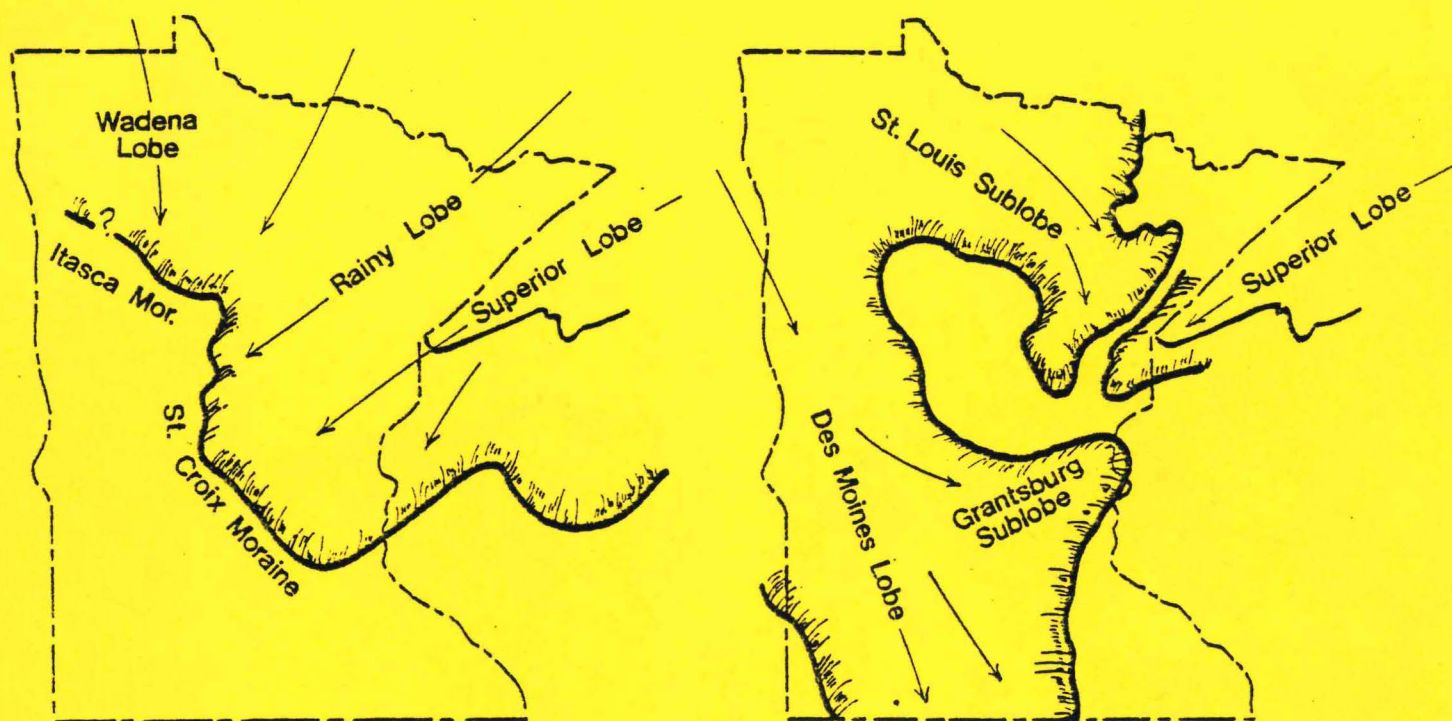


DEPARTMENT OF GEOLOGY, UNIVERSITY OF MINNESOTA
AT DULUTH

QUATERNARY GEOLOGY OF THE DULUTH AREA

BY

CAROL M. MOSS, RANDEE J. ZARTH AND CHARLES L. MATSCH



PREPARED FOR FIELD TRIP NO.3 OF THE NORTH-CENTRAL SECTION
GEOLOGICAL SOCIETY OF AMERICA 13TH ANNUAL MEETING AND THE
INSTITUTE OF LAKE SUPERIOR GEOLOGY 25TH MEETING

MAY 8-12, 1979

DULUTH, MINNESOTA

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QUATERNARY GEOLOGY OF THE HEAD OF LAKE SUPERIOR REGION

Regional Setting

Bedrock

The northwestern shore of Lake Superior lies generally parallel to the strike of a southeastward dipping sequence of lava flows and mafic intrusive rocks emplaced about 1.2 b.y. ago (Fig. 1). This Keweenawan volcanic pile called the North Shore Volcanic Group is composed mainly of basalt, but includes significant volumes of rhyolite and lavas of

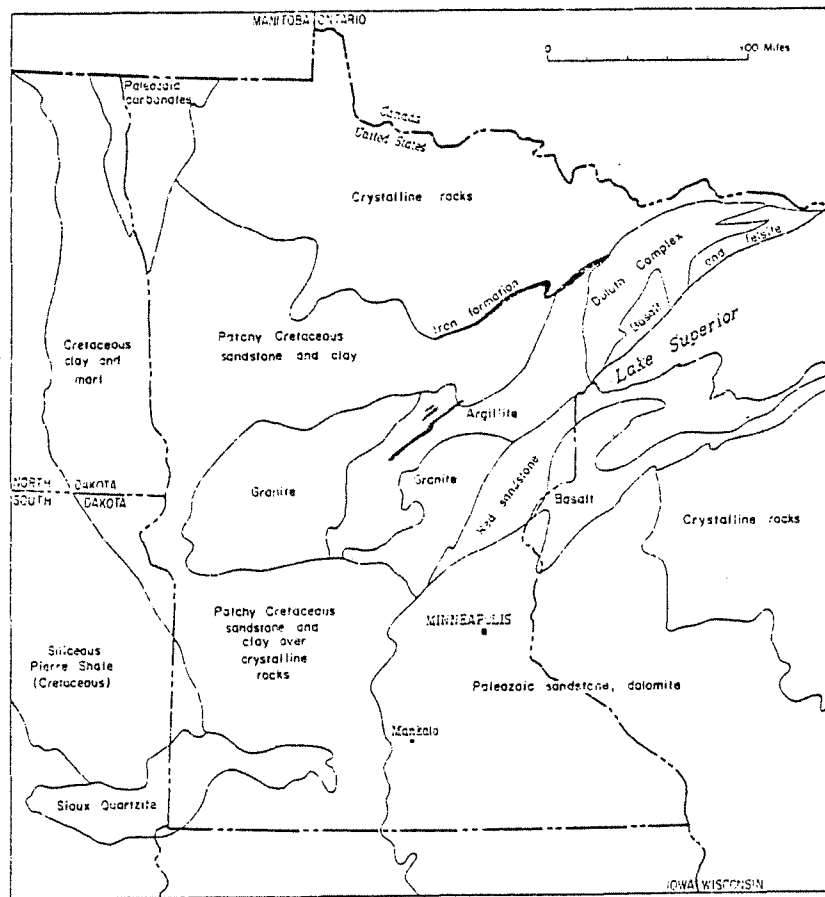


Fig. 1. General geologic map of Minnesota and adjacent states.

intermediate composition. The flows are estimated to be over 20,000 feet thick (Green, 1972). The largest of the associated intrusive bodies is the Duluth Complex, a meld of mafic material, mainly gabbro and anorthosite, but including the felsic rock granophyre. Smaller intrusions in the form of dikes and sills lace the entire section.

Geophysically, rocks of similar density are traceable as a gravity high southwestward as far as Kansas, and elsewhere in the Great Lakes region (Fig. 2). The belted configuration as well as the composition of the rocks suggests that the entire sequence represents an episode of crustal rifting and insipient sea-floor spreading. That the process aborted is indicated by the insignificant width of the mafic rock belt.

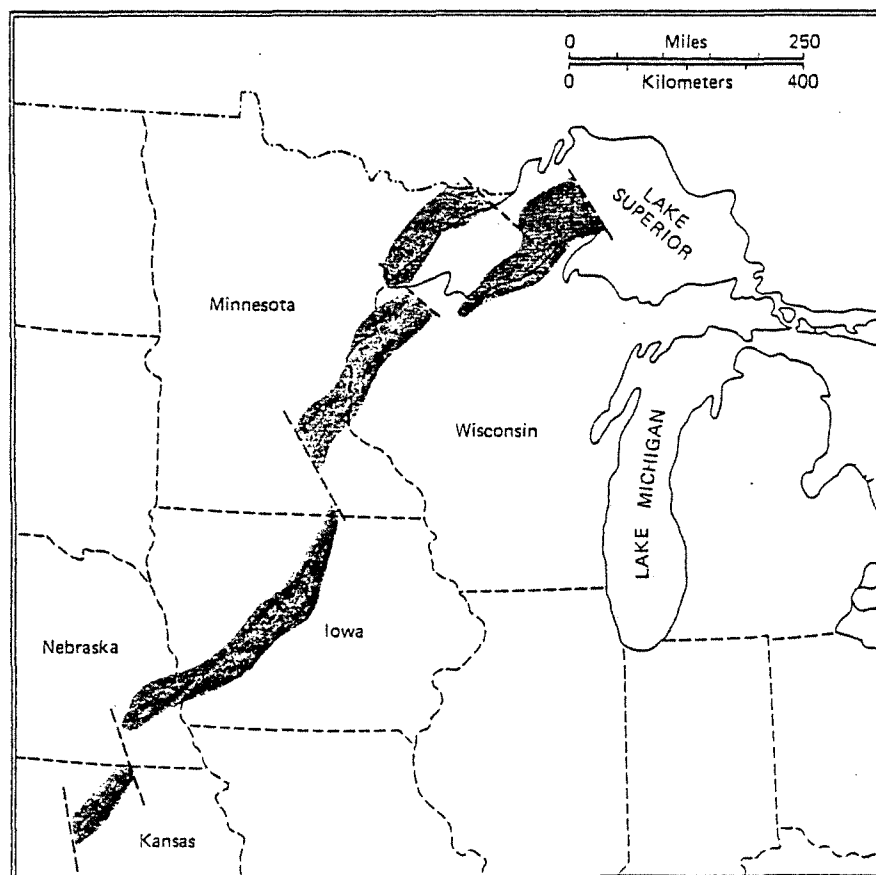


Fig. 2. The mid-continent gravity high outlines the distribution of basaltic rocks emplaced during a rifting event about 1.1 b.y. ago.

Following the cessation of volcanic activity, the last to occur in this part of the earth's crust, subsidence of the area resulted in the tilting of the entire sequence gently eastward. A thick wedge of clastic sediments accumulated in the subsiding basin. These Late Precambrian sediments include the arkosic Fond du Lac Formation and the Hinckley Sandstone.

Paleozoic marine transgressions either did not reach the western Lake Superior region, or the sedimentary record of such activity has been completely removed by erosion since deposition. Atop the Precambrian, and separated from it by a profound unconformity, is the Quaternary System.

Quaternary Geology

The structure and differential erosion of the Precambrian bedrock in the Lake Superior region resulted in the development of a pre-glacial lowland which had a direct effect on ice movement in northeastern Minnesota. The lowland channeled ice from the Laurentide Ice Sheet into individual lobes which periodically invaded the western Lake Superior region from the north and northeast.

Multiple glaciation of the region is evident from stratigraphic, geomorphic, and lithologic relations. The Superior Lobe generally moved southwest along the axis of the Lake Superior basin and west onto the upland, transporting sediment derived from the North Shore Volcanics, Duluth Complex, and Precambrian sandstones. Another ice mass, the Rainy Lobe, invaded from the north-northeast and deposited fragments of Precambrian crystalline rock (granite, gneiss, and gabbro), meta-sedimentary rocks, and iron formation.

Four main advances during the Wisconsin Glaciation are recognized and shown in Figure 3 (Wright, 1972). The earliest, or St. Croix Phase, involved concurrent movement of the Rainy and Superior Lobes in a southwesterly direction, with deposition of a sandy-matrixed till and formation of the St. Croix moraine in south-central Minnesota. The formation of the Toimi Drumlins in northeastern Minnesota, composed of gray to brown sandy till with a large percentage of gabbroic fragments, is attributed to this phase of the Rainy Lobe. A period of glacial retreat followed, and a vast system of tunnel valleys was eroded in the glacial drift by subglacial streams flowing in a southwesterly direction.

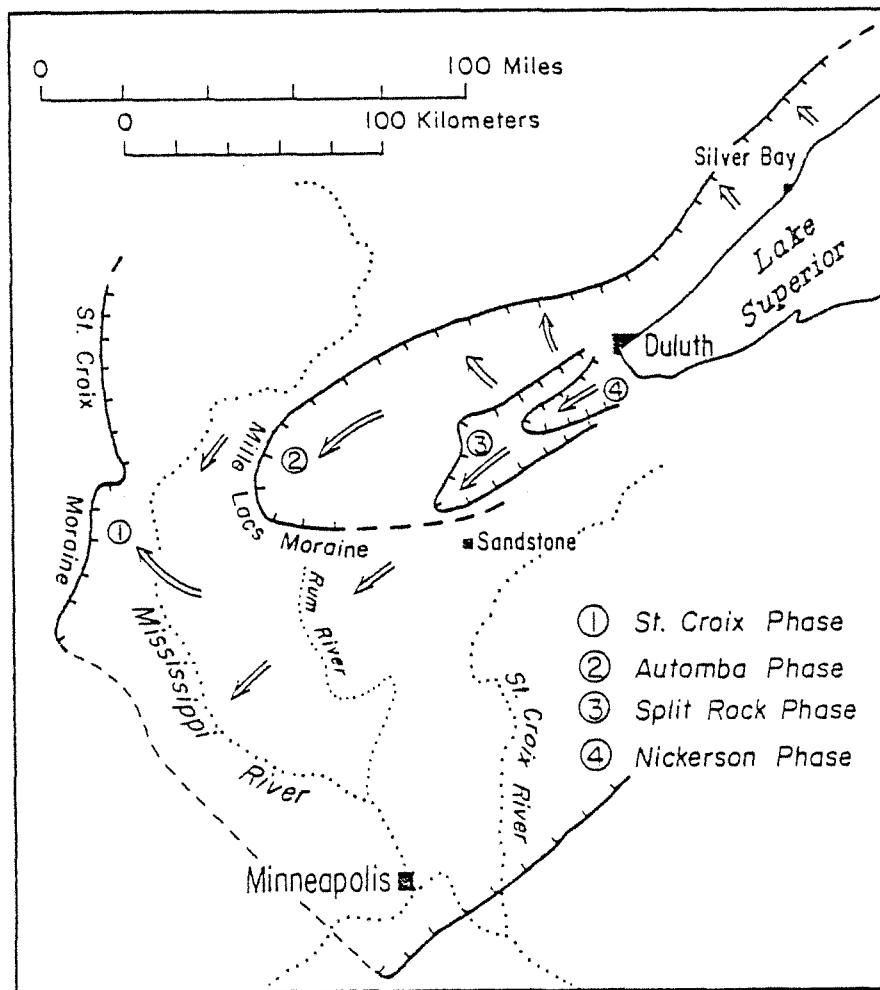


Fig. 3. Outline of ice margins during successive phases of the Superior Lobe during Late Wisconsin glaciation. (From Wright, 1973.)

The second, or Automba Phase, brought a readvance of the Superior Lobe out of the basin, this time in a more westerly direction. Movement continued as far west as the Mille Lacs Moraine, which borders the west and south sides of Mille Lacs Lake. The Automba drumlin field in western Carlton County is associated with this advance, as is the Highland moraine, which marks the northernmost extent of the lobe as it moved laterally out of the basin. The Rainy Lobe again advanced across the upland from northeast to southwest, forming the Vermilion moraine. After this phase, the Superior Lobe retreated far enough into the Lake Superior Basin to allow proglacial lakes to form around its margins. These lakes were sufficiently deep to allow deposition of silt and clay which was incorporated into glacial till during the next advance, or Split Rock Phase.

The third, or Split Rock Phase of Wright (1969) is marked by the advance of a small tongue of ice which moved southwestward in the Denham area, depositing a discontinuous layer of red clay-rich till on some of the eskers and tunnel valleys associated with earlier phases. A small field of drumlins was also formed in the Split Rock River Valley near Barnum.

