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Tills Underlying the Sediments of Glacial Lake Souris North-Central North Dakota

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TILLS UNDERLYING THE SEDIMENTS OF
GLACIAL LAKE SOURIS,
NORTH-CENTRAL NORTH DAKOTA

by

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ACKNOWLEDGEMENTS

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I would like to give special thanks to Mark Lord for his continual help in planning, completing, and presenting this thesis. His continual encouragement and prodding were instrumental in finishing this project.

ABSTRACT

During the Pleistocene, the Wisconsinan ice sheet retreated from North Dakota leaving a veneer of glacial drift over the landscape. In the north-central area of the state, as the Souris Lobe retreated, Glacial Lake Souris formed and deposited mostly sand and silt over a large area of till. The purpose of this study was to characterize the till beneath Lake Souris sediments and to determine which descriptive parameters are most useful for till data analysis.

The area of study is in McHenry and western Pierce Counties and is contained entirely within the Glacial Lake Souris basin. The North Dakota Geological Survey drilling rig was used to drill holes, 36 of which penetrated till; a total of 109 samples were collected. Till was characterized on the basis of textural and lithologic analyses, in addition to visual hand-sample descriptions. The textural analyses provided sand, silt, and clay percentages, whereas the lithologic analysis provided percentages of fragments of certain rock types (crystalline, carbonate, sandstone and siltstone, shale, and lignite) in the very-coarse sand fraction of the till. The best parameters for characterizing the till were percent normalized silt (silt % / silt % + clay %) plotted against percent normalized crystalline (xtal % / xtal % + carbonate %) and percent sand.

The lithologic data show an increase in percent crystalline rock fragments and a corresponding decrease in percent sandstone and percent carbonate fragments in a southeasterly direction.

Percentages of sandstone, siltstone, and lignite fragments peak in the center of the lake basin and decrease toward the edges. The textural data show that percent clay changes little throughout the basin while silt values are high in the basin center and sand is high near the basin margins.

The lithologic data indicate that differential resistance of rocks resulted in relative increases in the resistant rock types in the down-glacier direction. With the data obtained from the study, it was possible to identify two tills within the study area. The first till, an older unit, was found in several holes that formed a northwest-to-southeast-trending linear band near the southwest margin of the basin. The second, a younger till, was found throughout the basin.

INTRODUCTION

Purpose

The purpose of this study is to characterize the tills found beneath the sediments of Glacial Lake Souris, both texturally and lithologically, and to determine which parameters are best for characterizing tills in this study. The results of the analyses will be used to deduce the number of tills present in the study area. The area chosen was studied in conjuntion with a study done on Glacial Lake Souris by Mark Lord for his doctoral dissertation. Tills to the west in Ward County and to the east in Pierce County were studied by Kehew (1983) and Schnacke (1982), respectively, but tills hadn't been studied extensively in McHenry County. The information from this study could be used to correlate tills in the area and other parts of North Dakota.

Area of Study

The section studied is the Pleistocene sequence in the Glacial Lake Souris basin of McHenry County and western Pierce County of north-central North Dakota (Figure 1). Specifically, the area lies between T.151 N. and T.160 N. and between R.71 W. and R.80 W. (Figure 2). The area is located entirely within the Glacial Lake Souris basin.

NORTH DAKOTA

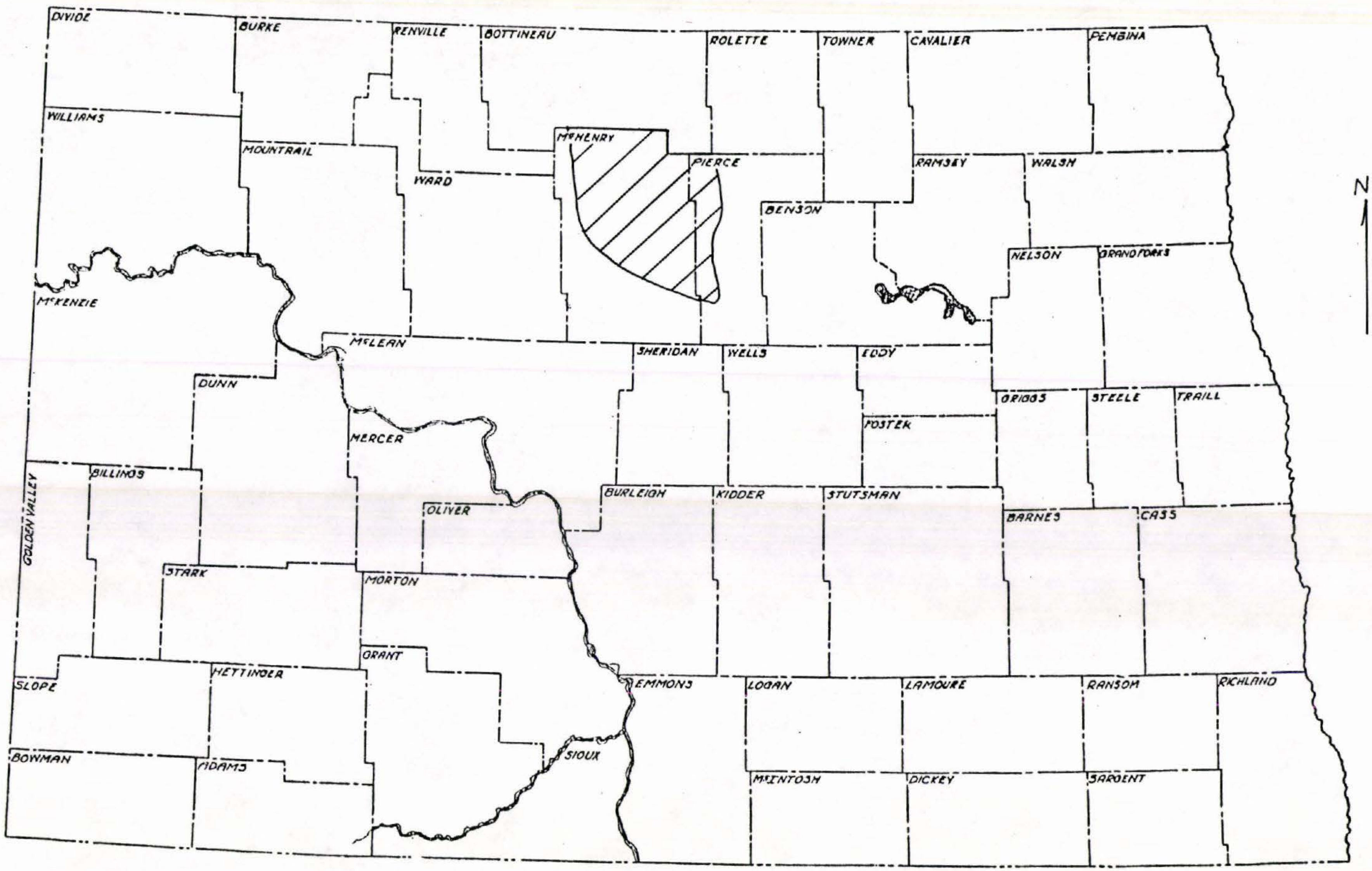


Figure 1. Area of Study

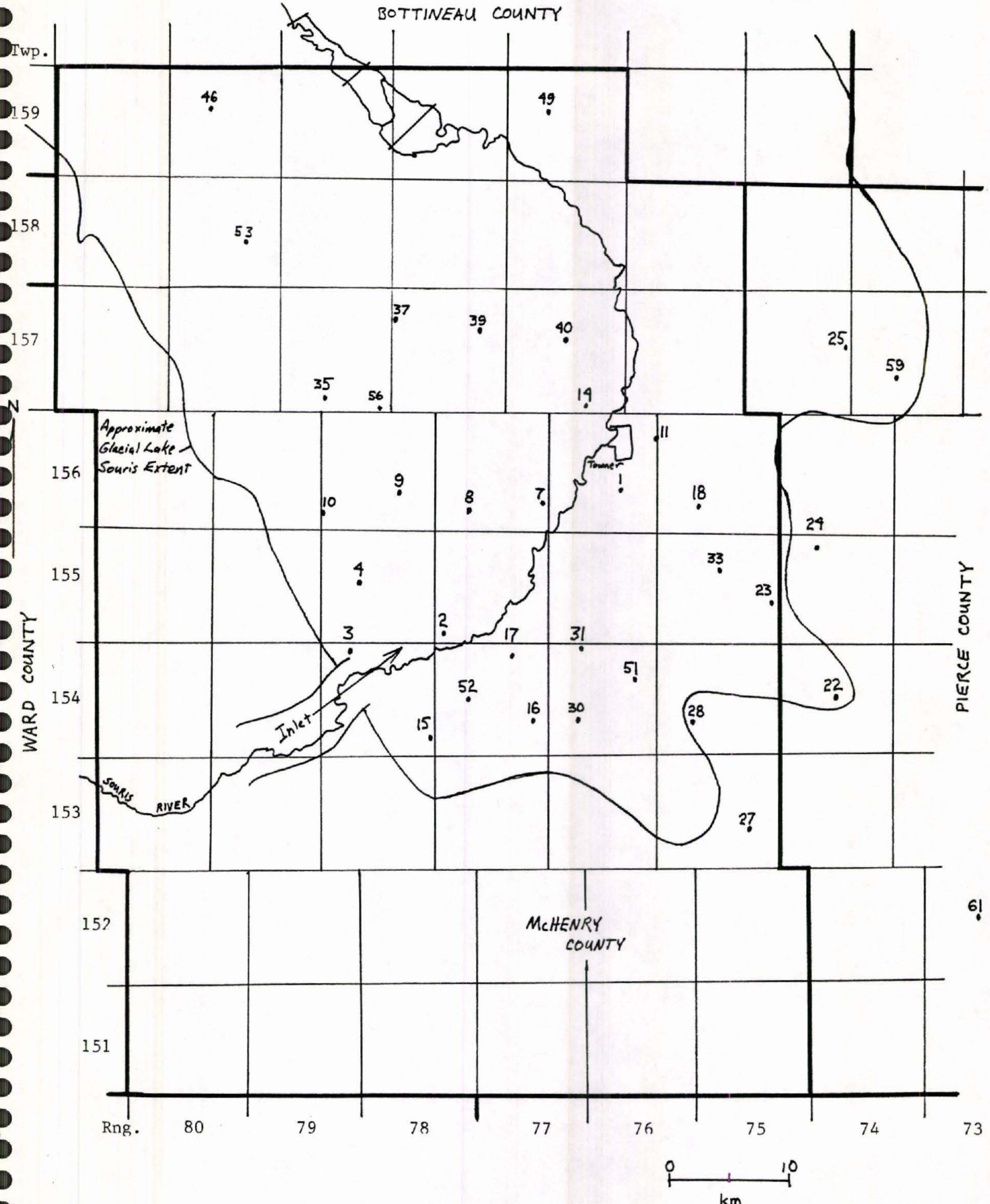


Figure 2. Location of sample holes within the Glacial Lake Souris basin.

Glacial History of the Area of Study

During the Pleistocene epoch, the Wisconsinan ice sheet extended as far south as Iowa and covered all but the southwestern corner of North Dakota. As the late-Wisconsinan glacier began to recede from North Dakota, it became too thin to flow over the Turtle Mountains and stagnated there about 12,000 years ago (Clayton, Moran, and Bluemle, 1980). At lower elevations, however, the glacier still flowed around the Turtle Mountains as two separate lobes, the Leeds and the Souris. The Leeds Lobe flowed southward around the east side of the Turtle Mountains and the Souris Lobe flowed southeastward around the west side (Figure 3) (Bluemle, 1985).

While the Leeds Lobe advanced to the Heimdal position, the Souris Lobe receded to near the Velva area. Then the Souris Lobe readvanced to the Martin Position (Figure 3) (Clayton, Moran, and Bluemle, 1980). During this time there was intense thrusting and fluting of sediments beneath the glacier (Figure 3) (Bluemle and Clayton, 1984). After this rather quick advance, the glacier began to recede again and Glacial Lake Souris formed in front of the ice (Bluemle, 1985). Eventually, it covered a rather large area of north-central North Dakota (Figure 4) and deposited a sequence of mostly sand and silt over the till (Bluemle, 1982).

