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PRE–LATE WISCONSINAN TILL STRATIGRAPHY OF NORTH-CENTRAL MINNESOTA

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OF NORTH-CENTRAL MINNESOTA

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By

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ABSTRACT

Continuous cores of complete Quaternary sections at more than 60 sites in north-central Minnesota yield evidence for at least nine pre-late Wisconsinan tills. Found only in the subsurface, they are of both northwest and northeast provenance. The oldest till—the Mulligan Lake of northeast provenance—does not have a recognized counterpart to the south. Tills of northwest provenance—Wirt Lake, Bigfork, Eagle Bend, Funkley, and Browerville—are correlated with tills recognized earlier in central Minnesota. The younger northeast-provenance tills—Shooks, First Red, and Saum—also are correlated with till units recognized in central Minnesota. The subsurface record indicates alternating northeastern and northwestern advances during each major glaciation in north-central Minnesota. The distinct couplets of northeast- and northwest-source tills imply shifting locations for the Labrador and Keewatin ice centers during the Pleistocene.

The Pleistocene stratigraphic sequence of Minnesota is divided into five informal "event" units based on the subsurface record. Evidence for the earliest of these—event V—is limited, but its tills are similar to tills of event X. During event W, ice carrying detritus of Rainy provenance extended from north-central Minnesota into central Minnesota. During this interval, ice carrying detritus of Winnipeg provenance moved south across and probably beyond Minnesota. During event X, ice carrying material of Superior provenance dominated flow from the Labrador center into north-central Minnesota at a time when ice carrying Rainy-provenance detritus apparently did not enter the state. Throughout event X, ice carrying Winnipeg-provenance detritus flowed southeastward into Minnesota, and probably again well south and east of the state.

Event Y was marked by a resurgence into central Minnesota of ice carrying Rainy-provenance debris, with ice carrying Winnipeg-provenance debris again flowing into the state in a more southward direction. The final event Z comprises the late Wisconsinan glaciation when Keewatin ice expanded from a direction more to the west of Minnesota (incorporating material of Riding Mountain provenance) than earlier advances of ice carrying Winnipeg-provenance material.

Sediments of event Y are probably Illinoian or older, whereas those of events X, W, and V are probably pre-Illinoian in age. The sedimentary record is evidence that the Keewatin and Labrador ice centers were both phenomena of the Laurentide ice sheet throughout the Pleistocene, although their locations probably shifted considerably through time.

INTRODUCTION

The diverse lithology of its subsurface glacial sediment and its mid-continent location indicate that the north-central Minnesota study area (Fig. 1) was repeatedly overridden by Pleistocene ice from two major centers of the Laurentide ice sheet (Fig. 2). During each major glaciation, the Labrador center sent ice into Minnesota from the northeast, and the Keewatin center from the northwest. Thick, complexly interlayered pre-late Wisconsinan glacial deposits are distributed south and west of the major Precambrian outcrop area of northeastern Minnesota as demonstrated by drift thickness mapping done by Olsen and Mossler (1982a).

The pre-late Wisconsinan glacial ice that advanced into north-central Minnesota from the Keewatin center incorporated detritus of Winnipeg provenance (Martin and others, 1989; Fig. 3). These sediments generally lack the characteristic shale fragments [derived from the Pierre Shale of Cretaceous age, which subcrops west of the Pembina Escarpment (Fig. 4)] that define late Wisconsinan deposits of Riding Mountain provenance (Meyer and Knaeble, 1996), such as those of the late Wisconsinan Des Moines and Koochiching lobes (Fig. 3). This difference implies that pre-late Wisconsinan Keewatin flow paths were different from the late Wisconsinan flow paths. Nevertheless, all of the Keewatin-source tills in Minnesota are characteristically rich in carbonate and commonly have a loamy to clayey texture.

The flow paths of Labrador ice moving into north-central Minnesota from the northeast seem to have varied little throughout Pleistocene time. The term Rainy provenance,

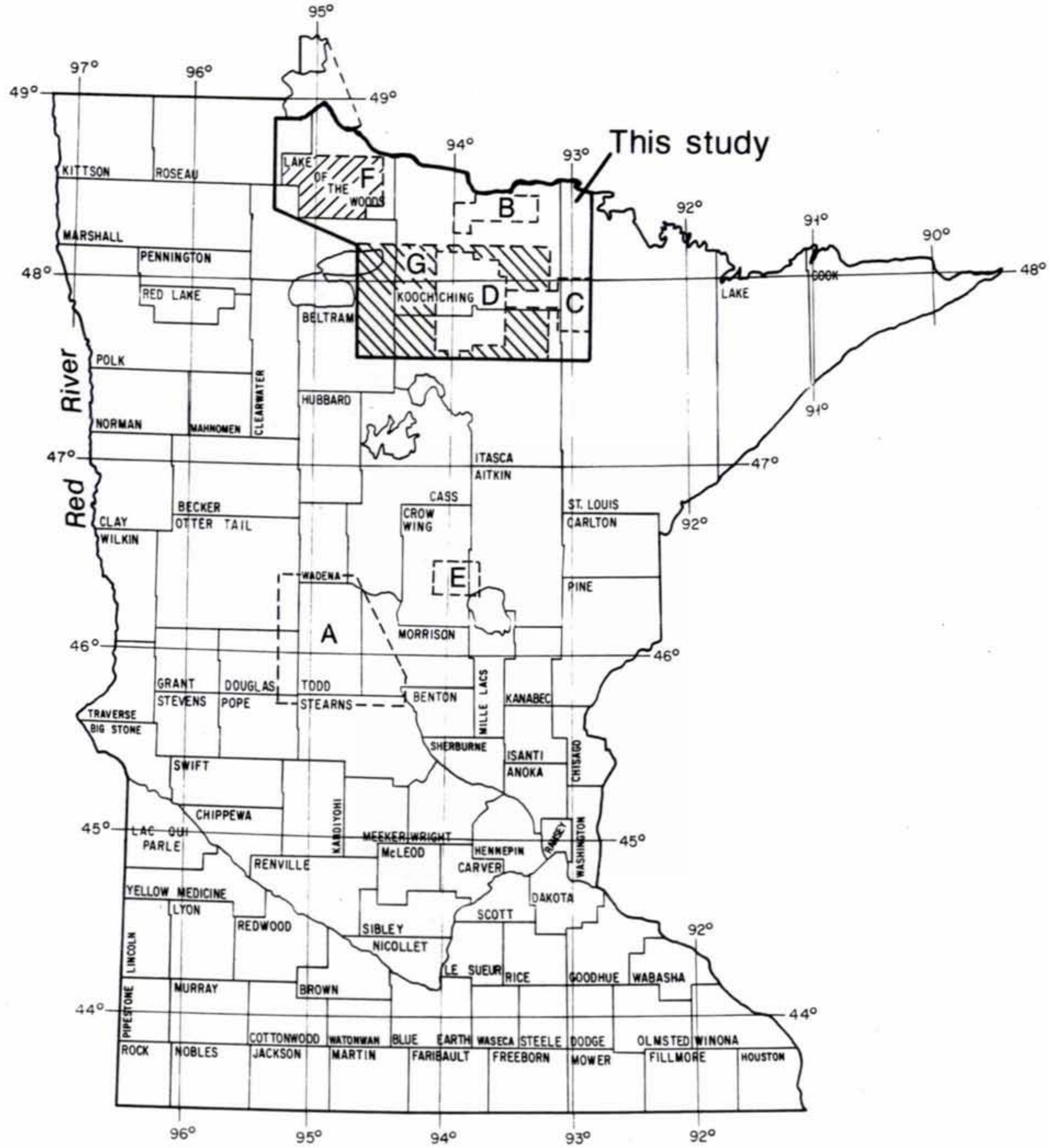


Figure 1. Location map of this and earlier studies: A, Todd County area (Meyer, 1986); B, Littlefork and C, Orr areas (Martin and others, 1988); D, Effie and E, Ironton areas (Martin and others, 1989); F, Lake of the Woods area (Martin and others, 1991); and G, "Koochibel" area [centered on Beltrami and Koochiching Counties] (Boerboom and others, 1989; Meyer, 1993), includes area D and part of C. Stearns County and Area A together are referred to as central Minnesota in the text.

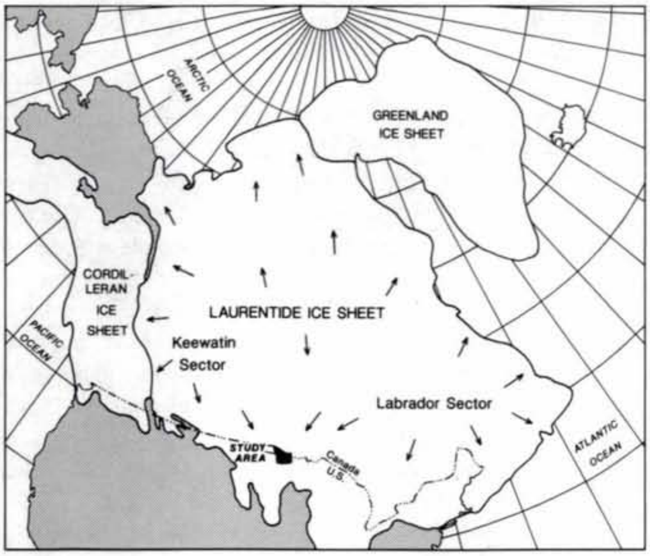


Figure 2. Approximate extent of main ice sheets during the late Wisconsinan glaciation; arrows indicate probable directions of ice flow at the glacial maximum (modified from Fulton, 1989).

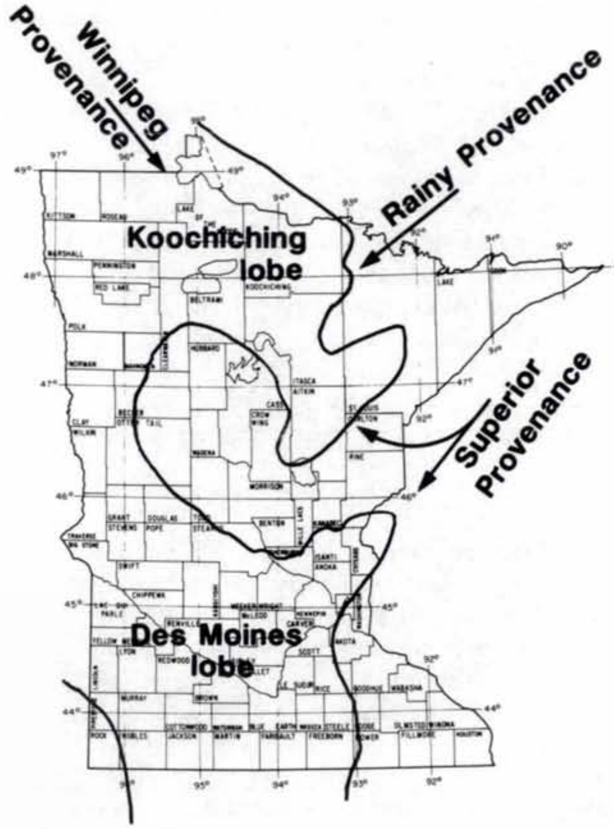


Figure 3. Generalized flow direction of ice carrying Winnipeg, Rainy, and Superior provenance detritus into Minnesota, and approximate maximum extent of the late Wisconsinan Koochiching and Des Moines lobes.

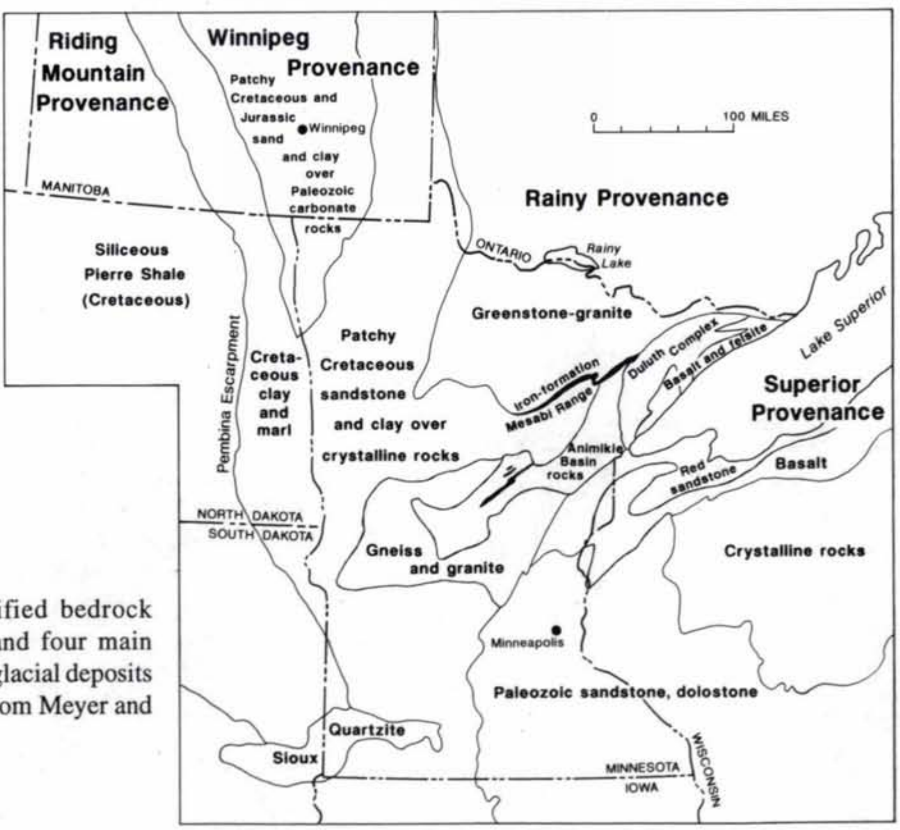


Figure 4. Simplified bedrock geologic map and four main provenances of glacial deposits in Minnesota (from Meyer and Knaeble, 1996).

from the broad area surrounding Rainy Lake (Elftman, 1898; Fig. 4), is therefore used to indicate the origin of northeastern-source glacial deposits of both late Wisconsinan (Rainy lobe) and pre-late Wisconsinan age. "Old" Rainy is a shorthand term used in this paper for Rainy-provenance sediment of pre-late Wisconsinan age. Ice from the Labrador center also moved into north-central Minnesota from the southeast via the Lake Superior basin, laying down distinctive red deposits containing Keweenawan rocks. Across central Minnesota, northeast-source ice advances preceded and alternated with northwest-source ice advances (Meyer, 1986). In north-central Minnesota, at least five pre-late Wisconsinan northwest-source tills are interbedded with four northeast-source tills (Fig. 5). All but the oldest of these correlate with till units first recognized in central Minnesota (Meyer, 1986).

PREVIOUS WORK

Winter and others (1973) mapped and described the Quaternary geology in the vicinity of the Mesabi iron range (Fig. 4), just to the southeast of the study area (Fig. 1). Their work was based primarily on the study of exposures in the many open-pit mines. They recognized an oxidized "bouldery" till that is probably an Old Rainy till, as it underlies

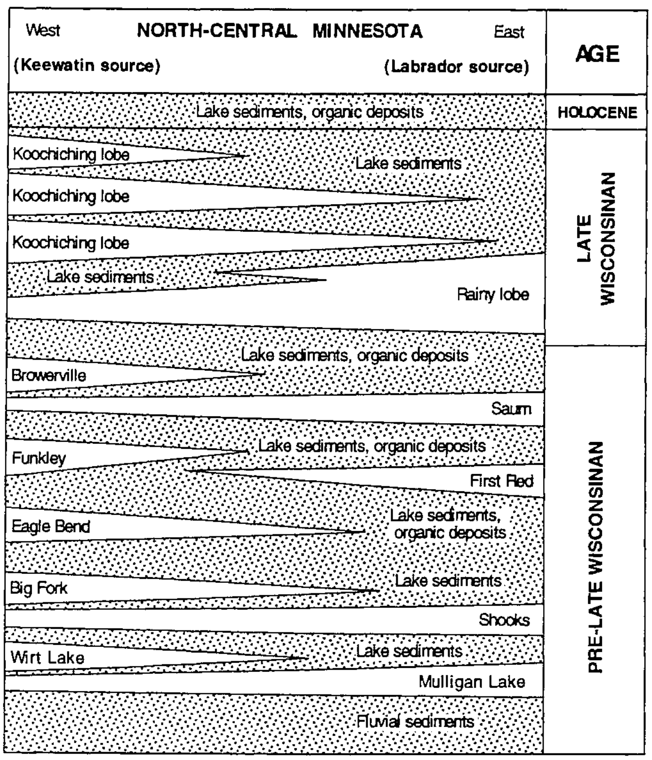


Figure 5. Time-distance diagram showing relative timing and extent of ice advances which deposited each till in north-central Minnesota. No scale is implied.

unoxidized "bouldery" (Rainy lobe) till. "Basal" tills recognized below the bouldery tills have uncertain stratigraphic relationships but probably are of both Winnipeg and Rainy provenance. University of North Dakota graduate students (Harris, 1975; Sackreiter, 1975) recognized two Winnipeg provenance tills in deep auger holes drilled southwest of the study area in southern Clearwater County (Fig. 1). Other work on the pre-late Wisconsinan subsurface till stratigraphy of north-central Minnesota did not commence until the late 1980s with two deep-coring projects of the Minnesota Department of Natural Resources, Division of Minerals (MDNR-Minerals): a 23-hole program in the Effie area (Fig. 1) of southern Koochiching and northern Itasca Counties (Martin and others, 1989) and a 19-hole program in Lake of the Woods County (Martin and others, 1991). An earlier coring project in the Littlefork and Orr areas (Martin and others, 1988) had encountered probable Old Rainy till in 2 of 19 holes, but little could be done in the way of stratigraphic analysis until other multiple-till sequences were encountered to the west and south. These projects introduced the rotasonic coring method to Minnesota stratigraphic studies. Resonant vibrations and limited rotation produce minimum sample compaction or disturbance. Representative 3.5-inch (9-cm) diameter cores of clay to sand to boulders can be obtained (Averill and others, 1986). Ontario Geological Survey workers carried out an extensive subsurface sampling program about this time across the International Boundary from Rainy River to Fort Frances (Bajc, 1991). They encountered pre-late Wisconsinan sediment in only a few locations.

Logs and sample cuttings of Quaternary sediment collected during bedrock core drilling by the Minnesota Geological Survey (MGS) in the Lake of the Woods area (Mills and others, 1987) and in parts of Koochiching, Itasca, and Beltrami Counties (Boerboom and others, 1989) were useful in filling gaps in the Quaternary sequence between core holes. Three of these rotary holes in Beltrami County, which apparently intersected multiple tills, were redrilled by rotasonic coring in 1992 as part of a Quaternary mapping and stratigraphy project supported by the Minerals Diversification program; all nine pre-late Wisconsinan tills described in this report were found (Fig. 6) in these holes. The project also provided the opportunity to sample in some detail till in core taken in the MDNR-Minerals Effie area study. Map M-76 (Meyer, 1993) included a brief summary of initial findings of this study. The present report seeks to integrate these results with those of the Lake of the Woods study (Martin and others, 1991) and to further correlate tills recognized in north-central Minnesota with those previously recognized in central Minnesota (Meyer, 1986).

METHODS

No outcrops of pre-late Wisconsinan till were found in the study area; this report relies entirely on the analysis of subsurface materials. Cores drilled during the 1992 project in Beltrami County were logged as in previous MDNR-Minerals programs, noting texture, Munsell color, reaction to hydrochloric acid, consistency, pebble abundance and type, presence of organic constituents, nature of contacts, and sedimentary structures. Till cored in these three holes, as well as 25 other holes from southern Koochiching and northern Itasca Counties, was sampled at intervals of 5 feet (1.5 m) or less. At least one pre-late Wisconsinan till was recognized in 18 of the 28 cores (Fig. 7; Appendix A). Particle-size analysis for 188 samples from these older tills was carried out, along with 126 grain counts (Table 1; Appendix B). The technique for counting 1- to 2-mm sand grains followed that described by Meyer (1986), except that monomineralic quartz was separated from other grains in the granite category. Clay mineralogy for 28 of these samples was determined by X-ray diffraction at the Soil Science Department of the University of Minnesota, St. Paul (Table 2). Pollen in five samples of bedded sediment was analyzed at the Archaeometry Laboratory of the University of Minnesota, Duluth (Huber, 1993).

In Lake of the Woods County pre-late Wisconsinan till units were encountered at 11 sites. Particle-size analysis and grain-count data were obtained for only 32 samples, and the clay mineralogy was determined for only eight samples (Table 2). Bulk chemical attributes of the matrix of the tills in this area determined by the MDNR-Minerals (Martin and others, 1991) provided an additional tool for differentiating the tills.

TILL UNITS

Pre-late Wisconsinan sediment generally increases in thickness and complexity to the west and south across the study area (Fig. 1). The Quaternary section in the eastern and northern part of the study area is dominated by late Wisconsinan deposits—primarily till and lake sediment of the northwest-source Koochiching lobe—deposited over a generally thin veneer of Rainy-lobe sediment (Martin and others, 1988, 1989). Multiple older tills are present only toward the edge of the area (Fig. 8), and individual tills, unlike those in central Minnesota, lack continuity. Evidently erosional processes dominated depositional processes throughout the Pleistocene over most of the study area. It is possible to recognize and differentiate the commonly thin and widely scattered pre-late Wisconsinan tills of north-central Minnesota only because of the availability of high-quality, continuous rotasonic cores.

Rainy-provenance sediment is characterized by an abundant assemblage of Archean rock clasts incorporated during ice advances across the greenstone-granite terrane of the Canadian Shield (Fig. 4). Rainy till is gray to greenish gray in its typically unoxidized state. In a few places the upper part of buried Old Rainy deposits is oxidized pale brown to yellow brown. In other places where an oxidized zone is absent, Old Rainy till can be distinguished from overlying Rainy lobe till by its greater compactness, somewhat higher average carbonate and clay content, and lower potassium content in the clay fraction (Martin and others, 1991). Although the carbonate content in both Rainy lobe and Old Rainy deposits increases to the west and south across the study area, the calcareous Old Rainy tills can be distinguished from interbedded Winnipeg tills by their sandy texture (Fig. 9), greenish-gray color, geochemical attributes, and low clay-mineral content (Table 2).

Winnipeg-provenance sediment deposited during at least five separate ice advances can be recognized in the study area (Fig. 5). Tills of the first two and the last advances—Wirt Lake, Bigfork, and Browerville—contain only moderate amounts of carbonate, presumably because of the flow path of the ice. It may be significant that a pre-late Wisconsinan, clayey, low-carbonate till of northwest source has been recognized in northwestern Wisconsin (Johnson, 1986)—far down-ice but along a reasonable flow path through north-central Minnesota. Calcareous, loamy, pre-late Wisconsinan till, which contains shale interpreted to have been derived from Cretaceous strata in Manitoba, is recognized even farther to the east in central Wisconsin (Attig and Muldoon, 1989). The generally high clay content of Winnipeg-provenance till probably reflects incorporation of Cretaceous marine and nonmarine (reworked saprolith) sediment by ice moving across southeastern Manitoba (Fig. 4).