Late-glacial and early postglacial activity is represented by extensive glaciolacustrine deposits and shoreline features at various levels, which developed during successive glacial lake stages as the Superior Basin was uncovered by melting of the Laurentide Ice Sheet. Winchell (1901) distinguished three lake levels in the western Lake Superior region: (1) "Glacial Lake St. Louis" at 345 m, (2) a lower, but more distinct level, Glacial Lake Nemadji (324 m), and (3) Glacial Lake Duluth 4 m lower than Glacial Lake Nemadji. Glacial Lake Nemadji

was recognized from lacustrine clays, beach features, and a channel at roughly 321 m, which drained by way of the Kettle and St. Croix River systems. In Winchell's view, Glacial Lake Duluth covered approximately the same area as Glacial Lake Nemadji but had an outlet at 316 m and drained by way of the Brule-St. Croix River system.

Leverett (1929) in addition to mapping Superior Lobe moraines, discussed the development of proglacial lakes. In his view, Glacial Lake Nemadji was a small lake, covering a maximum area of 130 km^2 , at an elevation of 321 m. It was bound on the northwest by the Thomson moraine and by the ice margin as it stood at the Fond du Lac moraine (Leverett, 1929). With further ice retreat, Lake Nemadji merged with several other small, proglacial lakes and eventually stabilized as Glacial Lake Duluth. Beach elevations at the western part of this lower lake range from 305 m to 318 m (Leverett, 1929).

G. M. Schwartz (1949) delineated strandline features of Glacial Lake Duluth at elevations of 325 m. He also noted the extensive clay and silt deposits associated with the lake plain, especially the varves found at the Wrenshall clay pits.

W. R. Farrand (1960) integrated much of the earlier shoreline data and added new observations in an attempt to correlate strandlines basin-wide. His results are shown in Table 1. Farrand considered the shorelines of Glacial Lake Nemadji, as described by Leverett, to be associated with Glacial Lake Duluth. The term Glacial Lake Duluth was modified

"...to include all those major water bodies which occupied the southwestern part of the Lake Superior basin and which discharged into the St. Croix River system via either the Moose Lake outlet or the Brule-St. Croix outlet or both."
(Farrand, 1960).

TABLE 1--LAKE STAGES. (after Farrand, 1960).

LAKE STAGE	AGE (B.P.)	ELEVATION (ft)	OUTLET
Sault			
Lake Superior		602	St. Marys River
Sub-Sault	1000	602	St. Marys River
Sault Beach	2000	602	St. Marys River
Algoma	3200	595-596	St. Marys Strait
Nipissing Great Lakes	4100	605-607	St. Marys Strait
Houghton Low Stage	8500	360	proto St. Marys R.
Post-Minong series	9000- 8500	?	St. Marys Strait
Minong	9200	420? 470?	St. Marys Strait & Au Train-White- fish Strait
Post-Duluth Beaver Bay Manitou Washburn Moquah Highbridge Sub-Duluth	10,000	650 765 850 870 920 955 1007	Au Train-Whitefish Strait? Marquette Marquette Marquette Huron Mts. Huron Mts.
Duluth	10,220	1035 1060 1070 1085	Brule-St. Croix R. Moose Lake and Brule-St. Croix
Epi-Duluth	10,700- 10,500	1100	Moose Lake; Brule-St. Croix

Recent work by H. E. Wright has contributed to working out stratigraphic sequences and relationships among ice lobes. In his interpretation of the development of glacial lakes following ice wastage, Wright supported the sequence proposed by Leverett: (1) the highest lake level of Glacial Lake Nemadji (318 m) and (2) the lower level of Glacial Lake Duluth near 305 m (Wright, 1972).

Quaternary Stratigraphy, Sedimentology and Geomorphic Features

Introduction

Surficial sediments in the western Lake Superior region can be broadly grouped into three types: those deposited during advances of the Superior Lobe, those resulting from retreat and stagnation of the glacial ice, and and sediments associated with the formation of Glacial Lake Duluth. Lodgement till, deposited by actively advancing glacial ice is exposed in, or underlies, most of the region. In a generally NE/SW-trending belt roughly parallel to Lake Superior, ice disintegration features of till and interbedded or associated sands and gravels predominate. A similarly trending belt of ground moraine parallels the present shoreline along the southern edge of the stagnant ice features. Lake clays with varying amounts of pebbles and boulders cover much of the remaining southern parts of the region.

Tills

Two tills of different ages, representing separate advances of the Superior Lobe are extensively exposed along the Lake Superior shoreline and in some of the deeper stream valleys. Visually and texturally, the tills are very similar, and unless seen in their stratigraphic sequence, it is difficult to distinguish the two. The contact between the two tills is generally sharp and commonly a stone line or a gravelly or sandy layer separates them.

Lower Till

The lower till is generally dark reddish-brown, silt-rich, stony and very compact. Fissility is developed locally. Although texture

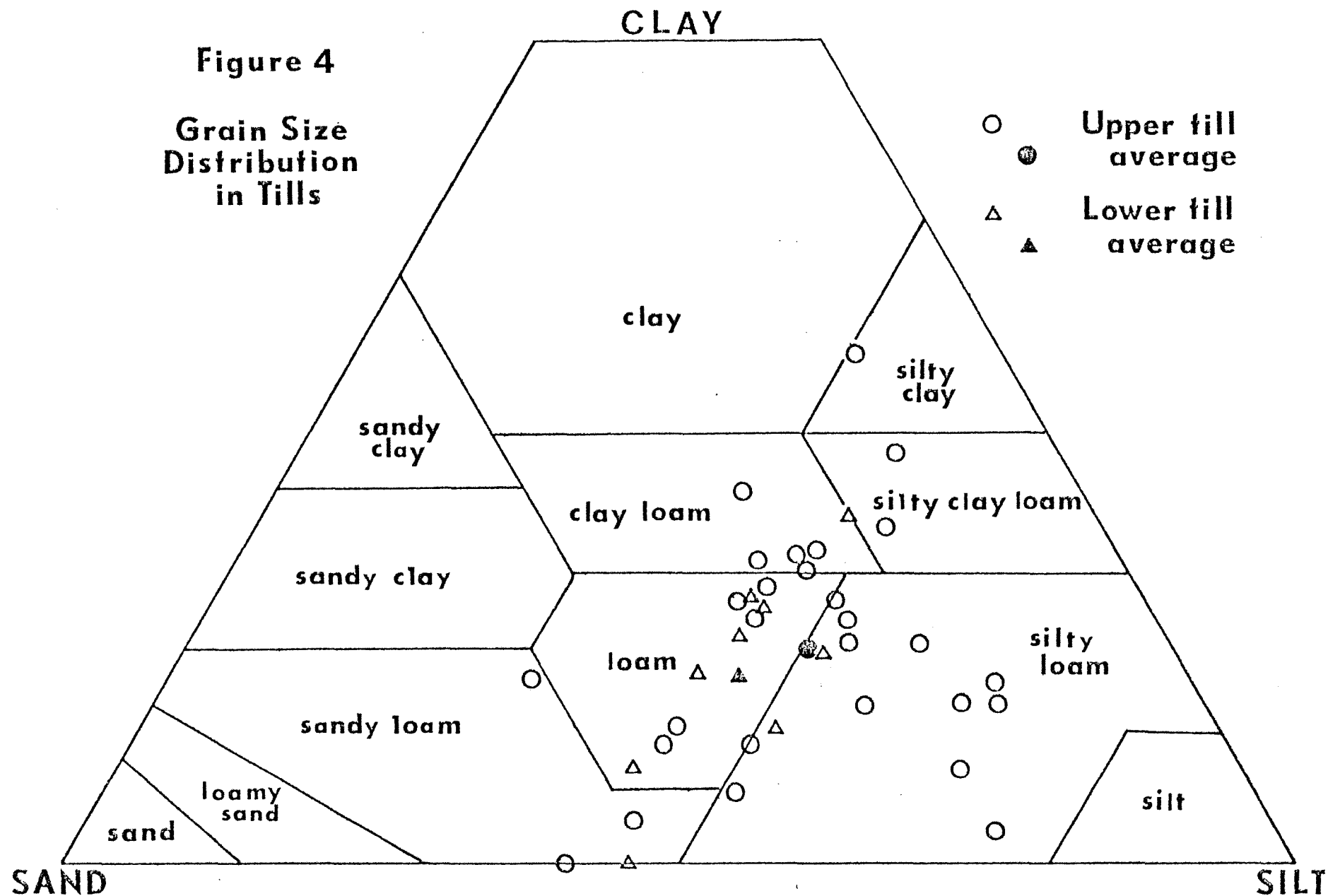
varies, most of the samples analyzed fall into the loam category (U.S. Department of Agriculture Soil Classification). Analysis of 9 samples from exposures northeast of Duluth averaged 36% sand, 46% silt, and 18% clay. Basalt fragments comprise greater than 50% of the 1-2 mm sand fraction, with gabbro and "red rock" fragments being the only other rock types of significance. Up to 25% of the clasts by volume are cobble or boulder size. This till is correlated with the St. Croix phase of the Superior Lobe as described by Wright (1969).

Upper Till

The upper till is the predominant surface material in upland areas away from the lake plain, including the Highland moraine. Its color is similar to the lower till, although in many exposures it appears to be more red-brown. Compactness varies among localities; in places, the sediment is as highly compacted as the lower till, while in other areas, the material is easily disaggregated by the fingers. Although the same Lake Superior region rock fragments are present (basalt, gabbro, "red rock" sandstone, etc.) and in the same general percentages as in the lower till, this till varies considerably in the amount of pebbles, cobbles and boulders which are present from locality to locality; some sections are extremely stone-poor.

Although variable in texture, the younger till is generally somewhat siltier than the lower till. Analysis of 28 samples from the Duluth vicinity shows an average composition of 30% sand, 50% silt and 20% clay (Fig. 4). Clasts of cobble or boulder size comprise at most 20% of the volume of the sediment. The textural variability may be due in part to the position of this till in the stratigraphic section; it

Figure 4
Grain Size
Distribution
in Tills



was probably partially derived from the various sediments left by the preceding glacial advance. Thus, reworked older drift of varying composition may comprise most of this till rather than material eroded directly from bedrock sources. This till has been attributed to advance of the Superior Lobe during the Automba phase (Wright, 1969).

Stratigraphic Type Sections

Although the two tills can be seen superimposed at many locations, probably the two best exposures are on McQuade Road in the French River quadrangle and in the City of Duluth along the shoreline at Leif Erikson Park (Stop No. 1 on the road log).

At Leif Erikson Park the lower till is a sandy, dark brown to dark red-brown, fissile sediment with abundant boulders. Clasts typical of the Superior Lobe are present. The upper till is more red-brown in color, more silt-rich, and at this location more cohesive than the lower till. A discontinuous boulder line marks the generally sharp contact between the two tills. This may represent an erosional surface developed between glacial advances. At this location the textural difference between the two tills is easily distinguished.

Along McQuade Road at the Sucker River, the same sequence is again exposed, although less textural difference is apparent between the two tills. The lower till at this location lacks the fissility of that at the Leif Erikson exposure; both tills at the McQuade location are compact and stony.

Fabric Studies

Orientation of the long axis and dip of elongated stones were measured for both tills at the McQuade Road location (Fig. 5). The majority of

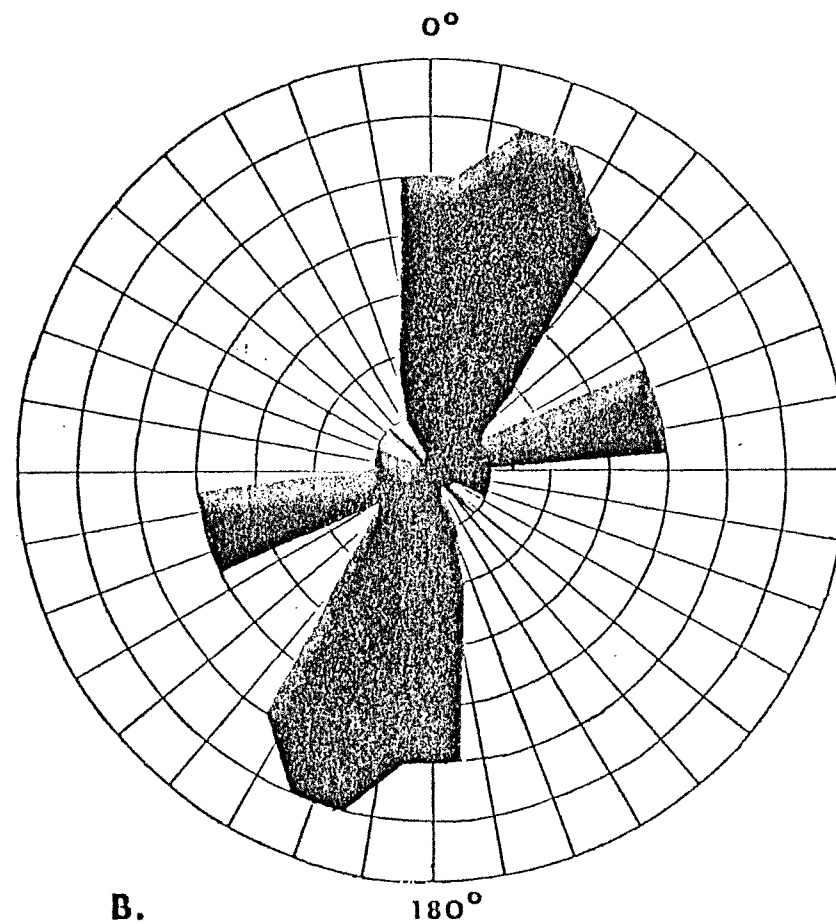
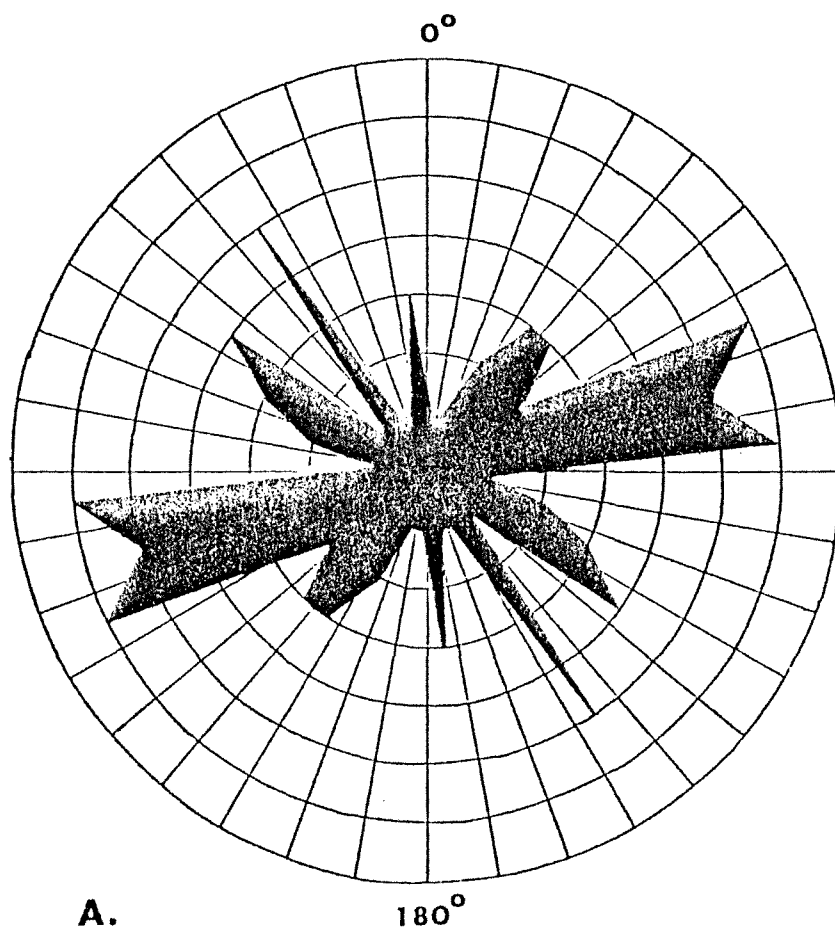


FIGURE 5: Orientations of longest axes of elongated stones in McQuade Road exposure. Each circle equals one stone. A) Upper till, B) Lower till; average regional striation direction associated with the deposition of this till is approximately N65°E.

elongated stones dip in an upglacier direction. In general, the long axes of stones in the lower till tend to lie approximately 45° from the direction of ice flow as inferred from the regional striation pattern. In the upper till, a similar pattern is evident, with a large concentration of stones lying nearly transverse to ice flow as inferred from regional features such as the Highland flutes. Both tills also show a slight concentration of elongated stones in the direction parallel to inferred direction of ice flow.

