Sedimentation Analysis and Glaciolacustrine Depositional Implications of Glacial Lake Minnesota

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under the supervision of Professor Jim Welsh

ABSTRACT

The purpose of this research was to investigate the sedimentology of Glacial Lake Minnesota. Sites found in irrigation ditches, river and road cuts, and gravel pits throughout Blue Earth County, Minnesota reveal the sedimentary record of the lake. Grain size from west to east across the lake basin. The site furthest to the west, near Watonwan Highway 30, contains the coarsest sediment (fine to medium sand) and displays features characteristic of deltaic deposition. Sites in the central region of study are characterized by finer-grained alternating silt and clay lake sediments, often interbedded with diamicton layers. We interpret the silt and clay layers to be varves. The eastern-most site consists of clay which we interpret was deposited in the center of the lake. The west-to-east variation reflects fining offshore and indicates that the primary source of sediment was from the west from Des Moines Lobe ice-marginal streams.

The varved sediments suggest a short-lived (tens of years) or shallow lake. The varves occur in variable in variable numbers (4 to 8) , suggesting that not all varves were preserved. Varves vary in thickness from 3 to 30 cm. Summer silt layers show extensive laminations indicating daily/monthly fluctuations or storm waves affecting a shallow lake. Diamicton layers are nearly identical to local New Ulm till and were formed either by ice-rafting or as mudflows.

The sites found show evidence of a glacial lake and are in accordance with previous Glacial Lake Minnesota knowledge. The sedimentary and topographic features in this area support a two-phase theory (as described by Richard Paulson) of Glacial Lake Minnesota[1].

[1] Rasmusson, Erin L., and Finch, Mary C., 1999, Sedimentology and distribution of Glacial Lake Minnesota deposits, Geological Society of America Abstracts with Programs, v.31.

ACKNOWLEDGMENTS

I would like to thank NSF REU for the research grant and opportunity to participate in the REU 1998 summer program, Gustavus Adolphus College for the use of their facilities and supplies, program coordinator and Geology Department chair Mark Johnson for his guidance and expertise, teaching assistants Katie Whitman and Heather McGiffert for their help, and Richard Paulson for his Glacial Lake Minnesota insight. A special thank you goes to my research partner Erin Rasmusson for her invaluable contributions in our study of the lake.

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1.1 *Introduction*

The study site for this research is Glacial Lake Minnesota, located in Blue Earth County, Minnesota. The purpose of this research was to investigate the sedimentology of Glacial Lake Minnesota. This was accomplished by locating sites, identifying sedimentary structures, and analyzing site distribution throughout the lake basin. Sample collection and subsequent analysis of sites contributed to interpretation of the history of the lake and its topographical features. New data compiled from the research allowed for correlation of information discovered to present glacial knowledge.

1.2 *Regional Quaternary Geology*

The Quaternary history of the Glacial Lake Minnesota vicinity begins during the Late Wisconsinan Glaciation. Proof of at least four glaciations at the end of the last ice age is present in southern Minnesota (Matsch, 1972). The last glacier to retreat from Minnesota was the Des Moines lobe glacier, a part of the Laurentide Ice Sheet system (Figure 1). Approximately 14,000 years ago, the Des Moines lobe progressed to its southernmost destination in the Des Moines, Iowa vicinity where it then began its final retreat (Ruhe, 1969). The Des Moines lobe retreated back across the Mankato area of Minnesota, located on the northern edge of Blue Earth County, and exposed it approximately 12,700 years ago (Jelgersma, 1962). The till deposited by the Des Moines lobe is referred to as the New Ulm Till, which is a "light olive-brown, calcareous clay loam till, containing pebbles predominantly of siliceous shale, limestone, dolomite, and granitic rocks"(Matsch, 1972).

As the Des Moines lobe retreated, it stagnated and re-advanced numerous times. The stagnating Des Moines lobe, while retreating through southern Minnesota, allowed the pooling of a pro-glacial lake called Glacial Lake Minnesota (Figures 2 and 3). Glacial Lake Minnesota sediments are seen mostly in Blue Earth County, MN, but they also extend into surrounding counties to the west, east, and south. Two specific stagnations created Glacial Lake Minnesota (Paulson, 1986). The lake pooled at the ice-marginal front of the southern tip of the retreating Des Moines lobe. As the Des Moines lobe retreated further, it pooled another large-scale, glacial lake called Glacial Lake Agassiz in the northern part of the Midwestern states. The outlet of Glacial Lake Agassiz, known as River Warren, scoured the Minnesota River valley just north of the older Glacial Lake Minnesota sediments (Wright, 1972).

The two stagnations of the Des Moines lobe that created Glacial Lake Minnesota, are referred to as Phase I and Phase II of the lake (Paulson, 1986). Figure 4 shows the approximate ice margin locations of the phases. Both phases differ from each other in elevation and in deposited sediment types. Phase I of the lake has been dated to 12,700 years, but the age of Phase II is yet to be determined (Pottenger, 1999). Phase II is located mainly in the northern half of Blue Earth County, Minnesota, and it covers reaches of the Watonwan, Maple, Le Seuer, Big Cobb, and Blue Earth Rivers as well as the towns of Good Thunder, Sterling Center, Mapleton, Vernon Center, Rapidan, and Lake Crystal. Ice marginal streams that fed the lake in Phase II are thought to have come in from the northwest forming the Lake Crystal Delta and then depositing the characteristic glacial lake varves. The life of the lake in Phase II was relatively short and information on the lake is minimal.

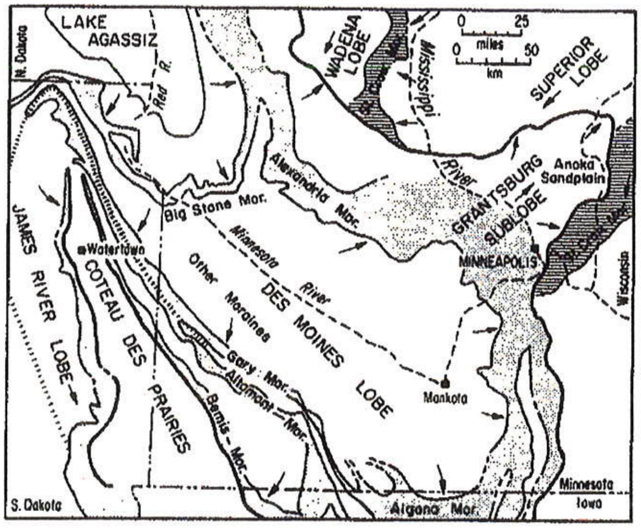


Figure 1. Glacial map of Minnesota indicates the southeasterly ice-flow direction of the Des Moines lobe from a northwest origin. In relation to the map, Glacial Lake Minnesota is located directly south of Mankato, Minnesota (figure from Matsch, 1972).

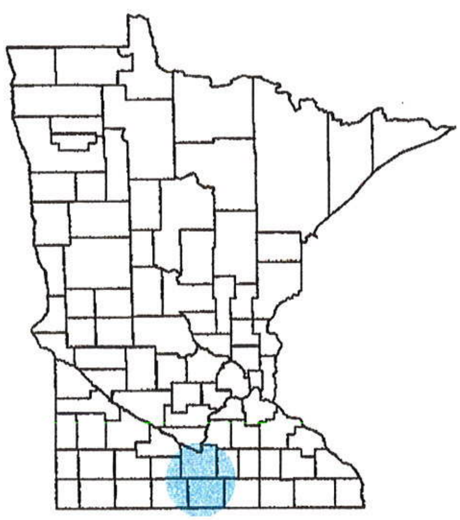


Figure 2: Location of Glacial Lake Minnesota.