Mulligan Lake Till

The oldest till described in this study is informally named after a small lake near hole OB-517 (Fig. 10), where the thickest (83 feet or about 25 m) massive section of this or any other pre-late Wisconsinan till was encountered. In this hole and in two (OB-320, KR-73) other holes, this Old Rainy till overlies Precambrian bedrock or saprolith. In contrast, in OB-520 this till is underlain by sand and is interbedded both with sand and gravel and with fine-grained lacustrine sediment. In OB-321 this till is interbedded with sand in its lower part and overlies oxidized sand, the base of which was not penetrated. The oxidized sand has a pebble content similar to that of the overlying Mulligan Lake till. Thus the sand could be a proglacial fluvial deposit laid down by meltwater emanating from ice that later buried it with Mulligan Lake till; alternatively, the oxidized sand could be a deposit related to an even older advance. The thickest section of sediment assigned to any pre-late Wisconsinan glaciation was also related to the Mulligan Lake advance. In OB-325 more than 161 feet (49 m) of mostly sand and gravel was penetrated without reaching the base. These sand and

Table 1. Till data summary

Till	Thickness Avg. (ft)	Thickness Range (ft)	Number holes w/data	Gravel (wt % sample)	Matrix texture (%≤ 2mm fraction) Sand	Silt	Clay	1-2 mm grains (% of sand)	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
Koochibel Area											
Browerville	24	3-59.5	5	6	37	41	22	7	75	25	1
Saum	10	3-25.	6	18	58	28	14	12	90	10	T
Funkley	38	24-51.5	2	5	40	40	21	7	54	46	1
First Red	3	-	1	5	51	31	19	6	83	17	1
Eagle Bend	31	2.5-47	3	4	22	38	40	7	55	45	1
Bigfork	10	6-14.	2	5	39	35	26	10	84	12	4
Shooks	18	4-35.5	9	9	50	30	20	10	92	8	T
Wirt Lake	13	11-15.5	2	7	42	34	24	12	82	12	7
Mulligan Lk	16	3.5-34	3	9	62	27	11	12	93	7	T
Lake of the Woods Area											
Browerville	11	6-14.5	3	4	42	33	25	10	79	21	T
Saum	27	19-36.5	3	8	64	24	12	11	92	8	0
Funkley	15	9.5-19.5	2	8	44	37	20	10	61	39	T
Eagle Bend	11	4.5-28.5	4	4	31	36	33	10	50	48	2
Bigfork	15	6-23.5	4	3	36	33	31	9	84	15	1
Shooks	37	14-79.5	3	6	53	28	19	10	89	11	T
Wirt Lake	11	9.5-12	2	6	44	27	29	9	86	13	1
Mulligan Lk	54	24-83.5	2	8	59	26	15	11	81	19	T
Two Areas Combined											
Browerville	18	3-59.5	8	5	39	38	23	8	76	23	1
Saum	16	3-36.5	9	15	60	27	13	11	90	10	T
Funkley	26	9.5-51.5	4	6	42	39	20	8	57	42	1
First Red	3	-	1	5	51	31	19	6	83	17	1
Eagle Bend	19	2.5-47	7	4	27	37	36	9	55	44	1
Bigfork	14	6-23.5	6	4	37	34	29	9	84	14	2
Shooks	23	4-79.5	12	9	50	30	20	10	91	9	T
Wirt Lake	12	9.5-15.5	4	7	43	30	27	11	84	12	4
Mulligan Lk	31	3.5-83.5	5	9	61	27	12	10	88	12	T

Under texture, gravel is percentage of total sample weight, whereas the sand, silt, and clay values are given as percentage of the 2-mm and smaller fraction. Very coarse sand (1- to 2-mm) lithology is divided between total Precambrian, Paleozoic, and total Cretaceous, and presented as a percentage of grains counted after the "unknown" category was excluded. The "unknown" value is a percentage of the total sample.

Table 1. Continued

Total Unknown Grains	1-2 mm size clasts: Precambrian rock types: Granitics	Quartz	Darks	Reds & Others	Cretaceous rock types: Limestone	Shell fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others
Koochibel Area											
1	74	10	15	1	40	16	42	1	1	1	0
1	73	8	18	1	17	0	33	17	16	17	0
1	75	9	15	2	0	0	73	0	20	7	0
3	46	16	19	20	50	0	0	0	50	0	0
1	69	17	14	2	26	21	0	35	0	13	5
3	65	26	8	1	46	5	1	44	0	4	0
2	72	16	11	1	13	0	31	0	31	25	0
3	69	24	7	1	57	7	7	23	2	5	0
2	69	21	8	2	0	0	0	0	97	3	0
Lake of the Woods Area											
1	61	25	13	1	22	0	0	0	0	0	78
3	49	36	14	1	-	-	-	-	-	-	-
1	64	20	16	1	0	0	0	0	0	100	0
1	48	33	18	1	58	0	0	6	0	19	17
5	42	42	14	2	27	0	0	0	0	14	59
2	49	37	13	1	17	0	0	0	0	50	33
2	56	32	11	1	16	0	0	0	0	0	84
1	55	28	17	1	50	0	0	0	0	0	50
Two Areas Combined											
1	69	16	14	1	31	8	21	T	T	1	39
2	65	17	17	1	17	0	33	17	16	17	0
1	70	14	15	1	0	0	37	0	10	54	0
3	46	16	19	20	50	0	0	0	50	0	0
1	59	25	15	1	52	4	0	12	0	18	14
4	50	37	12	1	33	2	1	15	0	11	39
2	66	21	12	1	14	0	18	0	18	36	14
3	62	28	9	1	37	4	4	11	1	2	42
2	63	24	12	1	25	0	0	0	49	2	25

The Precambrian category is divided into granitics, quartz, darks, and reds and others subgroups; values given are a percentage of total Precambrian grains counted. The total Cretaceous category is divided into limestone, shell fragments, gray shale, speckled shale, lignite, pyrite, and others subgroups; values given are a percentage of total Cretaceous grains counted. Most of the grains placed in the others Cretaceous subgroup in the Lake of the Woods area are quartz sandstone; several of these grains were also noted in the Koochibel area, but were placed in the "unknown" category.
T (trace) represents a value of less than 0.5 percent.

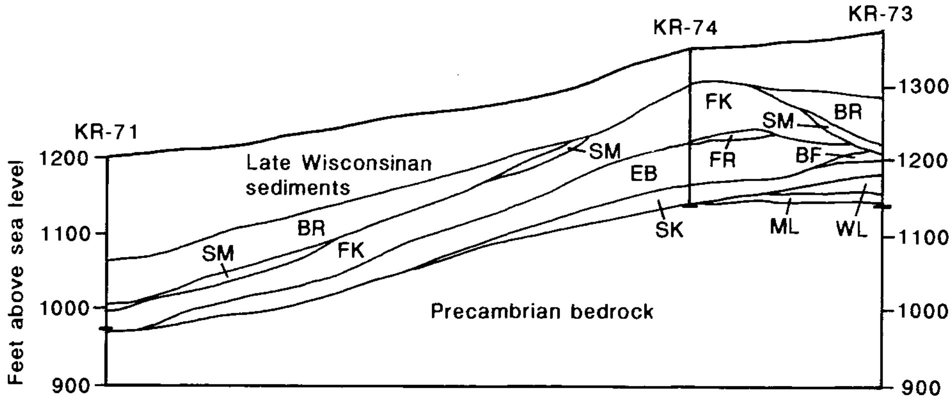


Figure 6. Cross section connecting till in three core holes drilled in Beltrami County. See Figure 7 for location. BR, Browerville; SM, Saum; FK, Funkley; FR, First Red; EB, Eagle Bend; BF, Bigfork; SK, Shooks; WL, Wirt Lake; and ML, Mulligan Lake till.

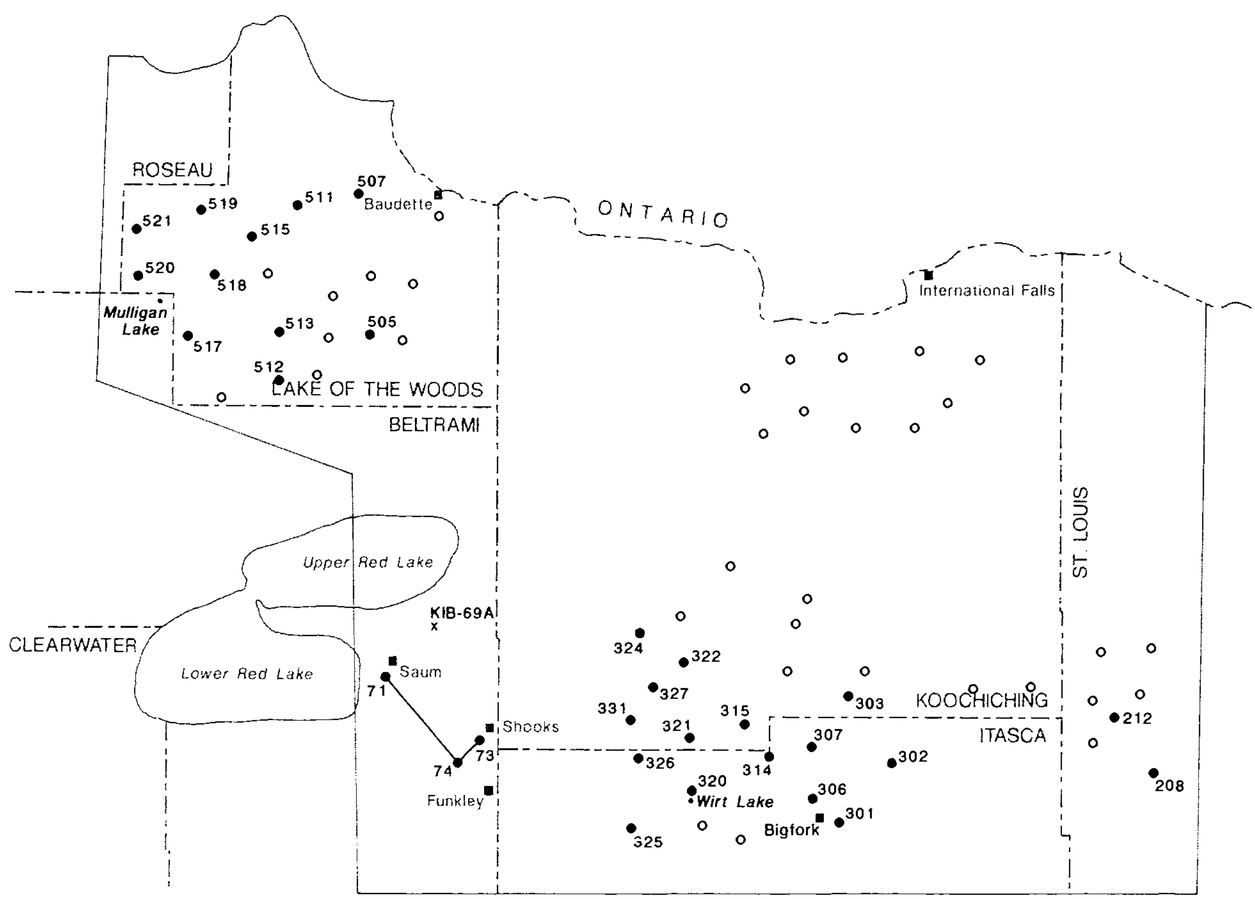


Figure 7. Locations of all rotasonic core holes in north-central Minnesota. Numbered and closed circles are holes that intersect pre-late Wisconsinan till. The position of the cross section on Figure 6 is shown, connecting holes KR-71, 74, and 73. A 2.5-inch (6.5-cm) diameter core of till from 138.5 to 146.5 feet in test hole KIB-69A (Appendix B) was taken during a bedrock coring program (Boerboom and others, 1989).

Table 2. Clay mineralogy summary
[E, expansible clays; M/I, mica/illite; K, kaolinite]

Till	Number samples	Mean scaled peak counts E	M/I	K	Mean total counts	Mean % of total count E	M/I	K
Koochibel area								
Browerville	4	205	46	178	429	48	11	41
Saum	3	155	45	140	340	46	13	41
Funkley	2	225	55	105	385	59	14	27
Eagle Bend	3	483	105	312	900	54	11	35
Bigfork	2	728	86	388	1202	61	7	32
Shooks	8	221	44	377	642	34	7	59
Wirt Lake	2	550	124	432	1106	50	11	39
Mulligan Lake	3	128	24	230	382	34	6	60
Basal Mulligan Lk	1	480	48	256	784	61	6	33
Lake of the Woods area*								
Browerville	2	292	255	552	1099	27	23	50
Saum	1	210	175	240	625	34	28	38
Eagle Bend	2	300	195	358	853	35	23	42
Bigfork	1	600	555	1920	3075	20	18	62
Shooks	1	75	140	330	545	14	26	60
Mulligan Lake	1	45	120	140	305	15	39	46

*Samples from Lake of the Woods area run by Hanna Research Center of Nashwauk, Minnesota.

gravel beds in the lowest part of the Mulligan Lake section, and at the lowest elevations, imply that meltwater was able to flow from the immediate area of the advancing Mulligan Lake ice front without being ponded behind the continental bedrock divide, as was Lake Agassiz in late Wisconsinan time. Meltwater may have flowed southwest and then northwest to the Red River Valley, following bedrock topographic lows (Olsen and Mossler, 1982b), eventually flowing between Keewatin and Labrador ice to Hudson Bay. The deep parts of bedrock valleys were thus filled mostly with fluvial sediment and till, rather than with lake sediment. Alternatively, the sand and gravel may have been concentrated in the bedrock valleys by turbidity currents at the base of a proglacial lake.

Lake clay below the younger Shooks till in OB-507 (Fig. 10) is light brown (7.5YR 6/3) and noncalcareous at depth, implying probable influx of meltwater carrying Superior-provenance detritus into the lake; a similar influx was noted in lake clay above late Wisconsinan Rainy lobe till in a number of cores from the area (Martin and others, 1991). This influx possibly indicates that ice carrying Superior-provenance detritus was blocking drainage of the lake to the south. This blockage may not have existed during the earlier Mulligan Lake advance. Possibly equivalent to the brown clay in OB-507 are the brownish (7.5YR 5/4) clay laminae within a 1-cm-thick bed of greenish-gray silt in 0B-505. The lake sediment in OB-505 overlies possible Mulligan Lake till.

The limited available data for the Mulligan Lake till show, as with other Old Rainy tills, an increase in carbonate content to the west (Fig. 10). Clay content also increases somewhat to the west in the Lake of the Woods area (Table 1). The lowest few feet (1 m) of Mulligan Lake till in hole OB-320 (Fig. 10; Appendix B) is more loamy in texture and has more carbonate. Accordingly this interval was assigned in earlier reports (Martin and others, 1989; Meyer, 1993) to an older ice advance that carried Winnipeg-provenance detritus. Differences in distinguishing attributes are not great,

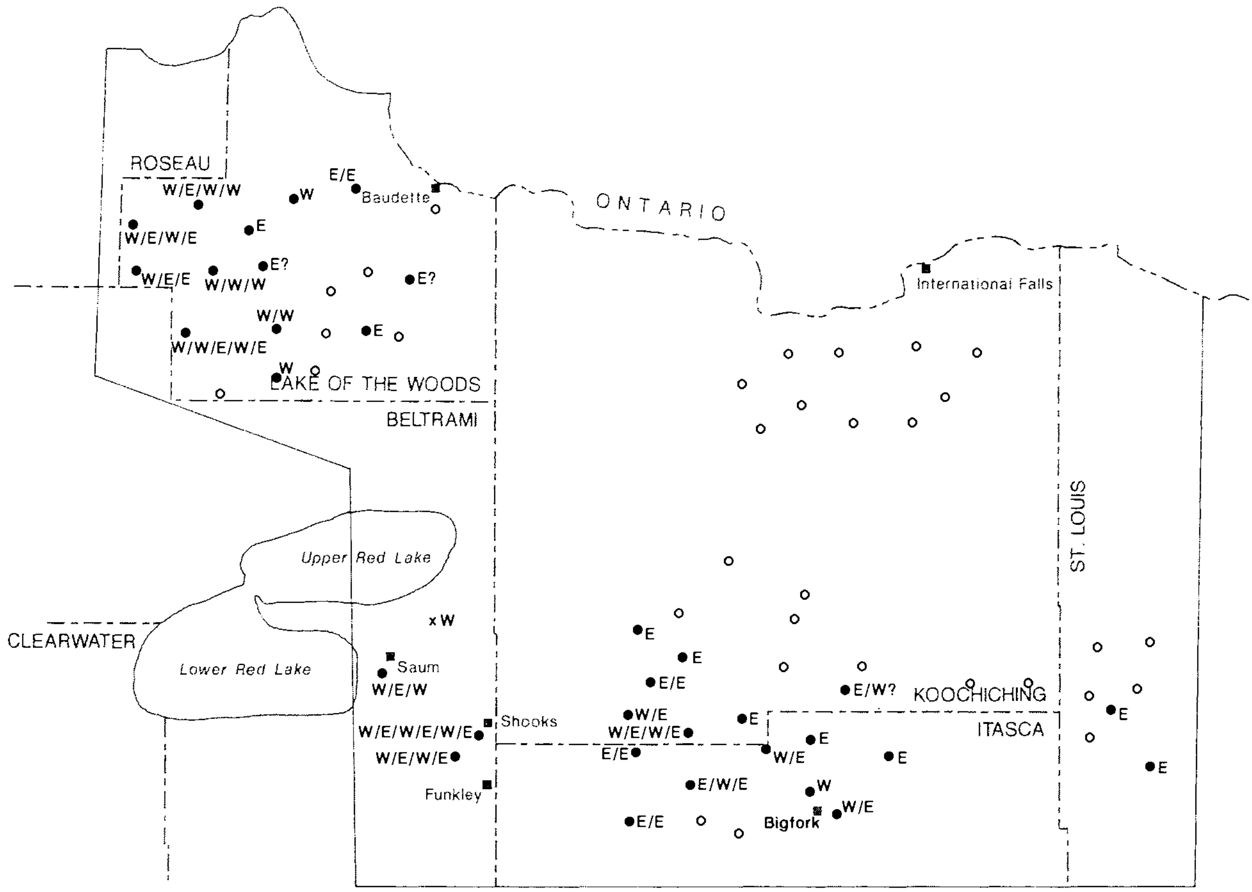


Figure 8. Sites where evidence of provenance of individual pre-late Wisconsinan tills was identified in cores. E, northeast; W, northwest provenance. Queried holes in the northwest may not have intersected pre-late Wisconsinan till, and are not indicated on Figure 7.

however, so the lowest meter of glacial sediment in OB-320 is now considered to be a mixed zone at the base of Mulligan Lake till. Although the mixed zone's carbonate content is not much greater than that of typical Mulligan Lake till, its clay-mineral peaks (Table 2) are similar to those of the younger, Winnipeg-provenance Eagle Bend till, which is carbonate-rich. A few clasts of Keweenawan red sandstone in the mixed zone imply that Superior-provenance ice was active in Minnesota prior to the Mulligan Lake advance. A carbonate-rich Winnipeg-provenance till and a Superior-provenance till recognized in cuttings from the bottom of deep test holes in central Minnesota may be older than the Mulligan Lake till (Meyer and Knaeble, 1996). This scant evidence seems to indicate that tills older than the Mulligan Lake till are yet to be discovered in the subsurface of north-central Minnesota.

The Mulligan Lake till is gradationally overlain by the Winnipeg-provenance Wirt Lake till in OB-320 and by lake sediments that grade into the Wirt Lake till in OB-517 and KR-73. In OB-321 and OB-520 the Mulligan Lake section is topped by thick deposits of lake sediment. This implies that ice carrying Winnipeg-provenance sediment advanced into a lake between it and the retreating margin of ice carrying Rainy-provenance sediment (Figs. 5 and 11). Thin, basal, Rainy-provenance till underlying the thick, sandy to silty lake sediment in OB-326 and OB-505 also may be Mulligan Lake till.

Wirt Lake Till

The oldest recognized Winnipeg-provenance till in north-central Minnesota is informally named after a small lake near hole OB-320 (Fig. 11), in which about 11 feet (3.4 m) of loamy till grades into the underlying Mulligan Lake till. The Wirt Lake till is loam to clay loam, but its texture ranges to sandy clay loam and sandy loam (Fig. 12). In OB-320 Wirt Lake till is overlain by a second Old Rainy till, the Shooks, which incorporated lake sediment toward its base. The Wirt Lake till is also topped by an erosional surface in KR-73 and OB-517, where it is overlain by the Shooks till (Fig. 13). At both of these sites the Wirt Lake till is unoxidized; in OB-320 it is unoxidized but deeply mottled. The apparently

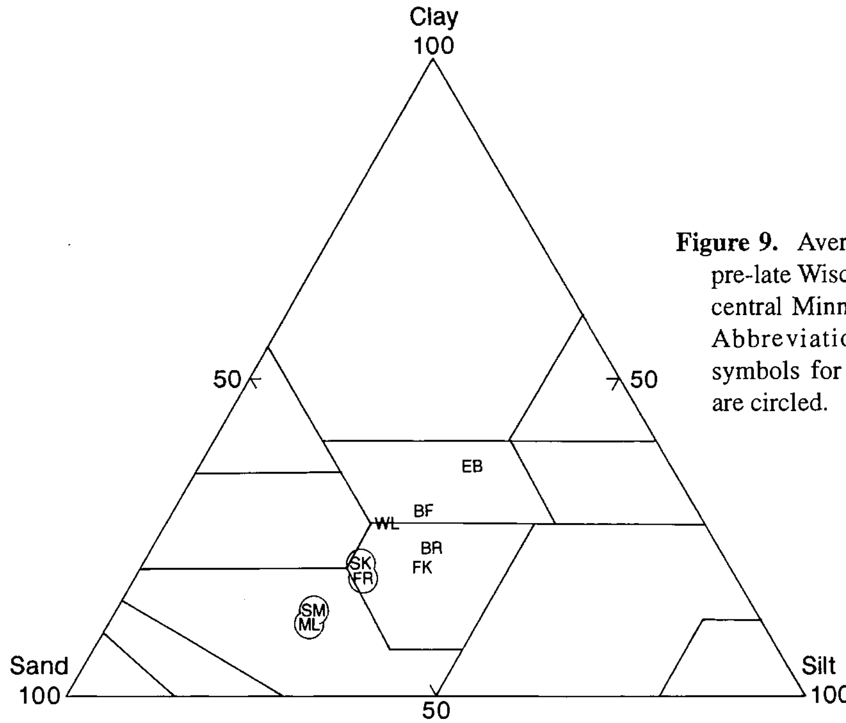


Figure 9. Average matrix texture of pre-late Wisconsinan tills of north-central Minnesota (from Table 1). Abbreviations as in Figure 6; symbols for Labrador-source tills are circled.

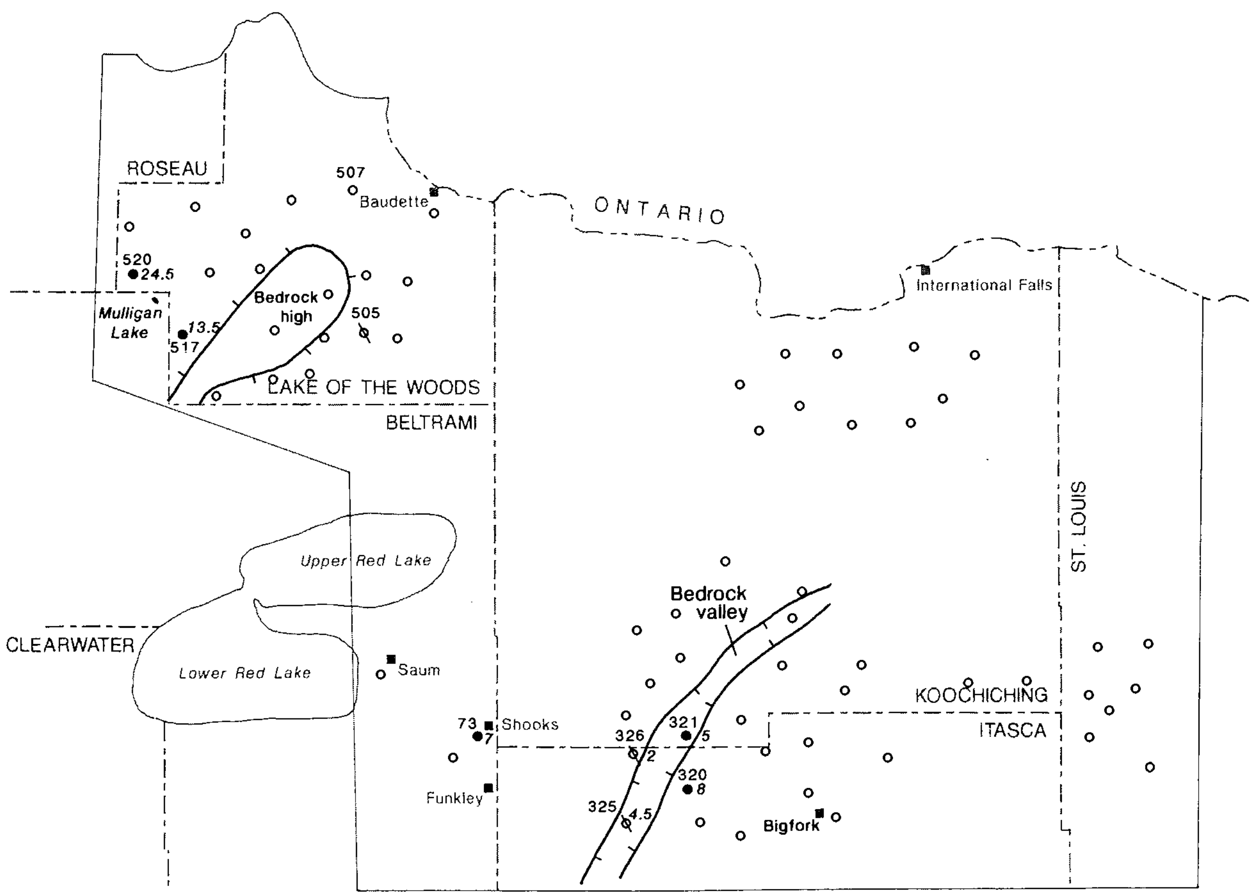


Figure 10. Sites where Mulligan Lake till (closed circles) and possible Mulligan Lake till (slashed open circles) were cored. Number on the right is average percentage Paleozoic carbonate in the 1-2-mm sand fraction. Core holes mentioned in the text are indicated by their number in this and subsequent figures.