Clast Composition

At both the Leif Erikson Park and McQuade Road exposures, grain counts of three size ranges were studied: clasts larger than 2 mm (up to and including roughly 4 cm), the 1-2 mm fraction, and the fraction less than 1 mm (Figure 6). Basalt is the predominant rock type in the 1-2 mm fraction as well as in the greater than 2 mm fraction. This is due in part to the abundance of basalt as the predominant bedrock type at and upglacier from the sample site. Physical characteristics of the bedrock are also important. The abundance of joints and vesicles makes the basalt flows more susceptible to breakdown by abrasion, plucking and grinding during a glacial advance. The gabbro and diabase with their more widely-spaced joints and fractures are more resistant to plucking and crushing. The less than 1 mm fractions show quartz to be extremely abundant. Granite from sources still farther northeast as well as sandstone from within the Lake Superior Basin are probably the source. Very little sandstone in the larger size range is an indication of its "crushability."

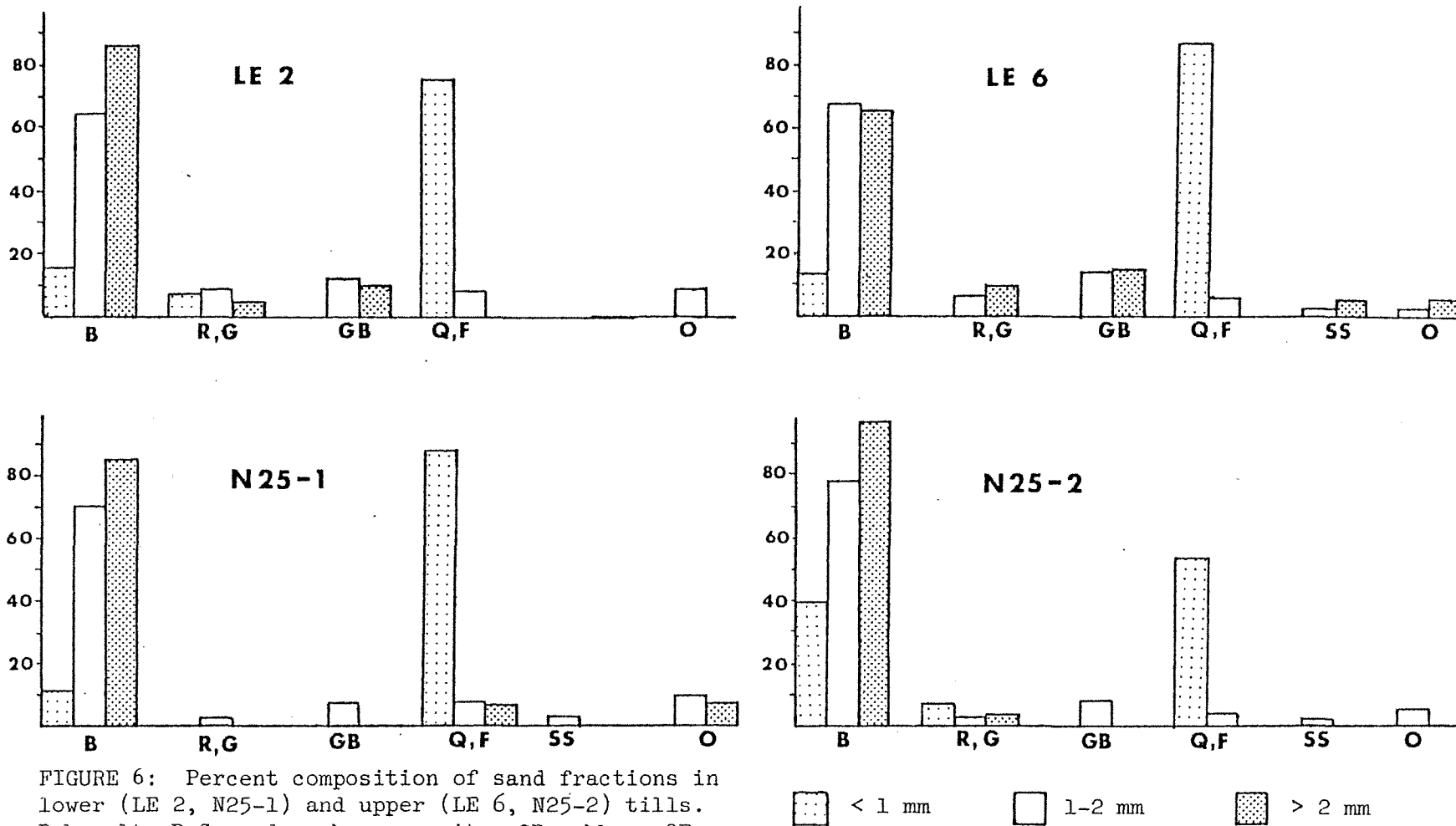


FIGURE 6: Percent composition of sand fractions in lower (LE 2, N25-1) and upper (LE 6, N25-2) tills. B=basalt, R,G= red rock or granite, GB=gabbro, Q,F= quartz or feldspar, SS=sandstone, O=other.

Ice Disintegration Features

In the areas west of the broad band of lacustrine clays, most of the topography reflects ice-marginal deposition of material from active as well as stagnant ice. A distinctive geomorphic feature, the Highland moraine, marks the northernmost edge of the Superior Lobe at its maximum advance during the Automba phase, and the Thomson moraine developed in the later Nickerson phase. Both features display great variability in sediment types over very short distances, and the landforms also indicate varying environments of deposition.

The following studies of a part of the Thomson moraine near Wrenshall, Minnesota are presented as an introduction to terrains originating from ice disintegration. The moraine is a hummocky complex of kames, kettles, disintegration ridges, and eskers. Local relief is varied but may be up to 20 m. These features are typical of an ice-disintegration environment. Ice-disintegration describes the processes involved in the break-up of a stagnant, wasting glacier.

Ice-disintegration features are of two major types: (1) controlled ice-disintegration and (2) uncontrolled ice-disintegration (Gravenor and Kupsch, 1959). Uncontrolled ice-disintegration results from equal forces acting in all directions forming unoriented features, such as kames, kettles, and general hummocky terrain. Controlled ice-disintegration occurs when there is break-up along fractures in the ice and when deposition is localized to form linear disintegration ridges and eskers.

Uncontrolled Ice-disintegration Features

Kames

Kames are conical hills or mounds of any size consisting of stratified sand and gravel. Kames are abundant in the northwest portion of

the Wrenshall quadrangle and are associated with the Thomson moraine. There they are generally small, reaching maximum dimensions of up to 0.5 km in length and 20 m in elevation. They have flat to rounded tops and varying slopes according to the texture of the underlying material. The kames are found to occur both as single, isolated hills and as composite hills which merge to produce ridge-like landforms. Texturally, these kames consist of poorly to moderately sorted, stratified sand and gravel, with boulders. The sand and gravel is in some places capped with fine sand to silt.

Kettles

Kettles are small basins created by the ablation of buried ice. Kettles found in the Thomson moraine area vary in size but are generally small, less than 1 km in diameter. Some display irregular shapes but most kettles tend to approach circularity. Kettles that are associated with kames tend to give a "pitted" appearance to the landscape and this "kettle and kame" topography is characteristic of ice-disintegration complexes.

F. G. Driscoll (1976) in a study of moraine lakes at the Klutlan Glacier, Yukon Territory, suggests lake development may be the result of (1) the melt-out of ice containing differing amounts of debris, resulting in an irregular depositional surface; or (2) uneven surface debris accumulations due to topographic reversals, resulting from slumping of sediment.

Superglacial lake development on a stagnant debris-covered surge lobe proceeds in five distinct stages as the buried ice melts (Driscoll, 1976): (1) accumulation of meltwater in low areas on the moraine; (2) expansion of the lake basin by both lateral and vertical melting, and the establishment of inlet and outlet streams; (3) accumulation of melt-out debris along lake perimeter, vegetation cover, and mass-wasting along steep shore areas;

(4) stabilized slopes, rounded lake bottom, areal expansion ceases, significant life in lake; (5) reduction in enclosing slopes, heavy vegetation on periphery, decrease in lake depth and areal extent, final melt-out of buried ice, increase in biomass.

Controlled Ice-disintegration Features

Linear Disintegration Ridges

The term linear disintegration ridge pertains to a ridge that originates during ice stagnation (Gravenor and Kupsch, 1959). Ridges of varying sizes, up to 12 m in height and several kilometers in length, are found within the Thomson moraine. Although these ridges are related to controlled disintegration, they appear gradational with uncontrolled features and are found with kettles and kames.

The linear ridges vary in composition from medium and fine sand to sandy gravels, although the latter is predominant. The stratified nature of the drift contained in these ridges suggests that they were open crevasses in the stagnating ice which provided a site for the accumulation of stratified sediments.

Sedimentology

The sediments associated with ice-disintegration in the Duluth area exhibit a wide variety of textural characteristics, geometries, and sedimentary structures. The sediments are generally poorly to moderately sorted, stratified sand and gravel. The geometry of the units varies from sheet deposits to pods and lenses. The grain size distribution shows abrupt changes and an extreme range of sizes from boulders to clay. The sediments are thin to thickly bedded, with some cross-bedding, faults, current and gravity structures. The clasts, generally

surrounded, are composed of Precambrian sandstone, basalt, rhyolite, gabbro, granite, gneiss, iron formation, slate, and graywacke. The sediments can be divided into five units based on their internal and external characteristics. These are (1) gravel, (2) horizontally-bedded sand, (3) cross-bedded sand, (4) silt and clay, and (5) diamicton.

A gravel pit along West Alcohol Road, SW $\frac{1}{2}$, SE $\frac{1}{2}$, Sec. 19, T48N, R16W, (Stop in road log) reveals good exposures of these sedimentary units and their structures. The exposures generally show abrupt vertical changes with an overall fining upward sequence in most sections.

One locality in the pit near the entrance shows fine to medium sand overlain by very coarse sand, gravel, and boulders, occasionally with mudballs. These units are overlain by laminated silt and clay which show discontinuous beds that are gently contorted in the lower 0.5 m. Lobes of overlying fine sand protrude downward into the silt and clay unit. The fine sand shows small scale cross-laminations with sets 2 cm in thickness. The sand is overlain by another silt and clay unit which shows load structures into an overlying medium to fine sand.

Another location, approximately 75 m to the northwest, shows the gravel to be the predominant sediment with lesser amounts of cross-bedded sand, horizontally-bedded sand, and diamicton. The gravel occurs in the basal 4.5 m of the section. The unit shows crude cross-bedding with sets to 0.5 m in thickness and often containing inter-stratified sand, less than 0.3 m in thickness. Overlying the gravel are the horizontally-bedded and cross-bedded sand units. These are inter-bedded with gravel-boulder lenses. Horizontally-bedded sand has bed thicknesses from 2-3 cm to 2 mm and the cross-bed sets are up to 0.5 m

thick. The sand exhibits scour and fill features in some localities, in addition to normal faults.

Cross-bedding measurements, from both the cross-bedded sand and the gravel unit, show that paleocurrent directions (n=12) for the West Alcohol Road Gravel Pit are generally to the northwest, but there is a considerable amount of scatter in the orientations.

Depositional Environment

The ice-disintegration complex west of Wrenshall is characterized by hummocky, kettle-kame topography, consisting of a wide range of sediment types and structures. The extreme range of grain size along with abrupt changes in texture and slump structures indicate that these sediments were deposited in close contact with stagnant ice (Flint, 1971). Sediment supplied to the complex originated from the stagnating ice mass. The abundance of granite and iron formation clasts (typical of Rainy Lobe sediment) suggests that there has been reworking of the older, underlying drift. The depositional environment of the sediment was one of large velocity fluctuations of the meltwater, which must have varied considerably as indicated by the rapid change in grain size.

In the west central portion of the Wrenshall quadrangle, the very hummocky terrain was the result of deposition in ice-walled basins and later wastage of the sediment-covered ice. There was abundant meltwater available which allowed the sorting and stratification of the sand and gravel.

An esker depositional environment is also observed. The esker was probably formed in a tunnel in the stagnant ice as evidenced by a single, steep-sided ridge containing longitudinally continuous sedimentary units

(Banerjee and McDonald, 1975). Current flow appears to have been to the southeast with the esker terminating in a delta in a lacustrine environment.

The sediments of the West Alcohol Road gravel pit may have been deposited in an ice-walled, fluvial environment, possibly by braided streams. The fining upward sequence, sand and gravel lenses, apparent channeling, scour and fill features, and floodplain silt and clay tend to support this hypothesis. Paleocurrents indicate major flow N60W with some directional variations which would be expected in a braided stream environment.

Another possibility is that the sediments were deposited in a large ice-walled basin. The predominance of gravel and boulders indicates the need for a proximal source of sediment. Slump structures, faults, and a diamicton support an ice-contact origin. The laminated silt and clay would have been deposited in a quiet water pool or lake, with an increase in current velocity or loading from overlying material causing convolutions.

In general, these sediments were deposited on, against, or under stagnant, wasting ice, and according to R. F. Flint (1971):

"In such a place (ice-contact environment) anything can happen and it often does."

GLACIOLACUSTRINE ENVIRONMENT

The western tip of the Lake Superior Basin contains geomorphic features and sediments associated with a glaciolacustrine environment. The morphology, stratigraphy, and spatial occurrence of various sedimentary facies are ascribed to the activities of Glacial Lake Duluth, which had a high-stand above 1100 feet. Geomorphic features and sedimentary deposits of Glacial Lake Duluth are well-displayed in the Wrenshall and Frogner 7-1/2 minute quadrangles, and the following discussion is largely concerned with that area.

Geomorphology

The lacustrine environment in the Wrenshall and Frogner quadrangles is characterized by well-developed beach landforms and extensive lake plains. These features may be compared to the marine shoreline profile typical of sandy, mainland coasts. Coastal areas are divided into three morphologic zones: (1) mainland, (2) nearshore, and (3) offshore.

The mainland area consists of older features, such as ancient strand-plains, alluvial plains, lagoons (or shallow, restricted bodies of water), or bedrock. Dunes are common, as a result of a large supply of loose sand, and are found bordering the beach.

The nearshore area, in a marine environment, extends seaward from the mainland and consists of two main zones: (1) backshore and (2) shoreface. The backshore is the area which is subjected to wave action only during extreme high water, usually generated by storms. Continuing seaward, the profile shows the shoreface zone. The shoreface is defined as

a submerged zone which extends to a depth where sand size material is not moved by normal currents (Harms and others, 1975). It is the shoreface that is affected by swash and backwash, breakers, and longshore currents, which transport sand across the entire zone.

The offshore area is not affected by normal wave action. Coarse sediment is transported into the offshore zone only under extraordinary conditions, such as storms or density currents (Harms and others, 1975).

The lacustrine complex in Wrenshall and Frogner quadrangles is divided into two main morphologic groups: (1) nearshore and (2) offshore, which are separated by a narrow transition zone. The nearshore profile shows two zones, the backshore and the shoreface. The backshore is narrow, usually less than 120 m in width. This merges with the hummocky terrain of the ice-disintegration complex previously discussed. The backshore is relatively flat, but in some places is marked by small discontinuous beach ridges. The shoreface in these quadrangles is expressed as a north-east trending belt, approximately 1.8 km in width. The shoreface here is basically a surface of no relief, sloping gently, 3 to 8 degrees, to the southeast and east.