Much of the till in the study area is covered by Glacial Lake Souris sediments. Isolated thrust hills poke through the lake sediments at several locations. Besides these and some river cut bank exposures, the till lies entirely beneath the

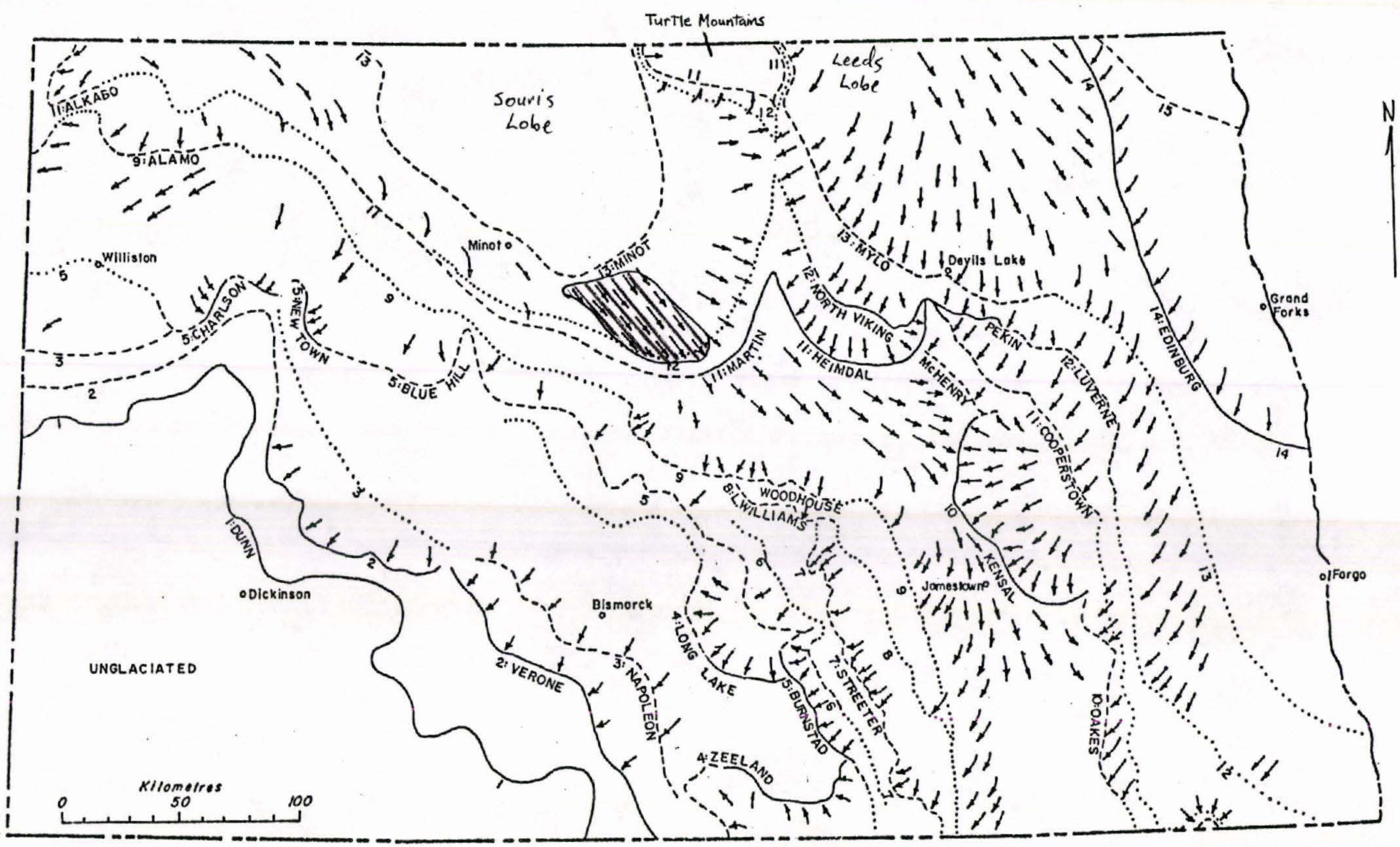
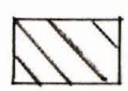


Figure 3. Ice-movement directions and margins of glacial advance (Clayton, Moran, and Bluemle, 1980)

 Area of fluting and thrusting.

NORTH DAKOTA

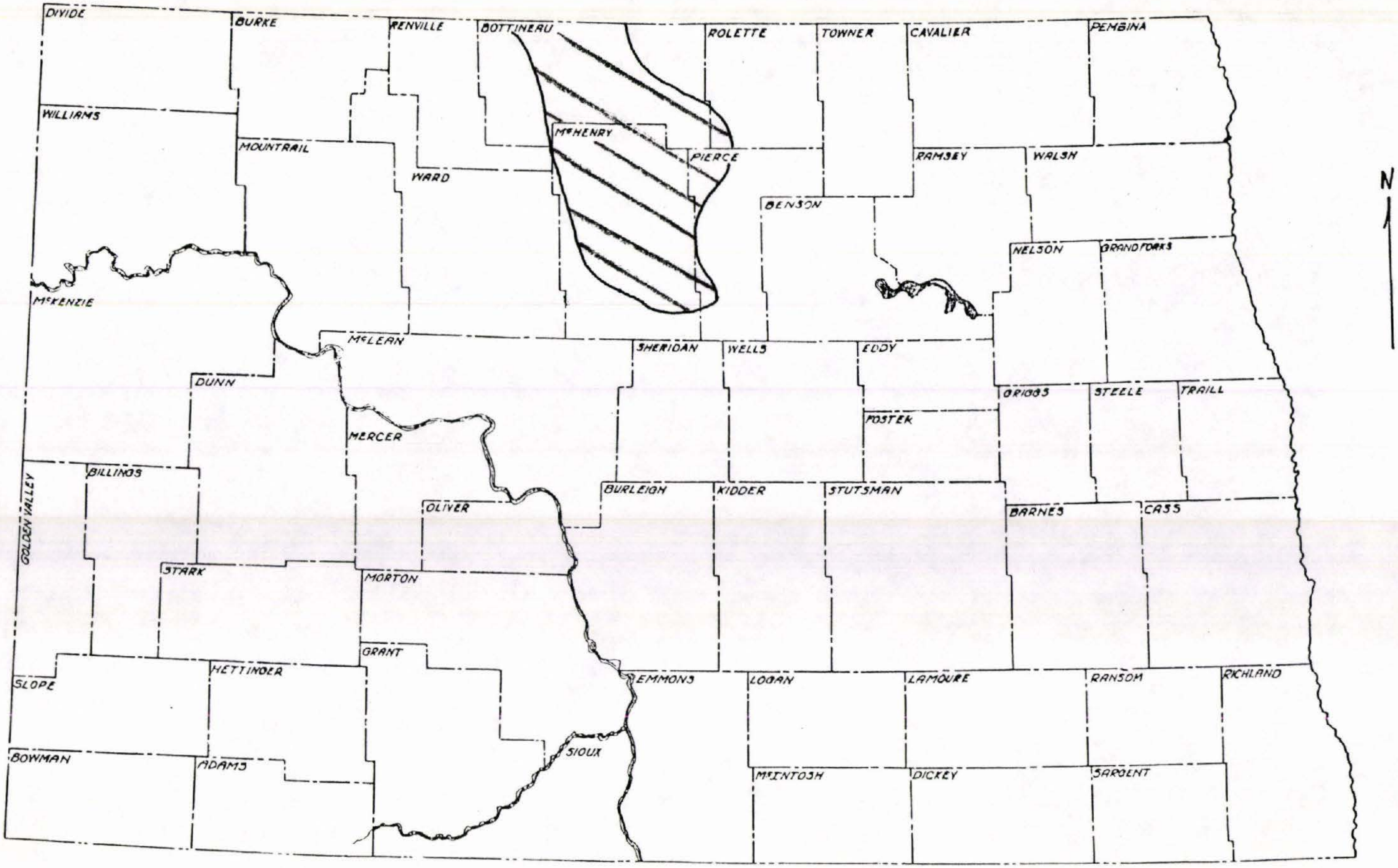


Figure 4.Glacial Lake Souris extent (Bluemle, 1982)

surface of the study area. To the south there is much till exposed on the Missouri Coteau. There is also water washed till surfaces in the northern end of the lake basin in Bottineau County.

Previous Works

Little work has been done with tills in McHenry County. A brief description of till facies is given in Geology of McHenry County (Bluemle, 1982). Two tills were described in Ward County in Geology and Geotechnical Conditions of the Minot Area, North Dakota (Kehew, 1983). Two tills were also described in Pierce County in Glacial Geology and Stratigraphy of southeastern Pierce and southwestern Benson Counties (Schnacke, 1982).

METHODS OF STUDY

Sample Collection

Samples for this study were collected during the summers of 1985 and 1986 in conjuntion with Mark Lord's doctoral dissertation on the coarse-grained sediments of Glacial Lake Souris. The samples were collected with the North Dakota Geologic Survey Mobile 50 Hollow-Stem Auger Drilling Rig. Flights were pulled straight out of the holes with no rotation to obtain good depth control and to avoid sample mixing. Samples were taken at 2.5 foot depth intervals. The depth to till ranged from 0 feet at hole number 3 at the southwest edge of the basin to 50 feet in the center of the lake basin. Holes were spaced to get an even distribution of samples throughout the basin. Thirty-six of the holes drilled penetrated till and 109 samples were collected and described in the field (figure 2). Three additional samples were collected by the author with hand auger at a depth of about three feet in September 1986.

Laboratory Analyses

Samples were described in detail in the laboratory for color, average grain size, maximum grain size, internal structures and other noticeable features such as weathering and presence of lignite. Samples were generally classified as massive or layered, sandy or silty, and weathered or non-weathered.

Next, all samples were analyzed textually to determine sand, silt, and clay content. The textural analysis was performed by Dave Lechner of the North Dakota Geological Survey using the hydrometer method described by Perkins (1977). From this procedure the percent of the sample of each of the size classes was calculated using the dry weight obtained for each class.

After the lithologic analyses, all samples were analyzed lithologically. This was done by completing grain counts of the very-coarse sand fraction of each sample. This provides the percentages of fragments of certain rock types: crystalline, carbonate, sandstone and siltsone, shale, lignite, and others. The very-coarse sand fraction was chosen for analysis because it was most useful for those doing lithologic analyses in the past (Perkins, 1977);(Schnacke,1982). Grain counts were accomplished using a binocular microscope, counting between 150 and 200 grains for each sample. From this data percentages were calculated for each lithologic class of each sample.

Data Analyses

The depth, textural, and lithologic data were analyzed by a number of methods. The depth values were subtracted from hole elevations to obtain a structure-contour map. This was done to show the elevation and topography of the upper till surface.

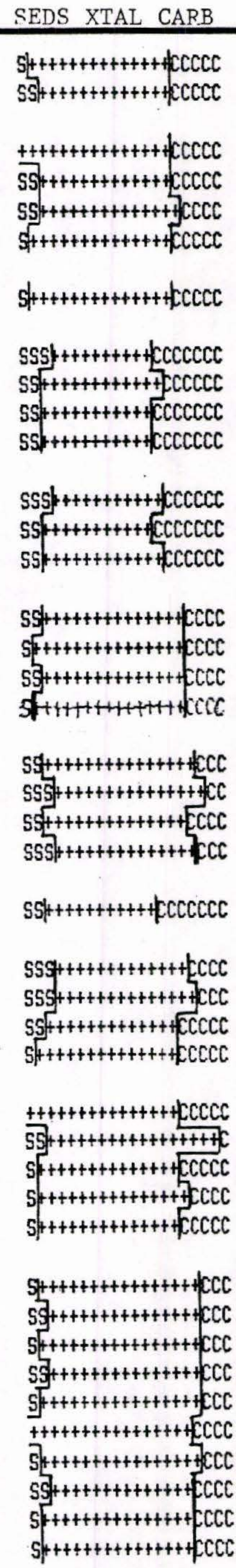
The textural data, broken into sand, silt, and clay ratios, were plotted as horizontal bar graphs for each sample. Percent sand was on the left, percent silt was in the middle and percent clay was on the right, Percent gravel was ignored for this study because it comprised too low of a percent of the total of each sample and because the average sample size was not large enough.

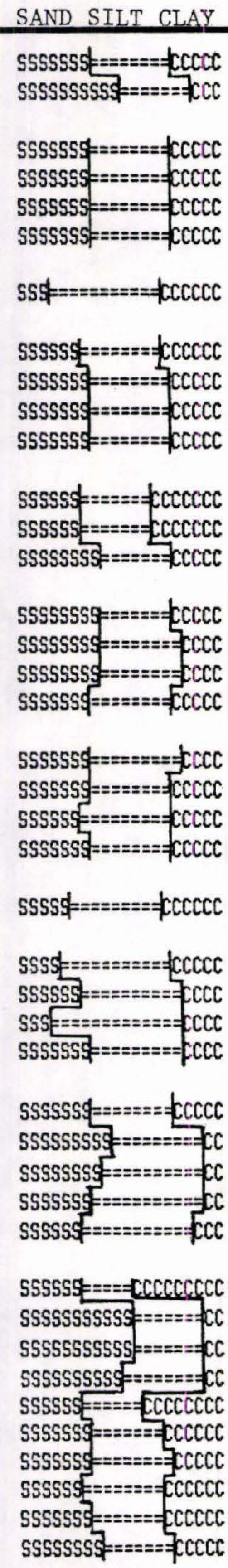
Each of the bar graphs for each hole were then stacked together in correct stratigraphic order (Table 1). This was done so that any variations in texture within a single hole could be easily recognized (Holes 37, 61, Table 1). Variations between holes were also recognized in this way.