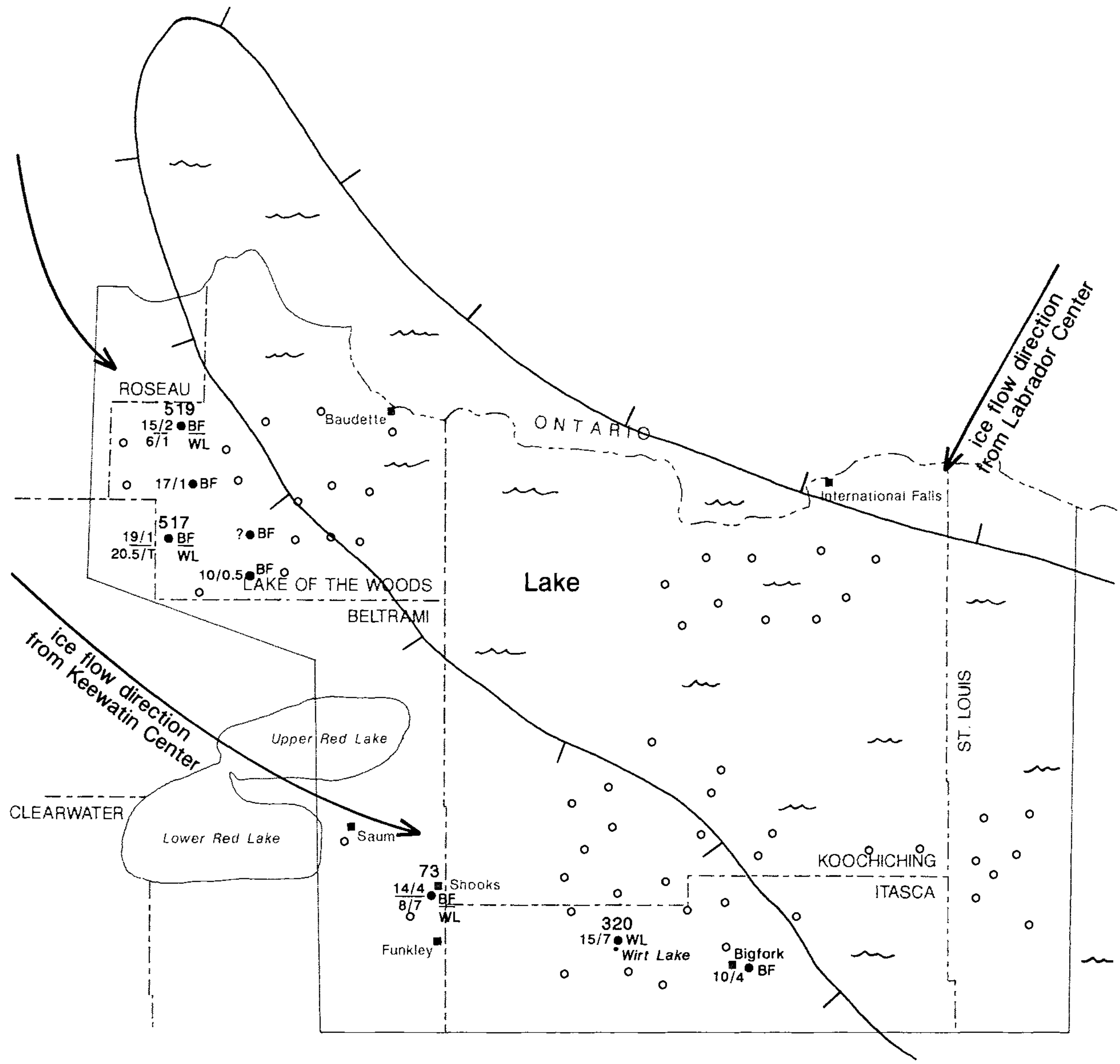


Figure 11. Sites where the Wirt Lake (WL) and Bigfork (BF) tills were cored. The left-hand number is average percent Paleozoic carbonate, and the adjacent number is average percent Cretaceous content of the 1-2-mm sand fraction. Also shown are the speculative flow directions and maximum extent of ice from the Keewatin center during deposition of both tills, with a proglacial lake and possible margin of ice from the Labrador center. (T = trace amount, ? = no data)

incorporated lake sediment in the overlying Shooks till is also mottled. In OB-519 unoxidized Bigfork till overlies oxidized dark-grayish-brown to dark-brown Wirt Lake till. The oldest named till in central Minnesota—the Winnipeg-provenance Elmdale till (Meyer, 1986; Meyer and Knaeble, 1996)—is correlated with the Wirt Lake till, because of similar stratigraphic positions and lithology and a sand fraction high in 1- to 2-mm grains (Table 1).

Ice that deposited the Wirt Lake till was clearly fronted by a lake during its advance into north-central Minnesota (Fig. 11), and evidence in OB-320 indicates that the ice probably also was fronted by a lake during its retreat. Apparently much of the clay deposited in this lake was eroded by the next glacial advance across the area and incorporated into the Shooks till.

Shooks Till

Unoxidized Rainy-provenance loam-textured till bounded above and below by similar unoxidized Winnipeg-

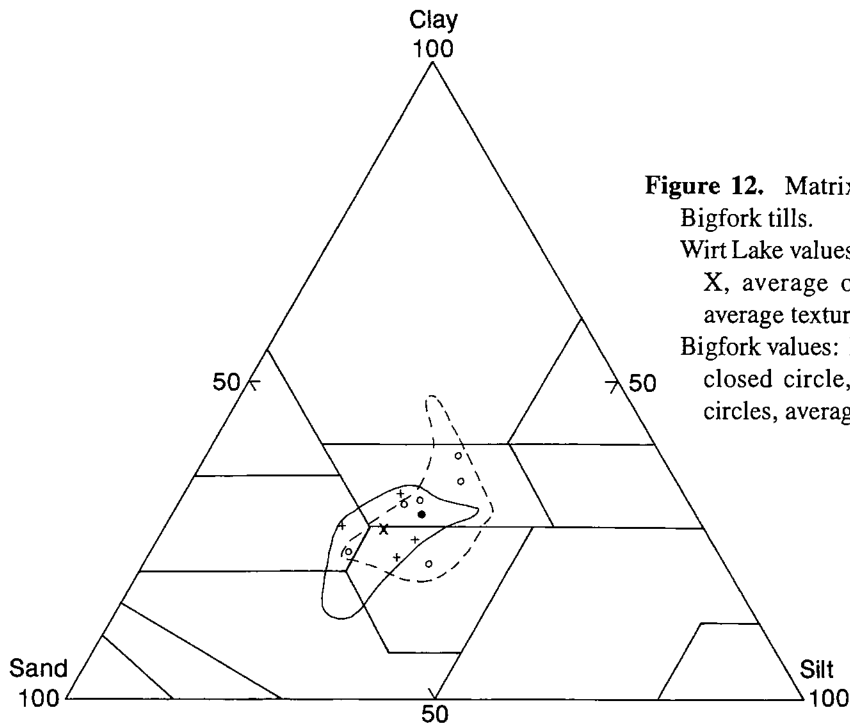


Figure 12. Matrix texture of the Wirt Lake and Bigfork tills.
Wirt Lake values: Solid envelope encloses range; X, average overall texture; plus symbols, average textures at each site.
Bigfork values: Dashed envelope encloses range; closed circle, average overall texture; open circles, average textures at each site.

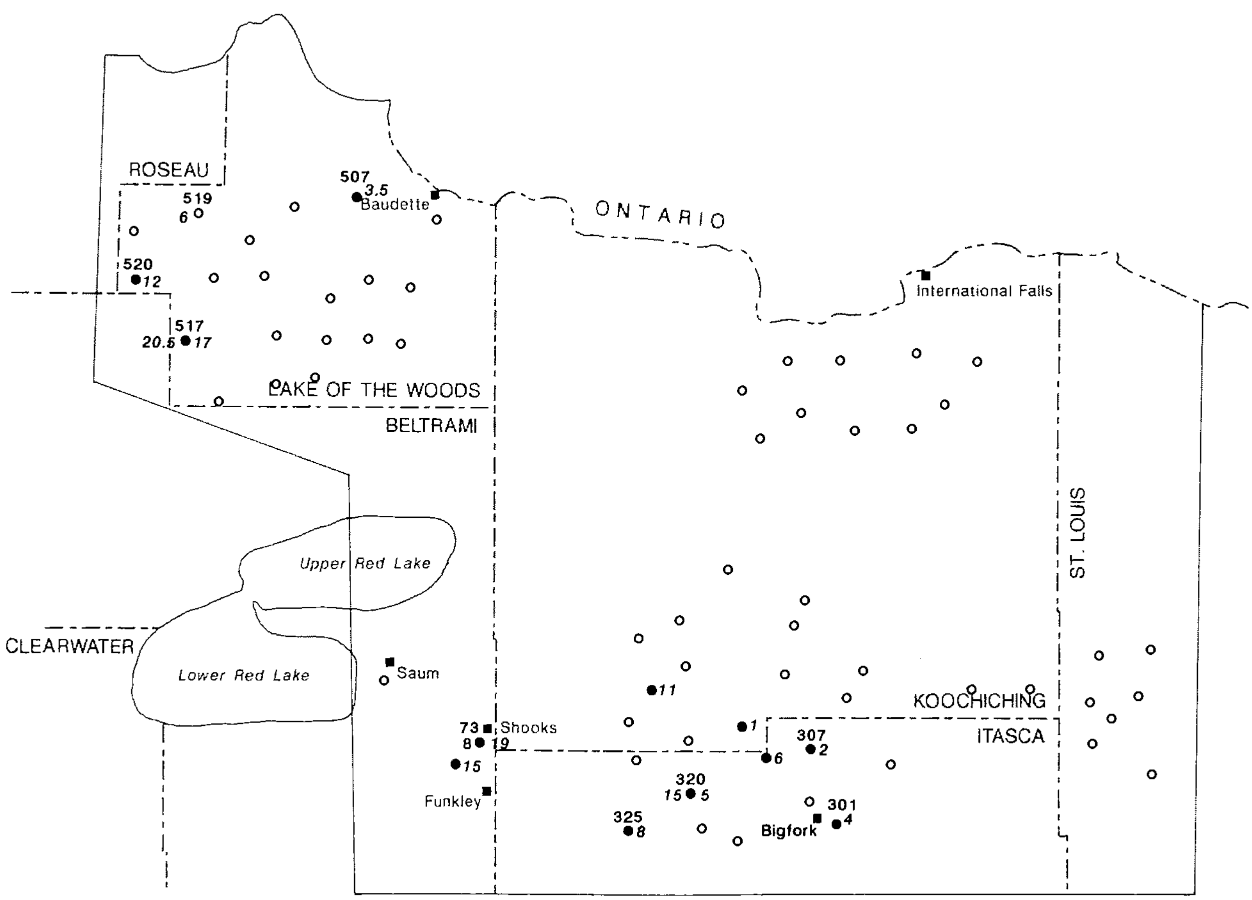


Figure 13. Sites where Shooks till was cored. Number on the right is average percent of Paleozoic carbonate content of the 1-2-mm sand fraction. At four sites—73, 320, 517, and 519—the number on the left is average Paleozoic carbonate of the underlying Wirt Lake till.

provenance tills in hole KR-73 is informally named after the nearby small town of Shooks (Fig. 13). The Shooks till is the most common pre-late Wisconsinan till in the subsurface of the Koochibel area. It mostly overlies bedrock east and north of subcropping Mulligan Lake till, and thus the Shooks advance probably was very erosive. The Shooks till differs from other Old Rainy tills by its greater clay content (Fig. 9), believed to be due to incorporation of underlying Winnipeg-provenance lake sediment, as can be observed in cores OB-307, 320, 325, and 507. Clay-mineral content is highest in the older Winnipeg-provenance tills, as shown by total counts in Table 2. The Shooks till has the highest proportion of clay minerals of any Rainy-provenance till, presumably again reflecting more incorporation of Winnipeg sediment.

Shooks till, however, ranges in texture from loam to sandy-clay loam to sandy loam. As such, its textural attributes overlap those of other Old Rainy tills (Fig. 14), and it can be identified positively only where other pre-late Wisconsinan tills are present to establish stratigraphic position. Although the Shooks till was found in the same hole as other Old Rainy tills at six sites, only in KR-73 were all three Old Rainy tills recognized (Fig. 6).

The Shooks till contains less Cretaceous material than the underlying Wirt Lake till, at least in the Koochibel area (Table 1). However, the Shooks till contains appreciable Paleozoic carbonate, generally as much (OB-517) or more (KR-73) than that observed in the underlying Wirt Lake till (Fig. 13). The carbonate must have been derived from a source other than the Wirt Lake till. That source, however, is problematic. The carbonate content in the Shooks increases to the west and south toward areas where tills of Winnipeg provenance are more abundant in the subsurface (Figs. 13 and 15). Carbonate content also increases to the west and south in the older Mulligan Lake till (Fig. 10), which overlies Precambrian rock in the few places where the basal contact was penetrated. The sediment in the basal part of the Mulligan Lake till in OB-320 was possibly derived from a carbonate-rich Winnipeg-provenance till that may be equivalent to the carbonate-rich Winnipeg-provenance till found below the Elmdale till in central Minnesota (Meyer and Knaeble, 1996). If so, the pre-Elmdale carbonate-rich till may be the source of Paleozoic carbonate in both the Mulligan Lake and Shooks tills. Clay content does appear to increase, together with Paleozoic carbonate clast content, in Mulligan Lake till, and thus supports a Winnipeg till source. However, because this correlation is not evident within the Shooks till, the bulk of its clay content was more likely derived from proglacial lake clay rather than from carbonate-rich till.

Alternatively, the source of the relatively high carbonate content in the Shooks and Mulligan Lake tills could be either unknown local outliers of Paleozoic carbonate along the east edge of the Williston basin, or long-distance transport of sediment from the Hudson Bay basin, the southwest edge of which may have been considerably closer to Minnesota than at present. Paleozoic carbonate rock slabs over 6 feet (2 m) across, found locally at the surface, lend credence to the first hypothesis. The virtual absence of marine Cretaceous detritus in the Mulligan Lake and Shooks tills supports both hypotheses, because no marine Cretaceous strata are reported between Minnesota and the Labrador ice center. On the other hand, carbonate-rich Winnipeg-provenance tills of north-central Minnesota also contain only minor amounts of Cretaceous clasts, especially at their easternmost subcrops (Fig. 16).

In central Minnesota, rotasonic drilling encountered an Old Rainy till above the Elmdale till at two sites (Meyer and Knaeble, 1996). That Old Rainy till was correlated with the Shooks till. In core hole OB-402 in the Ironton area (area E on Fig. 1), a Rainy-provenance till at or near the base of the Quaternary section is similar to the Shooks till, but unlike the Shooks till, it has some reddish streaks and Keweenawan pebbles, which indicate incorporation of older Superior-provenance sediment. The overlying Winnipeg-provenance till in this hole is similar to the Bigfork till, which overlies the Shooks till in the study area. The Bigfork-like till in OB-402 is overlain by a Superior-provenance till, which in turn is overlain by a Winnipeg-provenance till, similar to the Second Red and Eagle Bend tills overlying the Elmdale till in the Todd County area (Meyer, 1986).

The Shooks till is overlain by the next youngest till, the Bigfork till, at only three drill sites. At KR-73 and OB-301 the contact between the two tills is erosional, with unoxidized till overlying unoxidized till. At OB-517 the two tills are separated by 5 feet (1.5 m) of lake sediment. At OB-519 the Shooks till is absent and the Bigfork grades downward into lake sediment, which in turn overlies oxidized Wirt Lake till. Again it appears likely that as ice carrying Rainy-provenance sediment retreated, ice carrying Winnipeg-provenance sediment advanced, with both probably fronting the same lake (Figs. 5 and 11).

Bigfork Till

The town of Bigfork (Fig. 11) is the informal namesake for the Winnipeg-provenance till that occurs between the Shooks till below and the Eagle Bend till above. The fact that the Shooks till was found beneath the Bigfork till in only one of six holes in Lake of the Woods County, together with the fact that the Bigfork was the basal Quaternary unit in four holes, argues that the older tills were removed prior to deposition of the Bigfork till. It is likely that much of that erosion took place during glacially active periods in north-central Minnesota, especially if the terrain was as low-lying and poorly drained as it is today. Therefore I suggest that older tills below the Bigfork were largely removed by each succeeding glacial advance, and that the removal of each of

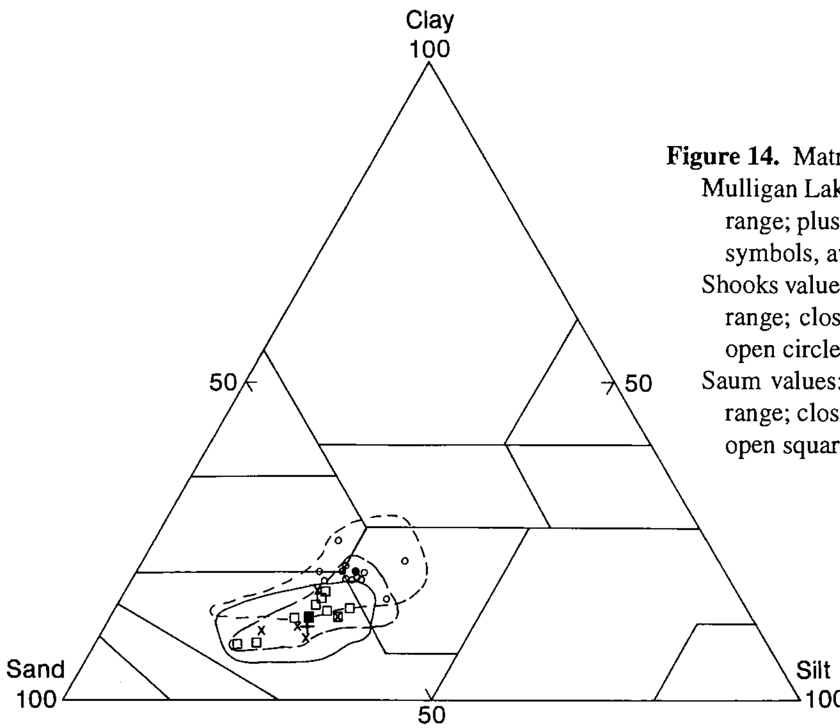


Figure 14. Matrix textures of Old Rainy tills.
Mulligan Lake values: Solid envelope encloses range; plus symbol, average overall texture; x symbols, average textures at each site.
Shooks values: Short-dashed envelope encloses range; closed circle, average overall texture; open circles, average textures at each site.
Saum values: Long-dashed envelope encloses range; closed square, average overall texture; open squares, average textures at each site.

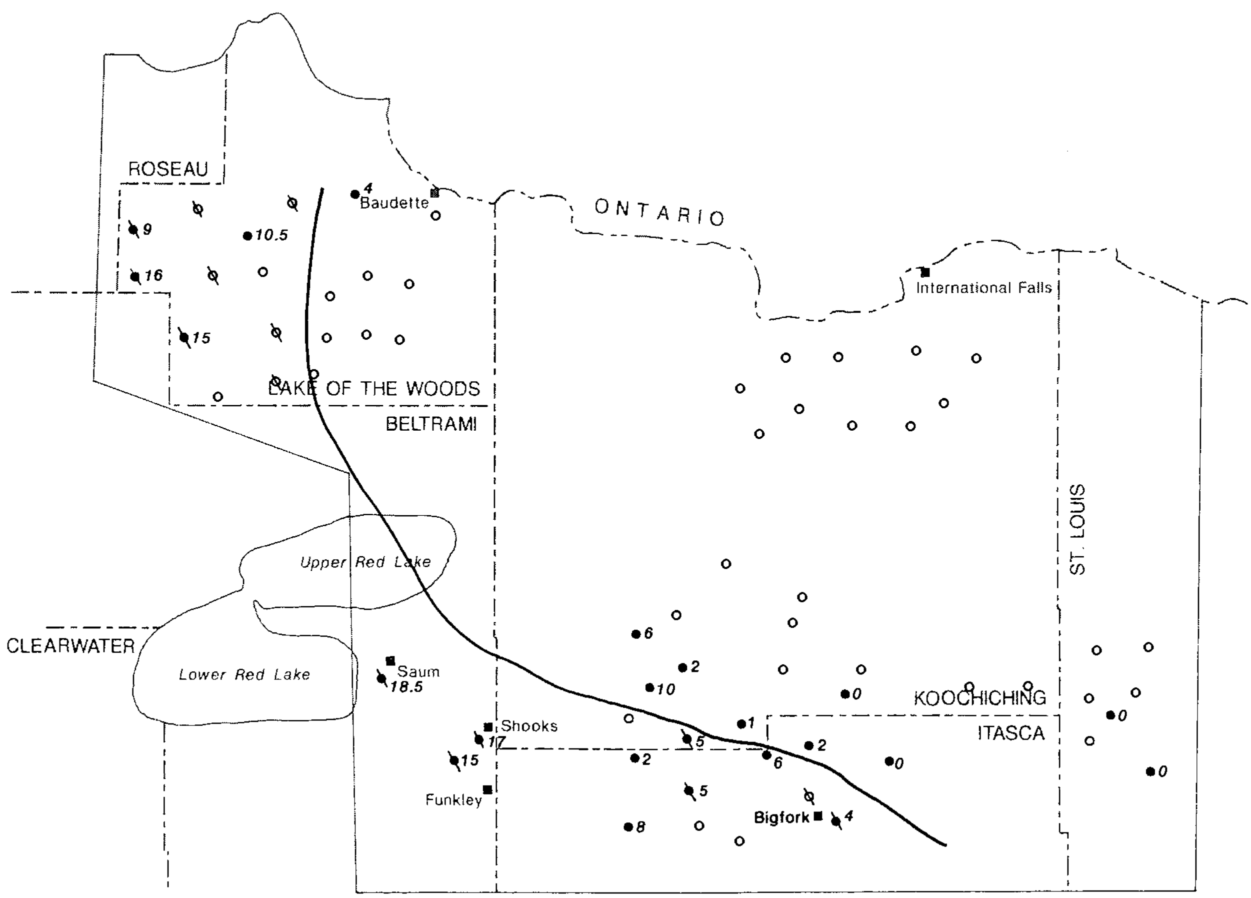


Figure 15. Location of sites, closed circles, where at least one Old Rainy till was cored. Adjacent numbers are average percent Paleozoic carbonate content of the 1-2-mm sand fraction of all Old Rainy tills cored. Slashed circles represent holes whose core included Winnipeg-provenance till older than the upper Old Rainy (Saum) till. The line across the study area is the approximate eastern extent of Winnipeg-provenance tills now present in the subsurface.