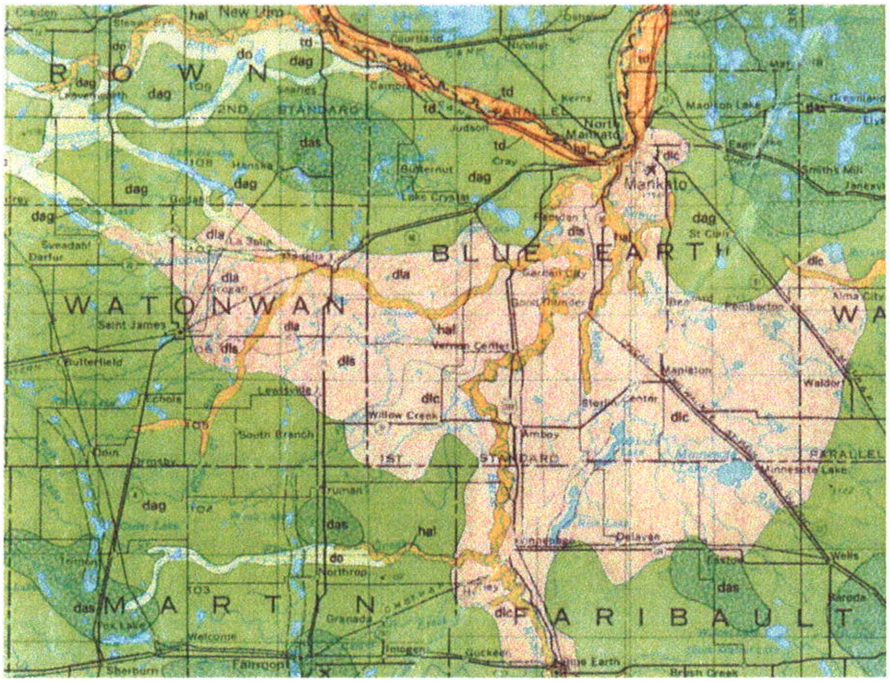


Figure 3. Approximate extent of Glacial Lake Minnesota. Glacial lake sediment indicated by **dla** (sand and gravel), **dls** (silt and fine sand), and **dlc** (clay and clayey silt). Ice marginal inlet streams are located in the northwest margin of the lake. (figure segment from the Hobbs and Goebel *Geologic Map of Minnesota*, 1982).

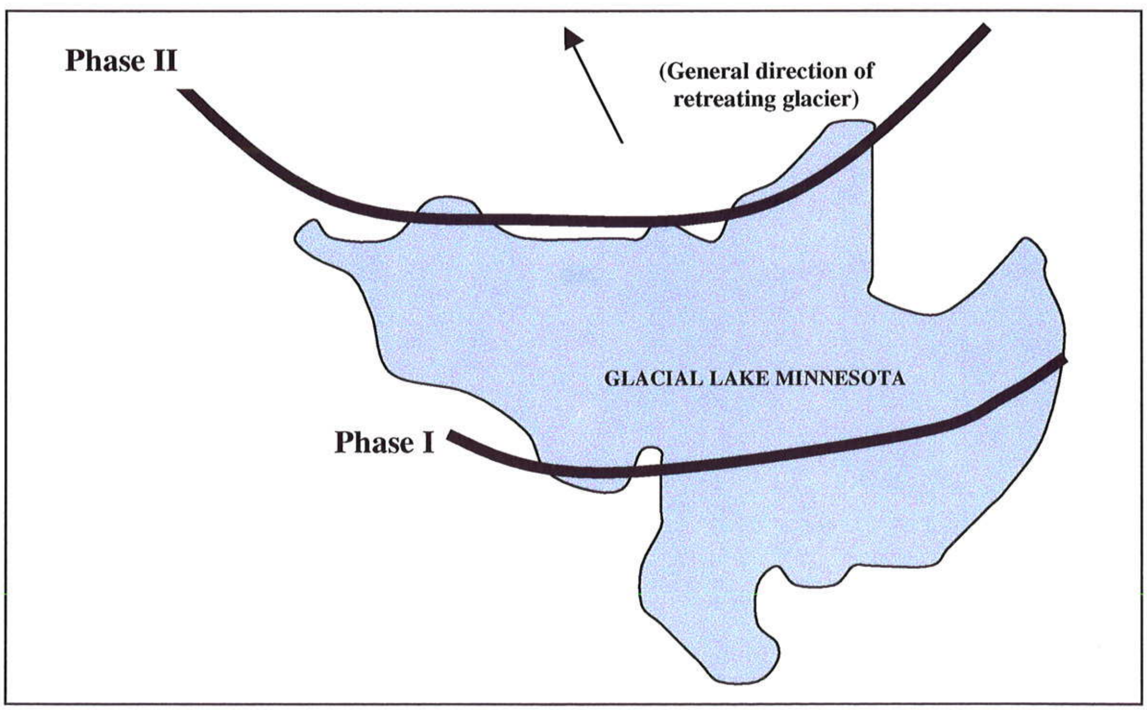


Figure 4. Estimated locations for the ice margins of the retreating Des Moines lobe in the Phase I and Phase II stages of the lake, as discussed by Paulson (1986). The Des Moines lobe was considered to stagnate in two significant locations during its retreat to pool the two phases of the lake.

1.3 *Previous Works*

Little previous work has been done on Glacial Lake Minnesota and exact boundaries and specificities are unknown. The location, approximate boundaries, and sediment description of the lake are shown on the H.C. Hobbs and J. E. Goeble 1982 *Geologic Map of Minnesota* (Figure 3). However, sedimentation knowledge beyond their lacustrine origin was relatively unknown until the soil studies by Richard Paulson in 1986. Information discovered by Paulson indicated that the expanse of lake sediments was larger than previously thought. Paulson was also the first to recognize evidence for two phases of the lake (Figure 4).

Phase I of the lake occupies much of Faribault County and is seen at maximum elevations of 1125, with a lake depth of approximately 45 feet. The approximate edge of the lake plain can be seen at one locality north of Elmore, MN at an elevation of 1,125 feet. Stratified silts and sands over till at 1,160-1,165 feet can be seen near Foster, MN. Elevations from Elmore to Winnebago of 1,070-1,085 feet are considered to be common elevations for the Phase I basin.

Evidence in the landscape between the Faribault-Blue Earth County line and Minnesota Highway 109 show the possibility of an ice-walled boundary, which may be the location of the ice margin in the Phase I of the lake (Figure 4). Near the town of Amboy, MN are the Pleasant Mound Hills and Sterling Center Hills, which have features that imply a southward movement of water and sediments, possibly through an ice-crevasse system. Sediment influx is interpreted from the deltaic characteristics of the soils in this vicinity. Tills over silts located along Faribault County Line are believed to be indicative of ice contact features, such as slumps off the southern margin of the glacier during the Phase I lake formation. In addition, the Algona Moraine, from the Des Moines lobe, may have been a natural boundary for the Phase I lake. Several possible ice-marginal stream inlets from the west are observed along Center Creek, and the outlet of the first phase cuts through the Algona Moraine via the Union Slough.

According to Paulson, Phase I of the lake is the southernmost and earliest phase. Soil samples of this phase were taken from deep borings near the city of Blue Earth, close to the center of the lake basin. The borings indicate 10-20 feet of water sorted materials that can be characterized as 3-5 feet of clayey sediments overlying silty stratified sediments. Paulson described the top 62 feet of the borings to be A-C horizon soils with a parent material of lacustrine clays, and the soils from 62-174 feet are soil horizon type 2C with a parent material of stratified silts and clays. Below 174 feet, the soils are type 3C and have a parent material of loam and clay loam glacial till. Soils from the Blue Earth area are collectively referred to as being part of the fine textured soils family.

Paulson's Phase II is the more recent and northern part of the lake, located north of the city of Blue Earth. The elevations of Phase II described appear to range from 990-1,040 feet. Sedimentary and soil information is present throughout Blue Earth County and also in parts of the surrounding counties to the east, west, and south. Near Delevan, at approximately 1,040 feet, is a level basin of very fine clayey sediments. Soils near Beauford were found also to be very fine clayey sediments. An elevation of 1,035 feet near Sterling Center, very fine and fine clayey sediments were observed. Parent materials in the Sterling Center vicinity are fine textured lacustrine clays until a depth of 70 feet, and then it is water-worked till until 96 feet when it becomes dense unoxidized grayish calcareous clay loam till (New Ulm Till). Soils in the Mapleton area are described as A, Bg, and Cg horizon soils with percentages of clay ranging from 55-77. Sites east of Mapleton were observed to have 20-40 inches of fine lacustrine sediments (Paulson, 1986).