Next, the sand, silt, and clay percentages for the upper till surface were plotted on a map of the study area and contoured to show the distribution of each size class within the study area. A longitudinal profile from hole 46 in the northwest corner of the study area to hole 27 in the southeast corner was drawn

Table 1. Textural and lithologic percentages of selected holes.

HOLE-DEPTH	SED %	XTAL %	CARB %	SAND %	SILT %	CLAY %
37.125	2.8	72.0	25.2	34.9	41.8	23.3
37.150	9.9	66.1	24.0	50.4	34.9	14.7
39.125	3.2	72.9	23.9	34.3	40.5	25.2
39.150	8.3	64.7	26.9	35.0	39.5	25.5
39.175	10.6	70.8	18.6	36.4	37.6	26.0
39.200	5.5	70.3	24.2	36.8	38.4	24.8
40.200	5.7	68.2	26.1	13.3	57.0	29.7
46.225	15.7	48.2	36.1	32.2	38.9	28.9
46.250	9.4	62.3	28.3	32.7	38.9	28.4
46.275	12.3	52.3	35.5	35.4	37.3	27.3
46.300	11.2	53.1	35.8	35.2	38.0	26.8
49.225	16.4	53.9	29.7	32.1	33.3	34.6
49.250	10.5	54.5	35.0	29.0	34.7	36.3
49.275	9.5	59.5	31.0	39.3	35.1	25.6
51.250	8.8	70.7	20.4	38.5	37.0	24.5
51.275	7.4	70.9	21.6	38.4	39.1	22.5
51.300	8.6	71.5	19.9	37.6	38.0	24.4
51.625	5.3	74.7	20.0	36.5	38.4	25.1
52.200	11.0	73.5	15.4	32.7	42.6	24.7
52.225	13.6	73.5	12.9	37.0	38.5	24.5
52.250	10.1	68.3	21.6	31.9	40.8	27.3
52.275	13.5	69.2	17.3	32.5	40.6	26.9
53.475	9.9	53.3	36.8	22.6	46.0	31.4
56.415	14.2	64.2	21.6	21.9	55.3	22.8
56.525	16.3	68.1	15.7	29.9	51.0	19.1
56.550	11.0	63.0	26.0	14.2	67.1	18.7
56.575	3.5	70.6	25.9	33.5	45.7	20.8
59.200	3.1	73.6	23.3	34.3	38.9	26.8
59.225	9.3	86.9	3.7	44.4	44.1	11.5
59.250	7.7	67.6	24.6	40.0	48.6	11.4
59.275	4.5	74.2	21.2	36.5	53.5	10.0
59.300	4.1	72.1	23.9	29.5	56.1	14.4
61.150	6.0	77.4	16.7	31.1	25.2	43.7
61.175	12.6	73.6	13.8	52.6	34.3	13.1
61.200	6.5	76.8	16.8	51.5	37.2	11.3
61.225	10.8	74.1	15.1	47.9	42.0	10.1
61.250	5.6	77.1	17.4	31.3	32.2	36.5
61.275	2.0	77.2	20.8	34.3	35.5	30.2
61.300	4.2	81.3	14.6	35.0	38.6	26.4
61.325	9.8	71.4	18.8	32.2	36.4	31.4
61.350	5.5	72.4	22.1	35.2	35.9	28.9
61.375	7.2	74.5	18.3	39.9	35.3	24.8





to show variation in texture in the down-glacier direction (Figure 5).

Like the textural data, the lithologic data were plotted as horizontal bar graphs using percent sedimentary fragments (% sandstone + % siltstone + % shale + % lignite) on the left, percent crystalline fragments in the middle, and percent carbonate fragments on the right. Again the graphs for each hole were stacked in stratigraphic order to show variations within holes and between holes (Holes 39, 52, 61, Table 1). These graphs were then plotted next to the textural bar graphs for comparison.

Again, like the textural data, lithologic data were plotted on maps of the study area and contoured. This showed the distribution of the five major rock type fragments in the upper till surface. Another longitudinal profile was drawn from hole 46 to hole 27 to show variation in lithology in the down-glacier direction.

Next, the values of four lithologic and textural parameters were graphed against one another on crossplots to yield six plots. These show the number of samples which meet certain lithologic and textural parameters (e.g., between 60% and 70% sand and between 15% and 30% sedimentary fragments). The parameters used for this analysis were percent sedimentary fragments, percent sand, percent normalized crystalline (% crystalline / % crystalline + % carbonate), and percent normalized silt (% silt / % silt + % clay). Normalized parameters are merely a means of simplyfying crossplots because they allow three variables to be plotted on a two-dimensional diagram.

TILL ELEVATIONS

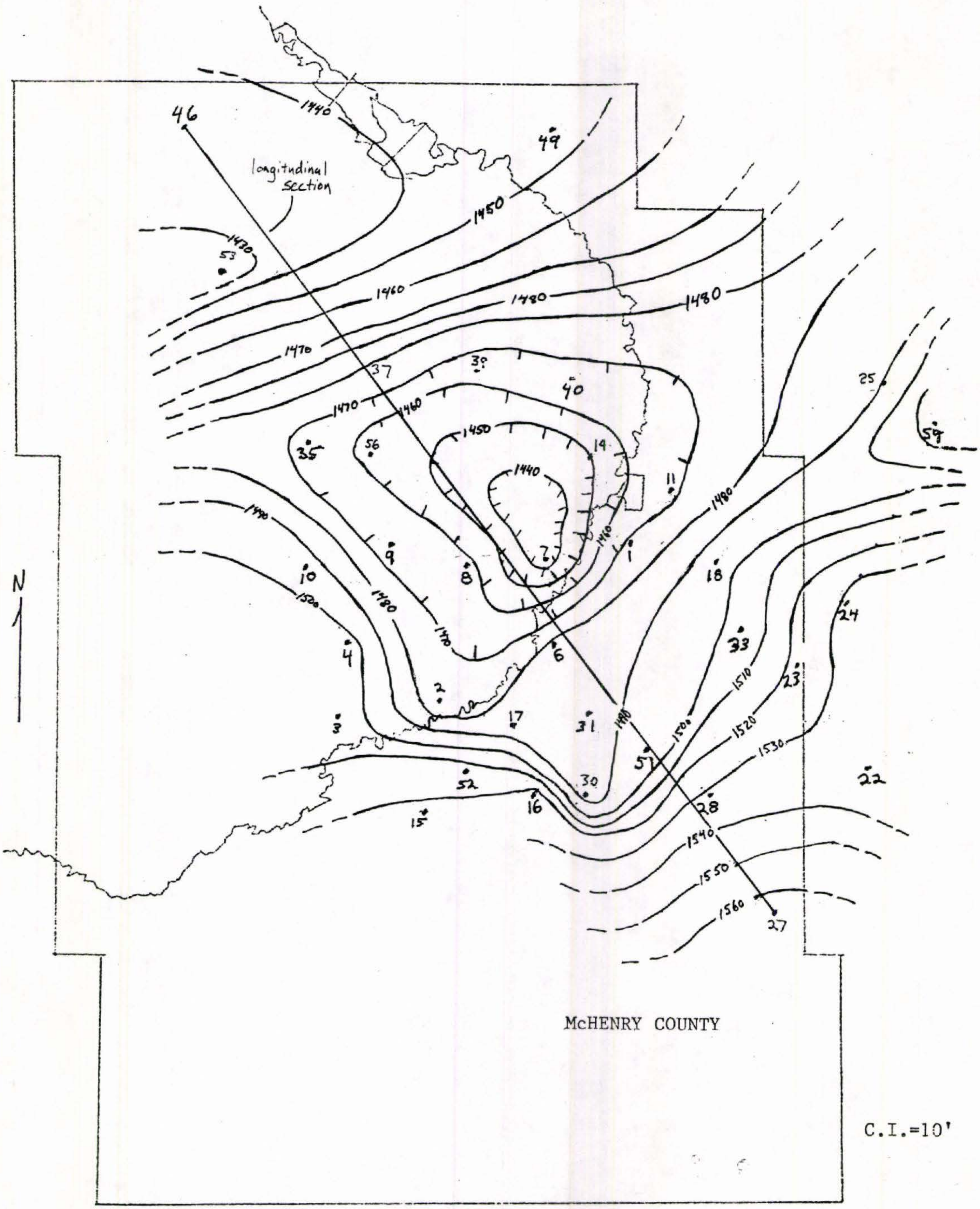


Figure 5. Structure-contour map of the upper till surface.

RESULTS

The structure-contour map of the till surface forms a depression roughly correponding to the Glacial Lake Souris basin (Figure 5). Values increase from 1435 feet in the center of the depression to 1560 feet at the southeast margin. Greatest increases are seen to the north and south with lesser increases to the east and west.

The distribution of sand (Figure 6) shows high percentage values in a northwest to southeast trending linear band near the southwest boundary of the study area. Values in this area peak near 50 percent sand. Values decrease away from the band to the northeast and southwest. Lowest values, about 15 percent, occur in the northeast corner of the study area.

Unlike sand, silt distribution (Figure 7) does not have any pattern to it. There is an irregularly shaped high surrounding three holes that have over 50 percent silt. Away from the peak, values drop below 40 percent.

The clay percentages map (Figure 8) shows a rather broad depression in the center of the study area. There also is a trend of decreasing percent clay form northwest to southeast. Values range from approximately 15 percent in the depression to 30 percent in the northwest.

The longitudinal plot from hole 46 to hole 27 (Figure 5) show a slight increase in sand and a slight decrease in clay in the down-glacier direction (Figure 9). Silt shows no net

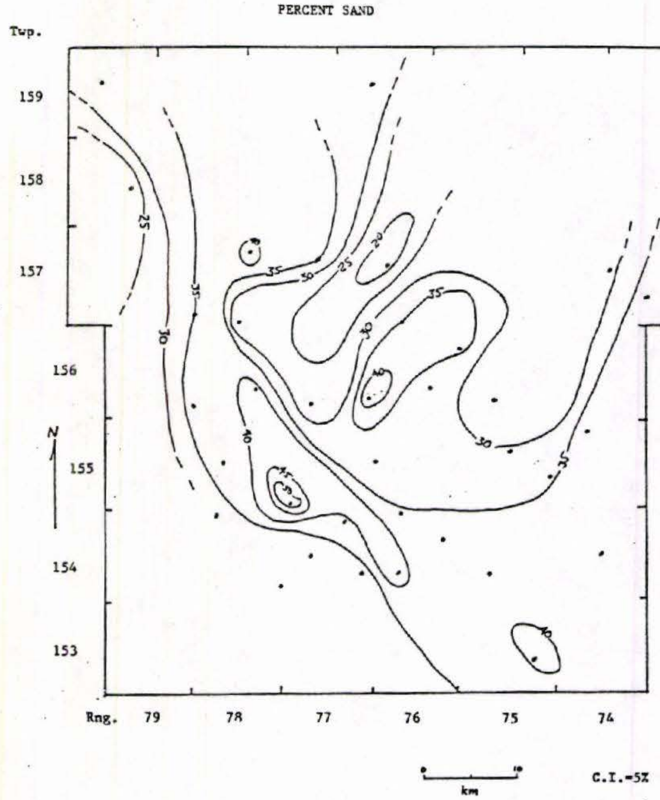


Figure 6. Contour of percent sand.

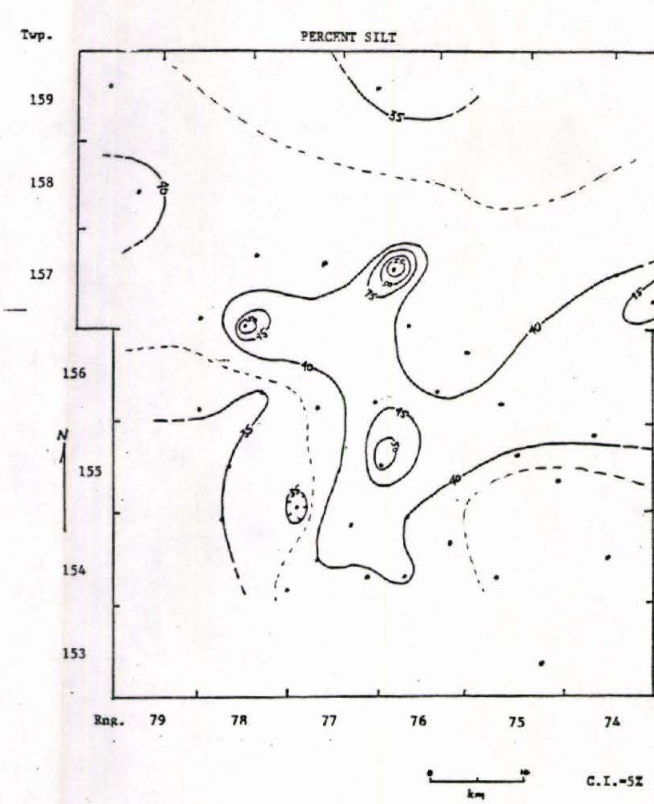


Figure 7. Contour of percent silt.