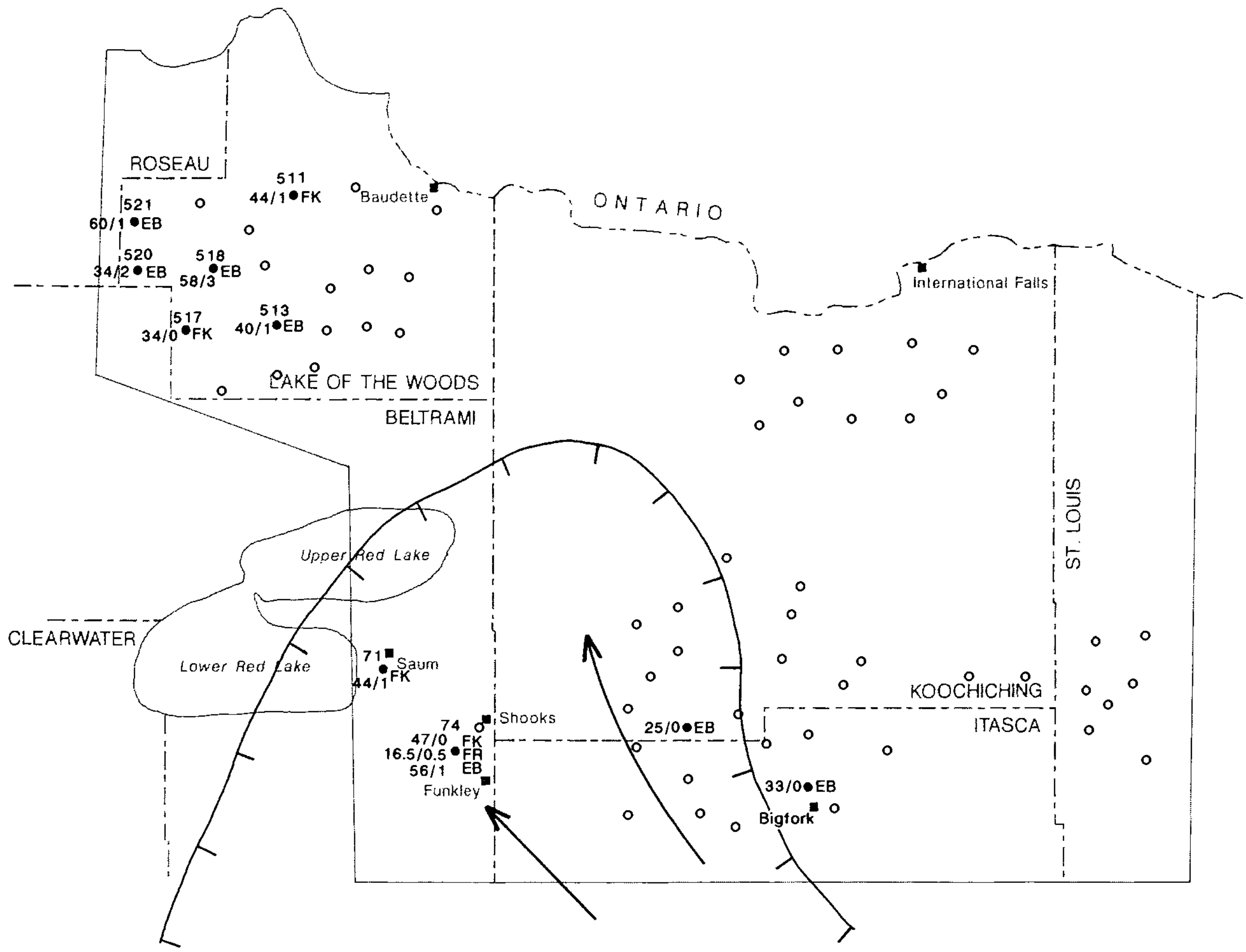
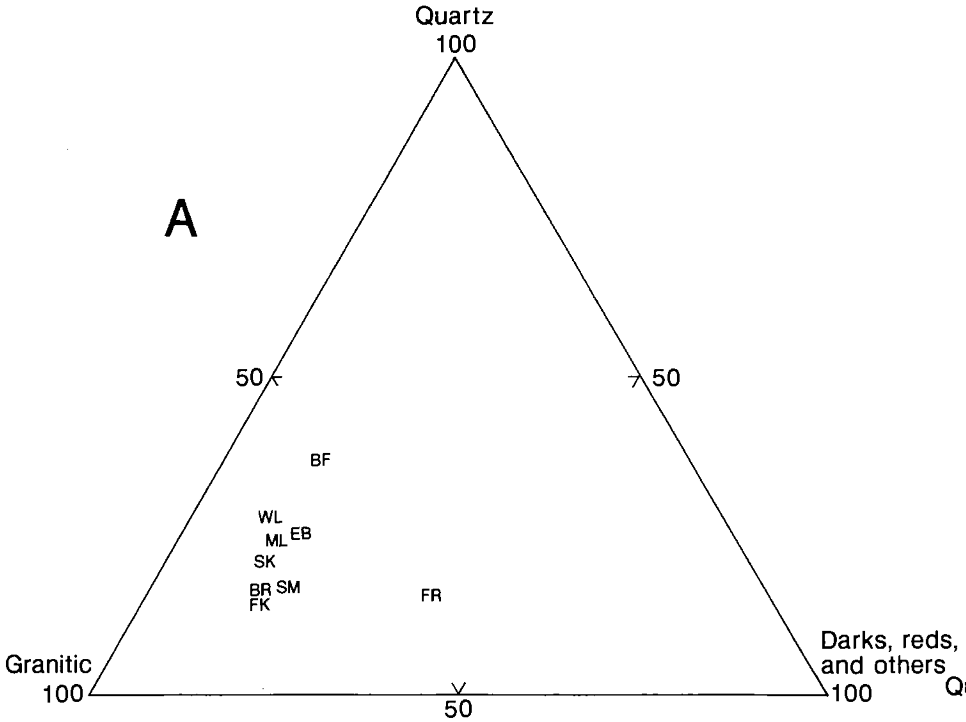


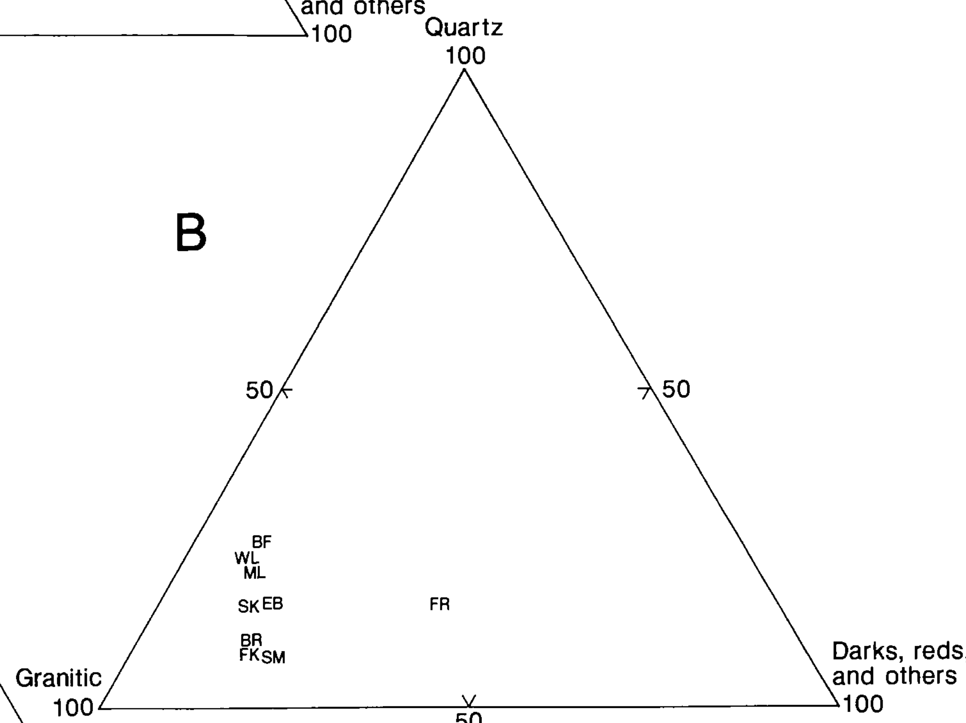
Figure 16. Sites where Funkley (FK), Eagle Bend (EB), and First Red (FR) tills were cored. Left-hand numbers are average percent Paleozoic carbonate content, and the adjacent numbers are average percent Cretaceous content of the 1-2-mm sand fraction. The speculative maximum extent reached by the First Red ice advance, which is also shown, is based on the distribution of Keweenawan pebbles in younger sediment and the underlying bedrock topography of the underlying bedrock.

the older tills did not necessarily require great periods of time to accomplish.

As in the Wirt Lake till, Paleozoic carbonate content in the Bigfork till is low for a Winnipeg-provenance till (Table 1). Cretaceous clasts are present in appreciable amounts in the Koochibel area, but again as in the Wirt Lake till, they are rare in Lake of the Woods County. This difference may be attributed to flow paths of the ice (Fig. 11) or to the presence of small outliers of marine Cretaceous strata in the intervening Red Lake lowlands.

Wirt Lake till contains more sand than Bigfork till (Fig. 12). The Wirt Lake glacier probably acquired the additional sand as it passed over more sandy sediment (Mulligan Lake till and related bedded deposits) than did the later Bigfork ice advance (Shooks till and related bedded deposits). More quartz (Fig. 17a-c) and less Cretaceous content in the Bigfork till may reflect somewhat different flow lines, or possibly less marine and more nonmarine Cretaceous strata were available for incorporation during the Bigfork advance. Bigfork till also has a higher content of unknown 1- to 2-mm grains (Table 1), which are primarily saprolith-derived material, again implying a greater marine Cretaceous cover or slightly different flow lines for the Wirt Lake advance. The percentage of quartz decreases upward in Old Rainy tills in the Koochibel area (Fig. 17b), implying a progressive decrease in available saprolith for incorporation through the Pleistocene. Anomalously high values for quartz and unknowns in OB-507 skewed results for the upper two Old Rainy tills in Lake of the Woods County (Fig. 17c). Decreasing quartz and low unknowns in younger Winnipeg-provenance tills probably result from both difference in ice-flow direction and less saprolith available for incorporation.





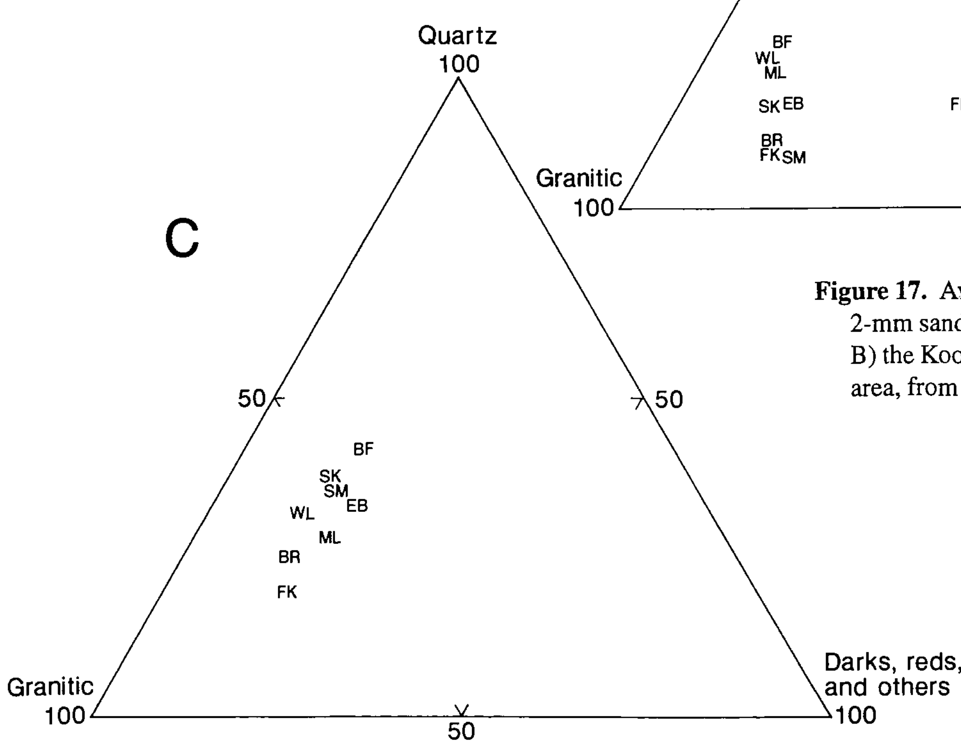


Figure 17. Average Precambrian lithology of the 1-2-mm sand fraction of each till for A) both areas, B) the Koochibel area, and C) Lake of the Woods area, from Table 1. Abbreviations as in Figure 6.

Limited data (Table 2) indicate that expansible clay minerals are slightly more common in the Bigfork till than in Wirt Lake till. These two tills have the highest clay-mineral content of all tills sampled in north-central Minnesota.

Correlation of the Bigfork till with till in central Minnesota (Meyer, 1986) is problematic. Like the Wirt Lake till, the Bigfork till is similar to the Elmdale till in that it contains relatively large amounts of Cretaceous sediment and relatively small amounts of Paleozoic sediment. In the few sections in central Minnesota where an equivalent of the Old Rainy Shooks till separating the Wirt Lake and the Bigfork tills is present, a hiatus exists between it and overlying till (Meyer and Knaeble, 1996). Other sections of Elmdale till could be equivalent to either the Wirt Lake or the Bigfork, so both tills are tentatively correlated here with the Elmdale till.

The Bigfork till in north-central Minnesota is oxidized grayish brown at five of the seven sites where it is recognized, indicating that at least some time elapsed before onset of the next glaciation. In fact, at four of these sites the top of this till appears to have been reduced—probably the result of a rising water table associated with a proglacial lake in front of the next ice advance (Fig. 5). The more intense oxidation at the top of Bigfork till in hole KR-73 reflects either a better drained location or re-exposure, because the next younger tills are absent in this core.

Eagle Bend Till

The Winnipeg-provenance till above the Bigfork till can be correlated with the Paleozoic carbonate- and clay-rich Eagle Bend till of the Todd County area (Meyer, 1986), and that name is used here. It differs from the type Eagle Bend till by having only about a quarter as much Cretaceous material. This difference is presumably due to different ice-flow lines. Additionally, the till in the north is about half as thick as in the central part of the state, but this difference in till thickness between the two areas was noted for all Winnipeg-provenance tills. The Eagle Bend till in the north on the average contains less clay and more silt and sand (Fig.

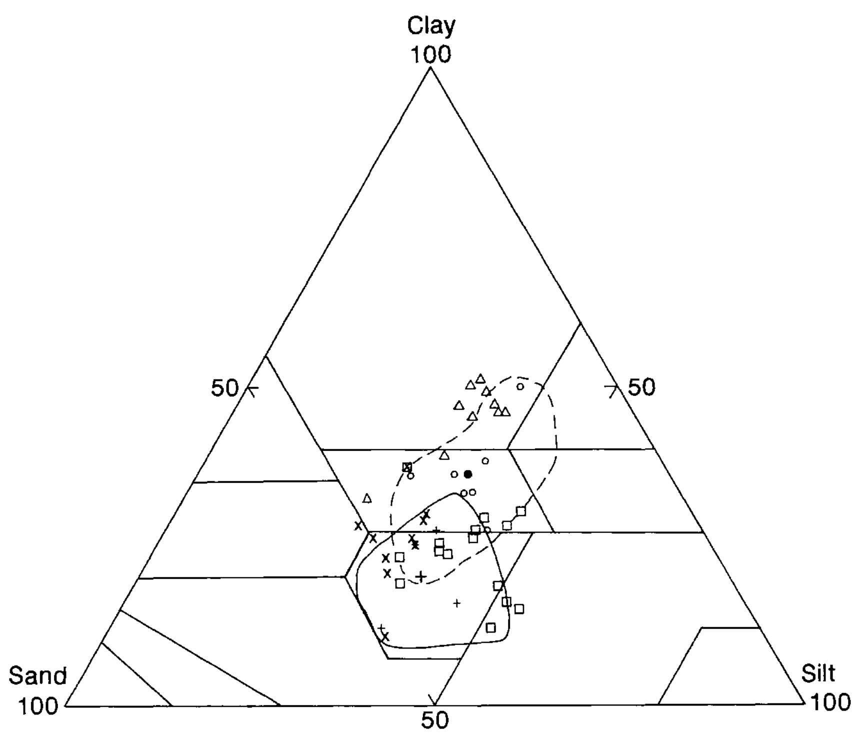


Figure 18. Matrix texture of the Eagle Bend and Funkley tills.

Eagle Bend values: Dashed envelope encloses range; solid circle, average overall texture; open circles, average textures at each site in north-central Minnesota; triangles, textures of individual till samples in the Todd County area of central Minnesota.

Funkley—and possibly correlative tills—values: Solid envelope encloses range; large plus symbol, average overall texture; small plus symbols, average textures at each site. X symbols, textures of individual Meyer Lake till samples; squares, textures of individual Green till samples in the Todd County area.

18). Textural differences between the two areas probably reflect more incorporated Labrador-source sediment in north-central Minnesota. In Todd County one drill hole penetrated Superior-provenance till—the Second Red till of Meyer (1986)—beneath the Eagle Bend till. Although this till unit was not found in north-central Minnesota, Keweenawan clasts were noted in Eagle Bend till there. These clasts were probably derived from a Second Red equivalent till, whose ice likely reached as far north as the later Superior ice advance that deposited the First Red till in hole KR-74 (Fig. 16).

The best example of the Eagle Bend till in north-central Minnesota is in the KR-74 core, where 47 feet (14 m) overlies Shooks till and in turn is overlain by the First Red till. Thin, organic-bearing lacustrine sediment between the Eagle Bend and the Shooks tills in this core has yielded pollen indicative of a spruce forest prior to burial, and algae indicate the seasonal presence of standing water (Huber, 1993). An inclusion of organic-bearing lake sediment some 20 feet (6 m) above the base of the Eagle Bend till implies that lacustrine sediments were considerably eroded and reworked by the subsequent ice advance. All other sites where the Eagle Bend till was encountered also showed lake sediments below or incorporated within the till. These observations contrast sharply with those in central Minnesota, where lake sediments are lacking. Thus the Eagle Bend till in central Minnesota probably was deposited south of the lake basins that supplied its high clay content, and any lake sediment was more thoroughly mixed within the till. This difference may also help explain the difference in texture of till from the two areas. Differences in grain size of overridden lake sediments in the two areas may also have contributed to the difference in till texture.

Most sections of Eagle Bend till encountered in central Minnesota were oxidized, some to considerable depth (63 feet or about 19 m). This thick oxidation zone implies a long hiatus, although the till was not deeply leached. Such oxidation zones are absent in north-central Minnesota, possibly because of subsequent erosion. However, at KR-74 the Eagle Bend is not eroded, and only the uppermost few feet (1 m) are reduced. The water table may have remained high in north-central Minnesota, as it did following the late Wisconsinan, preventing deep oxidation from occurring, whereas in central Minnesota the water table must have been much lower.

Organic silt interbedded with flow till and lake sediment in the upper part of KR-74 contains pollen that presumably reflects the environment on top of the stagnating Eagle Bend ice. A shrub parkland with scattered stands of spruce or individual trees of spruce is indicated, with standing water most of the year (Huber, 1993). Lake sediment above Eagle Bend till in OB-521 contains organic laminae whose pollen may yield more information on the nature of the hiatus before deposition of the succeeding First Red till.

First Red Till

Only one Superior-provenance till is recognized in north-central Minnesota. It occupies the same stratigraphic position as the First Red till of the Todd County area (Meyer, 1986), and that name is also applied here. It was encountered only in KR-74 (Fig. 16), where about 3 feet (1 m) of yellowish-brown (10YR 4/3) sandy to loamy till lies between Eagle Bend till below and Funkley till above (Fig. 6). A large proportion of Keweenawan clasts clearly sets the First Red apart from other tills in north-central Minnesota (Fig. 17; Table 1). Nonetheless the till lacks the reddish-brown color of Superior-provenance tills to the southeast, and it contains moderate amounts of Paleozoic detritus—both characteristics are attributed to extensive incorporation of underlying sediment. Similar characteristics in central Minnesota are attributed to incorporated Winnipeg-provenance sediment.

The First Red till has the least very coarse sand of the total sand fraction (Table 1), as was noted for this till in the Todd County and Stearns County areas in central Minnesota (Meyer and Knaeble, 1996). The Quaternary section penetrated in MGS hole 2000 in Todd County indicated that deposition was continuous from the First Red till to the overlying Winnipeg-provenance Meyer Lake till (Meyer, 1986).

Funkley Till

The Winnipeg-provenance Funkley till is named after a small town near hole KR-74 (Fig. 16). The core constitutes the most complete section of the till so far encountered. The Funkley contains more sand than the Eagle Bend till (Fig. 18) and has more Paleozoic carbonate detritus than the overlying Browerville till. On the basis of a few samples, the Funkley till has a much lower proportion of clay minerals than the Eagle Bend till (Table 2). The Funkley till was encountered at only four sites in the study area. It stratigraphically overlies the First Red till in KR-74; in OB-517 it overlies oxidized Bigfork till; and in OB-511 and KR-71 it overlies saprolith. At all four sites the top of the Funkley is unoxidized, an attribute that may reflect a consistently high water table.

Correlation of the Funkley till with units in central Minnesota is problematic. Because of its position above the First Red till and its lack of deep weathering, it could be correlated with the Meyer Lake till (Meyer, 1986). Both tills have a similar color and a similar percentage of dark Precambrian grains in the 1- to 2-mm fraction. However, the Funkley has other lithologic attributes [i.e., low quartz and high Paleozoic content (Table 1)] that are similar to those of the Sauk Centre till of Meyer and Knaeble (1996; formerly Green till of Meyer, 1986) in central Minnesota. Therefore the Funkley till is tentatively correlated here with both the Meyer Lake and Sauk Centre tills, which are thought to have been deposited during the same glaciation. It is also likely correlative with the Gervais Formation of northwest Minnesota (Harris and others, 1974, 1995), and with Unnamed Unit 1 of southern Clearwater County (Harris, 1975; Sackreiter, 1975; Fig. 1).

Organic silt at the top of the Funkley section in KR-74 yields pollen indicative of tundra, and the type of algae present implies a depositional basin that contained year-around standing water (Huber, 1993). The organics in the silt may be reworked from the organic-rich Funkley till below, but the common wood fragments in the till (as in the Meyer Lake till of central Minnesota) imply that the Funkley ice advance overrode a forest, not tundra.

Saum Till

The uppermost Old Rainy till in north-central Minnesota is informally named after the small town near hole KR-71 (Fig. 19); in this core 5.5 feet (1.7 m) of sandy till is found above Funkley and below Browerville till. The Saum till at KR-71 is less rocky and contains more Paleozoic detritus than at most other sites in the study area. Nevertheless KR-71 is proposed as the type locality, because it is the only place where the next tills above and below are preserved. The Saum till generally resembles Mulligan Lake till, but contains less quartz and more dark Precambrian fragments in the 1- to 2-mm clast fraction (Table 1), and has a generally more stoney fabric. It can be distinguished from the Shooks till by textural differences (Figs. 9 and 14), although in the Koochibel area the Saum has less quartz and more dark Precambrian fragments in the very coarse sand fraction (Fig. 17b).