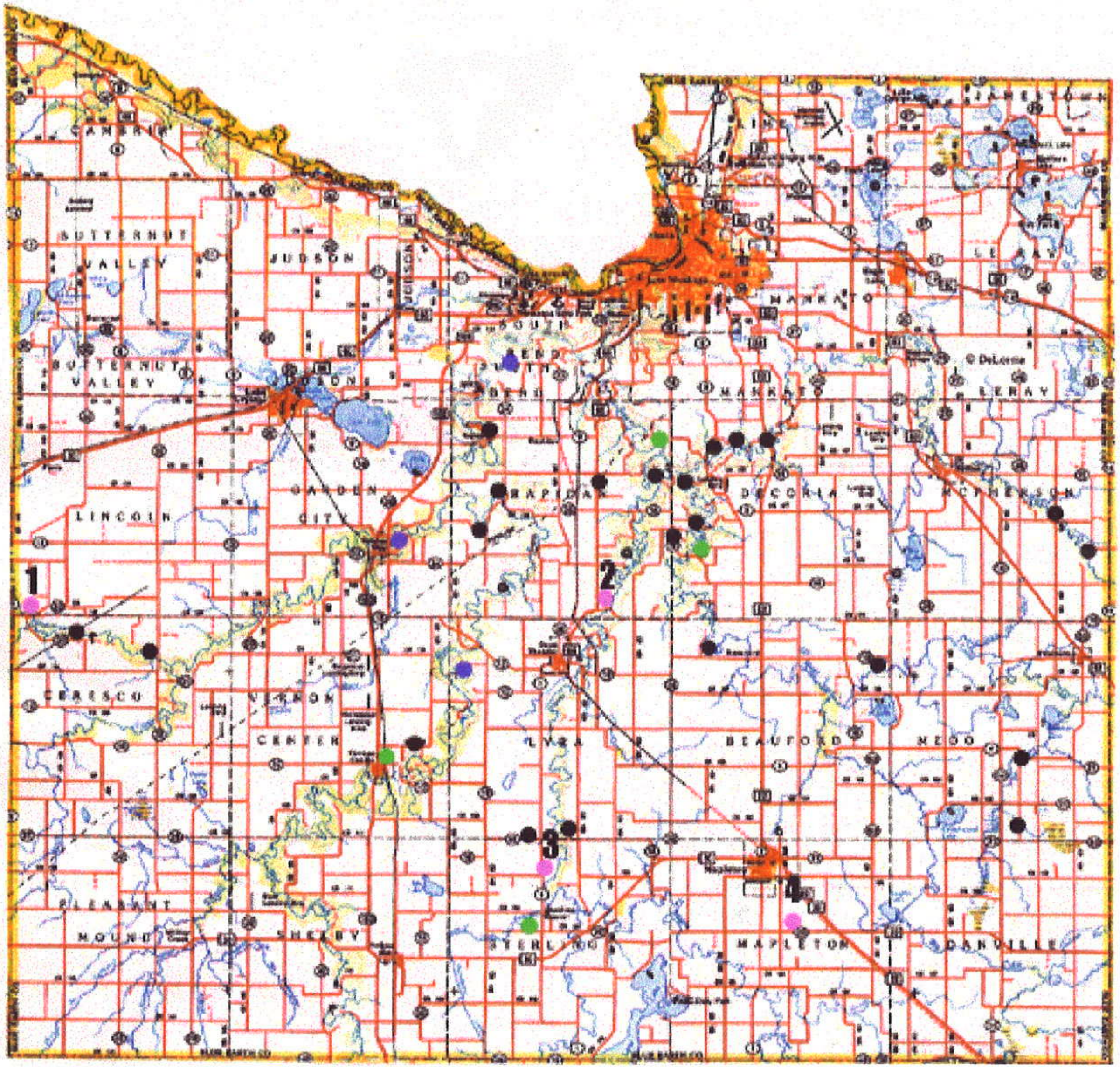
Paulson the eastern portion of Blue Earth County and beyond to show evidence of delta formation from ice-marginal inlet streams. Phase II has ice marginal inlet streams from the northeast and two outlets streams: one through the Le Sueur River near Otisco and Vista Village, MN and another through Dutch Creak into the Cannon River. Sands, fine sands, and silts at an elevation of 1090 near Madelia are considered to be part a delta system created by a glacial meltwater stream that entered along the edge of the Des Moines lobe. Near St. James is the beginning of a delta complex for the second phase of Glacial Lake Minnesota. The delta system was created by ice marginal streams entering the lake plain from the northwest along the south fork of the Watonwan River. The system is collectively referred to as the Lake Crystal Delta (Paulson, 1986). Sediment elevations between Lake Crystal and Madelia are around 1,030-1,040 feet. Parts of the delta show fine and very fine sands with textured strata, as well as some stagnant ice features. Typically, the delta shows a finer grading of grain size from sands in the western portion to coarse silty sediments to the southeast and ultimately to fine silty sediments east of Garden City (Paulson, 1986). Sites with Phase II deltaic or other lacustrine sedimentary evidence are found near the towns of St. James, Lake Crystal, Madelia, Garden City, Rapidan, Good Thunder, Sterling Center, Amboy, Lewisville, and Mapleton.

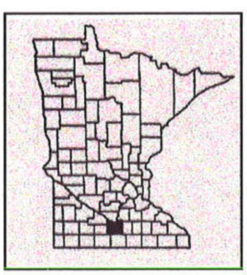
Other information on the Phase I of Glacial Lake Minnesota was discovered by Lisa Pottenger through the 1998 REU program. Specifically, a radiocarbon date for a peat layer located in Phase I sediments was determined to be 12,700 years old and can be used to give age of the earlier part of the lake (Pottenger, 1999). Pottenger's site is located on the Blue Earth River between the towns of Winnebago, MN and Blue Earth, MN. Sediments at Pottenger's site show peat, laminated blue silts, fine sands with climbing ripples, and a few diamicton layers over a basal New Ulm Till. At the very top of the site are approximately five varves typical of Glacial Lake Minnesota sedimentation.

2. Site Descriptions

2.1 *Field and lab methodology*

Methods of study began with the interpretation of eighteen different topographic quadrangles in the Glacial Lake Minnesota basin. The quadrangles were analyzed for possible Glacial Lake Minnesota sediment outcrops along road and river cuts. These potential sites were then located in the field and examined in hopes of discovering evidence of lacustrine sedimentation. Many of the sites turned out to contain no evidence of lake sediments. However, eleven sites did contain lacustrine sediments, and the accessible sites were chosen for the research. Figure 5 shows the site locations examined and selected for research. The number of accessible sites made it possible for two people to work on this project. A fellow REU student, Erin Rasmusson, and I each evaluated four sites. Results from the research were then combined to interpret and determine the history of the lake. My sites consisted of three typical Glacial Lake Minnesota sediment sites and one delta exposure, labeled Sites 1 through 4 (Figure 5). At each site, photographs were taken, vertical profiles were created when possible, and samples were





Location of Blue Earth County, Minnesota

LEGEND

- = Sites 1 through 4
- = Rassmusson's sites
- = Inaccessible sites
- = No GLM sediment found

Figure 5. Site location map, Blue Earth County, MN. (county road map from "Minnesota Gazetteer")

collected. In addition, structural measurements were gathered on the sedimentary and deformational structures at Site 1.

From the samples collected, various lab tests were completed. Grain-size analyses of specific silt, clay, and diamicton layers were conducted. Lithology was determined for the zero phi sand grains found for each sample analyzed, and ternary diagrams were created and interpreted. Thin sections were also produced from the clays and laminated silts of the varved sediments at the Site 2. Field measurements of dip direction for sedimentologic structures such as ripples and deformational features were measured, and the information was combined into rose diagrams for interpretation.

2.2 *Site overviews*

The four sites analyzed for this paper are discussed from west to east across the basin, following the apparent path of sediment influx from the determined ice-marginal stream inlets in the northwestern portion of the basin. The first site discussed is located along the Watonwan River at its intersection with Highway 30 and is considered to be representative of delta sedimentation. The next two sites, one near the town of Good Thunder and another in the vicinity of Sterling Center, show varved sediments typical of glacial lake sedimentation. The fourth site, located in an irrigation ditch in Mapleton, is a fairly nondescript site indicative of presumed central lake sedimentation.

2.3 *Site 1: Watonwan River and Highway 30 intersection*

Site 1 is located at the intersection of Highway 30 and the Watonwan River on the western edge of Blue Earth County in the Perth 7.5 minute series topographic quadrangle (Figure 5). The site is exposed along the edge of the river and is characterized by mainly sandy material. Figure 6 shows a photograph of the study site. The portion of the site

Figure 6. Photograph of section observed at Site 1.

studied is approximately the upper 305 centimeters of the exposure (stratigraphic profile shown in Figure 7). The first diamicton layer at the bottom of the profile rests on sand, which continues below the section observed and was not studied due to vegetation cover. This diamicton layer is then overlain by a fine sand, and another diamicton layer. These three layers show evidence of deformation. This deformation is observed in the diamicton layers tendencies to thicken, amalgamate, and migrate into the sand layer between. Overlying these layers is a large section of very fine sand characterized by climbing ripples, which are cut by a series of faults. Faulting was only observed in this particular layer, and offset is difficult to determine due to the uniformity of the surrounding sediments. From the faults and ripples, strike and dip data was collected for further interpretation. On top of these fine sands are various sand, gravel, and diamicton layers, ranging in thicknesses from 1 to 40 centimeters. The lateral extent of the layers is unknown, and varied sizes could be attributed to till or sand pod formation rather than continuous layers. Also, some of the layers or pods include boulders. The top 60 cm of the site are sediments affected by soil processes, which are bounded on the bottom by a cobble/pebble layer.