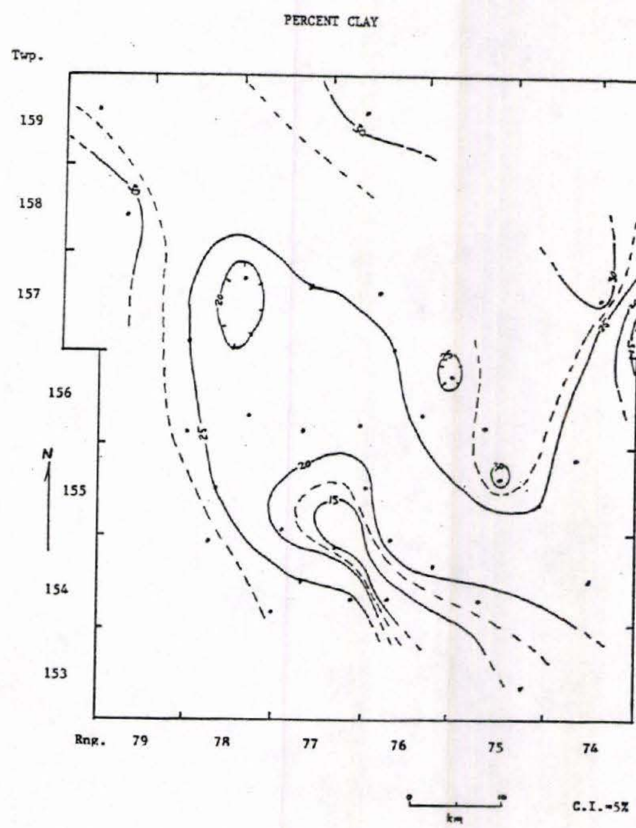


Figure 8. Contour of percent clay.

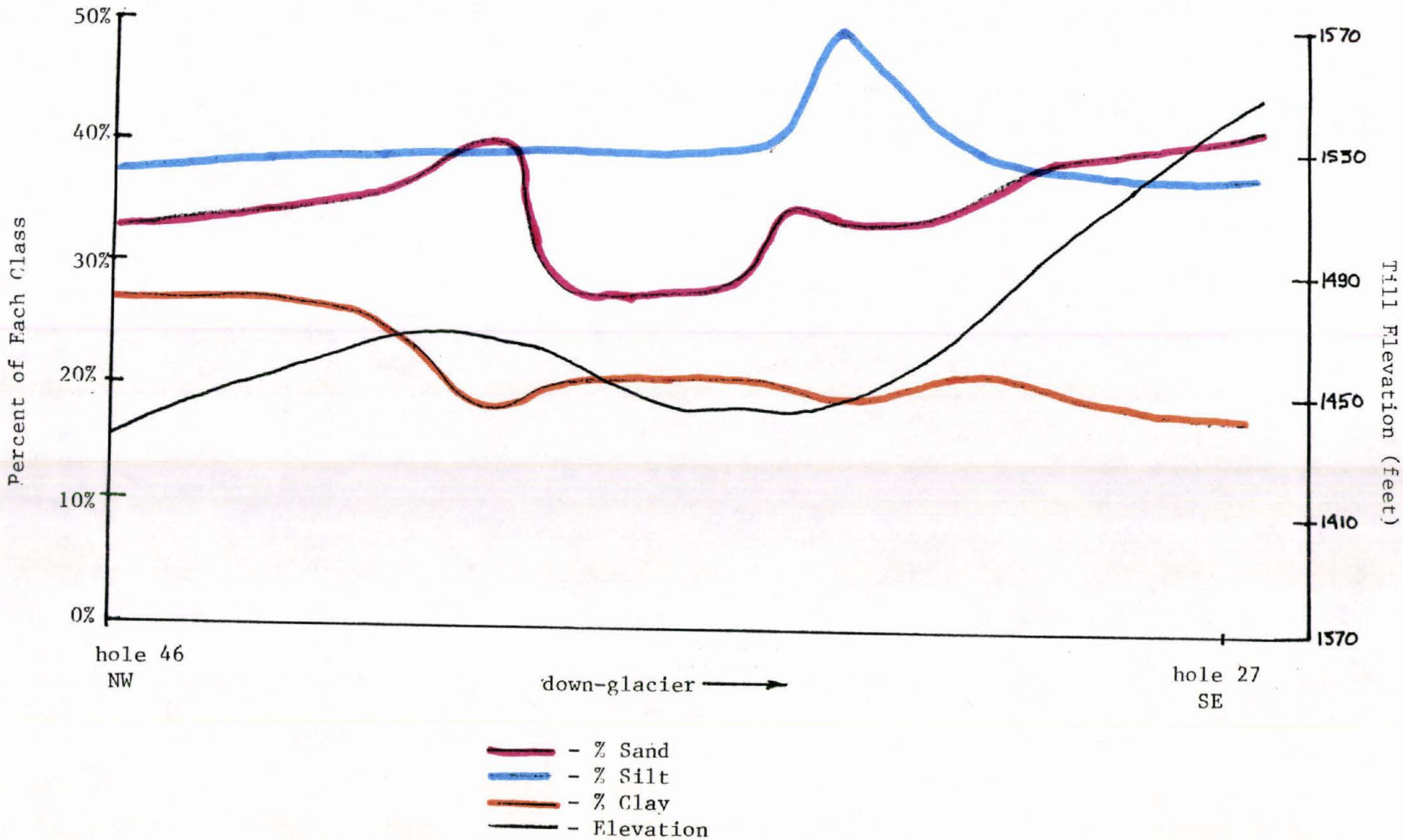


Figure 9. Longitudinal profile of textural values.

gain or loss. There are also local variations in texture which don't seem to effect the overall trends.

The lithologic data also show trends. The percent carbonate (Figure 10) at the till surface shows a distribution that is greatest in the northwest and decreases southeastward, or in the down-glacier direction. Values decrease from 36 percent to below 20 percent.

Percent shale (Figure 11) also decreases in the down-glacier direction. Values decrease rapidly in the north from 13 percent to 1 percent, but over the southern end of the area values are fairly constant, near 2 or 3 percent.

Sandstone plus siltstone percentages (Figure 12) repeat the decrease to the southeast, starting at 4 percent and going down to 1 percent or less. However, in the center of the basin there is a broad peak of increasing values, some over 8 percent.

Contradictory to the previously seen trend, crystalline rock fragments show a general increase in percentage in the down-glacier direction (Figure 13). Values incease from about 50 percent in the northwest to 75 percent in the southeast. There is also a slight drop in percentages in the center of the study area.

Percent lignite (Figure 14) is not very similar to the others in distribution. There is no lignite found in either the northern or southern ends of the basin but there is a broad peak of about 4 percent lignite in the center of the study area. It may be noted that some lignite values could be higher than they should

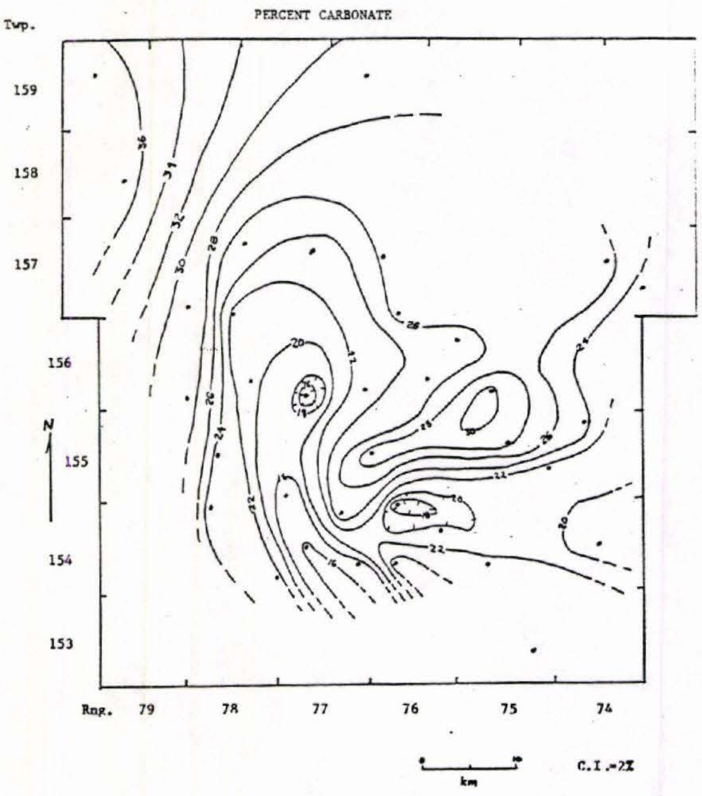


Figure 10. Contour of percent carbonate.

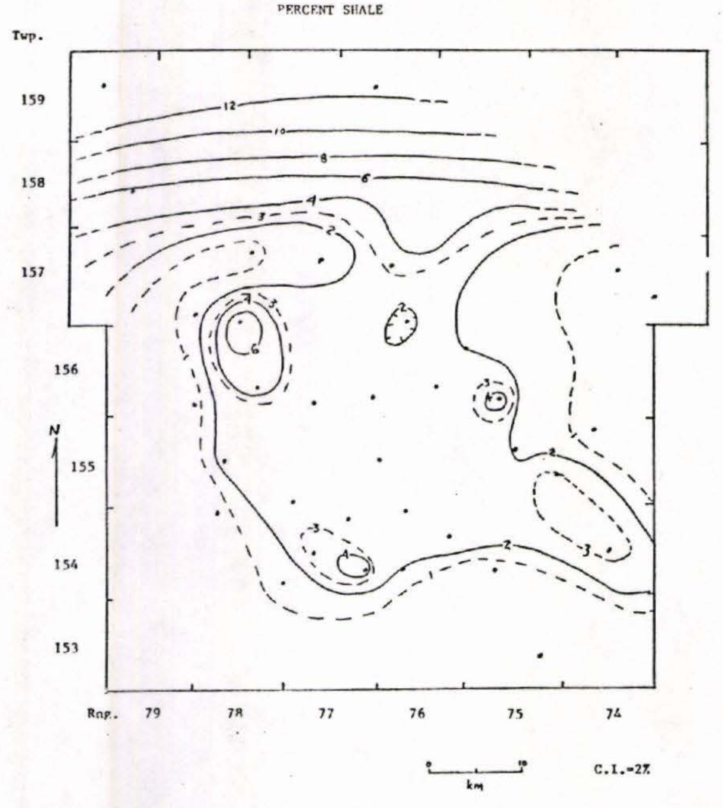


Figure 11. Contour of percent shale.

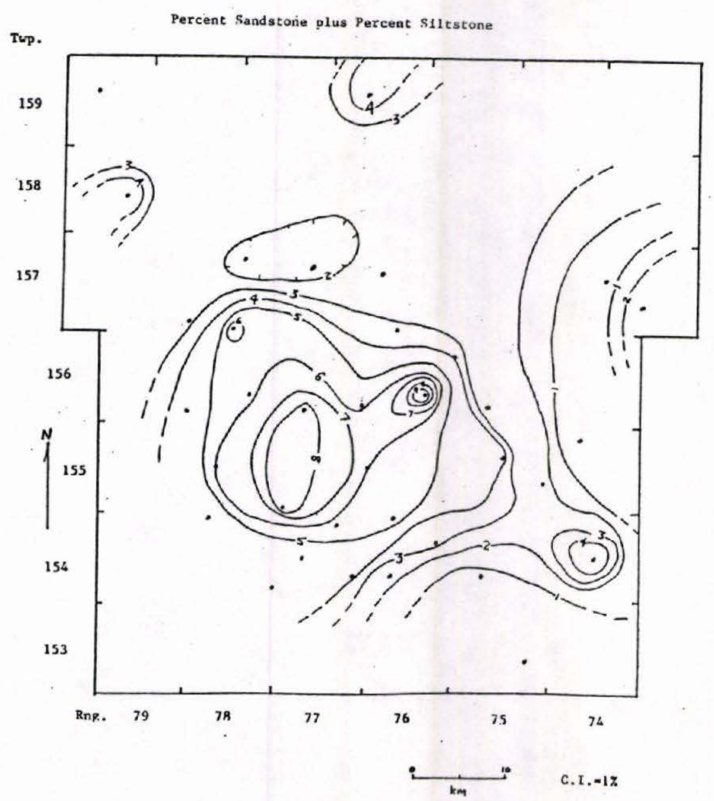


Figure 12. Contour of percent sandstone and siltstone.