The Saum till is correlated with the Sandy till of Meyer (1986) in central Minnesota, where it occurs beneath the

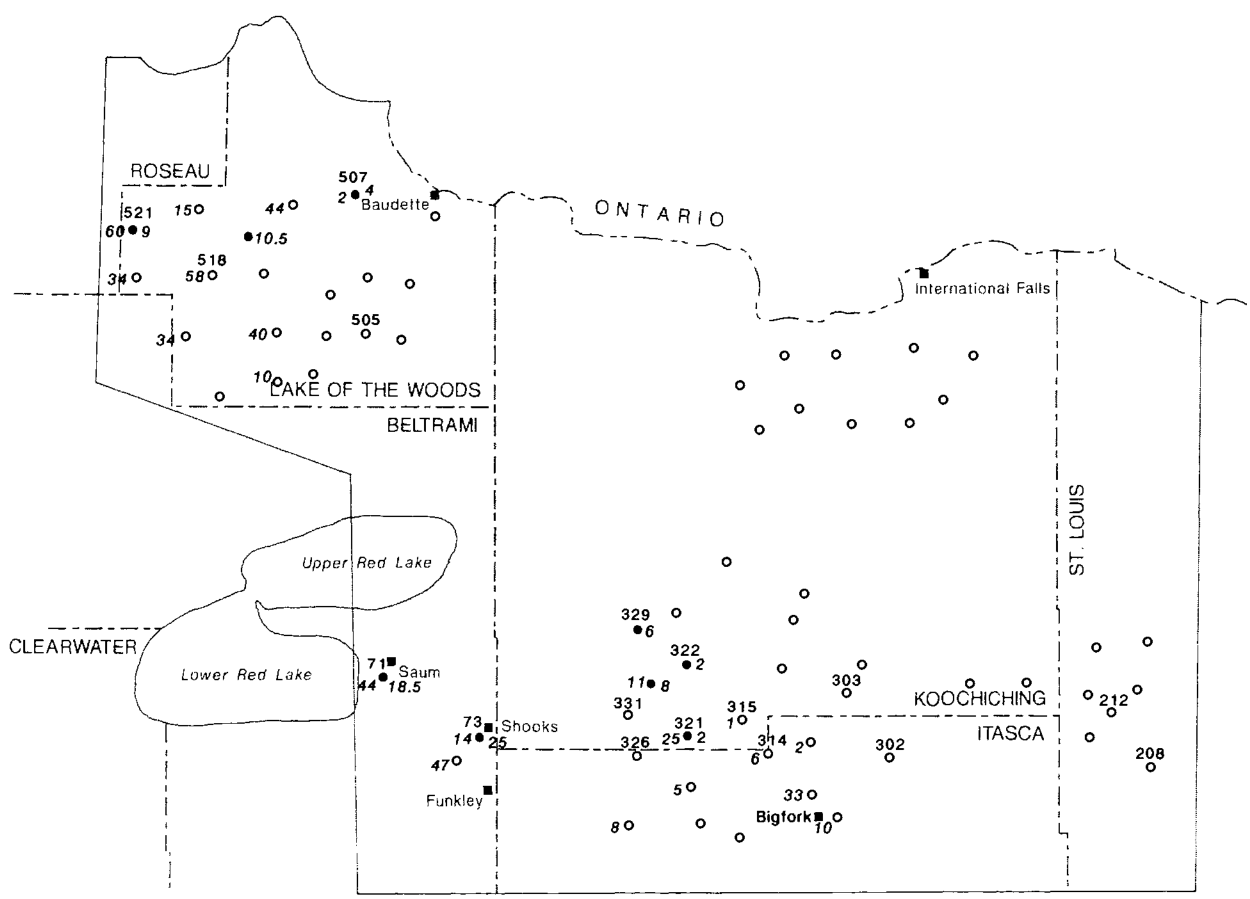


Figure 19. Location of sites (closed circles) where Saum till was cored. Numbers on the right are average percent Paleozoic carbonate content of the 1-2-mm sand fraction. Numbers on the left are percent Paleozoic carbonate content of the next older till, over which the Saum ice may have advanced.

Browerville till and above the Green (now Sauk Centre) till. The term Saum till is given preference in this report. The Saum till may correlate with till RRV-16 of the Crow Wing River group of northwest Minnesota (Harris and others, 1995). Existence of the Saum till implies a resurgence of ice carrying Rainy-provenance detritus across north-central Minnesota, following an apparently long hiatus after deposition of the Shooks till. The Saum overlies the Funkley till only in KR-71. Elsewhere it overlies bedrock or several of the much older till units. Thus the Saum advance, like other ice advances across northeast Minnesota, appears to have been very erosive of underlying sediment. An interglacial episode of unknown duration was identified between the Sauk Centre and Saum tills in central Minnesota (Meyer, 1986).

The data in Figure 19 imply that Paleozoic carbonate in the Saum till increases to the west, presumably derived from older carbonate-rich tills. The clay-size fraction also increases toward the west. In KR-73 (Fig. 6) the lowest foot of Saum till is a clayey carbonate-rich interval that could be a mixed zone or alternatively Funkley or Eagle Bend till in place.

In addition to six holes in the Koochibel area (Fig. 19), the Saum till is thought to be present in the lowest parts of OB-208, 212, 302, and 303, where a thin, noncalcareous (leached?), and oxidized (at 3 of 4 sites) till occurs below late Wisconsinan Rainy lobe till and above bedrock. Where only one thin, basal Old Rainy till is present, as in the above holes as well as in OB-314, 315, 322, and 505, it is difficult to assign the till to one particular Old Rainy unit.

In central Minnesota where it underlies younger Browerville sediments, the Saum is unoxidized (Meyer, 1986). However, where the Browerville is missing, as it is in north-central Minnesota in 0B-322, 329, and 507, the Saum till or related sediment is significantly oxidized. This relationship implies that the Browerville till may have buried the Saum till shortly after the Saum was deposited. In north-central Minnesota, however, there is evidence in core holes OB-321, 326, 331, and 518 for at least a short interstadial between these two advances. Similar evidence was encountered recently in a rotasonic hole in Stearns County in central Minnesota (Meyer and Knaeble, 1996).

In OB-321 (Fig. 19; Appendix A), the Saum till is overlain by a sequence of bedded sediment, the upper 14.5 feet (4.4 m) of which has massive to laminated organic zones. Pollen taken from the lowest organic zone indicates an arctic environment characterized by an open parkland having scattered stands of spruce and pine. Algae in the sample indicate a basin containing continuous standing water (Huber, 1993). Gravel above the organic interval, presumably deposited by meltwater flowing from Browerville ice, contains large, ragged pieces of wood, one of which yielded a radiocarbon date of greater than 40,600 years B.P. (Beta-27952). A second wood sample from the same interval was sent to a different laboratory for analysis, and was dated at 33,180 $\pm$ 980 radiocarbon years B.P. (ISGS-2090).

In OB-518 a thick sequence of lake sediments occurs below the Browerville till. Charcoal from the lower part of the lake sequence yielded a radiocarbon date of greater than 40,400 years B.P. (Beta-36394). These lake sediments do not overlie the Saum till, but rather overlie a carbonate-rich gravel probably related to the underlying Eagle Bend till. A piece of wood collected from Browerville till in Stearns County (Meyer and Knaeble, 1996) in central Minnesota yielded a radiocarbon date of greater than 45,000 years B.P. (Beta-82571). Deep weathering profiles in Browerville till buried below late Wisconsinan till in central Minnesota (Meyer, 1986) suggest that the 33,180 $\pm$ 980 radiocarbon years B.P. date is incorrect and that the Browerville and older tills are pre-late Wisconsinan in age.

In OB-326 bedded sediment related to the Saum advance is overlain by organic lake sediments. Pollen from reworked lake sediment at the base of the overlying late Wisconsinan Rainy till indicates a conifer forest in an arctic environment. Algae indicate a depositional basin containing year-around standing water (Huber, 1993). In OB-331 a small amount of organics were noted in thick lake sediments both above and below Browerville till. A foot (0.3 m) of Old Rainy sand above bedrock and below the lake sediments may be related to the Saum advance.

In summary, evidence from organic sediment between the Browerville and Saum tills suggest that sufficient time had elapsed for the growth of a boreal forest. A similar forest between the First Red and Meyer Lake advances in central Minnesota also has been postulated (Meyer, 1986). Evidence does not preclude paired advances from both ice centers during the same glaciation, however. Interestingly, the much more detailed record of late Wisconsinan sediment in north-central Minnesota does not yield any evidence for vegetation development between advances of Labrador and Keewatin ice (Fig. 5).

Browerville Till

The uppermost Winnipeg-provenance till in north-central Minnesota is informally named the Browerville, because it is correlated with the uppermost Winnipeg-provenance till of that name in central Minnesota (Meyer, 1986). It can be distinguished from the older Funkley and Eagle Bend tills primarily by its lower Paleozoic carbonate content (Table 1). It differs from the still older Bigfork and Wirt Lake tills by having more Paleozoic carbonate on the average, and in the Koochibel area by having less Cretaceous content. Clay-mineral content is also lower in the few samples analyzed (Table 2). The Browerville till is probably correlative with Unnamed Unit 2 of Harris (1975) and Sackreiter (1975) in southern Clearwater County (Fig. 1), and with till RRV-15 of the Crow Wing River group in northwest Minnesota (Harris

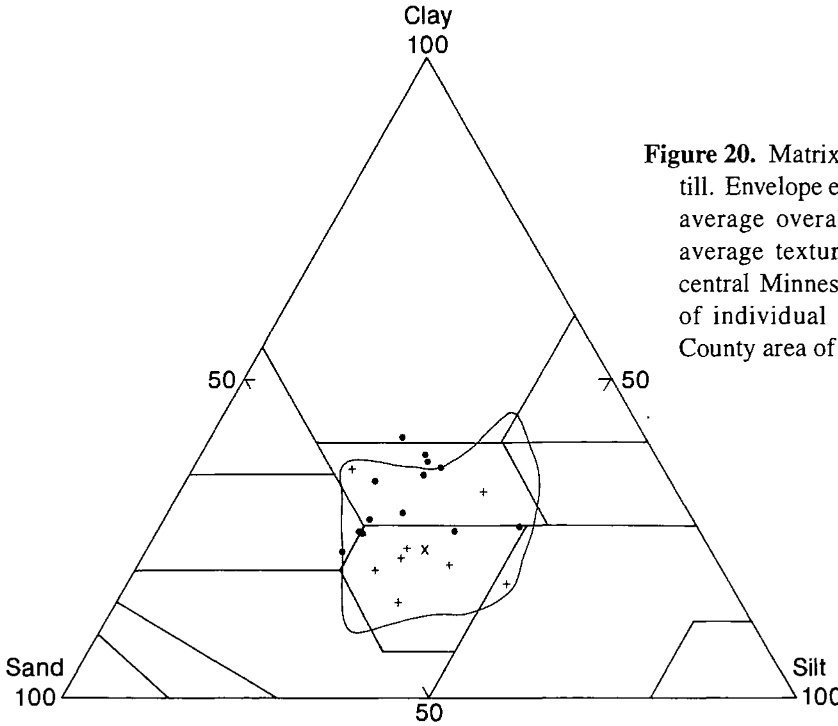


Figure 20. Matrix texture of the Browerville till. Envelope encloses range of values; X, average overall texture; plus symbols, average textures at each site in north-central Minnesota; solid circles, textures of individual till samples in the Todd County area of central Minnesota.

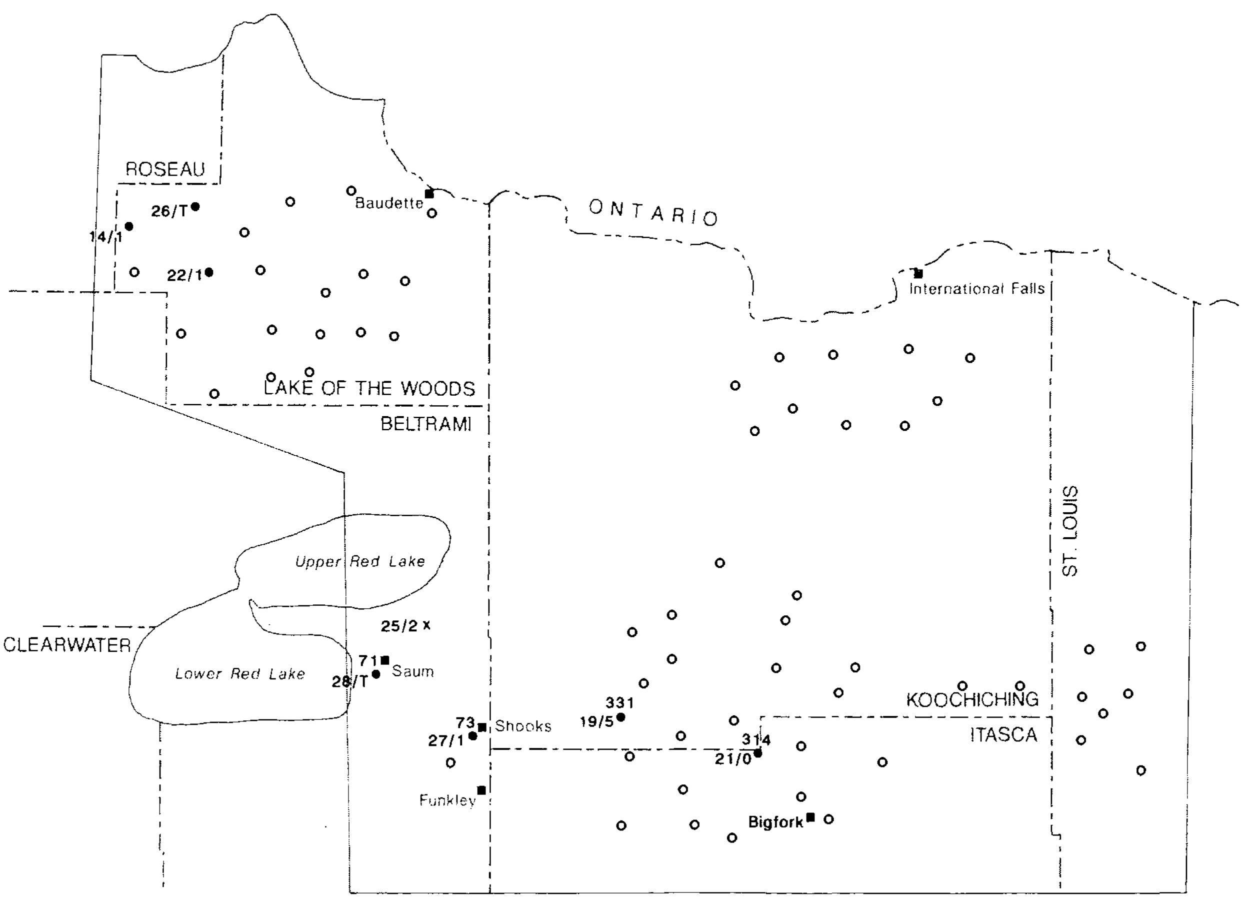


Figure 21. Sites where Browerville till was cored (closed circles); x, diamond-core hole KIB-69A (Appendix B). Left-hand numbers are average percent Paleozoic carbonate content, and the adjacent numbers are average percent Cretaceous content of the 1-2-mm sand fraction. (T = trace amount)

and others, 1995).

In north-central Minnesota the Browerville contains on the average more silt and less clay than in central Minnesota (Fig. 20). The section in north-central Minnesota also contains less Paleozoic detritus, and except for OB-331 (Fig. 21), considerably less Cretaceous detritus. The anomalous amounts of Cretaceous clasts in core OB-331 were possibly derived from a local outlier. However, the generally low percentage probably reflects ice-flow lines that passed more to the east across the Winnipeg lowland (Fig. 4) where little Cretaceous bedrock was present. There probably also was less Cretaceous material available for incorporation in the northern part of the Red River Valley than farther south.

Meyer (1986) has speculated that the Browerville ice advance was more lobate than previous advances that carried sediment of Winnipeg provenance. It also may be that the Browerville tills of north-central and central Minnesota have different attributes because the ice advance that deposited them was separated into two distinct lobes like the late Wisconsinan Koochiching and Des Moines lobes (Fig. 3), for example. Keewatin ice, as in the late Wisconsinan, may have initially been blocked to the east by Labrador (Saum) ice, causing extensive flow to the south, and only later allowing flow into north-central Minnesota. Such a blockage would in part account for the thinner Browerville deposits in north-central Minnesota, as there was less time for Browerville ice to carry sediment into the area. Although the Browerville till is much thinner in north-central Minnesota than in central Minnesota [average 18 feet (5.5 m) versus 79 feet (24 m)], at 59.5 feet (18 m) in KR-71, it is the thickest Winnipeg-provenance till section encountered. In the Todd County area of central Minnesota (Meyer, 1986), the Browerville is also the thickest till of Winnipeg provenance.

Like the late Wisconsinan Koochiching lobe (Martin and others, 1988), the Browerville ice advance into north-central Minnesota appears to have been fronted by a lake (Fig. 5)—most sections of till either overlie or contain incorporated lenses of lake sediment (except the thin till in OB-314, whose very silty texture probably reflects incorporated lake sediment). Browerville ice in the area also fronted a lake during its retreat—most till sections are buried by lake sediment. Very similar thick silty to sandy lake sediment with disseminated organics overlies Browerville till in core from OB-331 and KR-73, even though the Paleozoic and Cretaceous content in the two tills differs (Fig. 21).

In central Minnesota, a pronounced weathering profile at the top of the Browerville till implies that a relatively long period of time (Sangamonian?) elapsed prior to the deposition of overlying surficial late Wisconsinan till (Meyer, 1986). This hypothesis cannot be substantiated in north-central Minnesota. All known sections of the till in north-central Minnesota are unoxidized to the top, probably because the Browerville till there was buried by lake sediment. Thick lake sediment above Browerville till in KR-73 appears to reflect continuous sedimentation up to deposition of the overlying, apparently late Wisconsinan, Rainy lobe till. However, the whole sequence above the Browerville till could be late Wisconsinan.

USE OF GEOCHEMISTRY FOR TILL CORRELATION

MDNR-Minerals carried out an extensive geochemical investigation of samples from rotasonic cores drilled in Lake of the Woods County (Martin and others, 1991). They found certain elements in the silt-clay fraction and the nonmagnetic heavy-mineral concentrate to be helpful in differentiating till provenance. Sodium and titanium are in general higher in Rainy-provenance till, whereas mercury, boron, arsenic, nickel, zinc, lead, and potassium tend to be higher in Winnipeg-provenance till of the Lake of the Woods area. It is difficult to identify tills of the area by geochemical analysis, because samples are too few, but some differences can be recognized. For example, the Bigfork till has the highest boron content of any of the tills in Lake of the Woods County, differentiating it from the similar Wirt Lake till. The Bigfork also has a higher mercury content than the Wirt Lake, but the Eagle Bend till has the most mercury of any of the tills of the study area. Boron and mercury tended to increase with depth in the Old Rainy tills, including the basal Mulligan Lake till; this increase implies incorporation of underlying Winnipeg-provenance sediment, and supports the hypothesis that a pre-Mulligan Lake till of Winnipeg provenance exists in the subsurface of north-central Minnesota.

Differences between Rainy and Winnipeg-provenance tills were not as pronounced in samples taken from the three cores drilled in Beltrami County (KR-71, KR-73, KR-74; data filed at MDNR-Minerals in Hibbing). The large size requirements for heavy-mineral analysis led to combining more than one till in some samples, so only three samples were unambiguous Winnipeg tills, whereas six were Old Rainy till. Only titanium, arsenic, and boron seemed to have the same relative concentrations as corresponding till in Lake of the Woods County (mercury was not sampled). Even these three elements produced inconsistent results from samples of the Rainy-provenance Shooks till, presumably because of extensive incorporation of Wirt Lake or older Winnipeg-provenance sediment. This would imply that only a few, if any, elements may be useful for correlation of till units across large areas. Gowan (1993), however, in a study of six till units from central Minnesota, concluded that the geochemistry of the silt and clay fraction should be the primary tool for determining till provenance and stratigraphy.

STRATIGRAPHIC AND HISTORIC SYNTHESIS

Prior to the late Wisconsinan, tills of northeast and northwest sources in north-central and central Minnesota were deposited in discernible couplets (Fig. 22). Superior-

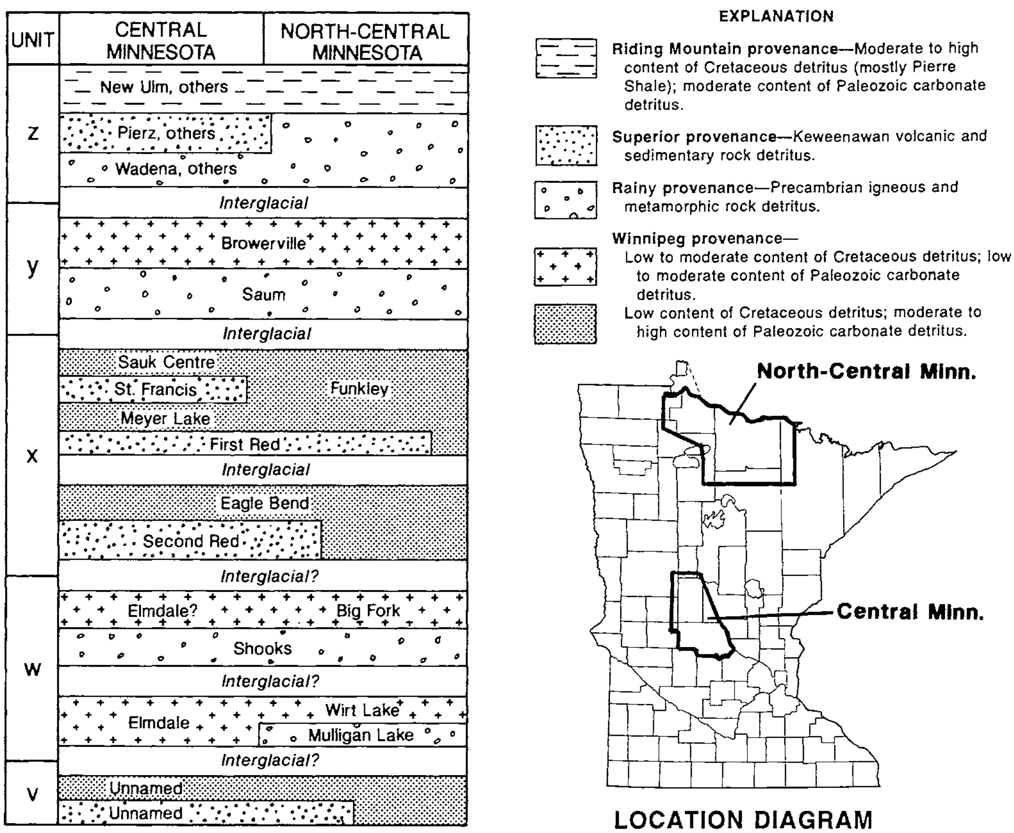


Figure 22. Event units of the Pleistocene of central and north-central Minnesota (from Meyer and Knaeble, 1996).

provenance tills were overlain by Winnipeg-provenance tills rich in Paleozoic carbonate but low in Cretaceous detritus, whereas Rainy-provenance tills were overlain by Winnipeg-provenance tills having moderate amounts of both Paleozoic carbonate and Cretaceous detritus. (Not until late Wisconsinan time was till rich in the Cretaceous Pierre Shale laid down in central Minnesota.) The switch from one group of tills to another in Minnesota may indicate a continent-scale change in ice-flow dynamics from one glacial period to the next. Minnesota is located approximately equidistant from the two major centers of the Laurentide ice sheet of the last glaciation (Fig. 2). I suggest that the couplets of northeast- and northwest-source tills imply shifting locations for the Labrador and Keewatin ice centers during the Pleistocene.

For discussion purposes, the pre-late Wisconsinan in Minnesota is divided into four informal "event" units—V, W, X, Y, and the term Z is reserved for the late Wisconsinan, the actual age of whose deposits is better constrained (Fig. 22). The boundaries between the units are based largely on lithologic attributes of constituent tills, but emphasis is placed here on the boundaries themselves, because they probably separate glacial events roughly synchronous across the North American continent. Even though the lithology of sediments on either side of these boundaries varies across the continent, the boundaries should be recognizable, if they were created by shifts in the locations of the respective centers of the Laurentide ice sheet during the Pleistocene. Although the boundaries should correspond to boundaries between glaciations, at least one of the proposed event units (X) likely includes sediment deposited during more than one glacial period.

Evidence for an early unit V period includes loamy till at the base of Mulligan Lake till in OB-320, which may be akin to Winnipeg-provenance tills of unit X; high carbonate content and Winnipeg-provenance geochemical attributes in the base of both Old Rainy tills of unit W; and very rare Superior-basin Precambrian clasts in unit W tills. Tills of unit V, tentatively recognized from drill cuttings in central Minnesota (Meyer and Knaeble, 1996), appear to be similar to those of unit X, and consequently imply similar ice-flow directions.