Grain-size analyses were performed by pipet analysis and lithologies were determined by analysis of the very coarse sand grains on three diamicton layers at this site (see Figure 7 for sample locations). The results were plotted on ternary diagrams. The diamicton layers, though similar to the basal till units found at the other Glacial Lake Minnesota sites, showed a distinct increase in sand content, specifically crystalline sand, and a decrease of clay (see Figures 18 and 19 and section 3.1). Although there was an increased amount of sand, the presence of shale and the color of the diamicton layers was

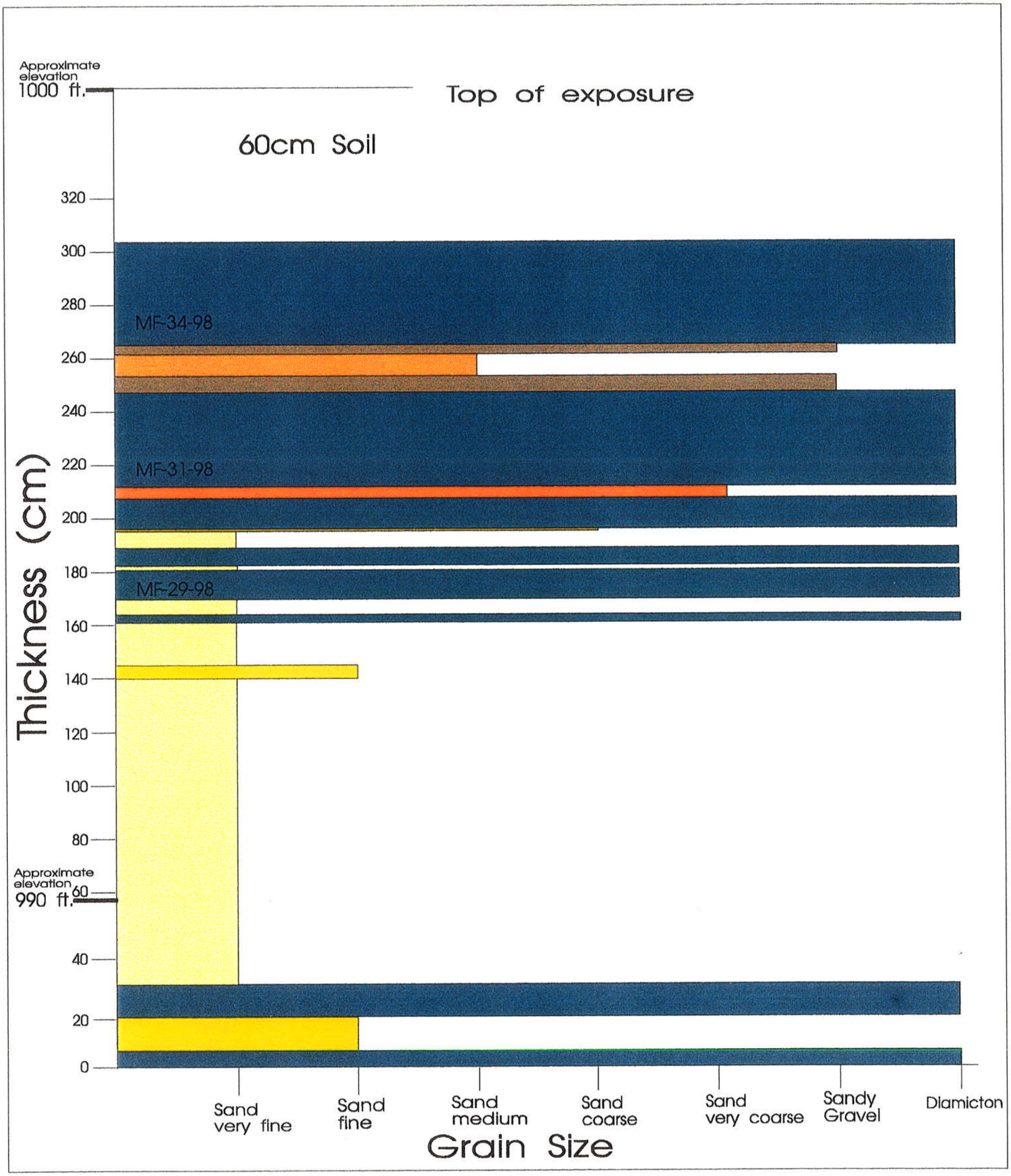


Figure 7. Straigraphic profile of Site 1.
(MF-31-98 and others indicate sample locations)

very similar to that of the New Ulm Till (see Table 1). Considering the amount of sand layers that are intercalated between the till layers at this site, an increase in sand content is not surprising.

The 107-centimeters of very fine sand at the site that contains the fault and ripple structures poses some interesting questions and additional data for interpretation. Figures 8 and 9 show the faults and ripples. Climbing ripples are many times associated with delta deposits (Prothero, 1996). With this in mind and to achieve a better understanding of what the ripples represent, the strike and dip of the ripple cross-laminae for fifteen typical ripples were measured (Table 2). The data was then compiled into a rose diagram to illustrate the findings (Figure 10). The information shown on the diagram indicates a current flowing to the southeast from a northwestern source. A rose diagram was also completed to compile dip direction data on the faults located in the very fine sands (data listed in Table 3). The dip direction results were extremely similar to that of the ripple cross laminae (Figure 11). The results for faulting, due to their uniformity of direction, can be interpreted to indicate growth faulting of the prograding delta as sediment shifted forwards (Reading, 1996). Therefore, this would also indicate a southeasterly flowing current and sediment influx. All in all, data from this site shows characteristics typical of deltaic sedimentation, indicating the possible presence of an ancient delta.

2.4 *Site 2: Near Good Thunder and Highway 66*

This site is located east of Highway 66 along the Maple River and north of the town of Good Thunder in the Good Thunder 7.5 minute series topographic quadrangle. The section observed is approximately the top 200 centimeters of the exposure (see Figure 13 for photograph). The stratigraphic profile, Figure 12, shows New Ulm Till at

Figure 8. Climbing ripples from the very fine sand layer at Site 1 (*pencil for scale).*

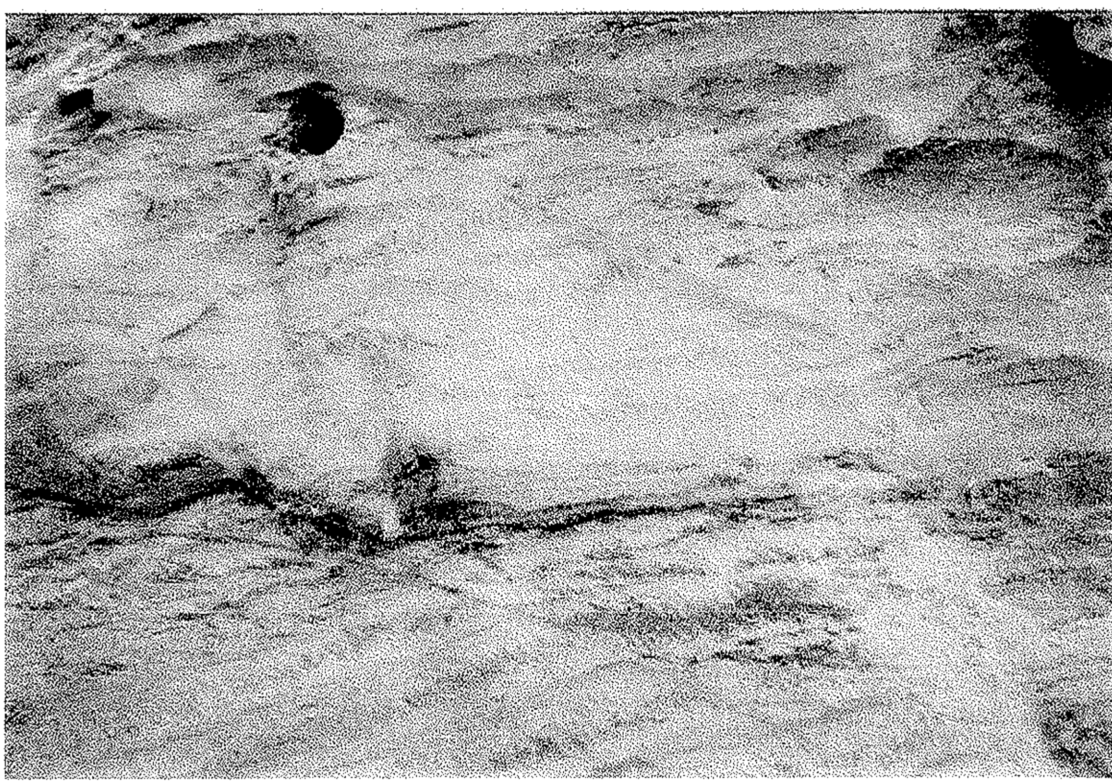


Figure 9. Two of the larger faults associated with the very fine sand layer.