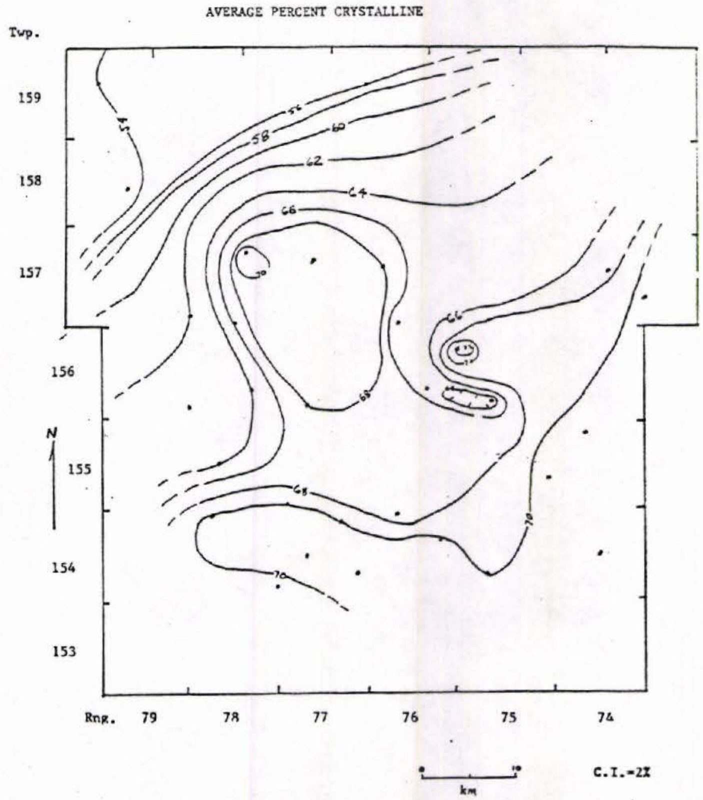


Figure 13. Contour of percent crystalline.

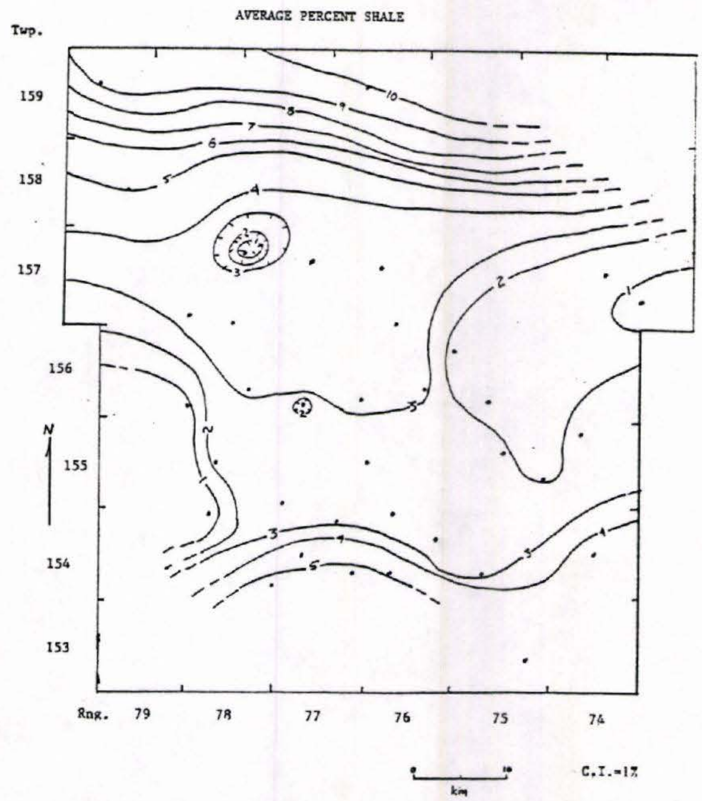


Figure 14. Contour of percent lignite.

be since lignite fragments break apart easily, quickly raising the number of individual grains within a sample.

The longitudinal profile from hole 46 to hole 27 (Figure 15) shows a great (25 %) increase in percent crystalline fragments down-glacier. Percent carbonate and percent shale show moderate decreases (about 10 % each). Percent sandstone shows a slight increase then a decrease to near 0 percent. Percent lignite shows an increase from 0 percent to near 5 percent and back down to 0 percent.

The crossplots were valuable for several reasons. Most of the plots show a main peak or node where most of the samples fell, and then another group of samples that plotted together, but off of the main node (Figure 16). One plot did not separate the samples well, but plotted all samples together in one node with many smaller peaks within it (Figure 17).

When the information from the crossplots was compared, it was found that the samples that fell outside of the main node on each graph were consistently the same tills from graph to graph. The samples were then split into two groups, main node group and side group. The textural and lithologic data were then averaged for each hole, depending on which group each the hole's samples belonged to. These average values were then plotted and contoured for the main till.

The basic result of averaging the data was to reduce the magnitudes of peaks and valleys on the contours, to give them

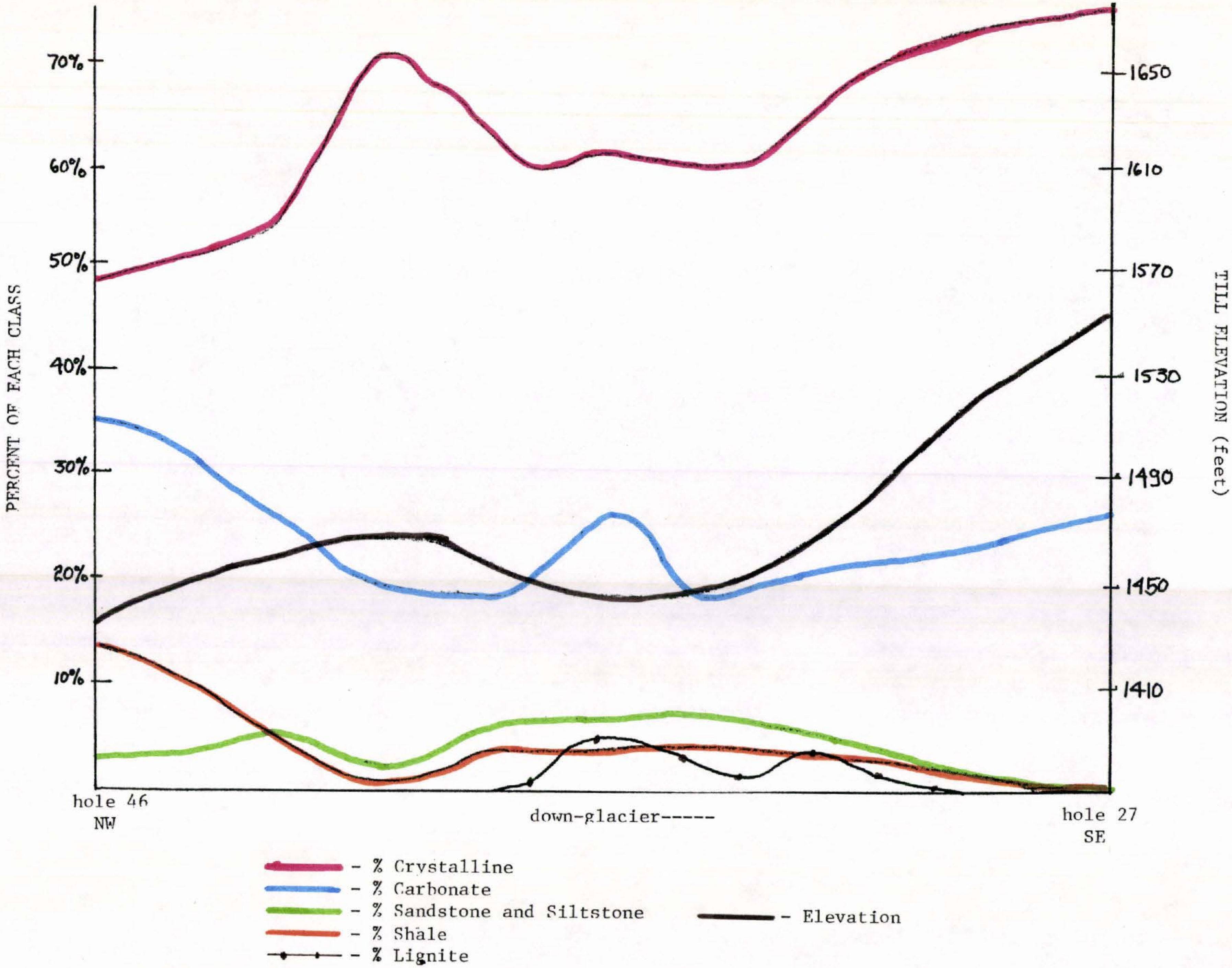


FIGURE 15. Longitudinal profile of lithologic values

CROSSPLOT OF
PERCENT NORMALIZED CRYSTALLINE
vs.
PERCENT NORMALIZED SILT

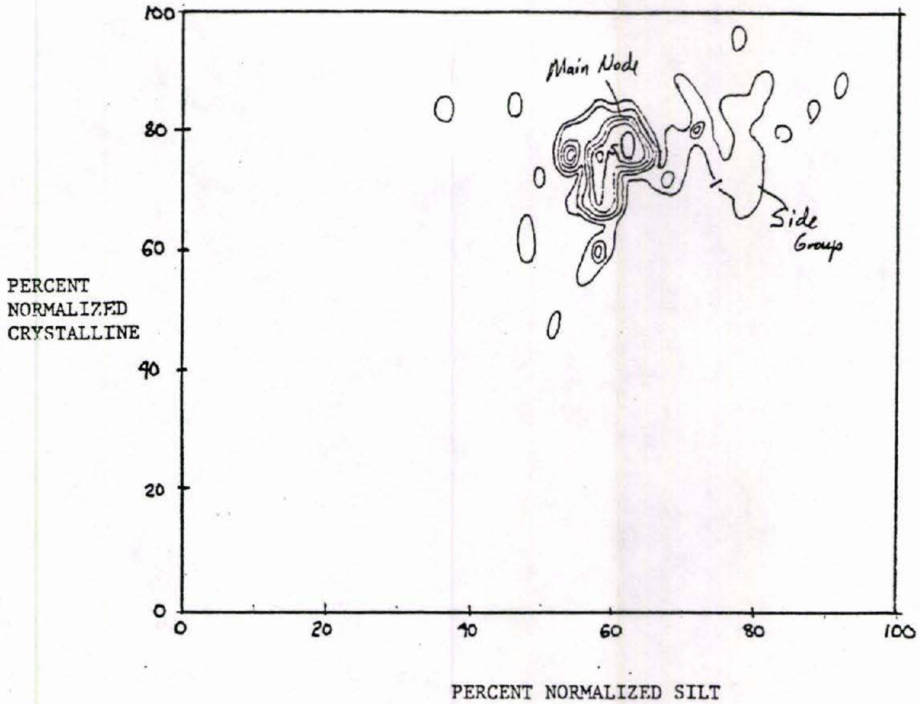
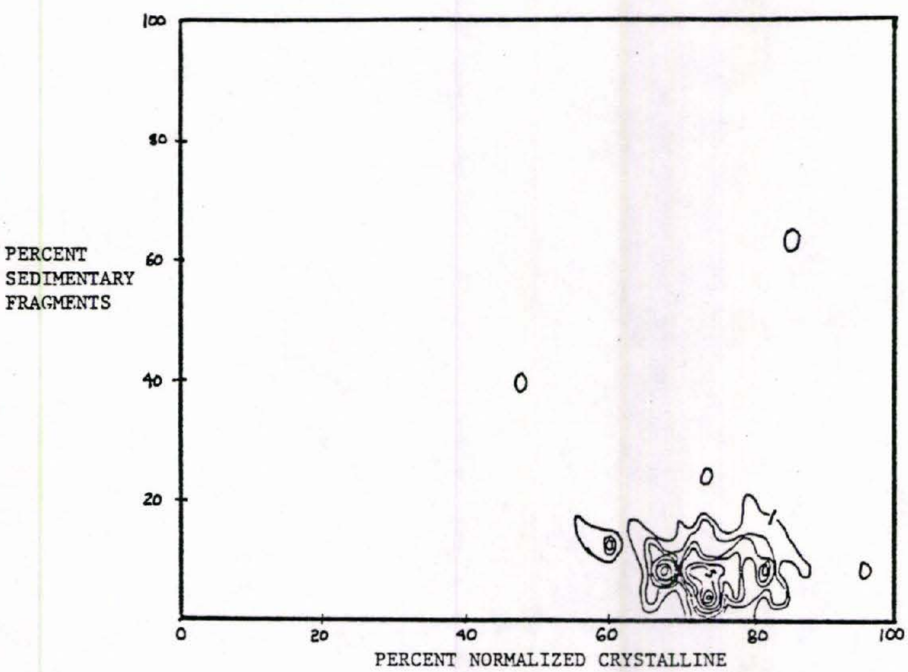


Figure 16. Crossplot showing two till groups. C.I.=1 sample

CROSSPLOT OF
PERCENT SEDIMENTARY FRAGMENTS
vs.
PERCENT NORMALIZED CRYSTALLINE



C.I.=1 sample

Figure 17. Crossplot showing no separation of samples.

less relief. Trends are basically the same and in fact, show up better on the contours (Figures 18 & 19).