In unit W time (Fig. 23) ice carrying Rainy-provenance detritus advanced farther into Minnesota than ice carrying Superior-provenance detritus, which apparently did not reach as far west as the Todd County area (Meyer, 1986). Evidence

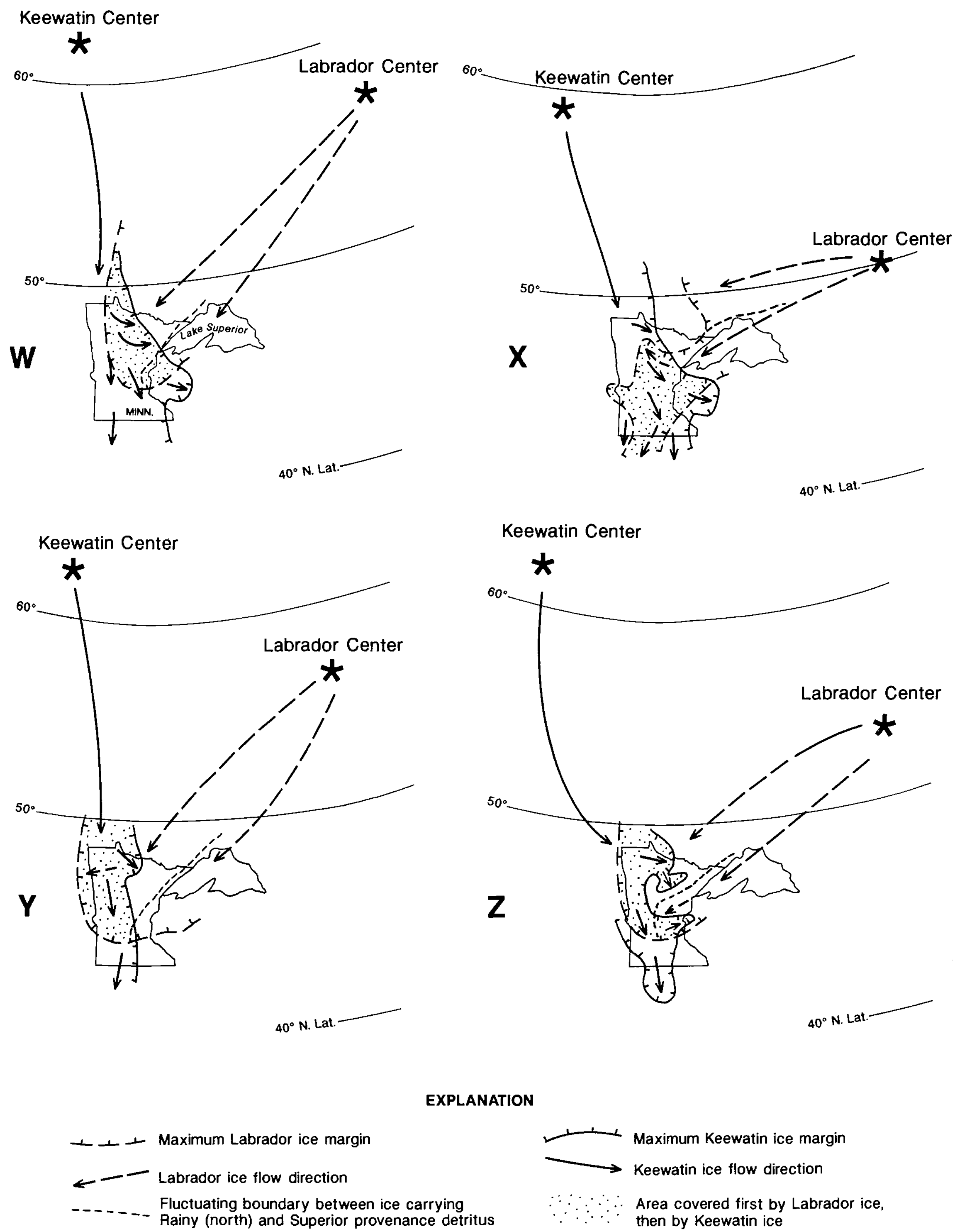


Figure 23. Speculative centers and margins of Labrador and Keewatin ice advances during event units W, X, Y, and Z. Tills of an early unit V imply ice-flow directions similar to those of unit X; see text for discussion.

of Superior-provenance sediment of this age is scant, and at only a few sites has unit W Old Rainy sediment been found south of the study area (Meyer and Knaeble, 1996). From central Minnesota south, till deposited by Keewatin ice appears to dominate the basal Pleistocene sediment record; flow of Keewatin ice into the state apparently was approximately due south, according to till lithology. Thus unit W deposits in Minnesota are characterized by the absence of Superior-provenance sediment except perhaps in east-central Minnesota, and by the presence of Old Rainy sediment at least as far south as central Minnesota. Keewatin sediment of unit W should be found in places across most of the state, at least in the central part of the state, characterized by low to moderate amounts of Cretaceous and Paleozoic detritus (Fig. 22).

In unit X time, ice carrying detritus of Superior provenance became the dominant expression of flow from the Labrador center across Minnesota, with no known record of ice carrying debris of Rainy provenance advancing into the state during this period. Keewatin ice flowed into and across Minnesota in a more southeastward direction during this time, carrying great quantities of eroded Paleozoic rock from the Winnipeg lowland. Possibly the respective ice centers of the Keewatin and Labrador sectors were farther apart than in the earlier sequence.

Unit Y (Fig. 23) saw a return of ice carrying Rainy-provenance detritus, which extended at least as far south as central Minnesota. Ice carrying Superior-provenance detritus apparently did not reach into central Minnesota at this time. Keewatin ice again flowed into the state in a more southward direction, indicating that the two ice centers may have again been closer to each other. One U-series date of greater than 350,000 years B.P. from marl at the base of unit Y (Meyer, 1986) suggests that units W and X are pre-Illinoian, whereas Y is pre-Illinoian, Illinoian, or early Wisconsinan.

It was previously thought (Wright, 1972; Meyer, 1986) that the early Wisconsinan was a period of extensive ice advance in Minnesota. But subsequent work by Eyles and Westgate (1987) and Curry (1989) implies that sediment attributed to the early Wisconsinan in Minnesota was probably deposited in the initial ice advances of the late Wisconsinan. The till below wood dated at 36,970±950 (Beta-8492; Meyer, 1986) and 36,900±1700 (ISGS-2089) radiocarbon years B.P. in MGS hole 2005 in central Minnesota is probably the pre-late Wisconsinan Saum till and not the late Wisconsinan Wadena till. Although both the Browerville and Wadena tills are absent at the site, it seems likely that the wood from MGS hole 2005 is from a forest present at the onset of the late Wisconsinan.

The Rainy lobe covered much of Minnesota in the late Wisconsinan, including the area mapped as Wadena lobe deposits in Hobbs and Goebel (1982; see Meyer, 1986), as did ice carrying Rainy-provenance detritus in unit Y, but in the last glaciation the Superior lobe moved into central Minnesota following the retreat of the Rainy lobe (Fig. 22; Meyer and Knaeble, 1996). The late Wisconsinan is placed in a separate unit Z (Fig. 23), however, primarily because of the dramatic and unprecedented shift of the Keewatin ice, flowing due east across northern Minnesota (Koochiching lobe, Fig. 3) and carrying a unique load of Cretaceous Pierre Shale detritus from southwestern Manitoba and eastern North Dakota into central and southern Minnesota (Des Moines lobe).

In summary, the till record in Minnesota yields evidence that the distinct Keewatin and Labrador centers were an enduring phenomenon of the Laurentide ice sheet, and that the locations of the ice centers probably shifted throughout the Pleistocene.

ACKNOWLEDGMENTS

This report is an outgrowth of collaborative work with the MDNR-Minerals, with special assistance from staff members Dennis P. Martin, Dale F. Cartwright, and David A. Dahl. Anthony C. Runkel of the MGS, among others, generated laboratory data used in the study. Extensive revisions were made to the text following critical review by G.B. Morey of the MGS. Kenneth L. Harris and Howard C. Hobbs of the MGS and Herbert E. Wright, Jr., of the University of Minnesota's Department of Geology and Geophysics also made many helpful comments.

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APPENDIX A—ABBREVIATED LOGS

(Footnotes are on page 37)

OB-208

Interval[1]	Description[1]	Unit[2]	Munsell color
0-108 (ft)	Late Wisconsinan sediment		
108-113	Dark loamy till, noncalcareous; only 1 foot recovered	OR	2.5Y4/1
113	Precambrian bedrock		

OB-212

Interval	Description	Unit	Munsell color
0-100 (ft)	Late Wisconsinan sediment		
100-104	Olive brown, gravelly loamy till, noncalcareous; dense; rich in local rock; more rocky with depth	OR	2.5Y4/4
104	Weathered Precambrian bedrock		

OB-301

Interval	Description	Unit	Munsell color
0-50 (ft)	Late Wisconsinan sediment		
50-64	Very dark gray, hard loamy till; some large pebbles to small cobbles	BF	5Y3/1 to 56' 5Y4/1 to 61', 5Y3/1 below
64-67	Olive gray loamy to sandy, rocky till, with smears of greenish saprolite	SK	5Y4/2
67-87	Dark gray loamy to sandy rocky till, hard	SK	5Y4/1
87	Saprolith		

OB-302

Interval	Description	Unit	Munsell color
0-63 (ft)	Late Wisconsinan sediment		
63-71	Greenish silty clay, noncalcareous; sand bed at 64.5', mostly silt with sand beds below 66'	OR	5GY5/1 and 5G5/1 to 5Y5/2
71-74	Boulder, gravelly sand, cobbles	OR	5GY6/1
74-76	Rocky, gravelly, sandy till; greenish gray, noncalcareous	OR	5G5/1
76	Saprolith		

OB-303

Interval	Description	Unit	Munsell color
0-136.5 (ft)	Late Wisconsinan sediment		
136.5-139	Coarse to very coarse sand	OR	10YR6/6 top foot then 2.5Y7/2
139-144	Olive gray gravelly sandy till; noncalcareous, very rocky, boulder last foot	OR	5Y5/2
144-149	Blue-green to gray, gravelly sandy till; calcareous with carbonate pebbles, but mostly reworked saprolith	W?	5B5/1 to N5/0
149	Saprolith		

OB-306

Interval	Description	Unit	Munsell color
0-84 (ft)	Late Wisconsinan sediment		
84-93	Dark gray clay till, hard	EB	5Y4/1
93-105	Gray clayey till, hard; 100.5-105 sand lenses	EB	5Y5/1
105-111	Dark gray clay till, hard	EB	5Y4/1
111-128.5	Dark gray loamy till, with saprolite smears; gravelly in upper part in places; sandy and silty laminae below 122.5'; clay till below 127'	EB	5Y4/1
128.5-129	Laminated clay to silt	EB	
129	Precambrian bedrock		

OB-307

Interval	Description	Unit	Munsell color
0-160 (ft)	Late Wisconsinan sediment		
160-206	No core		
206-212.5	Greenish rocky sandy till to gravelly sandy clayey till	SK	5GY5/1
212.5-226	Gray clayey till, looks mixed with lake sediment; loamy below 217', sandy by 223'	SK	5Y5/1
226	End of hole		

OB-314

Interval	Description	Unit	Munsell color
0-99 (ft)	Late Wisconsinan sediment		
99-102	Dark gray, compact, silty till; pebbly zone at top; 10YR4/2 mottling along joints	BR	5Y4/1
102-106	Dark gray, sandy to loamy till; cobbles at top and bottom	SK	5Y4/1
106-107	Sand over cobbly gravel	SK?	
107	Saprolith		

OB-315

Interval	Description	Unit	Munsell color
0-156.5 (ft)	Late Wisconsinan sediment		
156.5-162	Brownish, gravelly loam till; noncalcareous, rocky; slightly calcareous below 158'; boulder at base	SK	2.5Y6/4, 5Y5/3 by 158', 2.5Y5/2 by 160.5'
162	Precambrian bedrock		

OB-320

Interval	Description	Unit	Munsell color
0-135 (ft)	Late Wisconsinan sediment		
135-152	Olive, coarse-grained sand	SK	5Y6/4
152-155.5	Gray sandy till, with sand and silt laminae; loamy below 153.5'	SK	N5/0
155.5-158	Brownish loamy till; clay bed at 157' and at base	SK	10YR4/2, 5Y5/1 by 158'
158-165	Fining upwards sequence of sand	SK	5GY6/1
165-168.5	Greenish to gray loamy till; silty clay bed at top; mixed with clay last foot	SK	5GY5/1 to 5Y5/1
168.5-171.5	Mottled lake clay, hard; incorporated sediment?	SK	10YR4/2, 5Y5/1, 5Y4/1
171.5-173.5	Interbedded gravelly loam, sand, gravelly sand, and cobbles	SK	5Y5/1 and 2.5Y5/2
173.5-175	Gray to gray brown loamy till; hard; cobble at base, gradational contact	SK	5Y5/1-2
175-184	Dark gray loamy till with sand laminae at top; mottled to 179', clayey by 179' and very dark gray	WL	5Y4/1, 5Y3/1 by 179'
184-188.5	Dark gray clayey till, silty sand bed at top; sandy till by 186.5', rocky, mix zone	WL	5Y4/1
188.5-190	Gravelly sand	WL	2.5Y5/1
190-196	Gray sandy till, with sand beds	ML	5Y5/1
196-198.5	Dark gray loamy till	ML	5Y4/1
198.5	Saprolith		

OB-321

Interval	Description	Unit	Munsell color
0-131.5 (ft)	Late Wisconsinan sediment		
131.5-145.5	Gravelly sand with wood	BR	2.5Y5/1
145.5-154.5	Sand, well sorted	BR	2.5Y7/2

OB-321 Continued

154.5-169	Fine sand to silt with organic laminae	I	N6/0, 5Y6/1, 5GY5/1, 5Y5/1, 2.5Y4/1, 5GY4/1
169-172	Sandy silt with sand lenses	SM	N4/0 to 5GY4/1
172-173.5	Silty gravelly sand, cobble at base	SM	5Y5/1
173.5-176.5	Dark gray, gravelly sandy till	SM	5Y4/1
176.5-179	Greenish gray clay till; reworked lake sediment in last foot or so	EB	5GY5/1
179-190	Greenish gray sandy silt	ML	5GY6/1, 5/1
190-191.5	Greenish gray silty till	ML	5GY5/1
191.5-193	Greenish gray sandy silt, grades to till below	ML	5GY6/1
193-209	Greenish gray sandy till; gravelly in spots	ML	5GY5/1
209-211	Sand and gravel	ML	5Y5/2
211-220	Gray sandy till, abrupt lower contact	ML	5Y5/1
220-226.5	Sand with till lenses	ML	5Y6/1
226.5-231.5	Gray sandy till, grades to sand below	ML	5Y5/1
231.5-233.5	Sand, grades to till below	ML	5Y6/2
233.5-236	Gray sandy till	ML	5Y5/1
236-255	Sand, little gravel	OR	2.5Y6/4
255	End of hole		

OB-322

Interval	Description	Unit	Munsell color
0-172 (ft)	Late Wisconsinan		
172-182	Greenish sand	SM	5Y5/3 to 5GY5/1
182-183	Greenish silt	SM	5GY5/1
183-192	Brownish sand and gravel	SM	2.5Y6/3, 5/3
192-196	Rocky, gravelly, sandy to loamy till, with saprolite	SM	5GY5/1
196	Precambrian bedrock		

OB-325

Interval	Description	Unit	Munsell color
0-73.5 (ft)	Late Wisconsinan sediment		
73.5-81.5	Dark greenish gray, hard, sandy clay till; organics near top, mottled in upper part; loamy with depth	SK	5GY4/1 N4/0 by 76'
81.5-87	Dark gray clay to sandy clay till with clay beds	SK	5Y4/1
87-88	Lake clay	SK	2.5Y5/1
88-92	Dark gray sandy clay till with clay beds	SK	5Y4/1
92-94.5	Dark gray sandy till; gradational, interbedded lower contact	SK	N4/0 to 5Y4/1
94.5-111.5	Silt to fine sand	ML	5Y5/1, 2.5Y7/2, 5GY5/1
111.5-130.5	Gravelly sand	ML	5Y6/1
130.5-169.5	Fine sand	ML	2.5Y7/2, 5GY5/1
169.5-202	Gravelly sand	ML	
202-215.5	Fine sand	ML	
215.5-224	Gravelly sand	ML	
224-240	Cobbly gravel; last few feet gravelly loamy sand - till?	ML	
240-242.5	Gravelly sand	ML	
242.5-246	Cobbly sand, saprolite ball	ML	
246-258	Gravelly sand, with a few sandy till balls and cobbles	ML	2.5Y6/2
258	End of hole		

OB-326

Interval	Description	Unit	Munsell color
0-119 (ft)	Late Wisconsinan sediment		
119-120.5	Organic-rich silt; large cobble at base within sandy loam - base of late Wisconsinan; slightly to moderately calcareous		5Y4/1
120.5-129	Dark gray, hard, silty clay to clay, brown mottled, calcareous; sand in clay towards base	I	2.5Y4/1-3/1
129-133	Gray silty fine sand; organic silt bed at 130'	I	5Y5/1
133-136	Sand; cobble and greenish noncalcareous sandy till ball at 135'; cobble and gravel at base	SM	5Y6/1
136-152	Sand silt, noncalcareous	OR	5Y6/2, 7/2
152-196	Fine sand	OR	
196-204	Sand	OR	
204-220.5	Fine sand, sandy silt	OR	5Y6/2
220.5-229	Sandy silt to silt	OR	5GY5/1
229-230.5	Grayish brown, gravelly sandy to loamy till; rocky, with saprolite	OR	5Y5/2
230.5	Reworked saprolith		

OB-327

Interval	Description	Unit	Munsell color
0-153.5 (ft)	Late Wisconsinan sediment		
153.5-178.5	Gray, hard, loamy till; sandy by 159'; cobble at base	SM	5Y5/1
178.5-183	Silty very fine sand	SK	5Y6/1
183-184.5	Very fine sandy silt, with till bed	SK	5Y5/1
184.5-214	Gray, hard, sandy to loamy till; loamy below 196'	SK	5Y5/1
214-217	Dark greenish gray, hard sandy clay till	SK	5GY4/1
217-219	Sandy till and gravelly sand	SK	
219	Saprolith		

OB-329

Interval	Description	Unit	Munsell color
0-134.5 (ft)	Late Wisconsinan sediment		
134.5-139	Grayish brown sand and gravel; large cobbles, "washed" till?	SM	2.5Y5/2
139-146.5	Greenish gray, very rocky, very gravelly sandy till	SM	5GY5/1
146.5-147.5	Greenish gray, gravelly sandy till	SM	5GY5/1
147.5-149.5	Boulder		
149.5-154	Greenish gray sandy till; sandy clay till below 153'	SM	5GY5/1
154	Saprolith		

OB-331

Interval	Description	Unit	Munsell color
0-86 (ft)	Late Wisconsinan sediment		
86-149.5	Very fine sand; scattered organics	BR	2.5Y7/2
149.5-156.5	Dark gray, hard, clayey till; sandy and silty lenses; loamy in lower part	BR	5Y4/1
156.5-158.5	Silty very fine sand	BR	
158.5-163	Gray loamy till; interbedded silty sand and sandy till below 160'	BR	5Y5/1
163-164.5	Very fine silty sand	BR	2.5Y7/2
164.5-166.5	Silt to silty clay	BR	5Y5/1
166.5-183.5	Sandy silt, little organics	BR	5Y6/1
183.5-205	Silty very fine sand	BR	2.5Y7/2
205-206	Very coarse sand and granules	OR	
206	Precambrian bedrock		

OB-502

Interval	Description	Unit	Munsell color
0-163.5 (ft)	Late Wisconsinan sediment		
163.5-177	Greenish gray silty very fine sand	OR?	5GY5/1, 7/1
177	No core, bedrock at 180'		

OB-505

Interval	Description	Unit	Munsell color
0-150.5 (ft)	Late Wisconsinan till		
150.5-169.5	Dark greenish gray and gray silt	OR	5G4/1, 5Y5/1
169.5-224.5	Dark greenish gray silt to fine sand; little coarse sand below 193'; 7.5YR5/4 clay laminae at 211'	OR	5G4/1
224.5-225	Greenish gray gravelly sand	OR	5G6/1
225-228	Greenish gray rocky till; loose, slightly calcareous	ML?	5G5/1
228-232	Greenish gray, very poorly sorted sandy silt; loose, slightly calcareous	OR	5G5/1
232-234	Greenish gray sandy clay till(?) mixed with saprolite; slightly calcareous	OR	5GY5/1
234	Saprolith		

OB-507

Interval	Description	Unit	Munsell color
0-170 (ft)	Late Wisconsinan sediment		
170-184	Pale brown sandy till	SM	10YR6/3
184-192	Boulder	SM	
192-197	Sand	SM	10YR7/1
197-202	Gray very sandy till with sand beds	SM	5Y5/1
202-203	Gray silt to very silty till; compact	SM	
203-204	Boulder		
204-207	Rocky gravelly sand; grades to till	SK	
207-215	Very sandy till; loose; sandy by 211; compact by 212'	SK	
215-227	Silty sand, fining upwards; cobbly in lower part	SK	
227-228.5	Gray sandy till, compact	SK	5Y5/1
228.5-230	Cobbles	SK	
230-234	Gray sandy clay till, compact	SK	5Y5/1
234-237	Greenish gray silt and dark gray clay, abrupt upper contact; clay light brown and noncalcareous by 236'	SK	5GY5/1, 5Y4/1 7.5YR6/3
237-239	Gravelly sand	ML?	
239	Saprolith		

OB-511

Interval	Description	Unit	Munsell color
0-133.5 (ft)	Late Wisconsinan sediment		
133.5-138.5	Gray loamy till; compact	FK	5Y5/1
138.5-143	Greenish gray sandy till; till-saprolite mix	FK	10GY6/1
143	Saprolith		

OB-512

Interval	Description	Unit	Munsell color
0-84.5 (ft)	Late Wisconsinan sediment		
84.5-87	Gray sandy silt, mottled	BF	N5/0, 5Y5/2
87-89.5	Gray clay till with clay laminae; very compact	BF	5Y5/1
89.5-90.5	Greenish brown clay till; abrupt lower contact	BF	10YR5/2
90.5-104.5	Light grayish brown clayey till; compact; few silt laminae; gray in lower few feet	BF	10YR6/2 2.5Y6/1
104.5	Saprolith		

OB-513

Interval	Description	Unit	Munsell color
0-75 (ft)	Late Wisconsinan sediment		
75-79.5	Grayish brown clayey till; very compact; clay bed at 79'; grades into till below	EB	2.5Y5/2, 5Y5/1 by 76'
79.5-93	Grayish brown clayey till with saprolite	BF	10YR5/2
93	Reworked saprolith		

OB-514

Interval	Description	Unit	Munsell color
0-202.5 (ft)	Late Wisconsinan sediment		
202.5-208	Interbedded gray and greenish gray silt to fine sand, very well sorted	OR?	7.5Y6/1, 5BG6/1
208	No core, over saprolith		

OB-515

Interval	Description	Unit	Munsell color
0-176 (ft)	Late Wisconsinan		
176-191	Gray sandy till, more compact with depth	SM	10Y5/1
191-212.5	Greenish gray sandy till, compact; few sand beds	SM	5GY5/1
212.5	Precambrian bedrock		

OB-517

Interval	Description	Unit	Munsell color
0-55 (ft)	Late Wisconsinan sediment		
55-74.5	Gray, loamy to clayey till; compact; clayey towards base	FK	5Y5/1
74.5-98	Dark grayish brown clayey till; greenish grey colors to 79'; compact; silt bed at 80', silty till below; sandy 87-88'	BF	2.5Y4/2
98-103	Grayish brown clayey silt with dark gray clay laminae; sandy silty in last foot	BF	2.5Y5/2
103-117	Olive gray loamy till	SK	5Y5-4/2
117-121	Dark gray clayey till	WL	2.5Y4/1
121-129	Gray clayey till, dark gray below 125'; silty laminae in lower part, grades to lake sediment	WL	5Y5/1, 5Y4/1
129-136.5	Gray silty clay with clayey silt; thin flow till in few spots; interbedded with underlying till	WL-ML	2.5Y5/1
136.5-220	Gray sandy till, loose to firm; gravel bed at 146', sand beds 163-170'; compact with depth, rocky in places	ML	5Y5/1
220	Precambrian bedrock		