The shoreface zone is influenced by current action which is reflected in the presence of beach scarps, spits, an offshore bar, and a delta at elevations near 330 m. Wave-cut beach scarps in the shoreface dip 5 to 8 degrees to the southeast and are underlain by medium to fine sand with boulders and gravel concentrated at the base of the slope. The largest spit trends north-south and is located at the center of Sec. 1, T47N, R17W. It is 1.3 km in length and 0.5 km in width with side slopes of 3 degrees. The spit curves to the southwest indicating longshore currents flowing to the southwest. Several smaller spits are located in section 2.

An offshore bar, with up to 6 m of relief is found in SW $\frac{1}{4}$, Sec. 11, and W $\frac{1}{2}$, Sec. 4, T47N, R17W. It generally lies parallel to the former shoreline, 0.8 km lakeward, and extends for 2.4 km. Paleocurrent directions (four measurements) to the northwest indicate shoreward growth of the bar. A fan-shaped form, located in Sec. 31, T48N, R16W, is interpreted to be a delta. It is roughly 2.6 km² in area, relatively flat-surfaced in the north portion, with a foreset slope of 4 degrees to the southeast. A former ice tunnel, now containing an esker found to the northwest in the ice-disintegration complex, appears to have supplied the delta with meltwater.

Lakeward of the nearshore area is a transition zone which separates nearshore and offshore environments. The transition zone occurs as a northeast trending scarp between 300 and 309 m in elevation which slopes 3 degrees to the southeast. The sediments of this zone are transitional in nature between the nearshore sands and the offshore clays, with the sands and clays interfingering. This feature was misinterpreted by Leverett, Farrand, and Wright to be a strandline feature of Glacial Lake Duluth. It appears instead to be a depositional feature associated with the higher (330 m) elevation of Glacial Lake Duluth.

The offshore environment is represented by an extensive lake plain that covers the southeast quarter of the Wrenshall quadrangle and most of the Frogner quadrangle. A profile of the offshore from northwest to southeast shows it to be gently dipping to the east-southeast at less than 3 degrees. Two weak scarps are seen on the profile at elevations of 288 and 264 m, which may represent lower lake levels of the Highbridge and Washburn stages respectively (Farrand, 1960). The offshore area has

been deeply dissected by the Nemadji River and the Red River, a tributary of the St. Louis River. These streams have downcut as much as 42 m into the offshore sediments. Extensive slumping is very common along the stream valleys, indicating the instability of the underlying material.

Sedimentary Units

The sediments of the glaciolacustrine environment may be divided into four units: (1) horizontally-bedded sand, (2) cross-bedded sand, (3) laminated silt and clay with dropstones, and (4) massive clay with dropstones.

Horizontally-bedded Sand

This sand occurs widely throughout the nearshore zone as a sheet-like deposit, with a minimum thickness of 6 m. The grain size distribution shows moderately sorted sand with gravel and a mean grain size of 2ϕ (0.25 mm, medium-fine sand). Sedimentary structures are not abundant in the horizontally-bedded sand. The sand varies from finely laminated to medium bedded. The bedding planes are faint and difficult to recognize, giving a massive appearance to the sand. Heavy mineral laminae are present and help to distinguish bedding planes. Slightly inclined bedding at one locality gives a general paleocurrent direction to the south-southwest. The only other direction indicator available is a general fining of the sand on the shoreface from medium to very fine sand, suggesting currents flowing to the south.

The presence of a plane bed structure associated with the medium to fine grained, horizontally-bedded sand indicates an upper flow regime (Reineck and Singh, 1973). In the upper flow regime the main mode of

sediment transport is via continuous rolling of grains in sheets several grains thick (Reineck and Singh, 1973). Accordingly, the sediment transport is large.

Cross-bedded Sand

The cross-bedded sand occurs as ribbon type deposits. These deposits are generally small, less than 1.5 km in length and 0.5 km in width.

The grain size distribution for cross-bedded sand shows that this is moderately sorted. The mean grain size is 1.5 ϕ (0.35 mm, medium sand), although there is locally coarse sand and gravel. Cross-beds are the main sedimentary structures found in this unit. These occur as planar or tabular forms with sets up to 0.5 m in thickness. The cross-beds show good topset, foreset (inclined 25 degrees), and bottomset beds with laminae comprised of gravel, fine sand, or heavy minerals.

Paleocurrent directions indicate (1) current flow to the east-southeast (lakeward) and (2) current flow to the northwest (shoreward). The shoreward current direction is observed in the area of the offshore bar and indicates a shoreward growth of the bar.

Bedforms of small ripples and mega-ripples associated with the cross-bedded sand indicate transport and deposition in the lower flow regime (Reineck and Singh, 1973). The cross-bedding developed as a result of the migration of small current ripples and megaripples. In the lower flow regime, the resistance to flow is large and the sediment transport is small.

Laminated Silt and Clay

The laminated silt and clay occurs as extensive sheet-like deposits which are also associated with massive clay. The thicknesses of the laminated silt and clay varies from 0.5 to 15 m.

Texturally, two distinct populations are observed: high silt content and high clay content. The silt layer is moderately sorted with a mean grain size of 5.8ϕ (0.02 mm, medium silt). The unit is pale brown (Munsell color: 10 YR 6/3, dry) and consists of greater than 55 percent silt. The clay layer is reddish brown (Munsell color: 5 YR 4/4, dry) ^{is} and composed of greater than 75 percent clay, with silt generally less than 10 percent and sand 0 to 2 percent. In a few locations, carbonate concretions are found within the clay layers.

The sedimentary structures associated with the silt and clay are very thin to thin bedding, discontinuous and distorted bedding. The silt and clay beds vary from several millimeters to several centimeters in thickness, and change considerably within a stratigraphic section. Discontinuous bedding is contorted, showing small scale recumbent folds and lenses of silt.

The laminated silt and clay are rhythmites, alternating layers of different compositions, which may be varves if each couplet represents a single year of deposition (Reineck and Singh, 1973). These appear to have been deposited in the quiet water, deep portion of the basin. The abundance of clay indicates that the main mode of deposition was from the falling out of fine particles from suspension. The presence of silt would indicate more competent currents or turbulence, possibly during the summer thaw, which would periodically transport and deposit the silt.

Massive Clay

The massive clay, with the laminated silt and clay, comprises the major portion of the lake basin. Massive clay appears as a thick, sheet-like deposit which has lateral continuity. The exposed thickness of the

clay is up to 20 m. Texturally the clay content is greater than 75 percent with several samples showing greater than 90 percent. Silt comprises the remaining 10 to 25 percent of the sediment. The clays are reddish brown (Munsell color: 5YR 4/4, dry) to dark reddish gray (Munsell color: 5YR 4/2) where unoxidized and have a general massive appearance.

There are no visible laminae of coarser or different colored material, however in some exposures, the clay does show minor fissility, indicating an internal structure. The presence of massive clay suggests quiet, deep water deposition without apparent current activity.

Dropstones

Scattered within the massive clay and laminated silt and clay are individual clasts up to 10 cm or more in length. These stones are thought to have originated as ice-rafted material as evidenced by their sporadic occurrence, in addition to their large size which would otherwise require a competent current for transport.

Clay Mineralogy

Four samples from the laminated silt and clay and massive clay were analyzed by x-ray diffraction. These include a red clay lamina, a gray silt lamina, reddish gray massive clay, and reddish brown massive clay. There is little difference in composition, other than peak intensities, among these samples. The samples contain (1) quartz, (2) calcite, (3) dolomite, (4) plagioclase, (5) k-feldspar, (6) montmorillonite-illite mixed layer, (7) chlorite, and (8) possible hematite. This mineral group is consistent with those determined by Mengel and Brown (1976) for other clay samples in the Wisconsin portion of the lake basin.

These minerals were derived from the underlying weathered bedrock and older glacial sediments. The abundance of calcite and dolomite indicates a source in the drift of the St. Louis Sublobe to the northwest of the study area. Calcite is commonly found as vein fillings and amygdules in the flows of the North Shore Volcanics and could have been incorporated into the drift of the Superior Lobe. Another possible source for the carbonates is the Hudson Bay area with glacial transport of the sediment into the Wrenshall and Frogner area (Mengel and Brown, 1976).

Stratigraphy

Exposures along roadcuts and stream valleys in the lacustrine complex allow the stratigraphic relationships of the sedimentary units to be worked out. Subsurface data are available only for the area near Wrenshall and show the drift to be up to 115 m thick. Various sections are summarized in a schematic north-south cross-section (Figure 7). The section shows the basal unit as older drift or bedrock. These older units are overlain by (1) moderately sorted, probable nearshore sand, (2) massive clay with laminated silt and clay, and including dropstones, and (3) moderately sorted, fine to medium grained, horizontally- and cross-bedded sand. The presence of shallow water sand over deepwater silt and clay suggests progradation resulting in nearshore facies over offshore facies.

Depositional Environment

As shown on a surface plot of the sediments (Fig. 8), the mean grain size distribution changes depending on the distance from the shoreline. The nearshore facies is shown to be composed primarily of medium sand. The sand consists of both horizontally-bedded and cross-bedded units. Shoreface activity includes upper and lower flow regimes, as indicated by

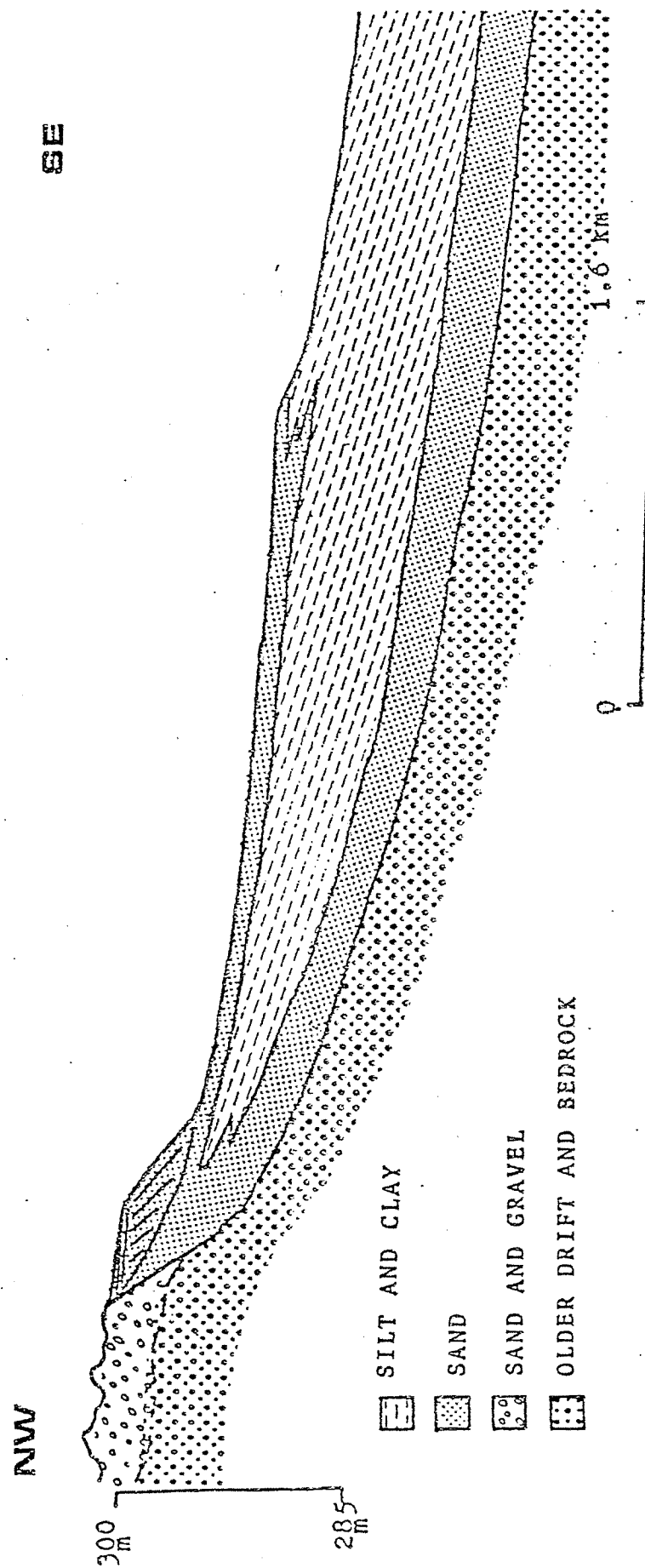
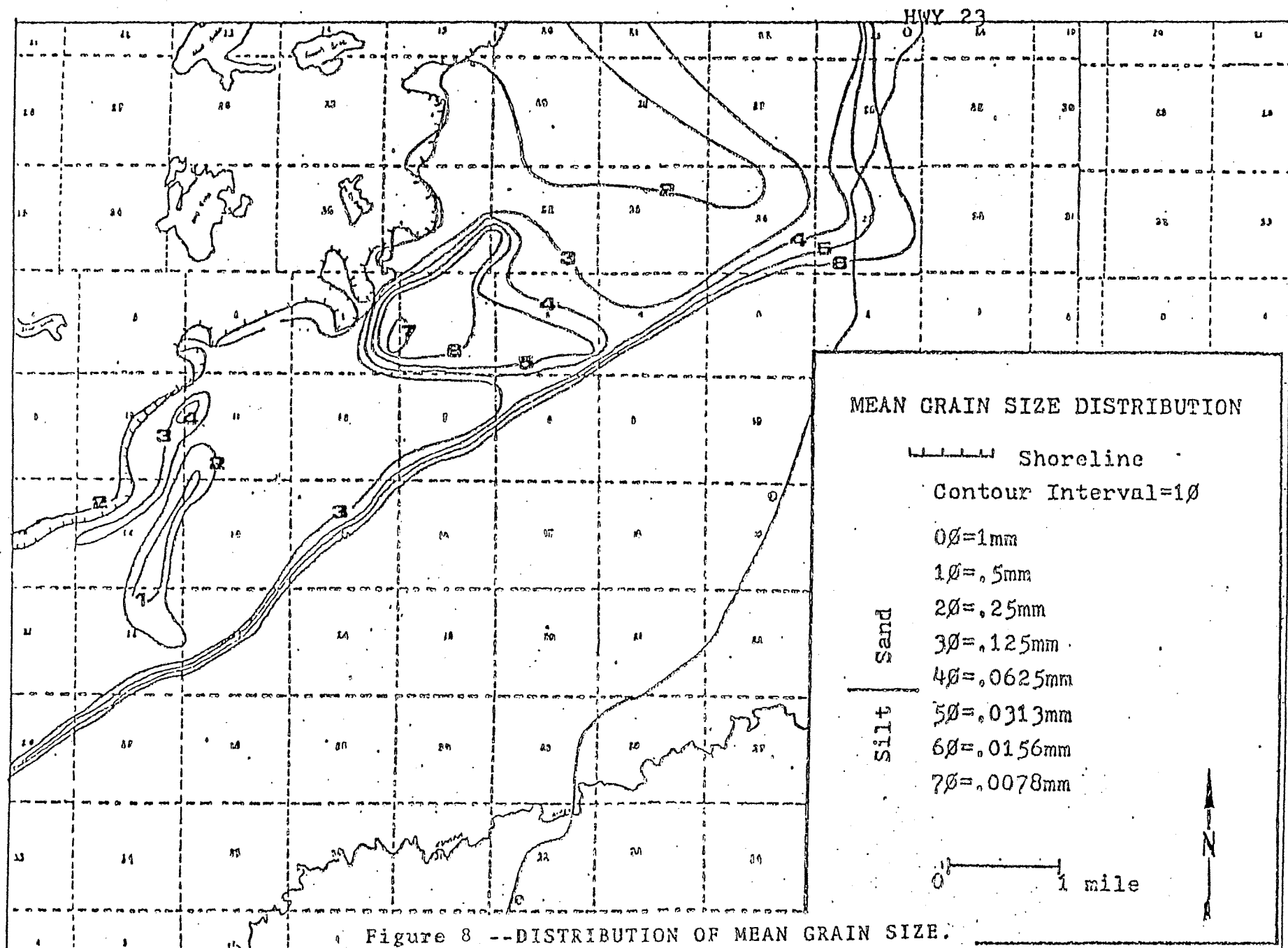