DISCUSSION

The variations in lithology are a result of several processes. First, till lithology is a function of source bedrock. Crystalline material is ultimately derived from the Canadian Shield. Carbonates are derived from lower Paleozoic units fringing the shield. Sandstone, siltstone, shale, and lignite fragments come from Cretaceous and Tertiary formations of North Dakota and southern Canada (Bluemle, 1985). Source material can also be any preexisting glacial sediments overridden by the advancing glacier.

Local increases of clastic sedimentary rock fragments on the contours are probably due to nearby bedrock formations (Figure 20). This could especially be the case for the lignite, which occurs as an isolated peak. This is also causing the minor variations in the longitudinal profiles (Figure 15).

Another trend in the lithology is the increase in percent crystalline fragments to the southeast (Figure 13). This corresponds to a decrease in most other fragments, particularly percent carbonate fragments and percent shale fragments. This is probably due to differential resistance of rock fragments. This results in a relative increase in the more resistant rock types, such as crystalline, in the down-glacier direction. It is assumed that the number of grains don't actually increase, but the percent

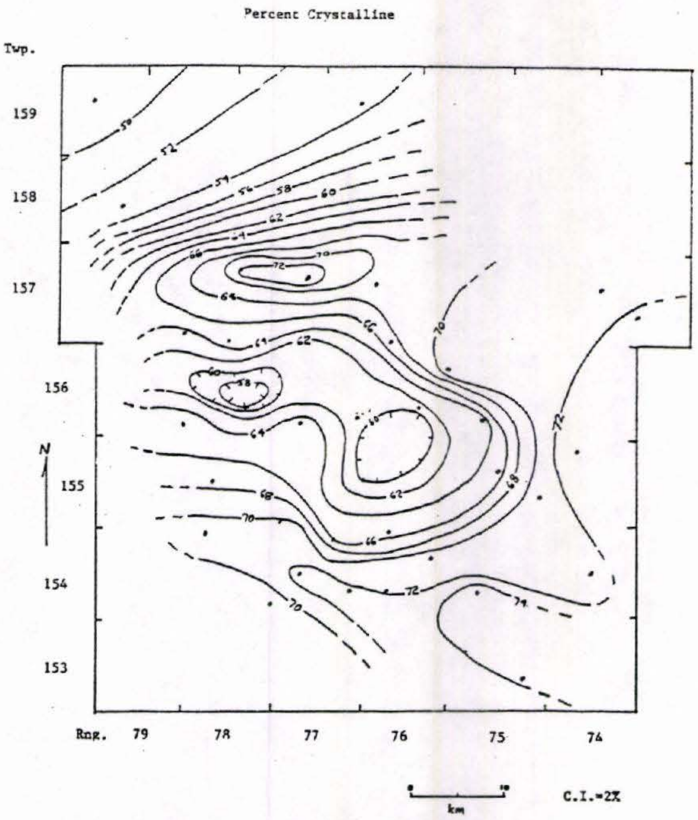


Figure 18. Contour of average percent crystalline - Main till.

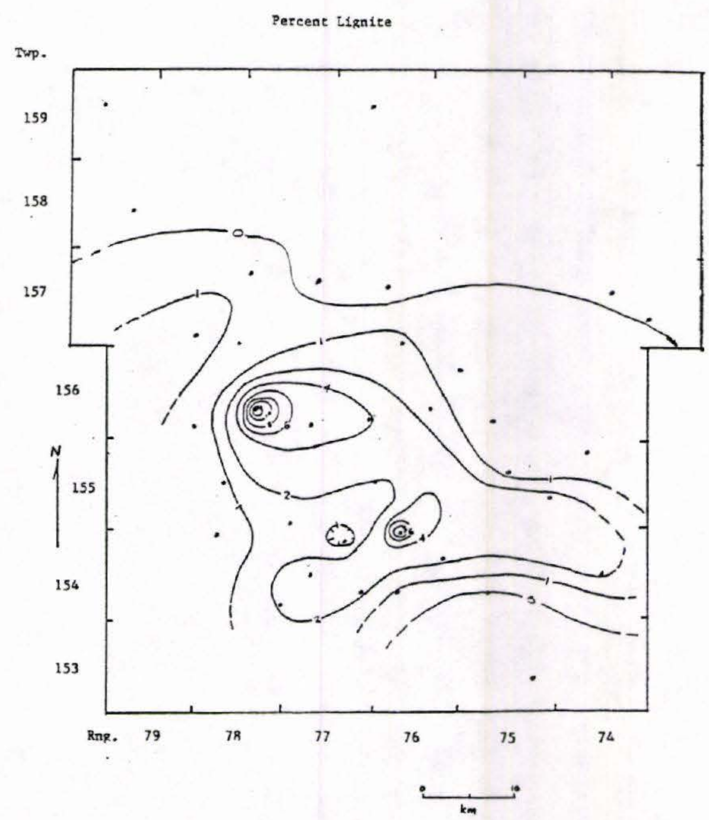
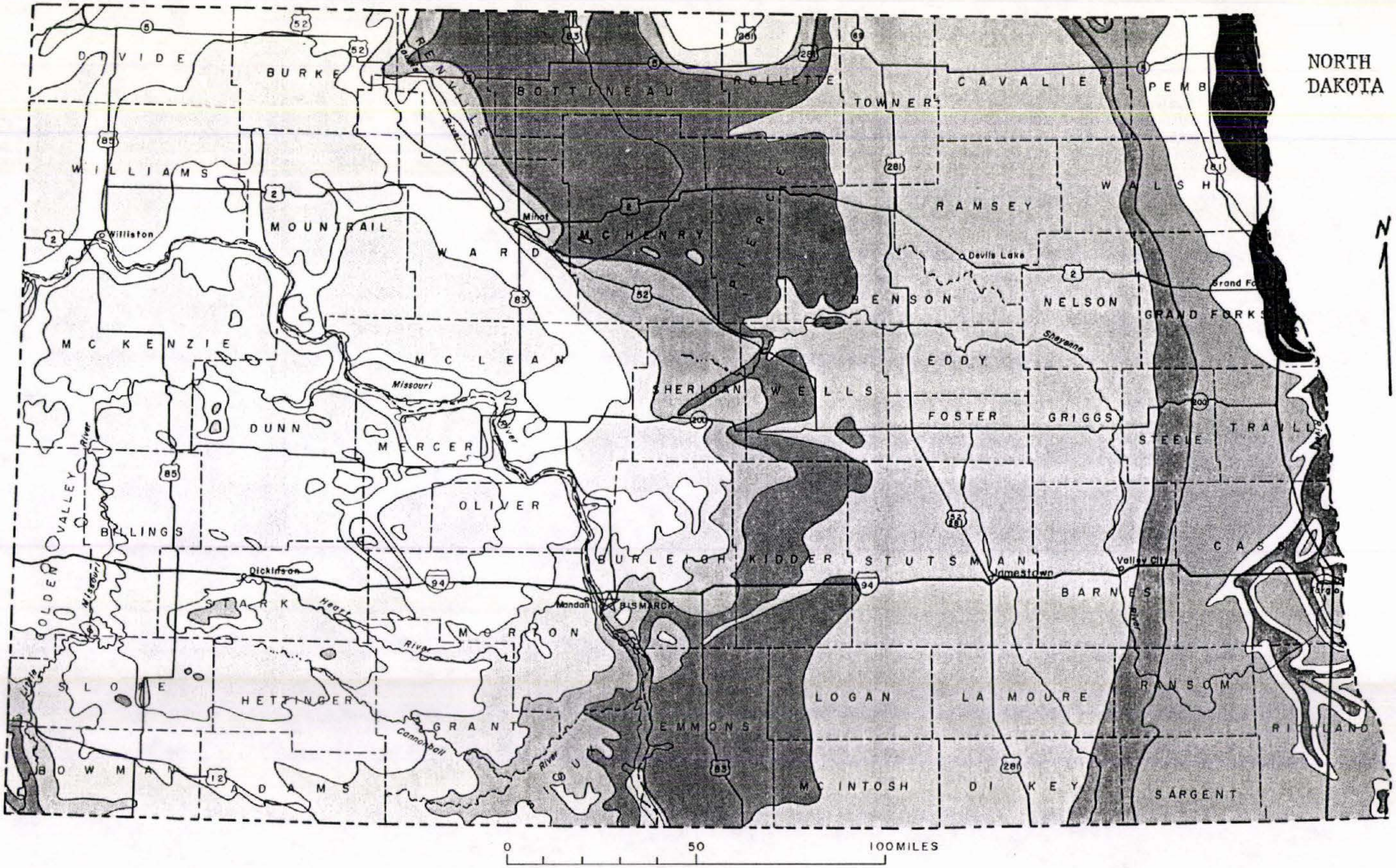


Figure 19. Contour of average percent shale - Main till.



TERTIARY SYSTEM

- White River Group
- Golden Valley Formation
- Sentinel Butte Formation
- Tongue River Formation
- Ludlow, Cannonball, Tullock Formations

CRETACEOUS SYSTEM

- Hell Creek Formation
- Fox Hills Formation
- Pierre Formation
- Niobrara Formation
- Carlile, Greenhorn, Belle Fourche, Mowry, Newcastle, and Skull Creek Formations
- Fall River and Lakota Formations

- JURASSIC ROCKS
- ORDOVICIAN ROCKS
- PRECAMBRIAN ROCKS

Figure 20. Generalized Bedrock Map of North Dakota (Carlson, 1973)

of the total does. This explains the increase in percent crystalline to the southeast and the decrease in the others.

The bar graphs of the textural and lithologic data (Table 1) can be used to show variations within holes and between holes as already discussed. By itself, the results of these analyses didn't seem extremely helpful, just as the contour plots of the textural data didn't seem very useful. But after analyzing the crossplots, the other information could be tied together.

The textural data, when plotted against the lithologic data on the crossplots, became useful in separating the main node samples from the side group samples. Then, the main group samples and the side group samples were all plotted on a study area map. Most of the samples of the side group were found to fall in a northwest to southeast trending linear band near the southwest margin of the study area (Figure 21). This position coincides with the band of high percent sand (Figure 6). The break between the two groups also can be seen in the bar graphs of several holes, such as 37 and 61 (Table 1). Because of the consistent differences between these two groups, it is likely that they represent two tills. Since the main till usually overlies the other till when both are present at one location, the main till is considered to younger. The younger till is found throughout the study area. Average textural and lithologic values were calculated for each of the tills (Table 2).

It is also possible that the side group samples are not from a separate till. The differences in texture and lithology

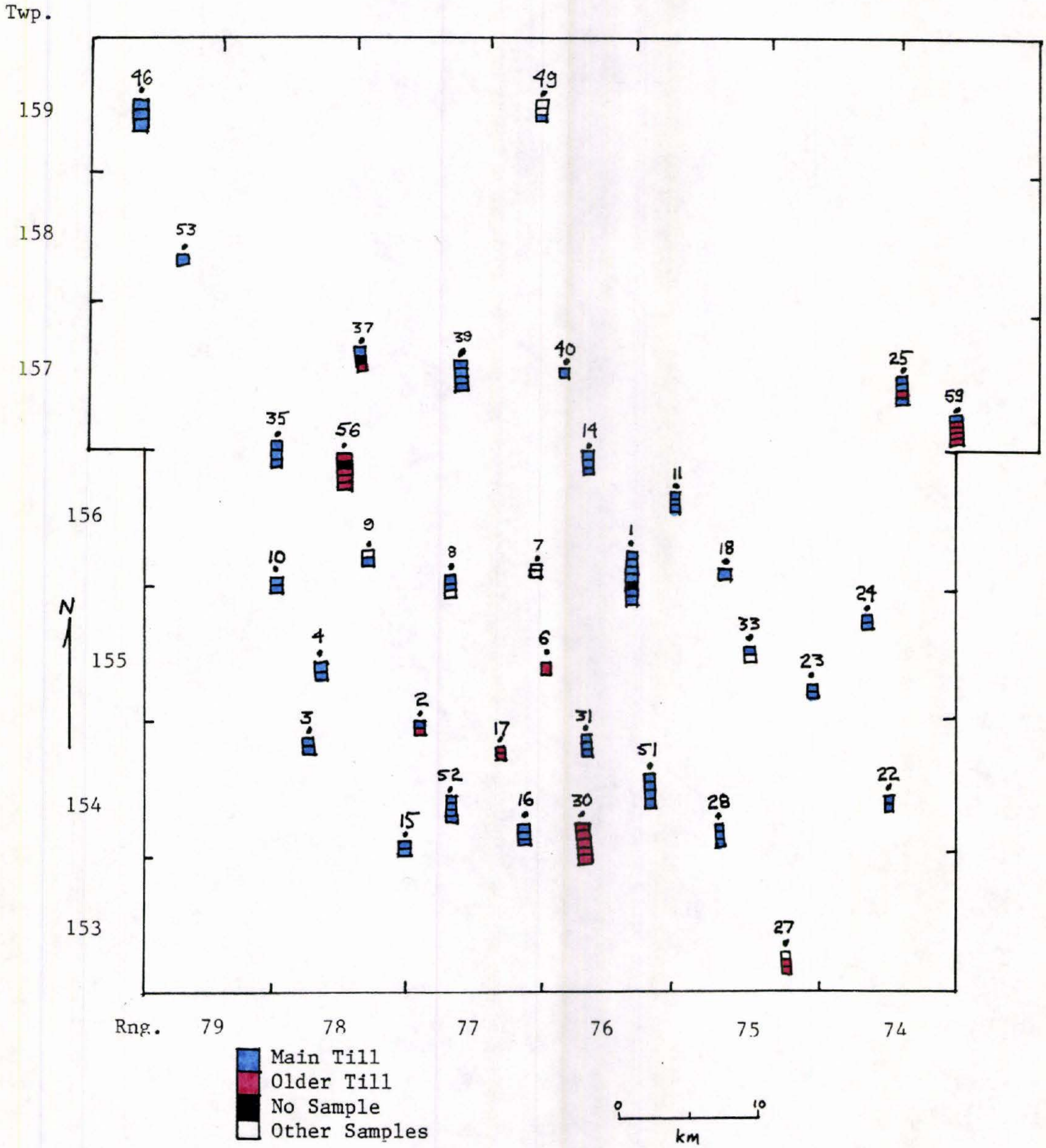


Figure 21. Tills present in the study area.