OB-518

Interval	Description	Unit	Munsell color
0-119 (ft)	Late Wisconsinan sediment		
119-128.5	Gray silt, very well sorted; till laminae below about 127'	BR	5Y6/1
128.5-134.5	Gray loamy till; compact; grades to silt below	BR	5Y5/1
134.5-186	Gray silt to very fine sand; well sorted; clay bed at 158', silty till layers 159-161'; charcoal, wood 175-177'	BR	10Y5/1
186-188	Gravelly sand with cobbles; very poorly sorted	EB?	
188-202	Gravelly sand, moderate to poor sorting; very dark gray clayey till 199.5-200.5'	EB	
202-203	Gray sandy silt flow till with ball of dark gray till	EB	5Y5/1
203-229.5	Dark olive gray clayey till; compact	EB	5Y3/2-1 2.5Y3/1 by 220'
229.5-235.5	Very dark gray clay laminated with sandy silt; abrupt lower contact	EB	

OB-518 Continued

235.5-251.5	Gray clayey till, grayish brown by 236.5'; compact; mixed with saprolith below 248'; mostly saprolith below 249.5'	BF	2.5Y5/1 10YR4/2
251.5	Saprolith		

OB-519

Interval	Description	Unit	Munsell color
0-99 (ft)	Late Wisconsinan sediment		
99-114.5	Gray loamy till; silty sand 100-101'; compact; sandy below 111'	BR	10YR5/1
114.5-115.5	Gravelly sand	BR	
115.5-128	Very fine to coarse sand	BR?	
128-131	Gray sandy silt, well sorted	BR?	10Y6/1
131-136.5	Cobbly silty sand and cobbles; boulder 134.5-136	SM	
136.5-139	Gravelly sand	W	
139-140	Very gravelly sandy silt till, loose	W	
140-145	Very dark gray sandy clay till, very compact	BF	5Y3/1-2
145-149	Olive gray silt grading to silty clay; more till-like with depth; gradational upper contact	BF	5Y4/2
149-152.5	Sandy silt, laminated with dark gray loamy till below 150.5'	BF	
152.5-162	Dark grayish brown to dark brown sandy clay till; compact	WL	2.5Y3/2 to 10YR3/3
162	Saprolith		

OB-520

Interval	Description	Unit	Munsell color
0-45.5 (ft)	Late Wisconsinan sediment		
45.5-96	Well sorted fine sand to very poorly sorted gravel, interbedded	W	
96-100.5	Greenish gray clayey till; sandy and gravelly zones	EB	2.5GY5/1
100.5-103	Very fine sand grading to sandy silt, poorly sorted	EB	
103-106	Gravelly sand, cobble	SK	
106-114.5	Greenish gray sandy till interbedded with gravelly sand	SK	2.5GY5/1
114.5-190	Greenish gray sandy till; compact; loam textured by 126', loam to sandy loam below 133', varying to sandy clay loam; rocky in places, abrupt lower contact	SK	2.5GY5/1
190-243	Gray silt to clayey silt, very well sorted	ML	10Y6/1
243-249	Interbedded clay to sandy silt with sandy till, transitional to till below	ML	
249-269.5	Gray sandy till with loamy zones and sand beds, clayey below 268' but abrupt lower contact	ML	10Y5/1 7.5Y4/1
269.5-275	Dark gray silty clay	ML	2.5Y4/1
275-278	Gravelly sand, very poorly sorted	ML	
278-287	Gray loamy till, compact	ML	5Y5/1
287-299	Gray very fine to coarse sand with cobbles		
299	Saprolith		

OB-521

Interval	Description	Unit	Munsell color
0-124 (ft)	Late Wisconsinan sediment		
124-135.5	Dark gray clayey till; compact; more coarse with depth; mixed with gravel towards base, clay bed at base	BR	2.5Y4/1
135.5-192	Gravel with gravelly sand beds; moderately sorted, to very poorly sorted with depth; cobbly in places below 160.5'	W	
192-207	Gray sandy till; more clayey below 204.5', grading to lake clay	SM	10Y5/1
207-211	Very dark gray clay to silty clay, reworked and mixed with loamy till	SM	5Y3/1

OB-521 Continued

211-217	Laminated clay, silty clay, and minor silt, with organics; much harder than above till; mostly silt in last foot, abrupt lower contact	EB	5Y3/1
217-222.5	Gray clayey to loamy till; silt bed 218-219'; compact	EB	5Y5/1
222.5-224	Gravelly sandy silt, grades to gravel below	EB	
224-256.5	Cobbly gravel, very poorly sorted; very abrupt lower contact	OR	
256.5-259	Greenish-gray very fine sand grading to silt	OR	10GY5/1
259-285.5	Interbedded very fine to very coarse sand	OR	
285.5-287.5	Gravelly sandy silt till(?), loose to firm, with incorporated saprolite	OR	
287.5	Saprolith		

KR-71

Interval	Description	Unit	Munsell color
0-139 (ft)	Late Wisconsinan sediment		
139-198.5	Gray to dark gray loamy till; massive; more sandy towards base, probably some mixing with till below; olive gray by 197' and sandy texture, very gradational lower contact	BR	7.5Y5-4/1, 7.5Y5/1 by 150', 7.5Y5-4/1 by 183', 7.5Y5/1 by 191.5', 5Y5/2 by 197'
198.5-204	Gray sandy till; cobble at base	SM	7.5Y5/1
204-226.5	Gray loamy till; gradational upper contact, little iron staining towards top; more clayey from about 212-215'; massive; mixed with silt last few inches	FK	7.5Y5/1, 7.5Y5-4/1 by 214', 7.5Y4/1 by 221'
226.5-229	Gray clayey silt and silt; disturbed bedding with till bed; gradational contacts	FK	5Y5/1
229-230.5	Gray clayey till; grades to silt below	FK	7.5Y5/1-2
230.5-231.5	Laminated silt and clayey silt; last few inches clayey till with greenish weathered pebbles and silt streaks	FK	
231.5	End of hole		

KR-73

Interval	Description	Unit	Munsell color
0-82 (ft)	Late Wisconsinan sediment		
82-98.5	Gray very fine sandy silt; massive, very well sorted; scattered rare coarse grains, also very fine wood, organic fragments; grades to sand below	BR?	5Y6/1
98.5-130	Silty very fine to fine sand; scattered coarse grains, organics, but generally very well sorted	BR?	
130-131.5	Gray silty clayey till; grades to sand below	BR	7.5Y5/1-2
131.5-139	Silty very fine sand; little wood	BR	
139-140	Very fine sandy silt		
140-154.5	Gray clayey to silty clayey till; silt and sand inclusions; abrupt lower contact	BR	7.5Y5/1-2
154.5-156	Laminated silt and clay, grades to till below	BR	5Y5/1
156-156.5	Gray silty clay till; abrupt lower contact	BR	7.5Y5/1
156.5-160	Coarse loamy till; cobble at base	BR	7.5Y5/1
160-164.5	Gray sandy till; more carbonate towards base, but abrupt lower contact	SM	7.5Y5/1
164.5-165.5	Gray clayey till with abundant carbonate; cobble at base	SM?	5Y5/1, 5Y6/1-2 at 165'
165.5-171.5	Olive brown loamy to sandy clayey till; much gray mottling in upper .5', less below; very dense; grades to very dark gray clayey till by 169'; cobble at base	BF	2.5Y5-4/4, 5Y3/1 by 169'
171.5-194	Gray loamy till; abrupt lower contact	SK	7.5Y5/1-2

KR-73 Continued

194-210	Very dark gray clayey till; loamy below 201'; dark gray loamy sand 202-203'; very dark gray loamy till below with sand beds; massive by 207'; abrupt lower contact	WL	5Y3/1, 5Y4-3/1 by 206'
210-222.5	Laminated silt and clayey silt with silty clay and very dark gray clayey till beds; grades to till below	WL	5Y4/1 and 5Y5/1 with 5Y3/1
222.5-226	Gray sandy till; mostly large cobbles of local bedrock below 225.5'	ML	5Y5/1, 10Y5/1 by 225.5'
226	Precambrian bedrock?		

KR-74

Interval	Description	Unit	Munsell color
0-46.5 (ft)	Late Wisconsinan sediment		
46.5-50	Dark gray, organic-rich silty clay loam; massive; grades to silt below	I	2.5Y4/1, 2.5Y3/1 by 47.5', 2.5Y4/1 by 49'
50-54	Greenish gray silt, grading to fine sand with depth; abrupt lower contact	FK	2.5GY6/1, 7.5Y5/2 by 52.5'
54-55.5	Silt grading to pebbly sandy silt grading to till below	FK	2.5GY6/1
55.5-56.5	Sandy to loamy till	FK	2.5GY6/1
56.5-60	Sand over sandy silt, grading to till	FK	
60-92	Greenish gray loamy till; organics, wood fragments below 67'; more brownish zones with larger wood fragments by 85.5'; sandy below 89' grading to sandy silt from 91'	FK	5GY5/1, 2.5GY5/1 by 63', 5Y4/1 at 67', 5GY5/1 at 74', 5GY6/1 by 75.5', 2.5GY5/1 by 84.5', 2.5Y5/1 by 85.5', 10Y5/1 at 89'
92-111.5	Greenish gray clayey till, grading to gray silty till by 95'; loamy till by 105', more sandy with depth, grading to gravelly sand below	FK	2.5GY5/1, 5Y6/2 at 95', 10Y5/1 at 97', 7.5Y5/1 by 101'
111.5-114	Very gravelly loamy sand	FK	
114-117	Light gray gravelly sand	FK	5Y7/1
117-120	Brown sandy till; loamy by 118' with sand streaks; 7.5YR6/2 fine sand bed at 119'; gravelly loam below	FR	10YR4/3, 10YR4/2 by 118'
120-124	Greenish gray loamy sand, grading to gravelly sandy loam by 123', and to till below	EB	2.5GY6/1
124-127	Dark gray clayey till; dense; grades to silt below	EB	5Y4/1
127-132	Gray silt to clayey silt; grades to till below	EB	5Y5/1
132-133	Dark gray clay till with sand inclusions	EB	5Y4/1
133-134	Organic-rich silt	EB	
134-135	Clayey silt with sand and clay laminae; abrupt lower contact	EB	5Y5/1
135-141	Dark gray clayey till; sand and silt inclusions to 139'	EB	5Y4/1
141-143	Silty clay with silt laminae; grades to till below	EB	5Y4/1
143-145.5	Dark gray silty clayey till	EB	5Y4/1
145.5-180	Dark gray clayey till; massive below pebbly zone at 147.5'; organic and pebbly sand inclusion at 158.5', clay till below	EB	5Y4-5/1, 5Y4/1 by 148'
180-182	Clayey silt grading to silt with organics by 180.5'	I	
182-205	Greenish gray loamy till; gray with olive gray mottles 184-188'; organic silt inclusion at 190'; sandy clayey till by 199', mixed with saprolite below 202.5'	SK	2.5GY5/1, 7.5Y5/1 by 184', 5Y4/1 by 188'
205	Saprolith		

[1]Sources of data: OB-200s (Martin and others, 1988), OB-300s (Martin and others,1989), OB-500s (Martin and others, 1991), KR cores (files of MGS and MnDNR-Minerals in Hibbing)

[2]Stratigraphic unit abbreviations: BR, Browerville; SM, Saum; FK, Funkley; FR, First Red; EB, Eagle Bend; BF, Bigfork; SK, Shooks; WL, Wirt Lake; ML, Mulligan Lake; I, Interglacial; OR, Old Rainy, undifferentiated; W, Winnipeg provenance, undiff.

APPENDIX B—TILL TEXTURAL AND SAND-COUNT DATA

(Footnotes are on page 66)

Drill Hole OB-301

Strat. unit[1]	Sediment type	Depth feet	Gravel[2]	Matrix Texture[3]			% 1-2mm Clasts	1-2 mm size clasts4		
				Sand	Silt	Clay		Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BF	Till	51	6	38	41	21	11	86	11	3
BF	Till	55	4	41	39	20	11	88	7	5
BF	Till	59	7	41	38	21	11	84	10	6
BF	Till	62	5	40	38	22	12	85	11.5	3.5
BF avg			5.5	40	39	21	11	86	10	4
SK	Till	66	8	52	29	19	14	-[9]	-	-
SK	Till	70	6	48	30	22	14	96.50	3.50	0
SK	Till	74	11	47	29	24	14	-	-	-
SK	Till	77	7	53	32	15	13	-	-	-
SK	Till	80	6	50	33	17	12	94	6	T[8]
SK	Till	83	6	54	29	17	13	-	-	-
SK	Till	86	8	54	30	16	12	97	3	0
SK avg			7	51	30	19	13	96	4	T

Drill Hole OB-302

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm Clasts	1-2 mm size clasts		
				Sand	Silt	Clay		Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
OR	Till	75	26	63	25	12	14	100	0	0

APPENDIX B—CONTINUED

Drill Hole OB-301 Continued

1-2 mm size clasts

Precambrian[5]				Cretaceous[6]							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others[7]	Unknown Grains	Grains Counted
52	32	15	1	50	7	7	29	0	7	0	2	452
68	21	11	T	23	0	6	71	0	0	0	4	342
65	24	10	1	76	0	0	24	0	0	0	2	315
74	17	8	1	18	0	0	82	0	0	0	2	330
65	23	11	1	42	2	3	51	0	2	0	3	360
-	-	-	-	-	-	-	-	-	-	-	-	-
80	11	8	1	0	0	0	0	0	0	0	3	416
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
73	17	7	3	0	0	0	0	100	0	0	4	481
-	-	-	-	-	-	-	-	-	-	-	-	-
72	21	5	2	0	0	0	0	0	0	0	3	467
75	16	7	2	0	0	0	0	100	0	0	3	455

Drill Hole OB-302 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
33	12	54	1	0	0	0	0	0	0	0	6	494

Drill Hole OB-303

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
OR	Till	141	40	76	16	8	36	100	0	0
W?	Till	145	23	74	21	5	29	-	-	-

Drill Hole OB-306

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
EB	Till	90	1	15	35	50	3	-	-	-
EB	Till	94	4	24	45	31	7	65	35	0
EB	Till	98	7	25	44	31	7	65	35	0
EB	Till	102	2	41	31	28	4	56	44	0
EB	Till	106	1	11	41	48	4	-	-	-
EB	Till	110	1	11	40	49	2	-	-	-
EB	Till	113	10	36	42	22	10	56	44	0
EB	Till	116	20	40	35	25	9	65	35	0
EB	Till	120	3	43	37	20	8	79	21	0
EB	Till	124	2	37	42	21	2	-	-	-
EB	Till	127.5	3	22	35	43	7	83	17	0
avg EB			5	28	39	33	8	67	33	0

Drill Hole OB-303 Continued

1-2 mm size clasts

Precambrian					Cretaceous							Total	Total
Granitics	Quartz	Darks	Others		Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
83	8	9	0		0	0	0	0	0	0	0	1	274
-	-	-	-	-	-	-	-	-	-	-	-	-	-

Drill Hole OB-306 Continued

1-2 mm size clasts

Precambrian					Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others		Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
74	14	11	1		0	0	0	0	0	0	0	0	300
69	11	18	2		0	0	0	0	0	0	0	1	245
76	13	11	0		0	0	0	0	0	0	0	0	293
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
66	7	27	0		0	0	0	0	0	0	0	0	399
69	12	17	2		0	0	0	0	0	0	0	1	404
79	8	13	0		0	0	0	0	0	0	0	0	424
-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	14	14	1		0	0	0	0	0	0	0	1	278
72	11	16	1		0	0	0	0	0	0	0	1	335

Drill Hole OB-307

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SK	Till	206	13	72	14	14	13	98	2	0
SK	Till	210	46	50	26	24	13	97	3	0
SK	Till	214	8	29	42	29	6	-	-	-
SK	Till	217	5	40	32	28	6	98	2	T
SK	Till	220	17	44	35	21	9	99	1	0
SK	Till	223	1	56	25	19	3	-	-	-
SK	Till	226	7	69	16	15	12	98	2	0
SK avg			14	51	27	21	9	98	2	T

Drill Hole OB-314

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	100	4	30	52	18	6	79	21	0
SK	Till	103	22	59	24	17	17	96	4	0
SK	Till	106	4	41	37	22	10	92	8	0
SK avg			13	50	31	20	13.5	94	6	0
SK	Gvlly sand	106.5	24	83	17	-	-	89	11	0

Drill Hole OB-307 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
70	12	17	1	0	0	0	0	0	0	0	1	389
71	6	22	1	0	0	0	0	0	0	0	2	422
-	-	-	-	-	-	-	-	-	-	-	-	-
68	17	15	0	0	0	100	0	0	0	0	3	416
71	11	16	2	0	0	0	0	0	0	0	1	550
-	-	-	-	-	-	-	-	-	-	-	-	-
64	23	12	1	0	0	0	0	0	0	0	0	415
69	14	16	1	0	0	100	0	0	0	0	1	438

Drill Hole OB-314 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
73	11	14	2	0	0	0	0	0	0	0	1	417
84	7	8	1	0	0	0	0	0	0	0	3	225
76	16	8	T	0	0	0	0	0	0	0	1	309
80	11	8	1	0	0	0	0	0	0	0	2	267
73	4	22	1	0	0	0	0	0	0	0	2	291

Drill Hole OB-315

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SK	Till	158	21	44	36	20	6	99	1	0
SK	Till	161	21	41	35	24	12	99	1	0
SK avg			21	43	36	22	9	99	1	0

Drill Hole OB-320

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SK	Till	152	15	62	31	7	9	94	6	0
SK	Till	155	3	49	31	20	7	95	5	0
SK	Till	158	4	42	39	19	10	-	-	-
SK	Till	166	13	46	38	16	17	97	3	0
SK	Till	173.5	7	43	39	18	11	95	5	0
SK avg			-	48	36	16	11	95	5	0
WL	Till	176.5	14	57	28	15	15	78	18	4
WL	Till	179.5	11	40	33	27	18	49	28	23
WL	Till	182.5	4	34	38	28	11	88	8	4
WL	Till	185.5	9	36	36	28	12	87	10	3
WL	Till	186.5	6	55	32	13	9	91	9	0
WL avg			9	44	33	22	13	78	15	7
ML	Till	190	8	64	24	12	12	93	5	2
ML	Till	193	3	54	36	10	10	92	8	0
ML	Till	197	7	50	34	16	12	89	11	0
ML avg			6	56	31	13	11	91	8	1

Drill Hole OB-315 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
70	13	13	4	0	0	0	0	0	0	0	1	237
49	6	45	0	0	0	0	0	0	0	0	0.5	330
59.5	10	29	2	0	0	0	0	0	0	0	1	283.50

Drill Hole OB-320 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
80	15	5	0	0	0	0	0	0	0	0	2	393
82	15	3	0	0	0	0	0	0	0	0	2	277
-	-	-	-	-	-	-	-	-	-	-	-	-
78	18	4	0	0	0	0	0	0	0	0	1	227
80	16	3	1	0	0	0	0	0	0	0	1	352
80	16	4	0	0	0	0	0	0	0	0	1.5	312
78	17	3	2	77	0	8	0	0	15	0	3	301
61	25	12	2	33	9	48	0	0	10	0	0.5	390
75	24	1	0	73	0	0	27	0	0	0	2	306
73	22	4	1	67	0	0	22	11	0	0	2	347
53	34	13	0	0	0	0	0	0	0	0	3	265
68	24	7	1	63	2	14	12	3	6	0	2	322
73	24	2	1	0	0	0	0	100	0	0	2	548
60	28	11	1	0	0	0	0	0	0	0	4	303
71	25	4	0	0	0	0	0	0	0	0	1	406
68	26	6	T	0	0	0	0	100	0	0	2	419

Drill Hole OB-321

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Sand	134	17	89	11	-	-	91	9	0
BR	Gvlly sand	139	30	98	2	-	-	87	13	0
BR	Sand	143.5	10	96	4	-	-	-	-	-
I	Overbank	156	0	52	32	16	0.40	-	-	-
SM	Till	175	20	54	32	14	11	98	2	0
EB	Till	177	1	13	37	50	5	75	25	0
ML	Till	191	1	26	62	12	3	-	-	-
ML	Till	194	13	65	28	7	8	97	3	0
ML	Till	197	11	58	33	9	7	-	-	-
ML	Till	200	12	61	32	7	8	98	2	0
ML	Till	203	27	67	26	7	9	-	-	-
ML	Till	206	8	65	24	11	7	95	5	0
ML	Till	209	19	62	24	14	7	-	-	-
ML	Till	212	8	68	23	9	8	94	6	0
ML	Till	215	5	63	28	9	5	-	-	-
ML	Till	218	5	60	27	13	5	96	4	0
ML	Till	227	7	67	23	10	6	91	9	0
ML	Till	230	8	73	20	7	7	-	-	-
ML	Till	235	3	66	22	12	5	94	6	0
ML avg			10	62	28	10	7	95	5	0
ML	Sand	246	10	93	7	–	-	-	-	-
ML	Sand	255	12	93	5	2	-	-	-	-

Drill Hole OB-322

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SM	Sand	189	5	92	8	–	-	-	-	-
SM	Till	192	41	64	23	13	14	98	2	T
SM	Till	195	23	48	32	20	18	98	2	0
SM avg			32	56	28	17	16	98	2	T

Drill Hole OB-321 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
69	15	13	3	0	0	0	0	0	0	0	1	552
70	12	14	4	0	0	0	0	0	0	0	1	429
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
64	12	23	1	0	0	0	0	0	0	0	0.5	561
84	7	8	1	0	0	0	0	0	0	0	0	212
-	-	-	-	-	-	-	-	-	-	-	-	-
74	14	12	0	0	0	0	0	0	0	0	0.5	310
-	-	-	-	-	-	-	-	-	-	-	-	-
69	11	20	0	0	0	0	0	0	0	0	0	265
-	-	-	-	-	-	-	-	-	-	-	-	-
74	14	12	0	0	0	0	0	0	0	0	1	307
-	-	-	-	-	-	-	-	-	-	-	-	-
69	17	14	T	0	0	0	0	0	0	0	2	379
-	-	-	-	-	-	-	-	-	-	-	-	-
70	16	14	0	0	0	0	0	0	0	0	2	399
74	18	8	0	0	0	0	0	0	0	0	0	332
-	-	-	-	-	-	-	-	-	-	-	-	-
73	15	11	1	0	0	0	0	0	0	0	0	424
72	15	13	T	0	0	0	0	0	0	0	1	345
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-

Drill Hole OB-322 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
-	-	-	-	-	-	-	-	-	-	-	-	-
73	2	24	1	0	0	100	0	0	0	0	0.5	251
93	2	4	1	0	0	0	0	0	0	0	0.5	343
83	2	14	1	0	0	100	0	0	0	0	0.5	297

Drill Hole OB-325

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SK	Till	74	6	46	22	32	6	94	6	0
SK	Till	76.5	4	56	24	20	6	93	7	0
SK	Till	79.5	5	51	30	19	6			
SK	Till	82.5	3	35	23	42	5	91	9	0
SK	Till	85.5	2	49	27	24	5			
SK	Till	89	2	47	26	27	5	95	5	0
SK	Till	92.5	3	65	21	14	5	89	11	0
SK avg			4	50	25	25	5	92	8	0
ML	Gvlly sand	115	38	97	3	-	-	-	-	-
ML	Sand	171	12	97	3	-	-	-	-	-
ML	Gvlly sand	221	31	99	1	-	-	-	-	-
ML	Till?	238	48	78	19	3	26	95	5	0
ML	Sand	246	7	97	3	-	-	-	-	-
ML	Till balls	254.5	9	72	25	3	18	96	4	0
ML avg			28.50	75	22	3	22	95.5	4.5	0

Drill Hole OB-326

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
OR	Till ball	135	34	65	26	9	11	100	0	0
OR	Sand	202	1	99	1	0	-	97	3	0
OR	Till	229.5	27	52	37	11	16	98	2	0