Figure 7 --SCHEMATIC NW-SE CROSS-SECTION

(R.J. Zarth, 1977)



(R.J. Zarth, 1977)

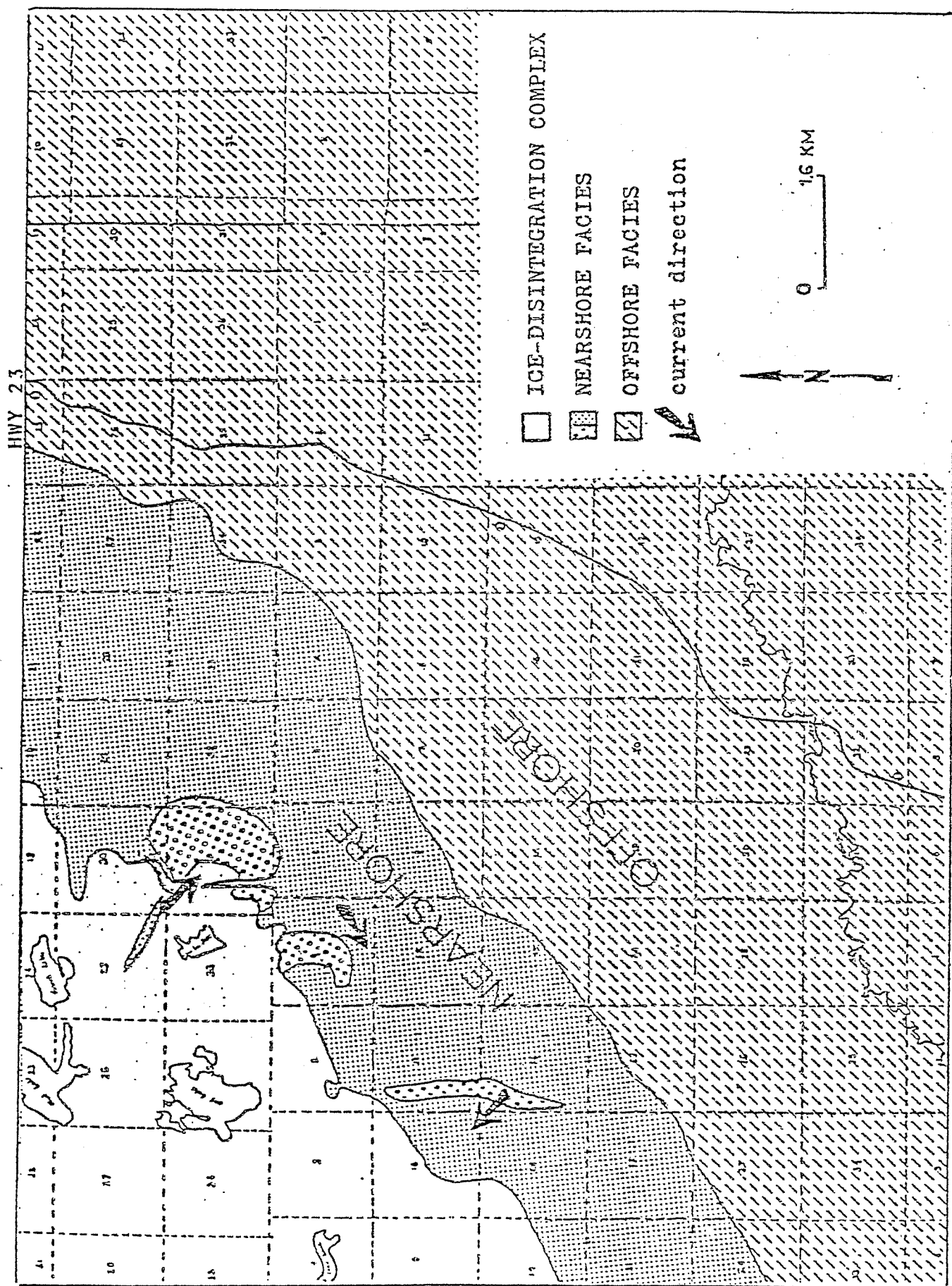


Figure 9 --GENERAL FACIES MAP.
(R.J. Zarth, 1977)

bedforms. The current directions to the southwest parallel the shoreline, causing the formation of spits (Figure 9). The offshore bar formed subaqueously and paleocurrents show a shoreward growth, possibly due to storm waves. The north-central portion of the study area has very fine sand and silt relatively close to the shoreline, suggesting lower current strength.

Deltaic sedimentation shows an upper surface of sand, with very fine sand and silt on the prodelta slope. Two narrow valleys radiate south and west from the feeding esker. These may represent remnant distributary channels cut into the delta, with the silt and fine sand as floodplain deposits, as suggested by their standard deviations (Folk and Ward, 1957).

There is an abrupt grain size change in the lake basin from predominantly sand to predominately silt and clay (Fig. 8). This boundary, which can be traced laterally, occurs between 300 and 309 m in elevation and is represented by a northeast trending scarp. The zone shows varying textures with interfingering sand, silt, and clay. The variety in sediment type reflects the changes in current strength. This abrupt change in slope and sediment type is here interpreted to represent the depositional front of a coarse grained shelf of Glacial Lake Duluth.

The offshore facies occurs south and east of the transition zone (Fig. 8). It is composed of laminated silt and clay, massive clay, and dropstone deposits. These sediments were derived from the wasting ice lobe and meltwater streams draining the ice-disintegration complex. Offshore sedimentation must have occurred primarily as the settling of sediment from suspension as evidenced by massive appearing clays.

The rhythmite couplets (silt and clay layer) are not gradational but occur as distinct layers. This would suggest deposition by two sedimentation pulses and modes of deposition (Ashley, 1975). The normal suspension sedimentation may have been periodically interrupted by density currents as underflows, interflows, and overflows. These flows result from the high suspended sediment content of meltwater streams from the ice-disintegration complex and ice lobe entering the lake. These flows have been described in present day Glacial Lake Malaspina, Alaska, by Gustavson (1975). These currents provide a mechanism for the deposition of the silt layers of the rhythmites during the summer months. This would result in clay being deposited continuously in areas not reached by current flows, and massive clays would form (Gustavson, 1975).

In addition, offshore occurrence of dropstone deposits, interbedded with silt and clay, suggest ice rafting of sediments as a depositional mechanism. The ice dammed Glacial Lake Duluth, with calving of the ice front, would produce massive icebergs which would release sediment over the lake basin as the ice would melt.

Vegetational History

Cores from bogs and lakes contain a history of plant succession in the form of pollen and macro-fossils, including seeds, woody fragments, and leaves. Studying quantitatively the contents of such cores at a particular site allows the determination of the time of arrival of plant migrants, as well as the reconstruction of the fabric of the plant communities at different times. All of these studies lead to the fuller view of the vegetational history within the time represented by the sediment core. As a data proxy for climate, the pollen record is

then transcribed into a history of climatic change. Sampling along the proper traverses allows the monitoring of the march of vegetation in the wake of retreating glaciers.

Most ponds and lakes in glaciated terranes deep enough to accumulate a significant sediment record originated as kettles on ice-cored end moraines. The vagaries of down-wasting of buried stagnant ice decree a complex natural history for the surface features of such a terrane. Topographic reversals are common because the hillslopes are extremely unstable: debris flows and slumps denude sediment-mantled slopes, fill depressions with colluvium, and thereby redistribute the insulation on the stagnant ice surface. Melting proceeds more rapidly on the bared slopes and hilltops. Differential melting transforms ice-cored hills into holes, and vice versa.

In such an unstable environment lakes and ponds are ephemeral. Sediment, including pollen and plant macro-fossils is not collected into a continuous and permanent record until a stable basin is formed, generally near the demise of the ice core. Melting to that point in the moraine's history may take thousands of years. Therefore, radiocarbon dates on bottom sediments in such lakes can be significantly younger than dates obtained from beneath basal till in the same moraine. For the same reason, cores contain an incomplete record of revegetation--generally the earliest part is missing. It follows that the best lakes for pollen studies are those that formed early in the history of deglaciation and that continued as stable catchments to the present.

In broad outline, the pattern of plant succession in Minnesota during the Late Wisconsin and post glacial is similar to that of the

entire Great Lakes region (Wright, 1976). Wolf Creek in central Minnesota (see Fig. for location WC) and Weber Lake in northeastern Minnesota are two sites that have been especially useful to reconstructing the vegetational history.

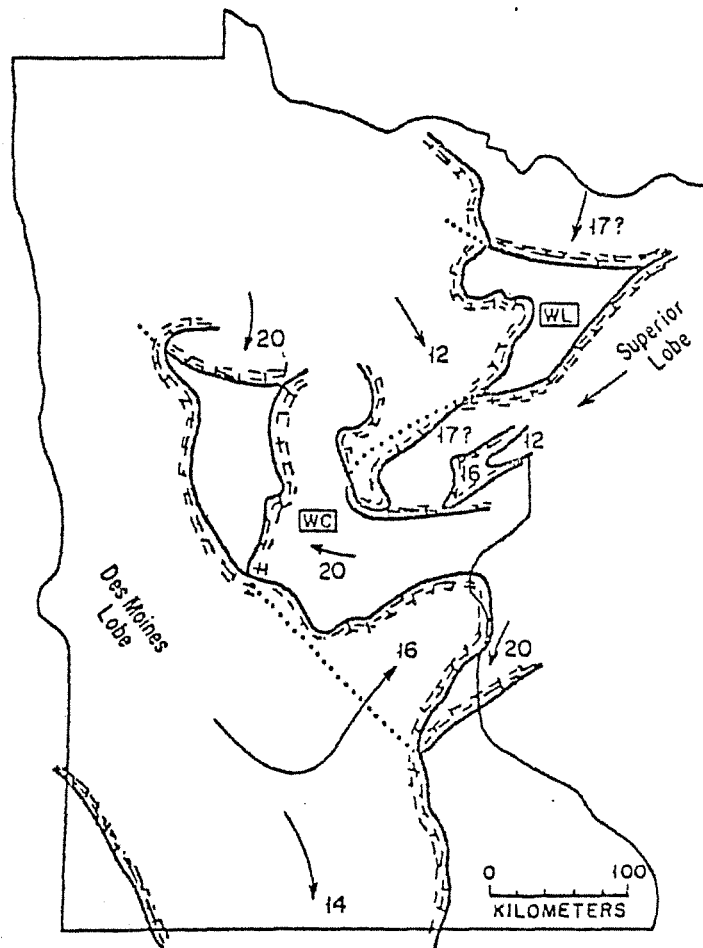


Figure 10. Major phases in the Wisconsin glaciation in Minnesota. Approximate dates in thousands of years. Note the non-synchronous maxima of the Superior and Des Moines lobes. Locations of Wolf Creek and Weber Lake are shown.

The oldest pollen zone at Wolf Creek represents an herb tundra, which prevailed from 20,500 yr BP until about 14,700 years ago. This was followed by shrub tundra and forest tundra. Spruce expanded into the area about 13,600 years ago and was the dominant species for about

4,000 years. Then, spruce was replaced by pine about 10,500 years ago. Cores from Weber Lake, situated farther northeast in the Toimi drumlin field, indicate that herb tundra persisted there until about 11,000 yr BP, with a rapid transition to shrub tundra and then spruce and finally pine.

A summary of the changes in major vegetation types and their relationships to glacial phases is shown in Figure 11.

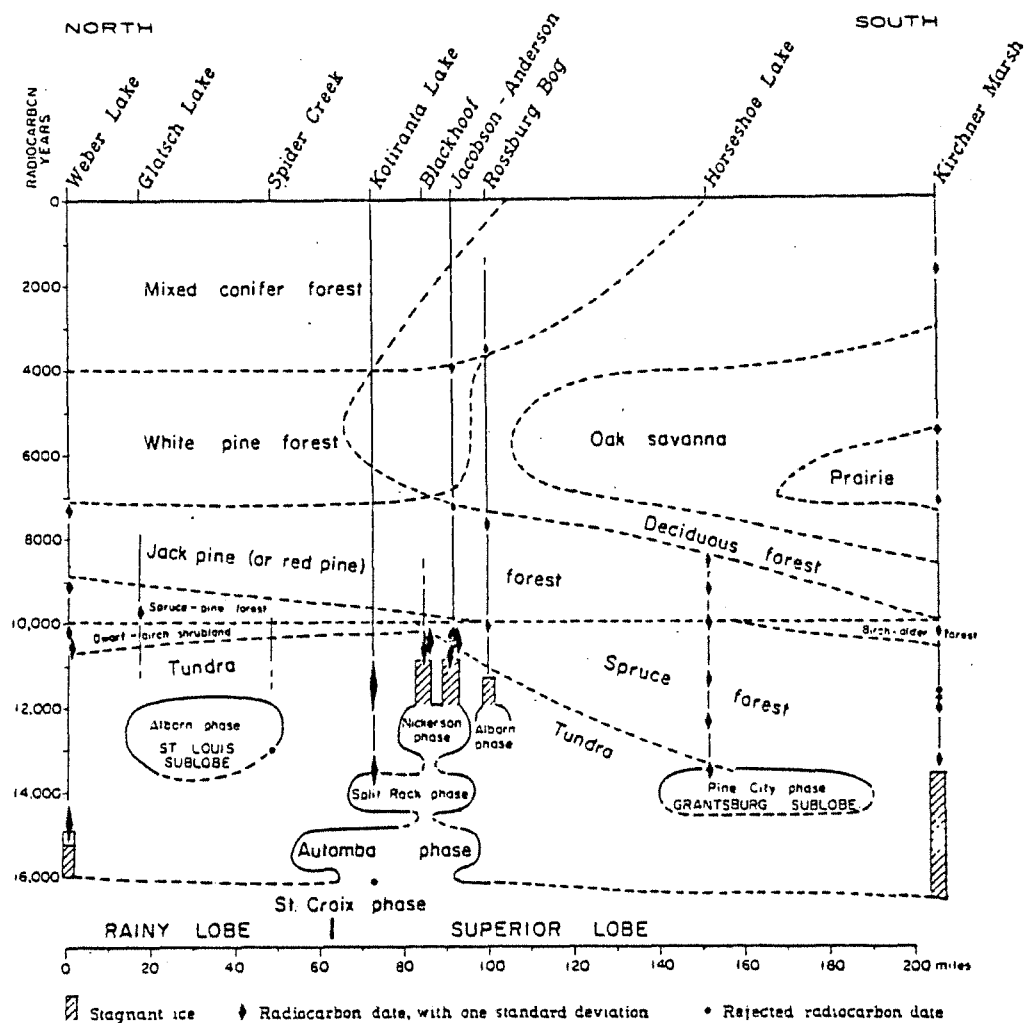


Figure 11. Transect from north to south in eastern Minnesota, showing times and areas of ice-lobe advance, as well as the changes in major vegetation types since glaciation, as inferred from pollen and seed analyses of lake sediment cores. (Courtesy H. E. Wright).

Glacial Materials and Soil Profiles

by

Royce Lewis, Soil Conservation Service

The kind of soil horizons and their sequence formed on well drained sites in the Duluth area generally can be correlated with the kind of glacial materials. The Ahmeek, Duluth and Ontonagon soils may be used as examples. See Figures 1 through 6 for some physical and chemical properties of these soils.

The Ahmeek soils are formed in noncalcareous, reddish brown, sandy loam till. Their sequence of horizons may be interpreted as A₁, A₂, Bhir, B_x, and C_x. The Duluth soils are formed in noncalcareous, reddish brown, loam till and have a sequence of horizons of A₁, A₂, Bhir, A₂, B_T, and C. The Ontonagon soils are formed in calcareous reddish brown, lacustrine sediment and have a sequence of horizons of A₁, A₂, B_T and C_{CA}.

The A₁ horizons of these soils have higher accumulation of organic carbon, lower bulk density and higher porosity than other horizons in the pedon (area of about 1 square meter). They are higher also in available water capacity (1/3 minus 15 bar water). They generally are higher in base saturation and pH than the horizons immediately below. They commonly are black.