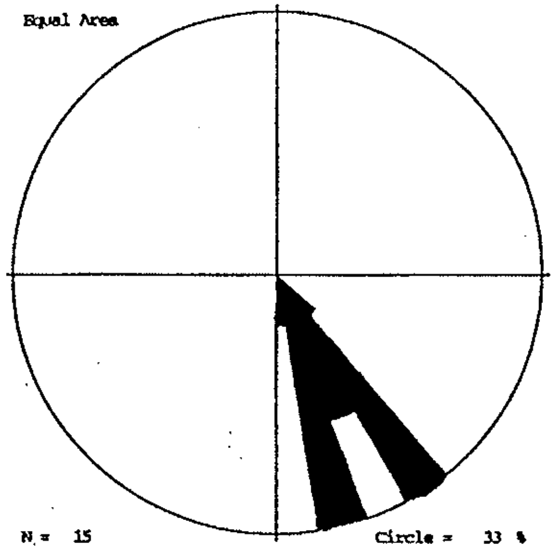


Figure 10. Dip direction of the ripple cross-laminae at Site 1.

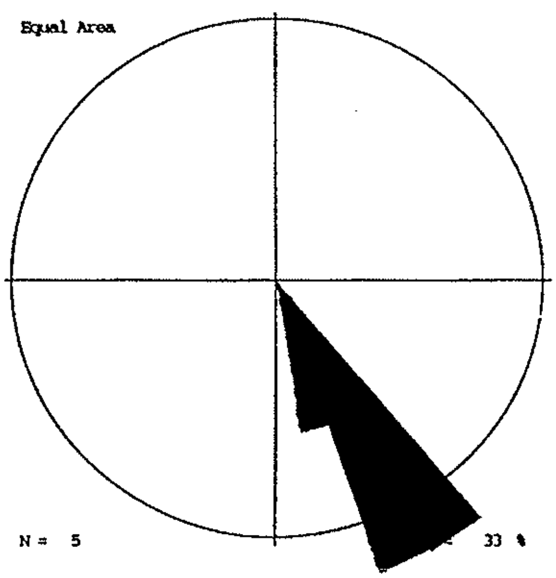


Figure 11. Dip direction of faults at Site 1.

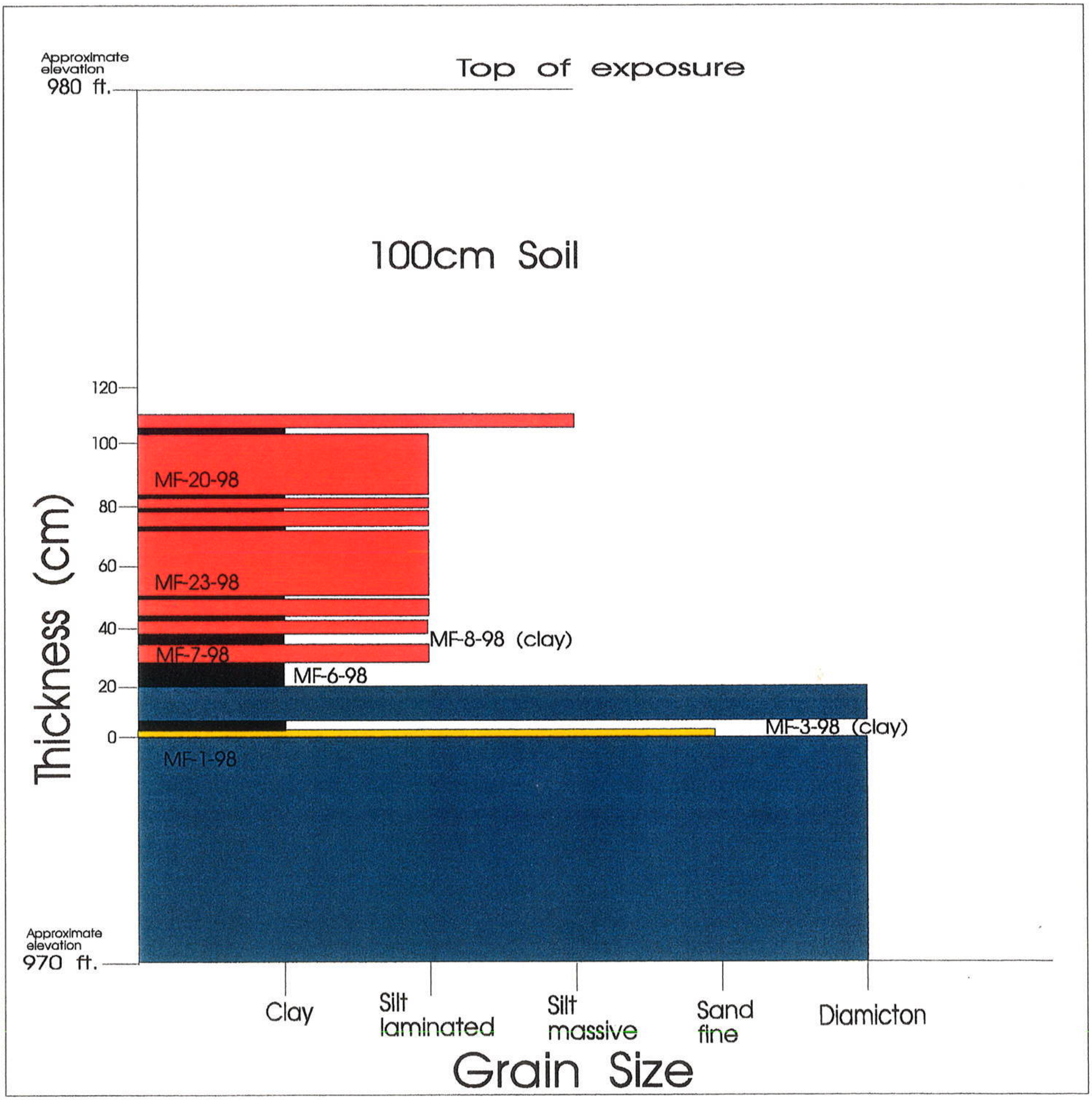


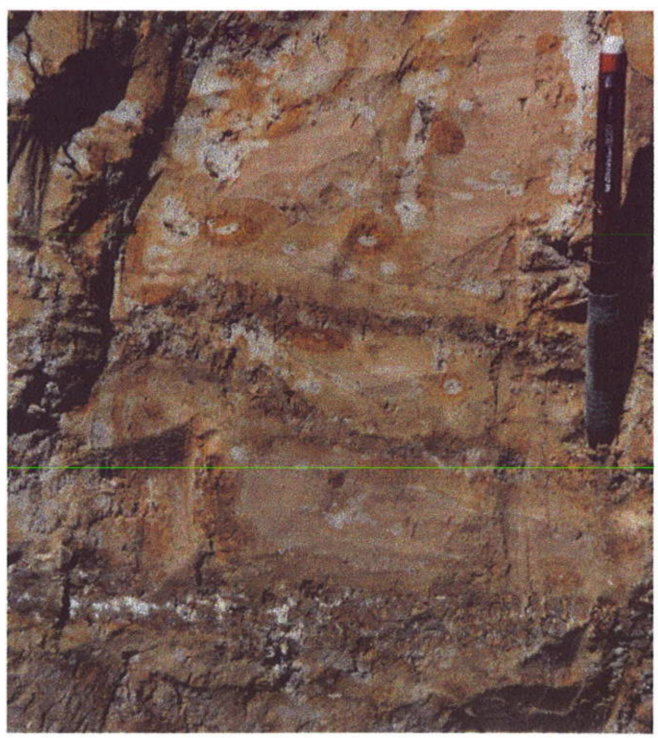
Figure 12, Stratigraphic profile for Site 2.
(MF-1-98 and others indicate sample locations)

the base of the exposure. A layer of laminated sand that alternates from fine to medium overlies this. On top of the sands is a clay layer followed by a diamicton layer that is clayey and contains silt balls. Overlying the diamicton layer is a clay layer that is then covered by alternating silt and clay layers. These coupled silts and clays indicate the presence of seven or more varves. It is difficult to determine the exact number of varves due to slight deformation and soil processes at the top of the exposure. The deformation of the clays and the fine laminations of the silt layers in the varves is depicted in Figure 14. This photograph is of three alternating clay and silt layers from the varved sediments. Thin sections were made from the bottom two clay and silt layers in the photograph. Examination of these under the microscope shows fine laminations in the silts and the aphanitic texture of the clays.