Table 2. Average Textural and Lithologic Values

Texture	Main Till	Older Till
% Sand	38.4	37.5
% Silt	38.1	46.0
% Clay	26.7	15.9
Lithology		
% Crystalline	3.3	2.2
% Carbonate	68.3	77.6
% Sandstone/ Siltstone	26.4	21.7
% Shale	3.8	3.7
% Lignite	1.4	1.8

could be due to sediments that were picked up by the advancing ice. These could be early glacial Lake Souris sediments or glacial sediments that were deposited during an earlier advance.

The best parameters used in this study for separating the two tills on the basis of texture and lithology were percent normalized crystalline versus percent normalized silt and percent sand versus percent normalized silt. This is because the differences between the two tills are actually their percent of sand, silt and crystalline rock fragments. The textural differences may reflect local sediments that were picked up by the glacier and redeposited. A possible source for the sediments could be an early Glacial Lake Souris. Since there is no crystalline bedrock near the surface of McHenry, the crystalline fragments were probably picked up from sediments.

SUMMARY AND CONCLUSIONS

To summarize, the information from this study seems to indicate that two tills are present in the study area. This agrees with Kehew's (1983) results in Ward County to the west, and with Schnacke's (1982) reults in Pierce County to the east. In this study, tills were characterized on the basis of texture and lithology. This data was then used in a variety of analytical techniques to find and describe any variations in the till. some of the techniques included bar graphs, contour maps, longitudinal profiles and crossplots. The crossplots proved most useful in differentiating the two tills.

APPENDICES

APPENDIX A : SAMPLE LOCATIONS AND DESCIPTIONS

N-FILE #	Twp	Rge	Sec	1/4	SAMPLE #	SECTION	COLOR	ACID	MAX CLAST	OTHER
N4201	156	76	22	ddd	W1-17	TILL	5Y 6/2	L	15mm	MASSIVE, SILTY
					W1-20	TILL	5Y 5/2	L	15mm	MASSIVE, SILTY
					W1-25	TILL	5Y 6/2	L	15mm	MASSIVE, SILTY
					W1-30	TILL	5Y 5/1	L	15mm	MASSIVE, SILTY
						SAND	NO SAMPLE			
					W1-37	TILL	5Y 5/1	L	15mm	MASSIVE, SILTY
					W1-45	TILL	5Y 6/2	L	8mm	MASSIVE, SILTY
N4202	155	77	31	dbb	W2-17.5	TILL	5Y 6/1	L	15mm	MASSIVE, SANDY
					W2-20	TILL	5Y 6/2	L	15mm	MASSIVE, SANDY
N4203	154	78	5	ada	W3-0	TILL	5Y 6/3	L	15mm	LAYERED, SILTY HIGHLY WEATHERED W/SUBANGULAR CLASTS
					W3-5	TILL	5Y 6/3	M	15mm	LAYERED , SILTY W/ANGULAR CLASTS
N4204	155	78	16	ccd	W4-12.5	TILL	5Y 6/2	L	15mm	MASSIVE, SILTY
					W4-15	TILL	5Y 5/1	L	8mm	LAYERED, SANDY
N4205	155	76	18	ccc	W6-22.5	TILL	5Y 6/2	M	8mm	MASSIVE, SILTY
N4206	156	77	25	dda	W7-37.5	TILL	5Y 6/2	L	50mm	LAYERED, SANDY
					W7-40	TILL	5Y 6/2	L	10mm	MASSIVE, SANDY
N4207	156	77	32	aaa	W8-55	TILL	5Y 5/1	L	4mm	MASSIVE, SILTY
					W8-57.5	TILL	5Y 6/2	M	3mm	LAYERED, SILTY
					W8-60	TILL	5Y 5/1	L	4mm	MASSIVE, SILTY
N4208	156	78	26	bba	W9-47.5	TILL	5Y 5/1	L	10mm	MASSIVE, SILTY
					W9-50	TILL	5Y 6/1	L	15mm	MASSIVE, SILTY
N4209	156	78	31	bba	W10-12.5	TILL	5Y 5/3	L	15mm	LAYERED, SILTY OXIDIZED
					W10-15	TILL	5Y 5/1	M	5mm	MASSIVE, SILTY
N4210	156	76	12	ada	W11-12.5	TILL	5Y 6/1	M	5mm	MASSIVE, SANDY
					W11-17.5	TILL	5Y 5/1	L	4mm	MASSIVE, SILTY
					W11-20	TILL	5Y 5/2	L	4mm	MASSIVE, SILTY
N4211	157	76	35	ccc	W14-15	TILL	5Y 5/1	L	25mm	MASSIVE, SANDY
					W14-17.5	TILL	5Y 6/1	M	4mm	MASSIVE, SILTY
					W14-20	TILL	5Y 6/1	L	4mm	MASSIVE, SILTY
N4212	154	78	36	aaa	W15-27.5	TILL	5Y 5/1	L	6mm	MASSIVE, SILTY
					W15-30	TILL	5Y 5/1	L	5mm	MASSIVE, SILTY
N4213	154	77	25	bba	W16-15	TILL	5Y 5/1	M	5mm	MASSIVE, SILTY
					W16-17.5	TILL	5Y 6/1	L	20mm	MASSIVE, SILTY
					W16-20	TILL	5Y 6/1	L	7mm	MASSIVE, SILTY
N4214	154	77	2	ccc	W17-22.5	TILL	5Y 6/2	M	5mm	MASSIVE, SANDY
					W17-25	TILL	5Y 6/2	L	4mm	MASSIVE, SANDY
						m-c SAND				
N4215	156	75	28	ccc	W18-20	TILL	5Y 6/1	L	15mm	LAYERED, SILTY
N4216	154	74	21	ccc	W22-7.5	TILL	5Y 6/1	L	4mm	MASSIVE, SILTY
					W22-10	TILL	5Y 6/1	L	4mm	MASSIVE, SILTY
N4217	155	75	24	ddd	W23-12.5	TILL	5Y 5/2	L	3mm	LAYERED, SILTY WEATHERED
					W23-17.5	TILL	5Y 5/2	L	15mm	LAYERED, SILTY WEATHERED
N4218	155	74	4	ccd	W24-7.5	TILL	5Y 6/3	M	3mm	LAYERED, SILTY WEATHERED
					W24-10	TILL	5Y 6/3	M	5mm	LAYERED, SILTY WEATHERED LIGNITE PRESENT
N4219	157	74	13	aaa	W25-22.5	TILL	5Y 6/2	M	8mm	LAYERED, SILTY
					W25-25	TILL	5Y 5/2	M	5mm	LAYERED, SILTY
					W25-27.5	TILL	5Y 6/1	H	5mm	LAYERED, SILTY
					W25-30	TILL	5Y 5/1		5mm	LAYERED, SILTY
N4220	153	75	23	ddd	W27-5	TILL	5Y 5/4	H	8mm	MASSIVE, SILTY HIGHLY WEATHERED
					W27-7.5	TILL	5Y 6/3	H	15mm	LAYERED, SILTY
					W27-10	TILL	5Y 6/3	H	3mm	LAYERED, SILTY

APPENDIX A : SAMPLE LOCATIONS AND DESCIPTIONS

N-FILE #	Twp	Rge	Sec	1/4	SAMPLE #	SECTION	COLOR	ACID	MAX CLAST	OTHER
N4221	154	75	29	aaa	W28-15	TILL	5Y 6/3	M	5mm	LAYERED, SILTY HIGHLY WEATHERED
					W28-17.5	TILL	5Y 6/3	M	5mm	LAYERED, SILTY HIGHLY WEATHERED
					W28-20	TILL	5Y 5/1	L	2mm	LAYERED, SILTY LIGHTLY WEATHERED
N4222	154	76	29	aaa	W30-45	TILL	5Y 6/2	H	30mm	MASSIVE, SILTY
					W30-47.5	TILL	5Y 6/2	M	10mm	MASSIVE, SILTY
					W30-50	TILL	5Y 6/1	M	40mm	LAYERED, SILTY W/ABUNDANT LIGNITE
					W30-52.5	TILL	5Y 6/1	M	5mm	LAYERED, SILTY
					W30-55	TILL	5Y 5/1	M	4mm	MASSIVE, SILTY
N4223	154	76	5	aaa	W31-25	TILL	5Y 6/1	L	10mm	MASSIVE, SILTY
					W31-27.5	TILL	5Y 5/1	M	15mm	MASSIVE, SILTY
					W31-30	TILL	5Y 5/1	L	8mm	MASSIVE, SILTY
N4224	155	75	15	bbb	W33-12.5	TILL	5Y 6/2	L	20mm	MASSIVE, SILTY
					W33-15	TILL	5Y 5/1	L	8mm	MASSIVE, SILTY
N4225	157	78	33	bbb	W35-25	TILL	5Y 6/2	M	15mm	MASSIVE, SILTY
					W35-27.5	TILL	5Y 6/1	L	10mm	MASSIVE, SILTY
					W35-30	TILL	5Y 5/1		10mm	MASSIVE, SILTY
N4226	157	78	12	bbb	W37-12.5	TILL	5Y 6/1	L	8mm	LAYERED, SILTY
						LACUSTRINE CLAY				
					W37-15	TILL	5Y 6/2	M	5mm	LAYERED, SANDY
N4227	157	77	11	ccc	W39-12.5	TILL	5Y 5/1	M	5mm	LAYERED, SILTY
					W39-15	TILL	5Y 6/2	M	8mm	LAYERED, SILTY
					W39-17.5	TILL	5Y 6/1	M	8mm	LAYERED, SILTY
					W39-20	TILL	5Y 6/2	M	8mm	LAYERED, SILTY
N4228	157	76	16	aaa		c-SAND				
						TILL(diamict)				
						SILT				
						SILT				
					W40-20	TILL	5Y 6/2	H	10mm	MASSIVE, SILTY
N4229	159	79	16	bbb	W46-22.5	TILL	5Y 5/1	L	10mm	MASSIVE, SILTY
					W46-25	TILL	5Y 5/2	M	15mm	LAYERED, SILTY
					W46-27.5	TILL	5Y 6/1	M	4mm	MASSIVE, SILTY
					W46-30	TILL	5Y 6/1	M	5mm	MASSIVE, SILTY
N4230	159	76	17	aaa	W49-22.5	TILL	5Y 5/2	L	10mm	LAYERED, SILTY
					W49-25	TILL	5Y 6/2	M	10mm	LAYERED, SILTY
					W49-27.5	TILL	5Y 6/1	M	5mm	MASSIVE, SILTY
N4231	154	76	11	ddd	W51-25	TILL	5Y 5/1	L	10mm	MASSIVE, SILTY
					W51-27.5	TILL	5Y 5/1	L	10mm	MASSIVE, SILTY
					W51-27.5	TILL				
					W51-30	TILL	5Y 5/1	L	8mm	MASSIVE, SILTY
					W51-32.5	TILL	5Y 5/1	L	10mm	MASSIVE, SILTY
N4232	154	77	20	aaa	W52-20	TILL	5Y 6/1	M	20mm	MASSIVE, SILTY
					W52-22.5	TILL	5Y 6/1	L	20mm	MASSIVE, SILTY
					W52-25	TILL	5Y 6/1	M	20mm	MASSIVE, SILTY
					W52-27.5	TILL	5Y 6/1	L	30mm	MASSIVE, SILTY
N4233	158	79	22	aaa		CLAY				
					W53-47.5	TILL	5Y 5/2	H	30mm	LAYERED, SILTY
N4234	157	78	36	ccb		vf-SAND				
					W56-41.5	TILL	5Y 6/2	H	15mm	LAYERED, SILTY
						vf-SAND				
					W56-52.5	TILL	5Y 6/2	H	20mm	LAYERED, SILTY
					W56-55	TILL	5Y 6/2	M	20mm	LAYERED. SILTY
					W56-57.5	TILL	5Y 5/2	M	10mm	LAYERED, SILTY
N4235	157	73	28	bab	W59-20	STRAT.DIAM.	5Y 6/3	M	10mm	LAYERED, SILTY WEATHERED
					W59-22.5	STRAT.DIAM	5Y 6/3	M	20mm	LAYERED, SILTY WEATHERED
					W59-25	TILL	5Y 6/1	M	10mm	MASSIVE, SILTY
					W59-27.5	TILL	5Y 6/1	M	10mm	MASSIVE, SILTY
					W59-30	TILL	5Y 6/1	M	10mm	LAYERED, SILTY
N4236	152	73	15	bdb	W61-15	TILL	5Y 5/1	M	4mm	MASSIVE, SILTY
					W61-17.5	TILL	5Y 5/1	M	4mm	MASSIVE, SILTY
					W61-20	TILL	5Y 6/1	L	4mm	MASSIVE, SILTY
					W61-22.5	TILL	5Y 6/1	L	4mm	MASSIVE, SILTY
					W61-25	TILL	5Y 5/1	M	8mm	MASSIVE, SILTY
					W61-27.5	TILL	5Y 5/1	M	8mm	MASSIVE, SILTY
					W61-30	TILL	5Y 5/1	L	8mm	MASSIVE, SILTY
					W61-32.5	TILL	5Y 5/1	L	8mm	MASSIVE, SILTY
					W61-35	TILL	5Y 5/1	L	8mm	LAYERED, SILTY
					W61-37.5	TILL	5Y 5/1	L	8mm	LAYERED, SILTY