The A₂ horizons generally are discontinuous within a pedon of Ahmeek and Duluth soils and are continuous in the Ontonagon soils. They are horizons of maximum removal of clay, iron or aluminum, which results in a concentration of quartz or other resistant minerals in the sand and silt size. They are lighter in color than the underlying B horizons.

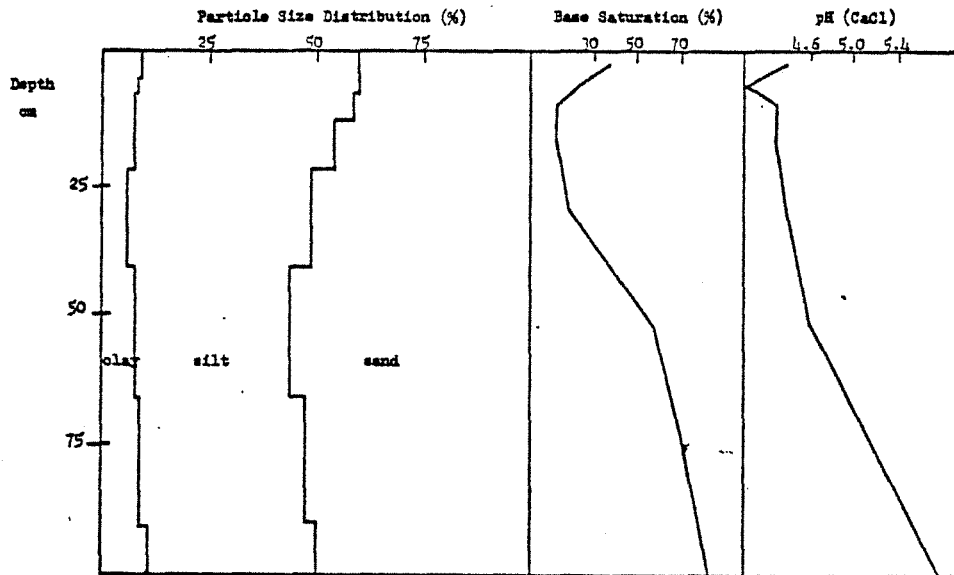
The Bhir horizons have significant accumulations of organic carbon, iron and aluminum coatings on sand and silt particles. They are low in

bulk density, base saturation and pH. They have also a higher cation exchange capacity per unit of clay than the underlying horizons. They are commonly reddish brown.

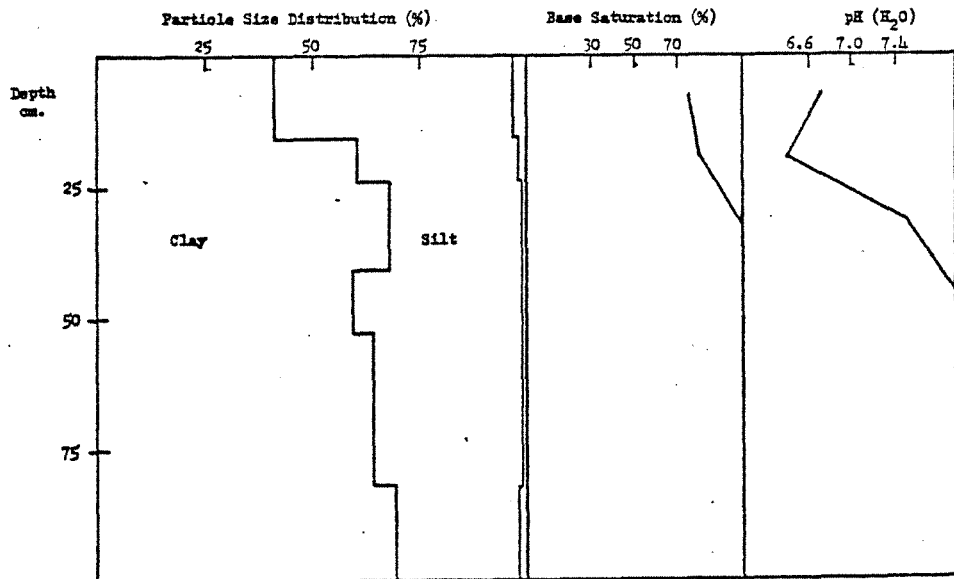
The B_T horizons have appreciable accumulations of translocated silicate clay particles as contrasted to the B_x horizons (in the Ahmeek soils); however they have higher bulk density and lower porosity than B_T horizons. The base saturation of the B horizons, and content of clay range widely among these soils. They seem to be a mark of the kind of glacial materials along with the properties of the C horizons.

The C horizons are presumed to be relatively little affected by biological activity and include accumulation of calcium and magnesium carbonate (C_{CA} horizons) and high bulk density (C_x horizons).

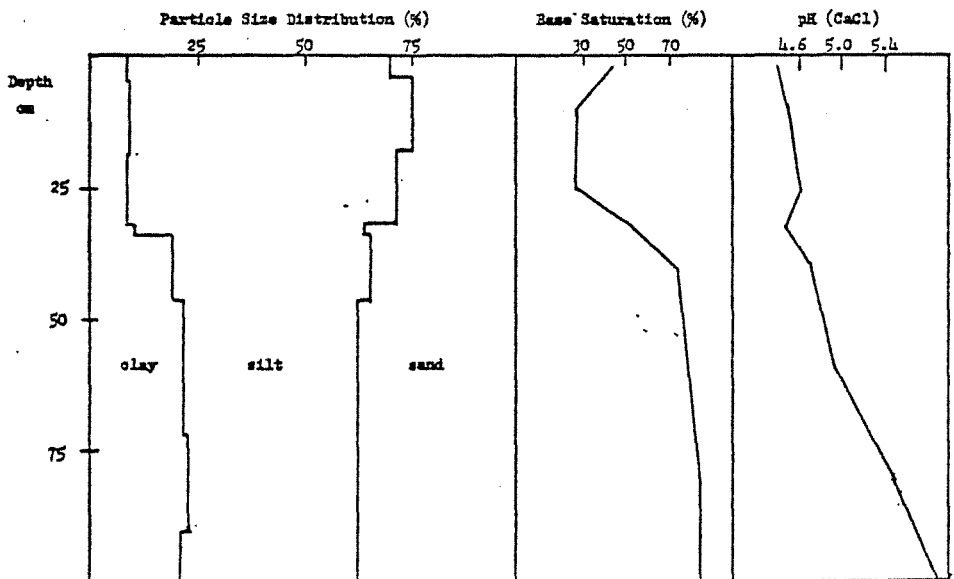
ARPEEK PEDON



Ontonagon Pedon



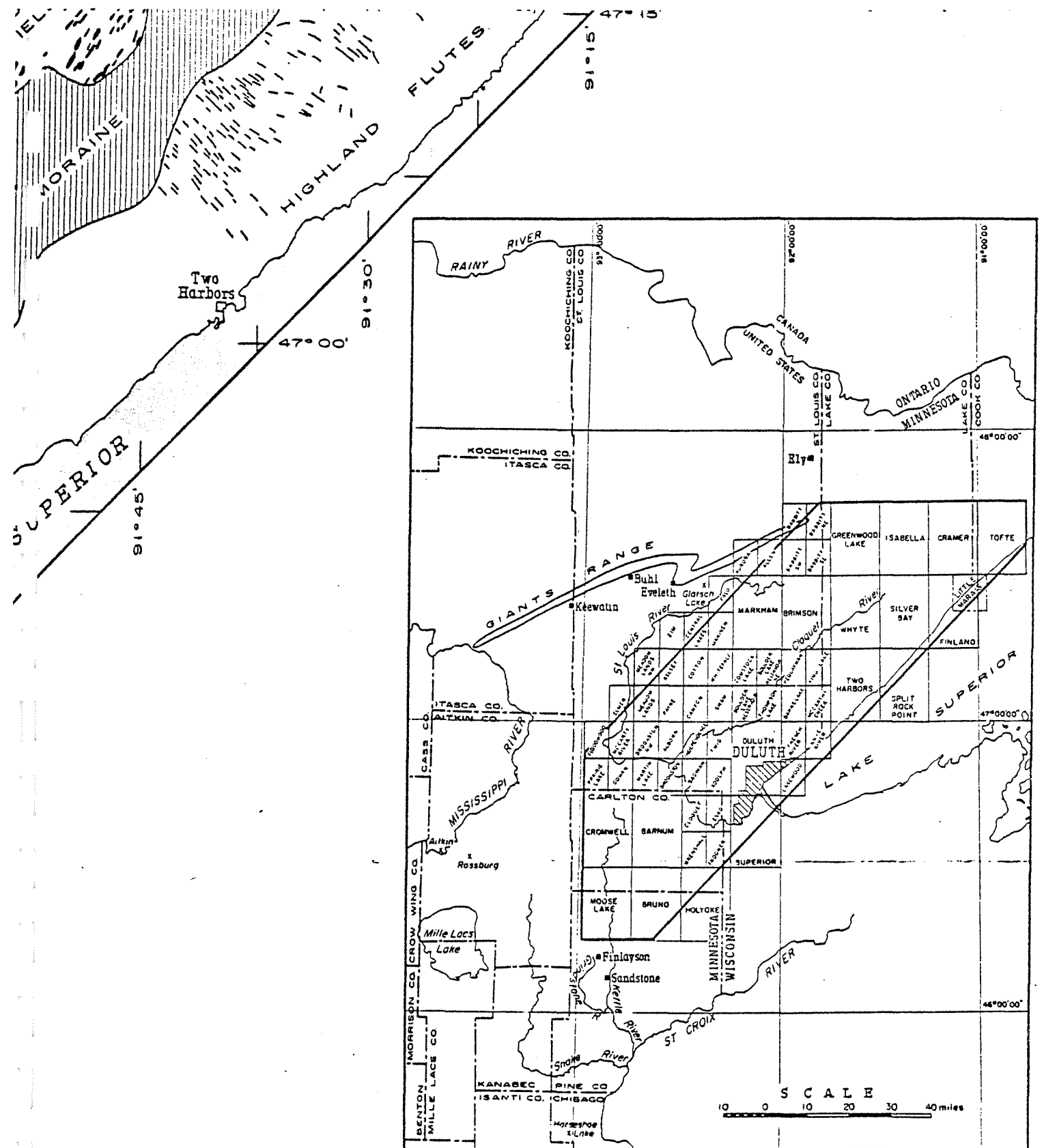
DULUTH PEDON



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INDEX TO QUADRANGLES STUDIED

EASTERN MINNESOTA SHOWING MAJOR GEOMORPHIC FEATURES

From: Wright, H.E., Jr., and Watts, W.A., 1969, Glacial and Vegetational History of Northeastern Minnesota, Minn. Geol. Survey Special Publication No. 11, 59 p.

ROAD LOG AND STOP DESCRIPTIONS

Mileage

0.0	0.0	Start. Normandy Village, Superior St., Downtown Duluth. Proceed to 3rd Ave. W., turn right. Proceed 2 blocks to 2nd St. W. Turn right. Proceed to 10th Ave. E. Turn right and continue to London Rd. Turn left and proceed to Viking ship at Leif Erikson Park on Lake Superior.
1.5	1.5	<u>STOP 1.</u> Leif Erikson Park. Exposures along the wave-eroded shoreline of Lake Superior show two different tills atop the striated and polished Keweenawan lava flows and interflow sediments. The unconformity between the Precambrian and Quaternary Systems encompasses over one billion years. Continue east on London Road
4.7	6.2	Lester River. Rocks are lava flows. A well-striated whaleback is exposed at the mouth of the stream. The river is popular with smelt and steelhead fishermen.
0.5	6.7	Turn right onto Lake Superior Scenic Drive. Many miles of shoreline were given to the City of Duluth by the Congdon family to be developed as public recreational areas. Notice the effects of recent wave erosion.
2.3	9.0	City of Duluth Water Supply Plant. On the left is the newly constructed filtration plant necessitated by the high amounts of fine-textured fibrous amphiboles suspended in the lake water. Source of the minerals is a taconite (low grade iron ore) processing plant at Silver Bay, which disposes of tailings into Lake Superior.
0.5	9.5	<u>STOP 2.</u> Turn right into scenic pull-out near Duluth Tent and Trailer Camp. Proceed along path to Lake Shore. A variety of glacial sediments, including tills and possibly glaciolacustrine sediments, is exposed along the shore, resting atop lava flows of the North Shore Volcanics. Continue east on Scenic Drive
1.7	11.2	Turn left onto McQuade Rd. (St. Louis Co. Rd. 33)

- 0.6 11.8 Intersection with Hwy 61 Expressway. Continue north on McQuade Rd. Exposures along the route are pebbly mud deposited in Glacial Lake Duluth. The road transects several flat benches that may be shoreline features.
- 2.9 14.7 Junction with Lismore Rd. Continue north on McQuade Rd.
- 0.7 15.4 STOP 3. Gravel pit on the right exposes a complex of cross-bedded outwash interpreted to be a delta constructed by a meltwater stream at its junction with Glacial Lake Duluth's highest stand in the area. Thin diamictons may be debris flows from high-standing ice-cored topography near the shoreline.
- Continue north on McQuade Rd.
- 0.9 16.3 STOP 4. Sucker River. Two tills exposed in the stream bank correlate with those along the Lake Shore. Here the upper, fine-textured till is far above the level of Lake Duluth, eliminating the possibility that it is of glaciolacustrine origin. Both tills contain a fabric resulting from the preferred orientation of elongate clasts. See general text for details.
- Make a U-turn carefully and return south on McQuade Rd.
- 3.5 19.8 Turn right onto Lismore Rd.
- 2.9 22.7 Outcrop on right is a coarse-textured felsic intrusive called "granophyre". In one view this rock type, which is common in the Duluth Complex, is a late-stage magmatic differentiate derived from basaltic magma during the crystallization of the Duluth gabbro.
- 3.4 26.1 Turn left onto Jean Duluth Rd.
- 5.2 31.3 Large outcrop of granophyre on right.
- 1.3 32.6 Intersection with Glenwood Ave. Continue on Jean Duluth Rd. and Skyline Pkwy.
- 1.0 33.6 Turn left onto Woodland Ave.
- 0.1 33.7 Turn right onto Arrowhead Rd.
- 1.5 35.2 Turn left onto Kenwood Ave.

- 1.1 36.3 Turn right onto Skyline Pkwy.
- 0.7 37.0 STOP 5. Turn left into parking lot of First Methodist Church. View of Duluth-Superior harbor. The outer natural barrier at the head of Lake Superior, called Minnesota and Wisconsin Point, is the largest fresh water bar in the world. Sand derived from till bluffs to the east along the south shore is moved to the lakehead by beach drifting. It began to form about 3,000 years ago. Segments of an inner bar are also visible. This feature was constructed during the slightly higher Nipissing level of the lake about 4,000 years ago.
- Continue west on Skyline Pkwy to Hwy 2.
Numerous outcrops of gabbro along the route.
- 8.3 45.3 Junction Hwy 2. Proceed through intersection to Thompson Hill Information and Rest Area. Gabbro bedrock along Hwy 2 is abraded and plucked into whaleback forms.
- 0.3 45.6 STOP 6. Thompson Hill Rest Area and lunch stop. Good views of the estuary of the St. Louis River. Very accessible are outcrops of the so-called layered series of the Duluth Complex, the result of episodic crystallization of different minerals in the magma chamber. Remember Bowen's reaction series?
- Exit on northeast side to Hwy 2 and Interstate 35 North.
- 2.1 47.7 Exit right onto Central Ave and Hwy 2.
- 0.2 47.9 Turn right onto Central Ave.
- 0.3 48.2 Stop sign. Turn right onto Raleigh St.
- 0.6 48.8 Stop sign. Turn left onto Grand Ave. and Hwy 23
- 8.0 56.8 Fond du Lac village limit. French fur traders were the first white men to see the "head of the lakes" region, about 1659. Twenty years later Daniel de Greysolon Sieur de Lhut raised the French flag on the shores of Lake Superior. In 1817 John Jacob Astor established one of his fur trading posts on the banks of the St. Louis River at Fond du Lac.
- 0.5 57.3 Junction Hwy 210. Keep left on Hwy 23.
- 0.5 57.8 Excavation on right exposes glaciolacustrine sediments associated with Glacial Lake Duluth.