In addition to thin sections, seven grain-size analyses of specific layers were performed on samples collected at this site. Analyses were performed on three silt and three clay layers from the varves, and one analysis was performed of the basal till unit. As shown in Figure 18, the silts and clays plot as expected, and the till plots in the area characteristic of the New Ulm Till (Matsch, 1972). These are all in correlation with lab particle data collected from soils in the Good Thunder area, which show average totals to be 11 percent sands, 50 percent silts, and 39 percent clays (Paulson, 1986). Lithologies of the very coarse sand grains found in these samples were also determined. The small amount of sand in the clays and silts do not reveal anything significant (Figure 19). However, the lithology for the basal till indicates a distinct presence of shale, which is significant in proof of its Des Moines Lobe origin (Matsch, 1972). Data compilation from this site is presented in Table 1.

Figure 13. (*left*) Photograph of Site 2. Striped layers at the top of the site are the lacustrine sediments. The layers are essentially horizontal and undeformed; however, upon closer examination, some minor deformation can be seen. Below the lacustrine sediments is the New Ulm Till.

Figure 14. (*right*) This shows the alternating silt and clay layers (varves) at Site 2. Three clay layers and their associated silt layers are visible. A mechanical pencil, for scale, is placed above the middle clay layer. Thin sections were made from samples taken at this location.



2.5 *Site 3: Sterling Center and County Road 1*

Site 3 is located south of Site 2 and near Sterling Center along County Road 1 in the Sterling Center 7.5 minute series topographic quadrangle (Figure 5). The sediments studied are approximately the upper 200 centimeters of the exposure along the Maple River (Figure 15). Comparable to Site 2, these sediments are also typical of Glacial Lake Minnesota deposits, and the lake sediments are also underlain by the New Ulm Till. They consist of alternating clay and silt layers of varying thicknesses, indicating a presence of at least five varves (Figure 16). As with any other Glacial Lake Minnesota site, the sediments are located just under the topsoil, which could mean that evidence of varves has been lost through soil forming processes, leaching, and plant root growth. The silts are laminated and the clay layers contain silt blobs. Figure 16 shows the warped varves, and Figure 17 shows the fine laminations of the silt. Discoloration of the silts in elongate forms marks evidence of root traces from plants. All of the structures are fairly warped and extremely desiccated. Samples were taken at this site; however, due to the bad preservation and lack of significantly different type of sediments or structures, no lab analyses were performed.

2.6 *Site 4: Mapleton irrigation ditch*

The material sampled was taken from an irrigation ditch north of Mapleton in the Mapleton 7.5 minute series topographic quadrangle. This is the easternmost Glacial Lake Minnesota site studied and is considered to be near the geographical center of the lake basin. According to soil studies done by Paulson (1986), soils in this region are very fine montmorillonitic, mesic soils in the Beauford series with a high shrink-swell factor and a tendency to be 60 to 90 percent clay. Consequently, the amount of expandable clays may

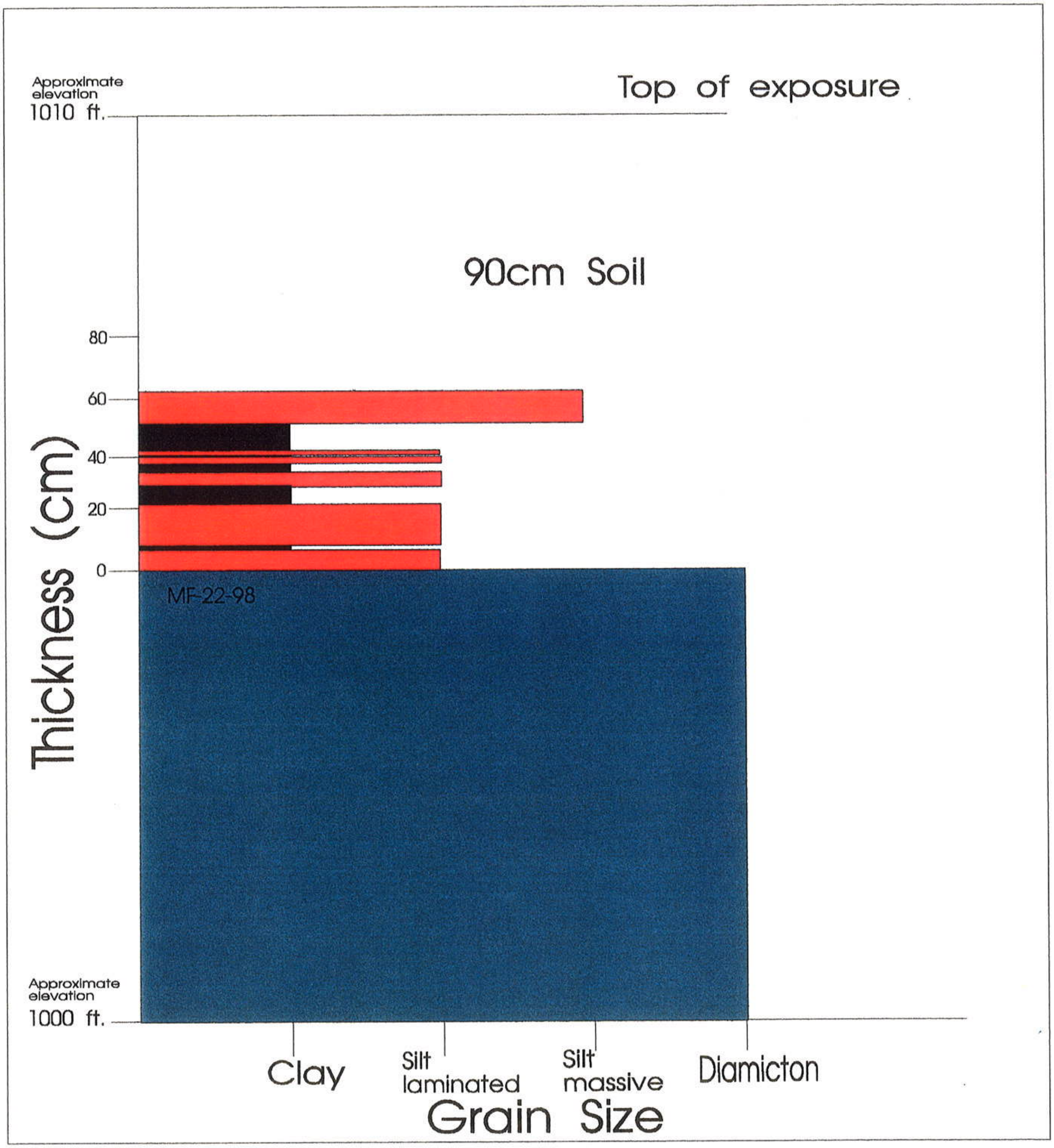


Figure 15. Stratigraphic profile for Site 3.
(MF-22-98 indicates sample location)

Figure 16. Photograph of Site 3 from topsoil to basal New Ulm Till (*knife for scale*).

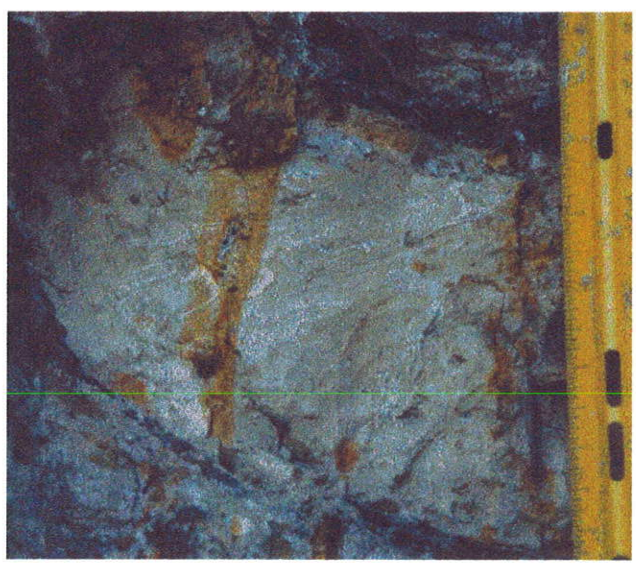


Figure 17. Close-up picture of silt laminations at Site 3 (*12 inch ruler for scale*).

account for the lack of preservation of original sedimentary structures at this site. Though no structures were observed, a sample of the material along the walls of the ditch was collected. Upon grain size analysis, it was noticed that the sample plotted almost exactly like the clay layers from the other localities (Figure 18). This high clay content lends credence to the theory that this locality is near the ancient center of the lake basin

2.7 *Erin Rasmusson's four sites*

The other Glacial Lake Minnesota researcher, Erin Rasmusson, also studied four sites within the basin. Two of her sites contained varves and two did not. Of the two sites that did not contain varves, they did contain laminated silts directly under the topsoil and were underlain by the shale-rich New Ulm Till. One of these sites was located on the Coopman property along the Le Seuer River in the Good Thunder 7.5 minute series topographic quadrangle. From the basal till to the soil, the following layers, in ascending order, are observed: sand, diamicton, silt, diamicton, silt, diamicton, and one final silt layer. The other site is located near Vernon Center along the Blue Earth River in the Amboy 7.5 minute series topographic quadrangle. It is 60 centimeters of partially laminated silts underlain by the basal New Ulm Till.