Drill Hole OB-325 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime- stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
72	19	9	0	0	0	0	0	0	0	0	0.5	414
77	12	11	0	0	0	0	0	0	0	0	2	424
-	-	-	-	-	-	-	-	-	-	-	-	-
67	21	12	0	0	0	0	0	0	0	0	1	266
-	-	-	-	-	-	-	-	-	-	-	-	-
71	22	7	0	0	0	0	0	0	0	0	3	379
63	22	15	0	0	0	0	0	0	0	0	0.5	267
70	19	11	0	0	0	0	0	0	0	0	1	350
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
62	12	26	T	0	0	0	0	0	0	0	1	350
-	-	-	-	-	-	-	-	-	-	-	-	-
67	20	11	2	0	0	0	0	0	0	0	1	304
65	16	19	1	0	0	0	0	0	0	0	1	327

Drill Hole OB-326 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime- stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
72	15	13	0	0	0	0	0	0	0	0	3	371
70	16	10	4	0	0	0	0	0	0	0	0	339
82	5	13	0	0	0	0	0	0	0	0	0	450

Drill Hole OB-327

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SM	Till	155	4	50	33	17	5	88	12	0
SM	Till	158	31	49	38	13	10	-	-	-
SM	Till	161	5	57	31	12	7	-	-	-
SM	Till	164	5	53	34	13	8	96	4	0
SM	Till	167	7	58	30	12	7	-	-	-
SM	Till	170	12	56	31	13	10	-	-	-
SM	Till	173	5	56	31	13	6	92	8	0
SM	Till	176	5	65	21	14	8	-	-	-
SM avg			9	56	31	13	8	92	8	0
SK	Till	187	4	63	21	16	6	94	6	0
SK	Till	190	5	51	31	18	7	90	10	0
SK	Till	193	5	44	31	25	6	89	11	0
SK	Till	196	2	53	31	16	6	-	-	-
SK	Till	199	1	43	35	22	5	-	-	-
SK	Till	202	3	47	33	20	6	89	11	0
SK	Till	205	5	46	35	19	6	-	-	-
SK	Till	208	4	46	34	20	6	-	-	-
SK	Till	211	2	46	33	21	6	83	17	0
SK	Till	214.5	3	53	25	22	7	-	-	-
SK	Till	217.5	15	78	14	8	11	-	-	-
SK avg			4	52	29	19	7	89	11	0

Drill Hole OB-329

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SM	Gvlly sand	136	27	90	6	4	-	-	-	-
SM	Till	140	61	54	34	12	20	95	5	0
SM	Till	143	58	57	30	13	27	-	-	-
SM	Till	147	31	66	24	10	22	93	7	0
SM	Till	150	3	58	29	13	6	-	-	-
SM	Till	153	7	50	28	22	12	93	6.5	0.5
SM avg			32	57	29	14	17	94	6	T

Drill Hole OB-327 Continued

1-2 mm size clasts

Precambrian					Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others		Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
54	21	25	T		0	0	0	0	0	0	0	2	261
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
74	8	18	0		0	0	0	0	0	0	0	0	245
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
73	7	20	0		0	0	0	0	0	0	0	0.5	302
-	-	-	-	-	-	-	-	-	-	-	-	-	-
67	12	21	T		0	0	0	0	0	0	0	1	269
77	13	10	0		0	0	0	0	0	0	0	1	275
63	22	15	0		0	0	0	0	0	0	0	2	411
63	24	13	0		0	0	0	0	0	0	0	0.5	445
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
68	18	14	0		0	0	0	0	0	0	0	T	416
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
77	11	12			0	0	0	0	0	0	0	1	489
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	18	13	0		0	0	0	0	0	0	0	1	407

Drill Hole OB-329 Continued

1-2 mm size clasts

Precambrian					Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others		Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	12	30	3		0	0	0	0	0	0	0	2	306
-	-	-	-	-	-	-	-	-	-	-	-	-	-
62	8	28	2		0	0	0	0	0	0	0	2	373
-	-	-	-	-	-	-	-	-	-	-	-	-	-
78	12	9	1		0	0	0	0	50	50	0	3	411
65	11	22	2		0	0	0	0	50	50	0	2	363

Drill Hole OB-331

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	149.5	3	35	36	29	5	74	20	6
BR	Till	153	2	30	43	27	6	75	21	4
BR	Till	156	4	42	36	22	5	78	18	4
BR	Till	159	8	43	33	24	7	75	21	4
BR	Till	162	12	54	35	11	7	79	15	6
BR avg			6	41	37	23	6	76	19	5
BR	Flow till?	166	1	6	44	50	5	-	-	-
OR	Gvlly sand	205.5	22	79	21	-	-	-	-	-

Drill Hole OB-507

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SM	Till	184	9	72	19	9	10	96	4	0
SK	Till	212	6	58	23	19	10	98	2	T
SK	Till	231	5	52	27	21	9.5	95	5	0
Sk avg			5.5	55	25	20	10	96.5	3.5	T

Drill Hole OB-511

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
FK	Till	135	9	51	37	12	10	55	44	1

Drill Hole OB-331 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
79	8	9	4	8	0	92	0	0	0	0	0.5	213
86	4	10	0	0	0	88	0	0	12	0	2	400
80	6	12	2	0	0	100	0	0	0	0	0	265
76	8	14	2	6	0	94	0	0	0	0	0	401
74	9	15	2	0	0	85	7	4	4	0	0.5	467
79	7	12	2	3	0	92	1	1	3	0	1	349
-	-	-	-	- -	-	-	-	-	-	-	-	-
-	-	-	-	- -	-	-	-	-	-	-	-	-

Drill Hole OB-507 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
36	48	15	1	0	0	0	0	0	0	0	7	428
35	53	12	0	0	0	0	0	0	100	0	3	355
30	57	13	0	0	0	0	0	0	0	0	4	310
33	55	12	0	0	0	0	0	0	100	0	3.5	364

Drill Hole OB-511 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
60	21	18	1	0	0	0	0	0	100	0	1	285

Drill Hole OB-512

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BF	Till	88	2	27	26	47	8	91	9	0
BF	Till	98	3	28	43	29	11	88	11	1
BF avg			3	27	35	38	9.50	89.5	10	0.5

Drill Hole OB-513

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
EB	Till	77	3	29	38	33	9	59	40	1

Drill Hole OB-515

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
SM	Till	179	9	63	24	13	9.5	89	11	0
SM	Till	200	6	61	26	13	9	90	10	0
SM avg			7.5	62	25	13	9	89.5	11	0

Drill Hole OB-512 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Reds & Others	Unknown Grains	Grains Counted
60	20	20	0	0	0	0	0	0	0	0	1	324
31	31	35	3	0	0	0	0	0	0	100	3	415
46	25	28	1.5	0	0	0	0	0	0	100	2	369.5

Drill Hole OB-513 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
46	31	22	1	67	0	0	0	0	33	0	2	336

Drill Hole OB-515 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
56	28	15	1	0	0	0	0	0	0	0	1	344
63	25	12	T	0	0	0	0	0	0	0	1	354
60	27	13	0.5	0	0	0	0	0	0	0	1	349

Drill Hole OB-517

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm	1-2 mm size clasts		
				Sand	Silt	Clay	Clasts	Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
FK	Till	60	6	36	37	27	9	66	34	0
BF	Till	86	3	29	37	34	7.5	80	19	1
SK	Till	106	7	50	31	19	9	83	17	T
WL	Till	119	8	36	31	33	9	81	19	T
WL	Till	127	5	41	28	31	10	78	22	0
WL avg			6.5	39	29	32	9.5	79.5	21	T
ML	Till	144	6	57	30	13	12	88	11	1
ML	Till	179	11	67	22	11	10	84	16	0
ML avg			8.5	62	26	12	11	86	14	0.5

Drill Hole OB-518

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm	1-2 mm size clasts		
				Sand	Silt	Clay	Clasts	Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	130	3	36	43	21	9	77	22	1
EB	Till	206	5	29	35	36	10.5	39	58	3
BF	Till	238	3	36	33	31	9	82	17	1

Drill Hole OB-519

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm	1-2 mm size clasts		
				Sand	Silt	Clay	Clasts	Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	104	6	47	33	20	10.5	74	26	T
BF	Till	142	4	50	27	23	9	83	15	2
WL	Till	156	6	49	24	27	9	93	6	1

Drill Hole OB-517 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
68	18	14	T	0	0	0	0	0	0	0	0.5	370
57	29	12	2	0	0	0	0	0	25	75	0.5	306
61	28	10	0.5	0	0	0	0	0	0	100	1	488
58	29	11	2	0	0	0	0	0	0	100	1	385
55	30	14	1	0	0	0	0	0	0	0	0	255
57	30	12	1	0	0	0	0	0	0	100	0.5	320
52	31	16	1	50	0	0	0	0	0	50	1	421
52	30	17	1	0	0	0	0	0	0	0	2	371
52	31	16	1	50	0	0	0	0	0	50	1.5	396

Drill Hole OB-518 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
62	23	14	1	0	0	0	0	0	0	100	0.5	372
33	49	16	2	64	0	0	27	0	9	0	0.5	364
39	48	11	2	40	0	0	0	0	0	60	12	433

Drill Hole OB-519 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
67	18	14	1	0	0	0	0	0	0	100	1	304
28	66	5	1	67	0	0	0	0	33	0	4	278
56	34	10	T	33	0	0	0	0	0	67	4	320

Drill Hole OB-520

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
EB	Till	100	2	35	29	36	8	64	34	2
SK	Till	107	6	59	26	15	10	86	13	1
SK	Till	127	6	49	30	21	10	90	10	T
SK	Till	148	5	59	25	16	9	87	13	T
SK	Till	171	8	53	25	22	10	88	12	0
Sk avg			6	55	27	18	10	88	12	T
ML	Till	250	11	62	22	16	10	77	23	T
ML	Till	279	5	51	31	18	10	74	26	T
ML avg			8	57	26	17	10	75.5	25	T

Drill Hole OB-521

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	125	4	42	22	36	10	85	14	1
SM	Till	195	8	58	27	15	12	91	9	0
EB	Till	220	4	29	44	27	11	39	60	1

Drill Hole OB-520 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
73	13	14	0	0	0	0	0	0	33	67	1	409
51	32	15	2	0	0	0	0	0	25	75	3	333
53	27	20	T	0	0	0	0	0	100	0	4	307
54	25	19	2	100	0	0	0	0	0	0	2	356
51	33	15	1	0	0	0	0	0	0	0	1	342
52	29	17	2	50	0	0	0	0	50	0	3	334.5
53	31	16	0	0	0	0	0	0	0	100	1	307
61	21	17	1	100	0	0	0	0	0	0	0	323
57	26	16	0.50	50	0	0	0	0	0	50	0.5	315

Drill Hole OB-521 Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
55	34	11	0	67	0	0	0	0	0	33	1	279
51	34	14	1	0	0	0	0	0	0	0	2	453
40	38	20	2	100	0	0	0	0	0	0	0.5	348

Drill Hole KR-71

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till ball	95	1	33	42	25		70	22	8
BR	Till	140	5	35	38	27	5	66	34	0
BR	Till	144	3	38	39	23	5	71	29	T
BR	Till	148	3	44	36	20	4	68	32	0
BR	Till	152	6	44	36	20	6	-	-	-
BR	Till	156	7	48	31	21	6	78	22	0
BR	Till	160	3	45	35	20	5	-	-	T
BR	Till	164	9	45	35	20	6	73	27	0
BR	Till	168	6	41	36	23	5	-	-	T
BR	Till	172	6	39	37	24	5	69	31	T
BR	Till	180	9	44	36	20	6	-	-	-
BR	Till	184	3	44	34	22	6	71	29	0
BR	Till-lk sed?	188	0.5	27	43	30	3	-	-	-
BR	Till	192	4	49	32	19	6	82	18	T
BR	Till	196	4	51	30	19	6	-	-	-
BR avg			5	42	36	22	5	72	28	T
SM	Till	200	4	57	27	16	6	84	16	0
SM	Till	204	3	56	29	15	8	79	21	0
SM avg			3.5	57	28	16	7	81.5	18.5	0
FK	Till	208	6	41	36	23	5	75	24	1
FK	Till	212	6	35	36	29	4	-	-	-
FK	Till	216	2	39	38	23	3	44	55	1
FK	Till	220	2	49	30	21	4	59	41	0
FK	Till	224	3	46	32	22	5	58	40	2
FK	Till	229	5	31	37	32	5	41	58	1
FK avg			4	40	35	25	4	55	44	1

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
79	7	14	T	4	0	76	0	20	0	0	1	316
70	13	16	1	0	0	0	0	0	0	0	1	225
73	10	16	1	100	0	0	0	0	0	0	0	263
75	8	15	2	0	0	0	0	0	0	0	1	257
-	-	-	-	- -	-	-	-	-	-	-	-	-
74	4	21	1	0	0	0	0	0	0	0	0.5	462
-	-	-	-	- -	-	-	-	-	-	-	-	-
78	7	15	0	0	0	0	0	0	0	0	0.5	324
-	-	-	-	- -	-	-	-	-	-	-	-	-
69	11	18	2	0	100	0	0	0	0	0	1	313
-	-	-	-	- -	-	-	-	-	-	-	-	-
77	6	16	1	0	0	0	0	0	0	0	0	344
-	-	-	-	- -	-	-	-	-	-	-	-	-
68	9	20	3	0	0	100	0	0	0	0	0.5	429
-	-	-	-	- -	-	-	-	-	-	-	-	-
73	9	17	1	33	33	34	0	0	0	0	0.5	327
73	7	20	0	0	0	0	0	0	0	0	0	256
72	9	17	2	0	0	0	0	0	0	0	1	302
73	8	19	1	0	0	0	0	0	0	0	0.5	279
65	11	22	2	100	0	0	0	0	0	0	1	282
-	-	-	-	- -	-	-	-	-	-	-	-	-
78	10	11	1	0	0	100	0	0	0	0	0	372
76	7	15	2	0	0	0	0	0	0	0	0.5	288
79	7	12	2	0	0	20	0	60	20	0	0.5	286
76	7	17	0	0	0	100	0	0	0	0	0	238
75	8	16	1	0	0	73	0	20	7	0	0.5	293

Drill Hole KR-73

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture Sand	Silt	Clay	% 1-2mm Clasts	1-2 mm size clasts: Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Flow till	130.5	7	18	43	39	11	70	30	T
BR	Till	142	3	16	40	44	10	-	-	-
BR	Till	146	3	23	41	36	8	77	23	0
BR	Till	150	3	18	49	33	9	75	24	1
BR	Till	154	7	31	36	33	9	71	29	0
BR	Till	158	6	49	35	16	13	69	31	0
BR avg			5	26	41	34	10	73	27	T
SM	Till	162	12	69	22	9	12	73	25	2
BF	Till	166	3	47	28	25	9	83	17	0
BF	Till	170	4	30	34	36	9	81	11	8
BF avg			3.5	39	31	31	9	82	14	4
SK	Till	174	13	50	31	19	11	82	18	0
SK	Till	178	8	47	31	22	9	-	-	-
SK	Till	182	7	49	32	19	9	82	17	1
SK	Till	186	12	50	30	20	10	-	-	-
SK	Till	190	7	50	31	19	11	78	22	0
SK avg			9	49	31	20	10	81	19	T
WL	Till	194	3	37	35	28	10	85	7	8
WL	Till	198	6	35	36	29	10	86	8	6
WL	Till	202	4	42	34	24	9	86	7	7
WL	Till	206	7	50	33	17	13	83	9	8
WL	Till	210	6	46	32	22	12	84	11	5
WL	Till	212.5	3	30	41	29	11	87	7	6
WL avg			5	40	35	25	11	85	8	7
ML	Till	223	11	63	28	9	8	90	8	2
ML	Till	225.5	9	72	15	13	11	94	6	T
ML avg			10	68	22	11	10	92	7	1

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
64	16	18	2	100	0	0	0	0	0	0	2	252
-	-	-	-	-	-	-	-	-	-	-	-	-
68	11	19	2	0	0	0	0	0	0	0	0	271
66	19	13	2	67	33	0	0	0	0	0	0.5	278
64	23	12	1	0	0	0	0	0	0	0	2	397
72	11	15	2	0	0	0	0	0	0	0	0.5	414
67	16	15	2	84	16	0	0	0	0	0	1	322
84	5	11	0	50	0	0	50	0	0	0	1	284
52	41	6	1	0	0	0	0	0	0	0	4	339
80	15	4	1	49	9	0	36	0	6	0	2	426
66	28	5	1	49	9	0	36	0	6	0	3	382.50
83	9	8	T	0	0	0	0	0	0	0	4	351
-	-	-	-	-	-	-	-	-	-	-	-	-
62	28	9	1	0	0	0	0	0	100	0	2	318
-	-	-	-	-	-	-	-	-	-	-	-	-
61	31	7	1	0	0	0	0	0	0	0	2	396
69	22	8	1	0	0	0	0	0	100	0	3	355
77	15	8	T	35	7	0	55	0	3	0	2	534
69	26	4	1	35	15	0	50	0	0	0	4	481
65	27	7	1	50	18	0	32	0	0	0	5	503
68	22	9	1	47	13	0	29	0	11	0	4	487
69	24	7	T	67	17	0	17	0	0	0	3	387
69	22	8	1	71	0	0	17	0	12	0	3	439
69	23	7	1	51	12	0	33	0	4	0	3.5	472
71	18	9	2	0	0	0	0	88	12	0	2	345
66	24	9	1	0	0	0	0	100	0	0	3	279
69	21	9	1.5	0	0	0	0	94	6	0	2.5	312

Drill Hole KR-74

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm Clasts	1-2 mm size clasts		
				Sand	Silt	Clay		Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
I	Org. sed	48	0	2	61	37	-	-	-	-
FK	Till	60	6	43	39	18	9	51	49	0
FK	Till	64	8	41	41	18	10	-	-	-
FK	Till	68	6	32	48	20	8	51	49	0
FK	Till	72	5	31	43	26	9	-	-	-
FK	Till	76	10	44	44	12	9	-	-	-
FK	Till	80	7	42	45	13	9	54	46	0
FK	Till	84	9	40	43	17	10	-	-	-
FK	Till	88	6	34	49	17	10	-	-	-
FK	Till	92	6	35	37	28	9	55	45	0
FK	Till	97	4	35	54	11	9	-	-	-
FK	Till	101	7	36	51	13	10	56	44	0
FK	Till	105	3	39	49	12	9	-	-	-
FK	Till	109	5	50	40	10	9	-	-	-
FK avg			6	39	45	16	9	53	47	0
FK	Silty S & G	112.50	54	75	23	2	33	-	-	-
FR	Till	117	5	58	29	13	4	79	21	0
FR	Till	119	5	43	32	25	8	87	12	1
FR avg			21	59	28	13	15	83	16.5	0.5
EB	Flow till	123	24	68	19	13	19	64	36	0
EB	Till	125	2	28	45	27	10	36	62	2
EB	Till	132.5	4	20	38	42	9	-	-	-
EB	Till	135.5	4	24	44	32	10	-	-	-
EB	Till	139	4	28	44	28	10	37	63	0
EB	Till	143	3	15	47	38	8	-	-	-
EB	Till	147	13	34	42	24	14	-	-	-
EB	Till	151	6	22	42	36	10	37	60	3
EB	Till	155	7	21	40	39	10	-	-	-
EB	Till	159	3	19	38	43	10	44	55	1
EB	Till	163	4	17	37	46	11	-	-	-
EB	Till	167	2	17	36	47	10	41	59	0
EB	Till	171	2	15	37	48	10	-	-	-
EB	Till	175	1	14	36	50	8	-	-	-
EB	Till	179	5	14	36	50	11	44	56	0
EB avg			6	24	39	38	11	43	56	1
SK	Till	183	3	48	29	23	8	83	17	0
SK	Till	187	4	50	30	20	8	-	-	-
SK	Till	191	3	50	28	22	9	84	15	1
SK	Till	195	4	50	28	22	9	-	-	-
SK	Till	199	4	52	26	22	9	87	12	1
SK	Till	203	6	62	25	13	14	-	-	-
SK avg			4	52	28	20	9.5	85	15	T

1-2 mm size clasts

Precambrian					Cretaceous								Total	Total
Granitics	Quartz	Darks	Reds & Others		Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	5	22	2		0	0	0	0	0	0	0	0	261
-	-	-	-	-	-	-	-	-	-	-	-	-	-
69	18	11	2		0	0	0	0	0	0	0	3	380
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
80	10	11	1		0	0	0	0	0	0	0	0.5	282
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
79	7	9	5		0	0	0	0	0	0	0	1	440
-	-	-	-	-	-	-	-	-	-	-	-	-	-
73	11	14	2		0	0	0	0	0	0	0	0.5	417
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
75	10	13	2		0	0	0	0	0	0	0	1	356
-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	12	17	15		0	0	0	0	0	0	0	0	364
36	19	20	25		50	0	0	0	50	0	0	6	483
46	16	19	20		50	0	0	0	50	0	0	3	423
58	23	17	2		0	0	0	0	0	0	0	2	409
58	27	13	2		50	13	0	12	0	25	0	2	440
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
74	14	11	1		0	0	0	0	0	0	0	1	412
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	28	11	5		29	0	0	43	0	14	14	3	283
-	-	-	-	-	-	-	-	-	-	-	-	-	-
72	19	9	0		0	50	0	50	0	0	0	2	294
53	37	9	1		0	0	0	0	0	0	0	1	272
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
85	9	6	T		0	0	0	0	0	0	0	1	384
65	22	11	1.6		26	21	0	35	0	13	5	2	356
84	9	7	T		0	0	0	0	0	0	0	0	293
-	-	-	-	-	-	-	-	-	-	-	-	-	-
82	10	6	2		0	0	50	0	50	0	0	1	373
-	-	-	-	-	-	-	-	-	-	-	-	-	-
65	27	6	2		100	0	0	0	0	0	0	5	405
-	-	-	-	-	-	-	-	-	-	-	-	-	-
77	15	6	2		50	0	25	0	25	0	0	2	357

Drill Hole KIB-69A

Strat. unit	Sediment type	Depth feet	Gravel	Matrix Texture			% 1-2mm Clasts	1-2 mm size clasts		
				Sand	Silt	Clay		Total Precambrian Grains	Total Paleozoic Grains	Total Cretaceous Grains
BR	Till	138.5	12	37	49	14	9	76	24	0
BR	Till	141.5	7	48	33	19	10	74	26	0
BR	Till	142.5	8	49	36	15	8	73	27	0
BR	Till	146.5	10	49	37	14	10	67	33	0
BR avg			9	46	39	15	9	72.5	27.5	0

[1]Stratigraphic unit abbreviations: BR, Browerville; SM, Saum; FK, Funkley; FR, First Red; EB, Eagle Bend; BF, Bigfork; SK, Shooks; WL, Wirt Lake; ML, Mulligan Lake; I, Interglacial; OR, undifferentiated Old Rainy provenance; and W, undifferentiated Winnipeg provenance.

[2]Gravel reported as weight percent of total sample.

[3]Matrix textures sand, silt, and clay reported as percentage of grains counted in the 2-mm and smaller size fraction.

[4]Reported as percentage of grains counted in the 2-mm and smaller size fraction after grains of the unknown category are excluded.

[5]Reported as percentage of grains counted in clasts of Precambrian derivation.

[6]Reported as percentage of grains counted in clasts of Cretaceous derivation.

[7]Other clasts of Cretaceous derivation from the Lake of the Woods area include grains of quartz sandstone; several of these grains also were noted in the Koochibel area, but were counted as part of the Unknown category.

[8]T (trace) represents a calculated value of less than 0.5 percent.

[9]- Not analyzed.

Drill Hole KIB-69A Continued

1-2 mm size clasts

Precambrian				Cretaceous							Total	Total
Granitics	Quartz	Darks	Reds & Others	Lime-stone	Shell Fragments	Gray Shale	Speckled Shale	Lignite	Pyrite	Others	Unknown Grains	Grains Counted
76	7	15	2	0	0	0	0	0	0	0	0	309
72	11	17	0	0	0	0	0	0	0	0	0.5	240
83	4	12	1	0	0	0	0	0	0	0	2	395
75	3	19	3	0	0	0	0	0	0	0	2	476
77	6	16	2	0	0	0	0	0	0	0	1.1	355