- 2.3 60.1 STOP 7. Turn right into scenic overlook. The St. Louis River and its tributaries have entrenched deep valleys into the sediments of Glacial Lake Duluth. Mass-wasting of the fine-grained sediments results in a distinctive rounded topography. Watch for bald eagles--an active aerie is a few miles upstream.

Continue south on Hwy 23.

(Following road log is approximated from topographic maps.)

- 1.7 61.8 Turn right onto Carlton Co. Rd 18 to Wrenshall. The route crosses the nearshore "continental shelf" of Lake Duluth.
- 2.2 64.0 Turn right into Wrenshall.
- 0.5 64.5 Turn left onto West Alcohol Rd. The route will climb gradually across nearshore glaciolacustrine sediments onto a hummocky bounding stagnation moraine, a part of the Thomson moraine.
- 1.3 65.8 STOP 8. West Alcohol Rd. gravel pit. Exposures show the sedimentary complexities of a moraine resulting from the stagnation and melting of dirty glacier ice.

Return to Wrenshall

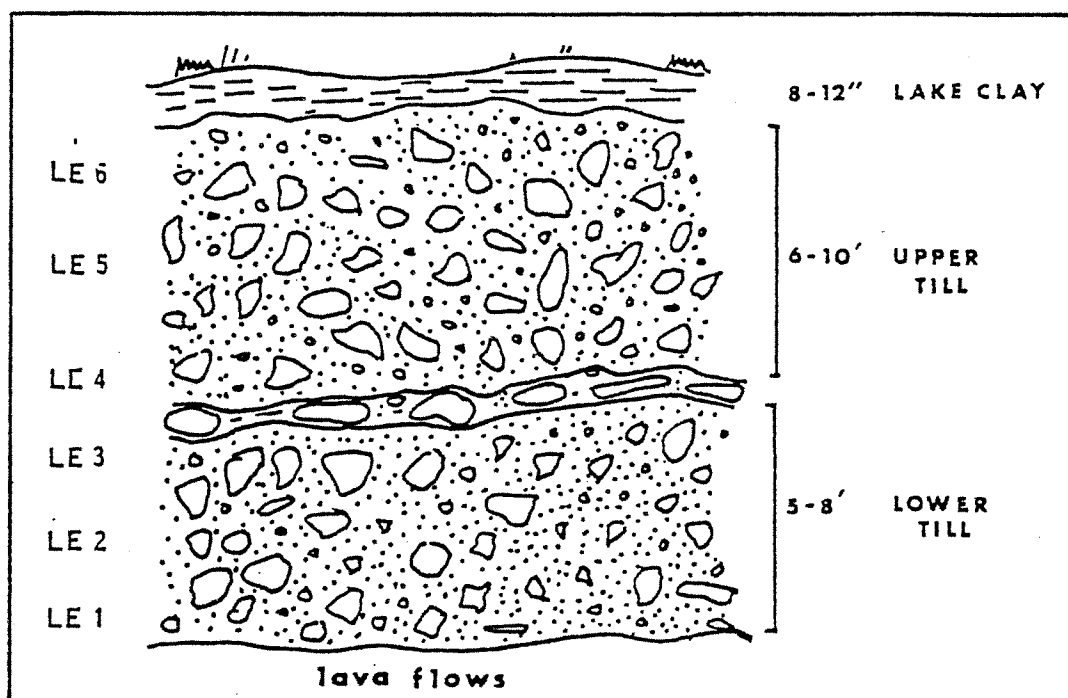
- 1.3 67.1 Turn left to Carlton. The lake plain narrows to a long embayment. Outcrops are Thomson Formation, a Middle Precambrian metasiltstone-slate.
- 4.2 71.3 Carlton. Continue north on Hwy 45. Numerous outcrops of Thomson Formation striking generally east-west in the form of miniature hogbacks (piggy backs?).
- 2.4 73.7 Junction Hwy 45 and I-35. Continue to Scanlon on Hwy 45.
- 0.3 74.0 Stop sign. Turn left on Hwy 45 toward Cloquet.

Prepare for sharp left turn

- 0.3 74.3 Turn left onto Washington Ave. (Carlton Co. Rd. 16)
- 1.4 75.7 Junction Hwy 33. Turn right and proceed into left lane.

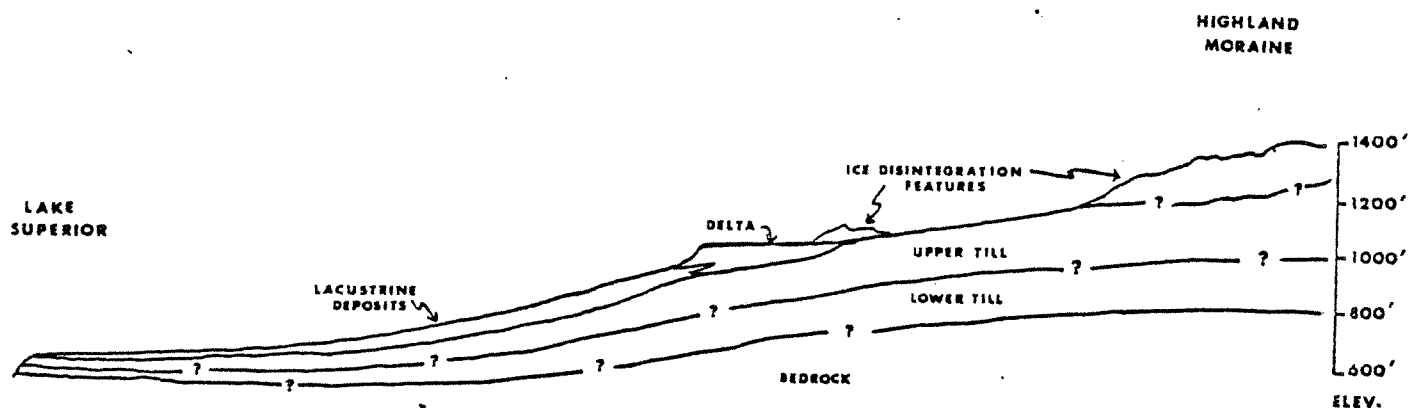
- 0.3 76.0 Turn left onto service road fronting National Guard Armory, then right toward Armory entrance.
- 0.1 76.1 Stop sign. Turn left to Pine Valley Park.
- 0.4 76.5 Turn left into City of Cloquet Public Works Dept. gravel pit.
- 0.1 76.6 STOP 9. Cloquet esker. Gravel pit exposes the internal structure of the highest esker in Minnesota. See the Wrenshall Quadrangle topographic map. Mixed bedrock lithology suggests erosion of older tills before final deposition of esker gravel.
- Retrace route to Armory
- 0.5 77.1 Turn left to Hwy 33 via service road to Pizza Hut.
- 0.2 77.3 Turn left (north) onto Hwy 33.
- 0.7 78.0 Junction Hwy 33 and Hwy 45. Continue north on Hwy 33.
- 0.1 78.1 St. Louis River.
- 0.9 79.0 Turn right onto North Rd (Carlton Co. Rd. 2)
- 1.7 80.7 STOP 10. Pit on left exposes the southeast end of a drumlin-like landform ascribed to the Automba phase of the Superior Lobe. Reworked clay displays slickensides produced by "drumlin-forming processes."
- Continue east on County Rd 2
- 7.0 87.7 Junction Midway Rd (St. Louis Co. Rd 13). Turn right to I-35.
- 1.9 89.6 Junction I-35. Turn left to I-35 northbound to Duluth. Rock outcrops are lava flows near the bottom of the North Shore Volcanics, of Late Precambrian age.
- 9.9 99.5 Exit from I-35 onto Superior St. in Duluth.
- 0.6 100.1 Normandy Inn. End of field trip.

DIAGRAM SUPPLEMENT TO ROAD LOG

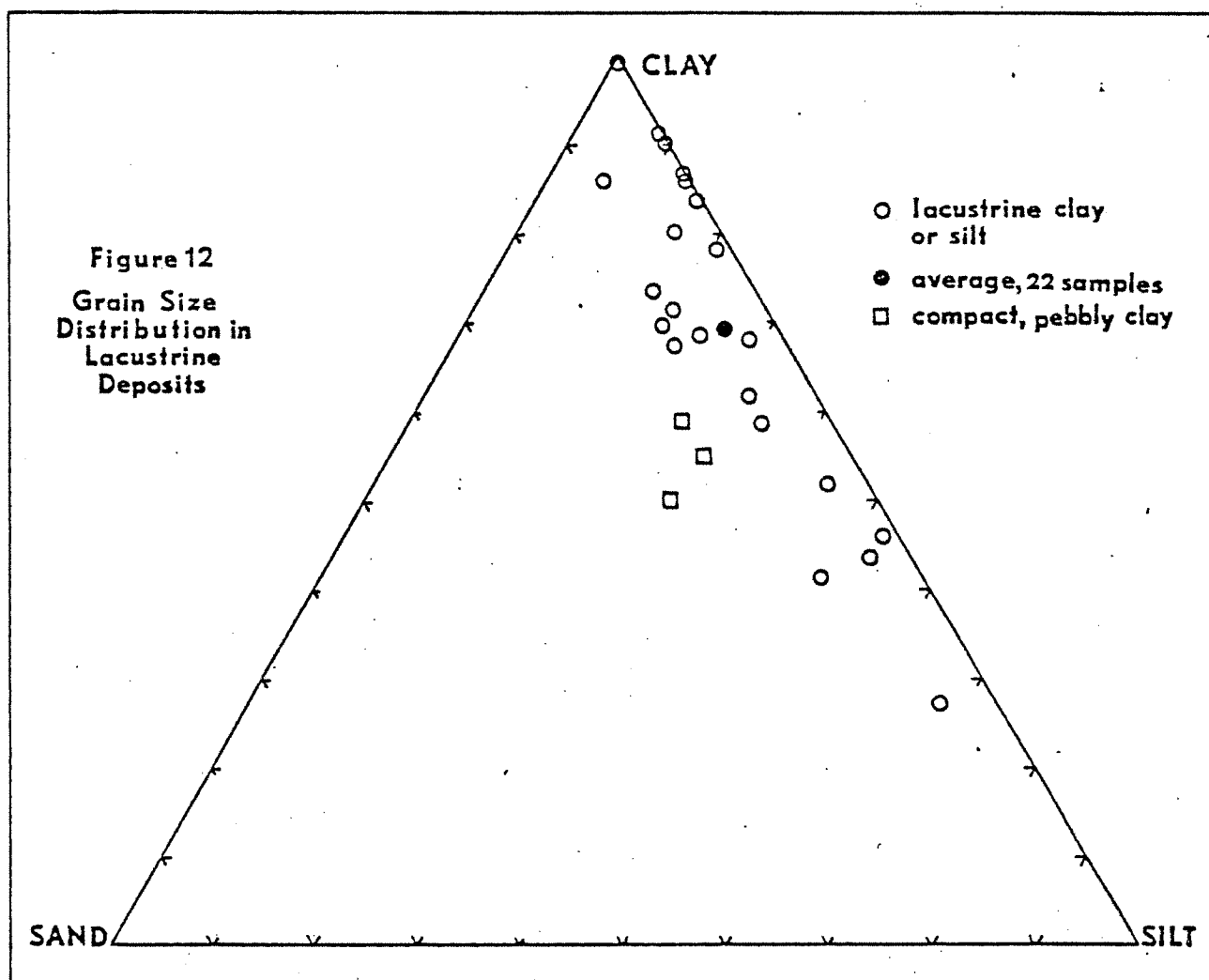


Stratigraphic section at Leif Erickson Park; Duluth, Minnesota. SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 23, T50N, R14W.

Textural composition of samples: LE 1, 34% sand, 45% silt, 21% clay; LE 2, 49% sand, 42% silt, 9% clay; LE 3, 39% sand, 43% silt, 18% clay; LE 4, 23% sand, 74% silt, 3% clay; LE 5, 20% sand, 65% silt, 15% clay; LE 6, 24% sand, 47% silt, 29% clay. C. M. Moss, 1977



DIAGRAMMATIC CROSS SECTION - FRENCH RIVER QUADRANGLE C. M. Moss, 1977



(C. M. Moss, 1977)

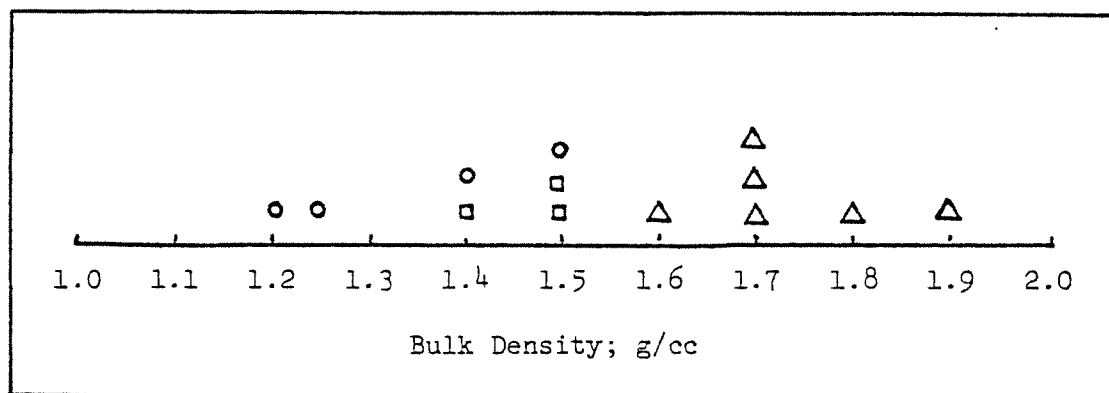
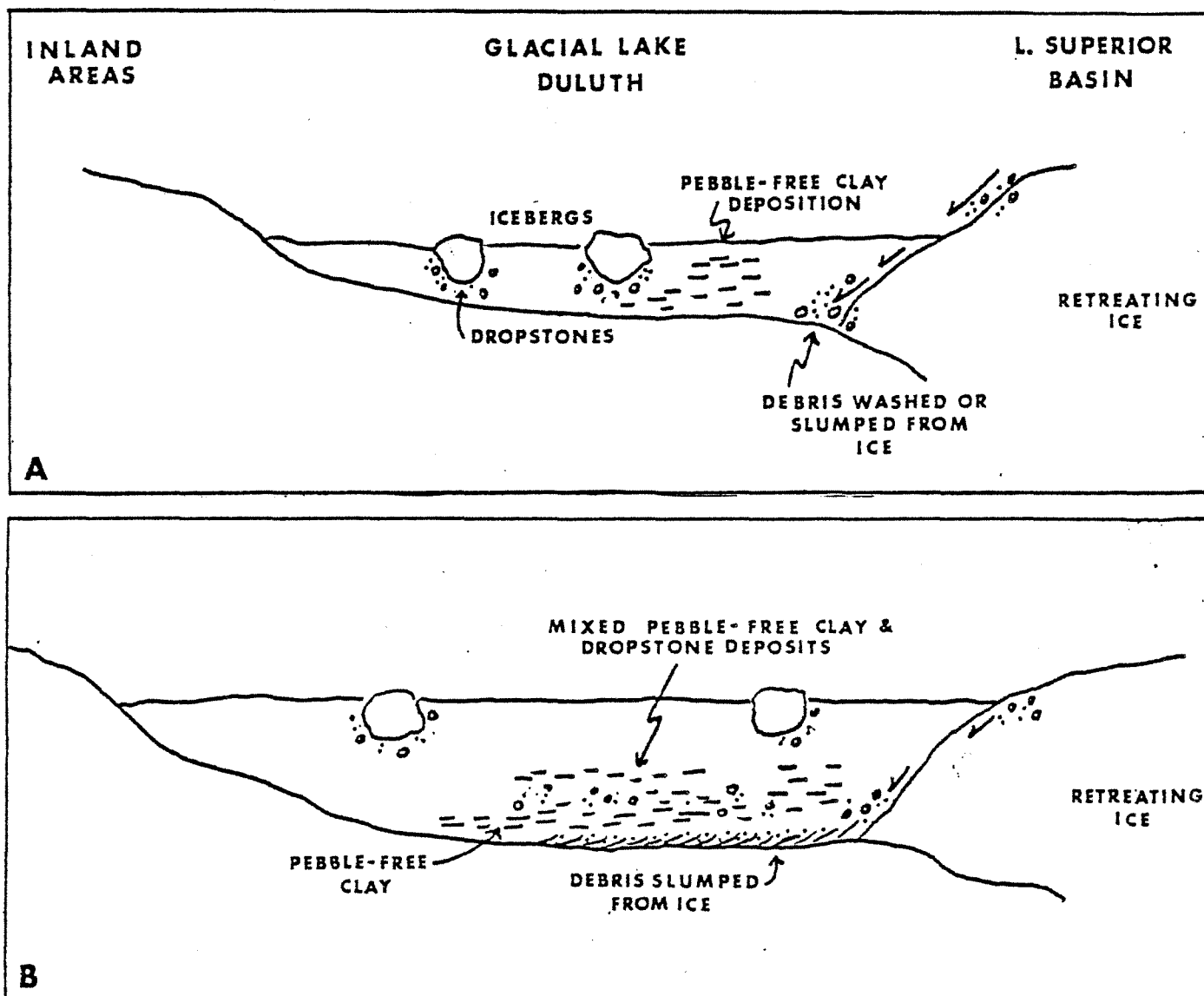