Rasmusson's two other sites are located in gravel pits, and each shows the presence of at least four varves. The site located in the gravel pit referred to as the Sinclair or Dinosaur pit is located in the Sterling Center 7.5 minute series topographic quadrangle and is approximately 10 feet in its entirety. It shows the varves directly under the soil followed below by layers of silt, clay, sand, and diamicton down to a base of sand. The sand layers vary in thickness, and the clay layers vary between 1 and 2 centimeter thick. The silt layers are finely laminated. The site located in the gravel pit referred to as the Prange pit is located in the Beauford quadrangle and consists of a New Ulm Till base overlain by layers of silt, clay, diamicton, and finally approximately four varves at the top directly under the soil. The majority of her lab analyses were made from this site. The basal till and diamicton layers plot like New Ulm Till on the ternary diagrams for grain size and provenance, and the silt and clay layers plot in the same vicinity as the other silt and clay layers for Glacial Lake Minnesota sites. Thin sections were also created from some of these samples. Information on these sites can be found in the attached appendices, courtesy of Erin Rasmusson.

3. Observations and Comparisons Between Sites

3.1 *Grain size and provenance analysis*

Figure 18 shows the grain size analyses of the sediments. Analyses were performed on three silts and three clays from Site 2, two basal tills from Site 2 and Site 3, three till layers from Site 1, and one soil sample from Site 4. The data shows that the silts and clays plot where they should, and the basal till units are all the same (New Ulm Till). The till layers at Site 1 are more sandy than the other tills. Analysis of the material from the irrigation ditch, which according to Paulson's research is near the center of the lake, showed that it is extremely rich in clay.

Figure 19 illustrates the very coarse sand lithologies of the samples. Lithology data shows that zero phi sand grains were found in most of the samples, but in very minute amounts in the clay and silt layers. The lithology diagram indicates that the basal tills plot in the correct vicinity of the New Ulm Till, and the till layers at the delta site show a higher content of crystalline rocks.

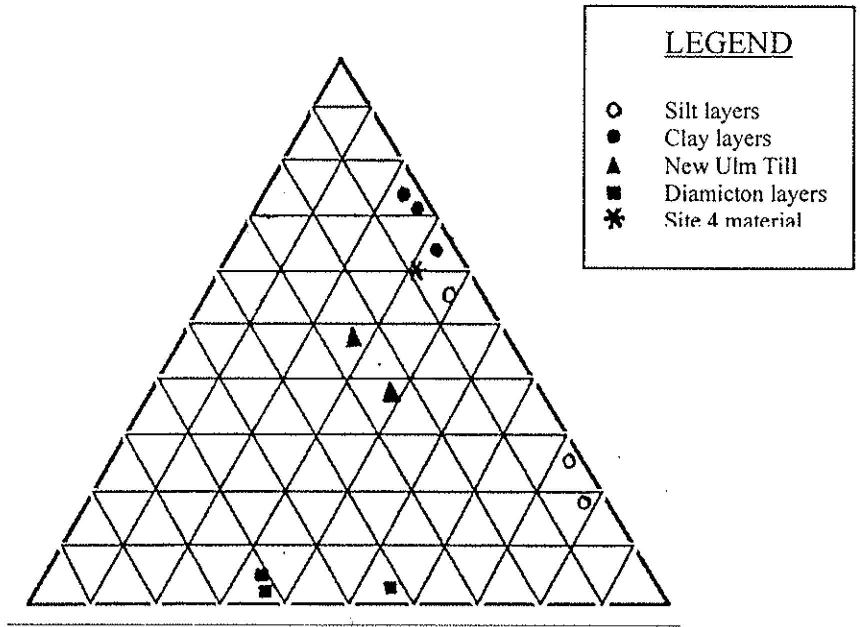


Figure 18. Grain size of Glacial Lake Minnesota sediments.

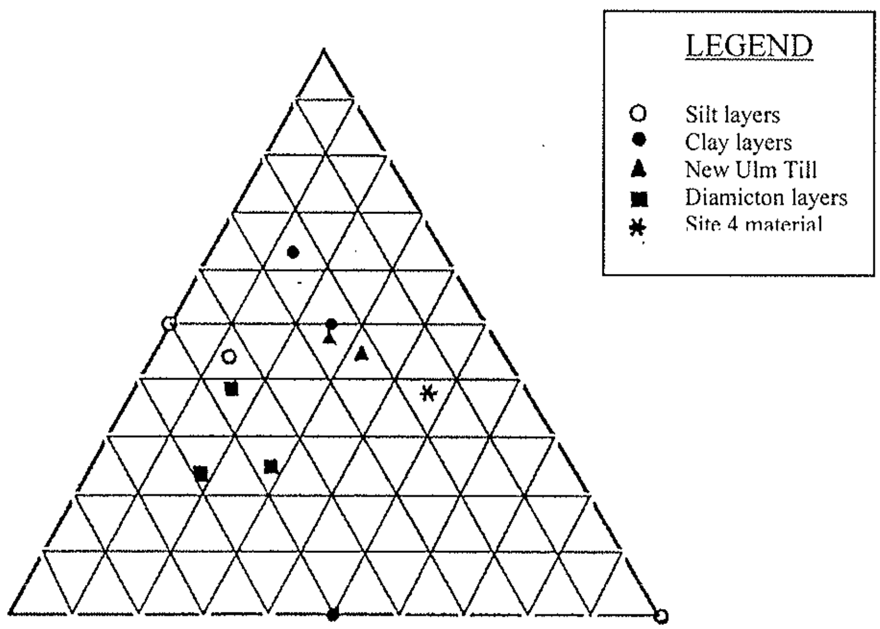


Figure 19. Very coarse sand lithologies of Glacial Lake Minnesota sediments.