APPENDIX B: LITHOLOGIC AND TEXTURAL DATA

	LITHOLOGY					TEXTURE		
	SHALE	CRYSTAL.	CARB.	SD+SLT	LIGNITE	SAND	SILT	CLAY
W1-17	2.7	60.5	25.9	9.5	1.4	32.7	39.2	28.1
W1-20	4.3	63.6	21.0	9.9	1.2	32.7	39.2	28.1
W1-25	3.5	65.7	22.4	8.4	0.0	31.0	40.5	28.5
W1-30	3.3	65.8	24.2	5.8	0.8	32.6	40.1	27.3
W1-37	3.4	72.1	19.0	4.1	1.4	36.3	35.8	27.9
W1-45	2.9	59.4	30.4	6.5	0.7	34.0	37.9	28.1
W2-17.5	2.2	70.6	16.9	8.8	1.5	50.4	31.0	18.6
W2-20	2.6	66.2	25.2	5.3	0.7	50.9	33.2	15.9
W3-0	0.7	71.1	23.2	4.2	0.7	37.1	34.0	28.9
W3-5	0.0	70.5	23.0	6.5	0.0	32.6	37.2	30.2
W4-12.5	2.3	67.7	23.3	6.0	0.8	36.8	37.1	26.1
W4-15	2.1	62.0	27.5	6.3	2.1	41.6	34.1	24.3
W6-22.5	2.7	60.0	29.3	6.0	2.0	33.9	51.5	14.6
W7-37.5	0.0	78.8	11.6	5.5	4.1	39.0	56.2	4.8
W7-40	0.8	81.1	15.7	2.4	0.0	45.2	48.9	5.9
W8-55	2.5	69.4	14.9	8.3	5.0	30.2	43.1	26.7
W8-57.5	3.1	68.5	20.0	5.4	3.1	29.5	43.6	26.9
W8-60	0.0	32.4	5.4	13.5	48.6	18.7	66.7	14.6
W9-47.5	4.3	58.0	20.3	5.1	12.3	47.2	32.2	20.6
W9-50	2.6	71.2	19.2	2.6	4.5	38.9	38.7	22.4
W10-12.5	0.7	65.5	29.0	4.8	0.0	36.7	35.7	27.6
W10-15	0.7	64.8	28.9	5.6	0.0	37.4	37.7	24.9
W11-12.5	2.0	70.5	23.5	4.0	0.0	41.3	38.3	20.4
W11-17.5	1.4	73.0	25.5	0.0	0.0	39.2	39.0	21.8
W11-20	1.9	74.7	20.3	2.5	0.6	35.4	39.8	24.8
W14-15	1.3	66.9	26.9	3.8	1.3	34.5	39.9	25.6
W14-17.5	3.1	65.8	26.1	5.0	0.0	35.2	38.8	26.0
W14-20	3.0	64.5	31.4	1.2	0.0	35.4	38.4	26.2
W15-27.5	1.5	69.2	22.3	4.6	2.3	33.6	38.7	27.7
W15-30	4.1	64.8	24.1	5.5	1.4	32.1	39.8	28.1
W16-15	4.3	72.1	17.1	4.3	2.1	35.3	36.1	28.6
W16-17.5	2.1	72.7	23.1	2.1	0.0	34.2	38.0	27.8
W16-20	2.2	70.9	22.4	1.5	3.0	32.8	38.1	29.1
W17-22.5	2.8	66.0	25.7	5.6	0.0	42.0	44.6	13.4
W17-25	1.4	80.9	11.3	2.8	3.5	39.6	42.4	18.0
W18-20	4.3	63.1	30.5	2.1	0.0	29.0	41.8	29.2
W22-7.5	3.5	70.4	19.7	4.2	2.1	42.4	36.2	21.4
W22-10	4.7	76.6	15.6	1.6	1.6	35.1	37.9	27.0
W23-12.5	3.1	71.1	21.1	2.3	2.3	34.9	40.5	24.6
W23-17.5	0.0	79.9	19.4	0.7	0.0	34.9	39.1	26.0
W24-7.5	0.8	73.4	25.0	0.8	0.0	36.7	40.9	22.4
W24-10	3.7	71.4	20.5	4.3	0.0	34.2	41.2	24.6
W25-22.5	0.0	71.9	26.7	0.7	0.7	28.3	41.6	30.1
W25-25	3.5	63.4	30.3	0.7	2.1	29.6	43.1	27.3
W25-27.5	3.3	66.9	24.5	5.3	0.0	24.7	37.9	37.4
W25-30	2.2	67.9	27.7	2.2	0.0	35.4	37.7	26.9
W27-5	0.0	74.2	25.8	0.0	0.0	43.9	36.0	20.1
W27-7.5	0.0	79.3	20.7	0.0	0.0	43.9	38.2	17.9
W27-10	1.9	72.3	25.8	0.0	0.0	42.7	39.5	17.8
W28-15	0.7	75.3	23.3	0.7	0.0	44.1	30.8	25.1
W28-17.5	3.4	71.2	24.0	1.4	0.0	36.1	39.1	24.8
W28-20	2.9	63.8	28.3	3.6	1.4	33.8	40.5	25.7
W30-45	1.3	71.1	24.3	2.6	0.7	44.1	43.6	12.3
W30-47.5	2.2	76.3	16.5	1.4	3.6	31.6	54.0	14.4
W30-50	2.2	78.1	19.1	0.5	0.0	41.7	45.9	12.4
W30-52.5	1.9	71.3	25.6	1.3	0.0	47.4	38.9	13.7
W30-55	1.9	77.3	18.2	0.6	1.9	47.9	37.5	14.6
W31-25	2.9	65.5	16.5	5.8	9.4	36.1	39.6	24.3
W31-27.5	2.2	70.4	23.7	1.5	2.2	34.8	41.1	24.1
W31-30	3.1	67.9	22.9	2.3	3.8	35.2	40.5	24.3

APPENDIX B: LITHOLOGIC AND TEXTURAL DATA

	LITHOLOGY					TEXTURE		
	SHALE	CRYSTAL.	CARB.	SD+SLT	LIGNITE	SAND	SILT	CLAY
W33-12.5	1.5	64.2	29.1	4.5	0.7	31.6	36.7	31.7
W33-15	4.1	72.1	23.8	0.0	0.0	30.1	38.2	31.7
W35-25	1.9	63.9	29.7	2.6	1.9	35.5	38.9	25.6
W35-27.5	5.2	64.7	25.5	3.3	1.3	33.9	40.6	25.5
W35-30	2.2	58.3	31.7	4.3	3.6	35.9	39.0	25.1
W37-12.5	0.7	72.0	25.2	1.4	0.7	34.9	41.8	23.3
W37-15	5.3	66.1	24.0	2.9	1.8	50.4	34.9	14.7
W39-12.5	1.9	72.9	23.9	1.3	0.0	34.3	40.5	25.2
W39-15	3.8	64.7	26.9	3.8	0.6	35.0	39.5	25.5
W39-17.5	6.2	70.8	18.6	4.3	0.0	36.4	37.6	26.0
W39-20	3.0	70.3	24.2	2.4	0.0	36.8	38.4	24.8
W40-20	3.2	68.2	26.1	2.5	0.0	13.3	57.0	29.7
W46-22.5	13.3	48.2	36.1	2.4	0.0	32.2	38.9	28.9
W46-25	5.7	62.3	28.3	3.1	0.6	32.7	38.9	28.4
W46-27.5	9.7	52.3	35.5	2.6	0.0	35.4	37.3	27.3
W46-30	9.5	53.1	35.8	1.7	0.0	35.2	38.0	26.8
W49-22.5	12.1	53.9	29.7	4.2	0.0	32.1	33.3	34.6
W49-25	9.1	54.5	35.0	1.4	0.0	29.0	34.7	36.3
W49-27.5	8.9	59.5	31.0	0.6	0.0	39.3	35.1	25.6
W51-25	2.7	70.7	20.4	3.4	2.7	38.5	37.0	24.5
W51-27.5	4.1	70.9	21.6	2.0	1.4	38.4	39.1	22.5
W51-30	3.3	71.5	19.9	2.6	2.6	37.6	38.0	24.4
W51-32.5	1.3	74.7	20.0	2.0	2.0	36.5	38.4	25.1
W52-20	3.7	73.5	15.4	4.4	2.9	32.7	42.6	24.7
W52-22.5	2.7	73.5	12.9	6.1	4.8	37.0	38.5	24.5
W52-25	2.9	68.3	21.6	2.4	4.8	31.9	40.8	27.3
W52-27.5	5.8	69.2	17.3	3.8	3.8	32.5	40.6	26.9
W53-47.5	5.3	53.3	36.8	4.6	0.0	22.6	46.0	31.4
W56-41.5	7.4	64.2	21.6	6.8	0.0	21.9	55.3	22.8
W56-52.5	1.2	68.1	15.7	4.2	10.8	29.9	51.0	19.1
W56-55	2.0	63.0	26.0	3.0	6.0	14.2	67.1	18.7
W56-57.5	1.4	70.6	25.9	2.1	0.0	33.5	45.7	20.8
W59-20	0.6	73.6	23.3	2.5	0.0	34.3	38.9	26.8
W59-22.5	2.8	86.9	3.7	6.5	0.0	44.4	44.1	11.5
W59-25	2.8	67.6	24.6	4.2	0.7	40.0	48.6	11.4
W59-27.5	0.0	74.2	21.2	4.5	0.0	36.5	53.5	10.0
W59-30	0.0	72.1	23.9	4.1	0.0	29.5	56.1	14.4
W61-15	0.0	77.4	16.7	6.0	0.0	31.1	25.2	43.7
W61-17.5	1.3	73.6	13.8	7.5	3.8	52.6	34.3	13.1
W61-20	0.0	76.8	16.8	4.5	1.9	51.5	37.2	11.3
W61-22.5	2.2	74.1	15.1	4.3	4.3	47.9	42.0	10.1
W61-25	1.4	77.1	17.4	4.2	0.0	31.3	32.2	36.5
W61-27.5	2.0	77.2	20.8	0.0	0.0	34.3	35.5	30.2
W61-30	0.7	81.3	14.6	2.1	1.4	35.0	38.6	26.4
W61-32.5	0.0	71.4	18.8	9.8	0.0	32.2	36.4	31.4
W61-35	1.4	72.4	22.1	2.8	1.4	35.2	35.9	28.9
W61-37.5	1.3	74.5	18.3	4.6	1.3	39.9	35.3	24.8
A1-2	0.0	64.2	33.3	2.5	0.0	33.8	37.6	28.6
A2-2	38.8	29.5	31.0	0.8	0.0	37.0	32.6	30.4

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