FIGURE 14: Comparisons of bulk densities of glacial sediments:
 □ = pebbly, compact clay
 ○ = laminated or massive pebble-free clays
 △ = sand- or silt-rich till

(C.M. Moss, 1977)



Model for deposition of clay facies in Glacial Lake Duluth. (A) earliest stages of deposition with material supplied from icebergs and retreating ice. Clays are carried away from the ice and are deposited in deeper water. (B) later stages of deposition; pebble-free clays continue to settle over slumped debris and icebergs drop coarser material over scattered areas. (Moss, C.M., 1977)

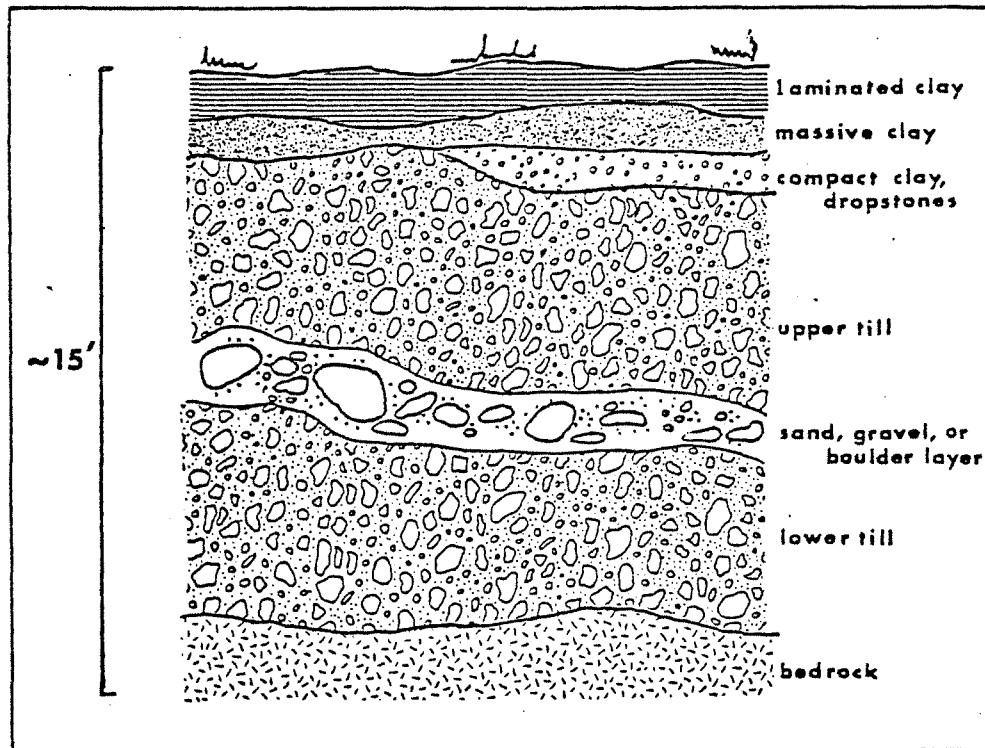
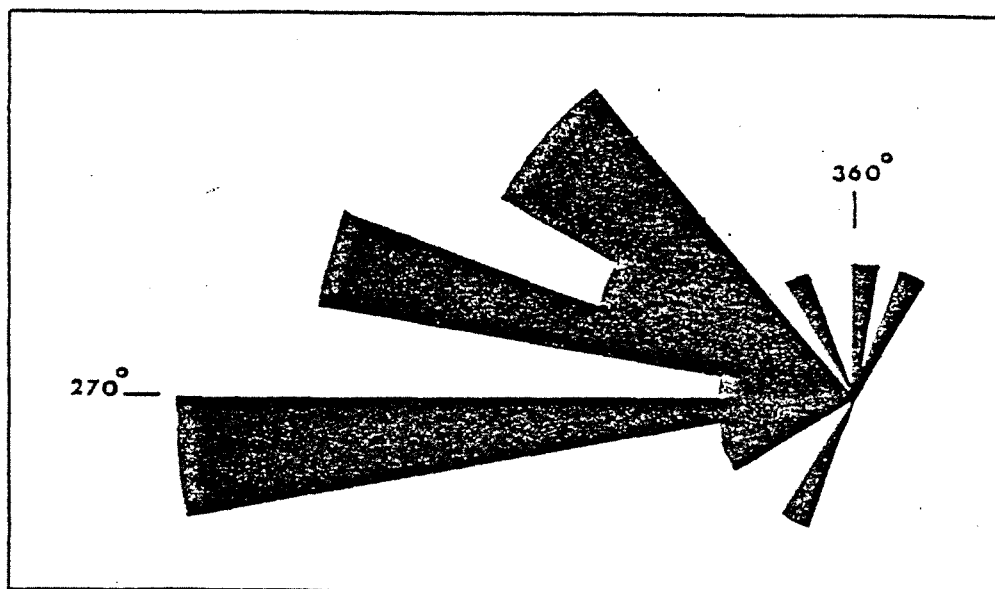


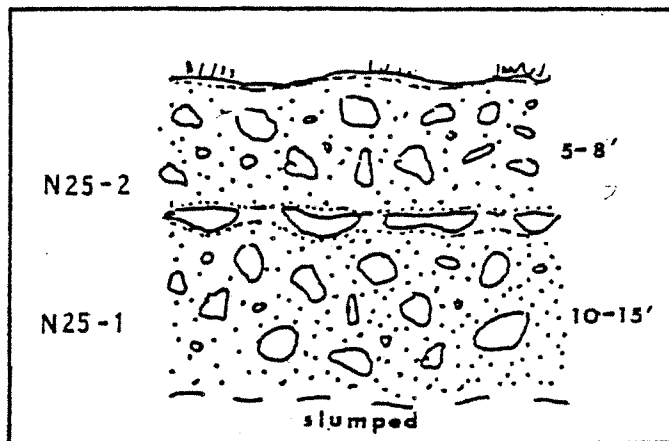
FIGURE 15: Composite stratigraphic section for locations below 1150' in French River quadrangle.

(C. M. Moss, 1977)

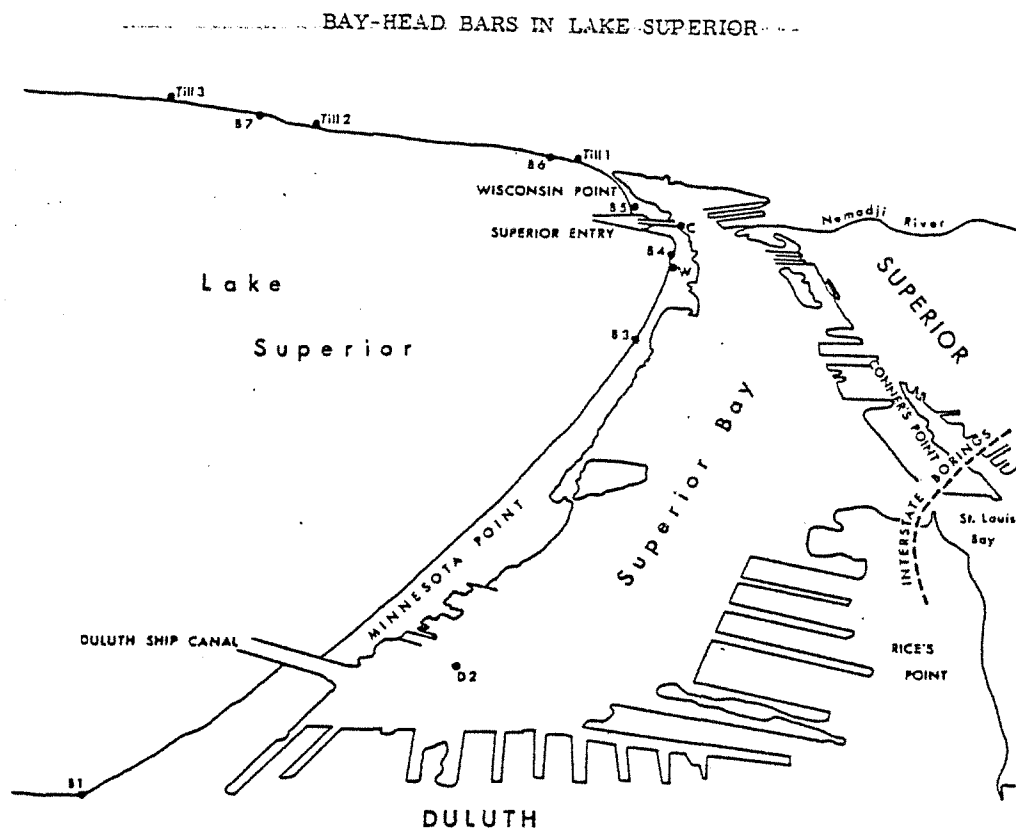


Measurements of planar cross bedding in deltaic sands and gravels. Section 31, T52N, R12W; 24 observations.

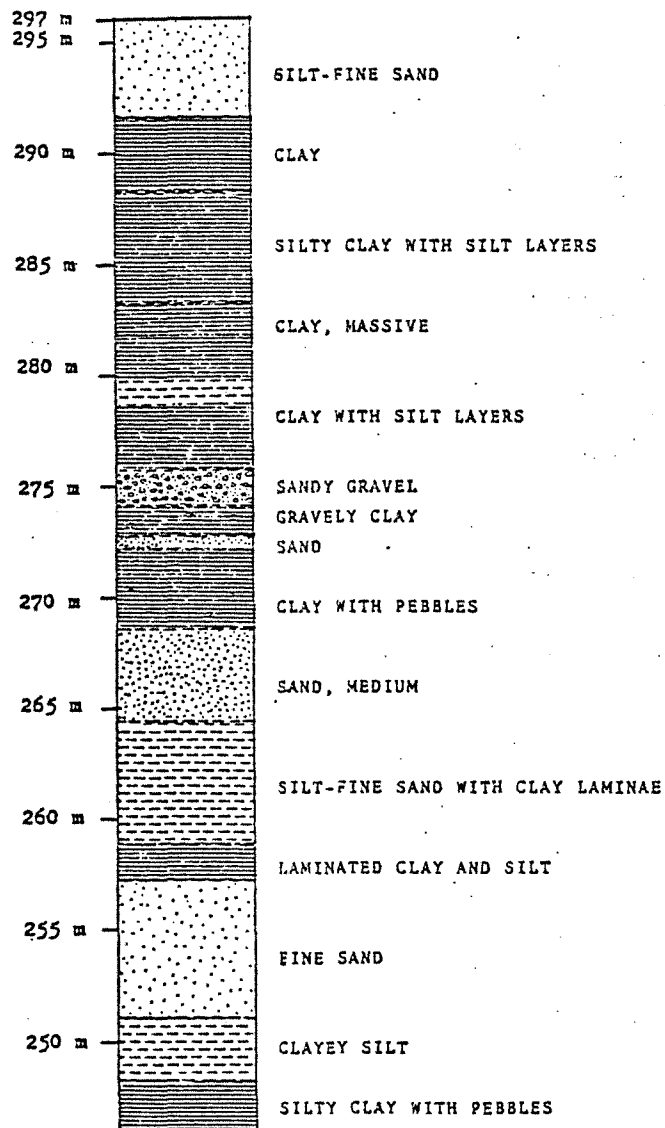
(C. M. Moss, 1977)



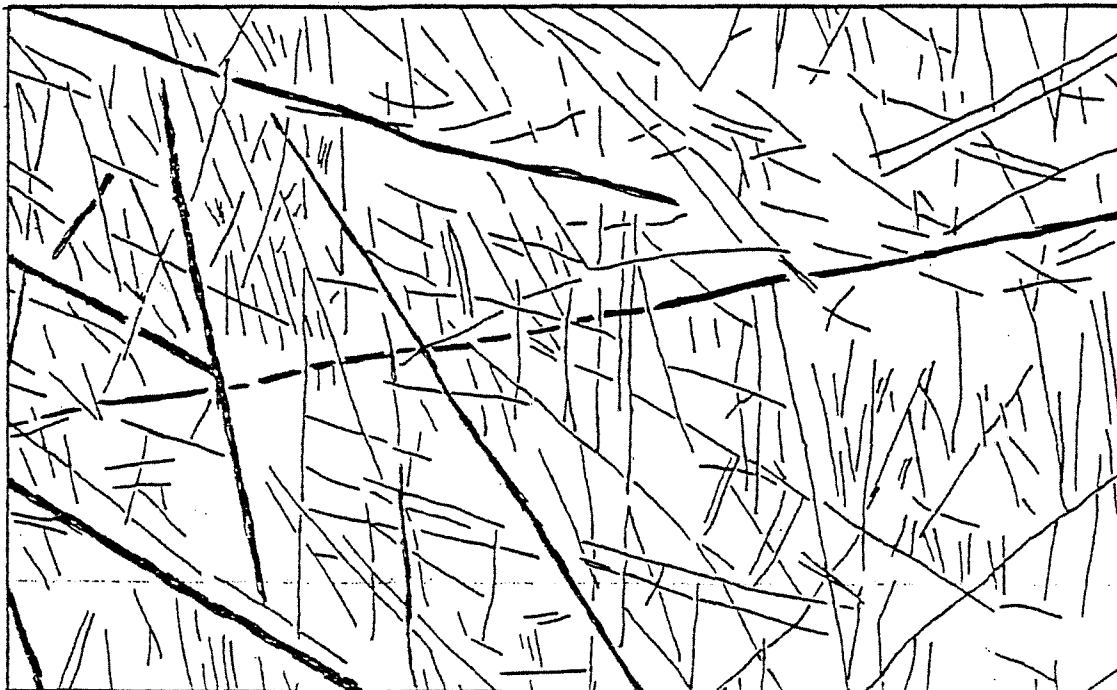
Stratigraphic section, McQuade Road at Sucker River;
SW 1/4, NW 1/4, Sec. 30, T 52 N, R 12 W and SE 1/4,
NE 1/4, Sec. 25, T 52 N, R 13 W. Textural composition
of samples: N 25-1, 32% sand, 44% silt, 24%
clay; N 25-2, 26% sand, 46% silt, 28% clay. (C. M. Moss, 1977)



Aerial oblique map of the Duluth-Superior Harbor (From Loy, W. G., 1963,
The Evolution of Bay-head Bars in Western Lake Superior, Publ. No. 10,
Great Lakes Research Division, Univ. of Michigan)



Wayside Rest, Esko Quadrangle, SW 1/4, SW 1/4, Sec. 13,
T 48 N, R 16 W. (Zarth, R. J., 1977)



Striated bedrock
from I-35 Thomson
Fm outcrop. Sketched
from photograph.
North is towards top
of figure; scale is
approx. 1.5.

(A. Norton)