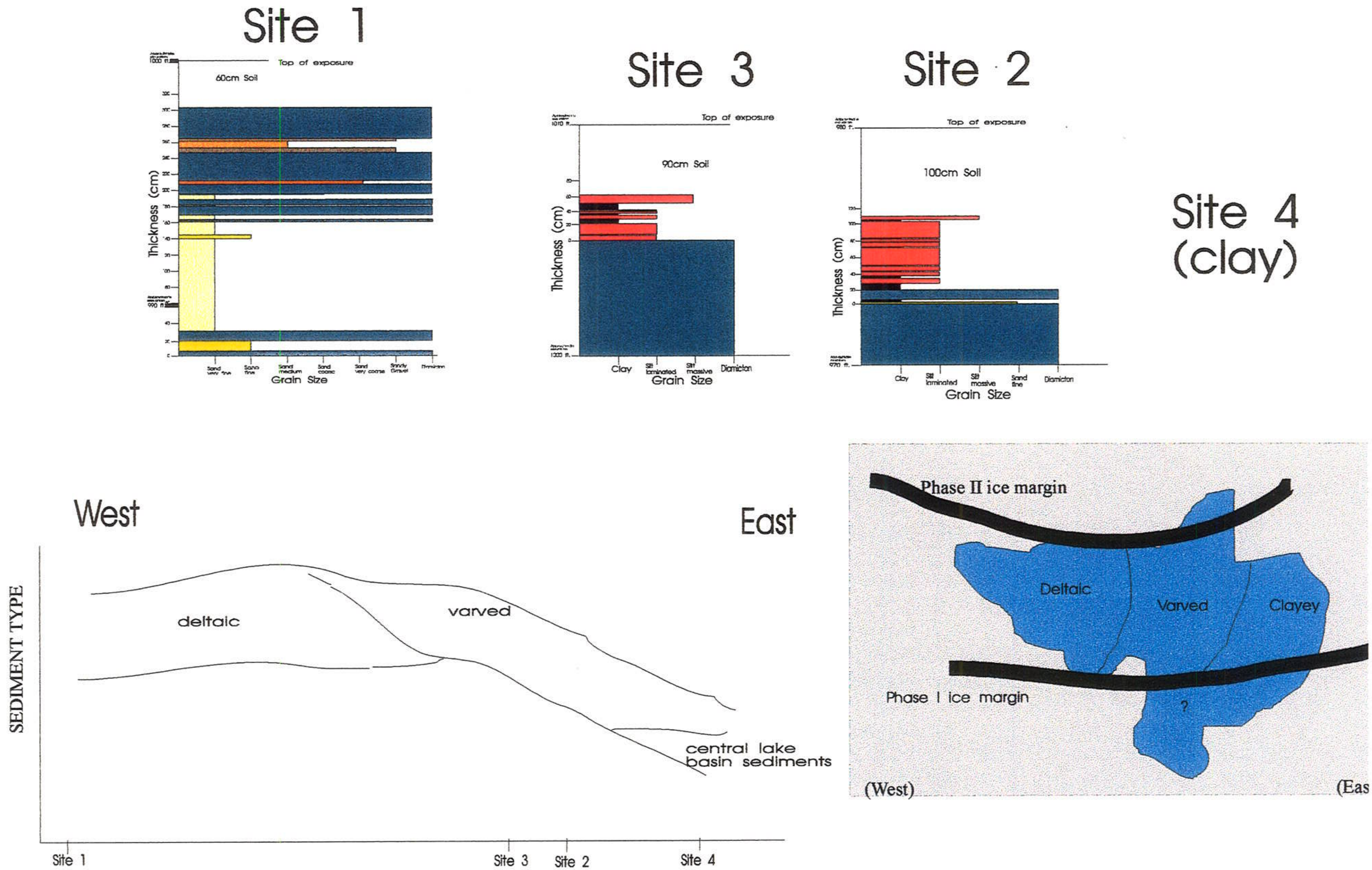


Figure 20. Schematic cross-section and sediment location map of the lake.

Elevations of sediments range from 1010 ft., at the greatest, to 980 ft. Thicknesses range approximately from 3-5 ft. for the varves and12+ for the delta. This diagram gives a visual representation of the placement of sediments across the basin sediments present at Site 4 occur in the appropriate place for the assumed central region of the basin.

4. Interpretations

4.1 *Varves*

Including all eight sites for the lake, the number of varves, where present, is between four and eight couplets. The presence of varves in few numbers indicates a relatively short lived and/or shallow lake. Though exact age and life span of the lake is unknown, the estimated existence of the lake could be tens or hundreds of years. The small number of varves would lead one to conclude that, at most, the lake was in place for 10 years. Although only up to eight varves are preserved at one locality, it could be hypothesized that varves were missing due to soil processes affecting the lake sediments in close proximity to the surface. However, if the lake was shallow, poor preservation of sediments is likely. In a shallow lake, the potential for varve preservation would be low due to reworking by waves during storms or other active times. The constant movement of a shallow body of water would hinder sedimentation.

The variability in varve thicknesses, especially noticeable in the silt layers, is not considered to be typical of most glacial lake varves. However, it has been observed that variable silt thicknesses is typical of varves deposited near the front of a delta (Ashley, 1975). This would appear to be consistent with the proximity of the Lake Crystal Delta to the sites researched.

4.2 *Silt Laminations*

Laminations are observed in almost every silt layer at each site. These could be explained by three hypotheses. First, the laminations could show daily, a period of days, or even monthly fluctuations in sediment load (Fraser, 1975). Second, they could be indicators of storms affecting a shallow lake by stirring up sediments and leaving a record of activity through the laminations. Third, the reworking of sediments by waves could have caused the laminations. This would also allow for less deposition of sediments. Regardless of the exact explanation for the laminations, it is obvious that a documentation of activity in the water can be interpreted from the presence of silt laminations.

4.3 *Diamicton Layers*

The origin of the diamicton layers was probably not a re-advancement of the Des Moines Lobe because of the thinness and multiple occurrences of the layers. More likely, the layers were caused by ice rafting and/or mudflows at the ice margin. Stagnated ice, either in the form of abandoned ice chunks or a margin of the retreating glacier, would carry sediments. As the ice melted or broke apart, sediments would flow off of it and be deposited among the lake and delta sediments, leaving the diamicton layers or pods discovered.

4.4 *The Site 1 Theory*

The sediments of Site 1 can be classified as a deltaic site, most likely part of the Lake Crystal Delta system. Previous knowledge from soil studies, and the presence of sands in various gradations, climbing ripples, and faulting all indicate strongly the existence of an ancient delta. Climbing ripples are associated with delta bedding (Prothero, 1996). In addition, the direction of the paleocurrent interpreted from the ripples verifies the accepted theory of sediment and water influx from southeasterly flowing ice marginal streams originating northwest of the basin. Growth faulting from movement of deposited sediments into front of a prograding delta probably caused the faults (Reading, 1996). This is shown by the uniform direction of the faults.

5. Conclusion

In conclusion, sediments from the sites observed in Blue Earth County, Minnesota are indicative of a glacial lake. The presence of varves, gradation of grain sizes across the basin, and delta sedimentation all shows evidence of the ancient lake. The sediment and structures information achieved through this research, combined with the previous knowledge gained from soil studies, give a more detailed description of the lake. Furthermore, lab analyses support present knowledge of Quaternary geology. In addition, the topographic features in this area indicate a Phase II of the lake through the differing elevations and sediments observed in comparison to those found in the southern part of the basin.

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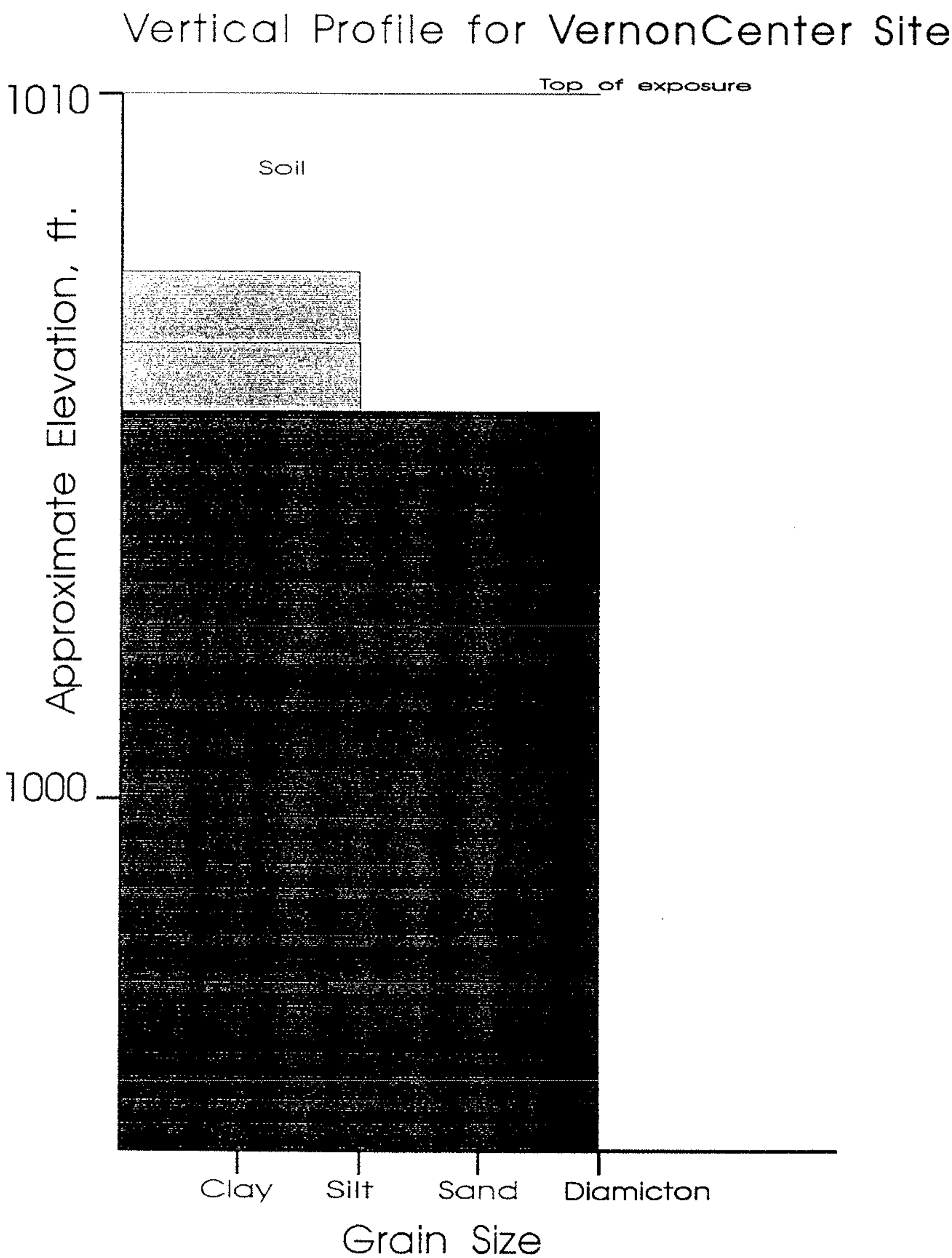
TABLES

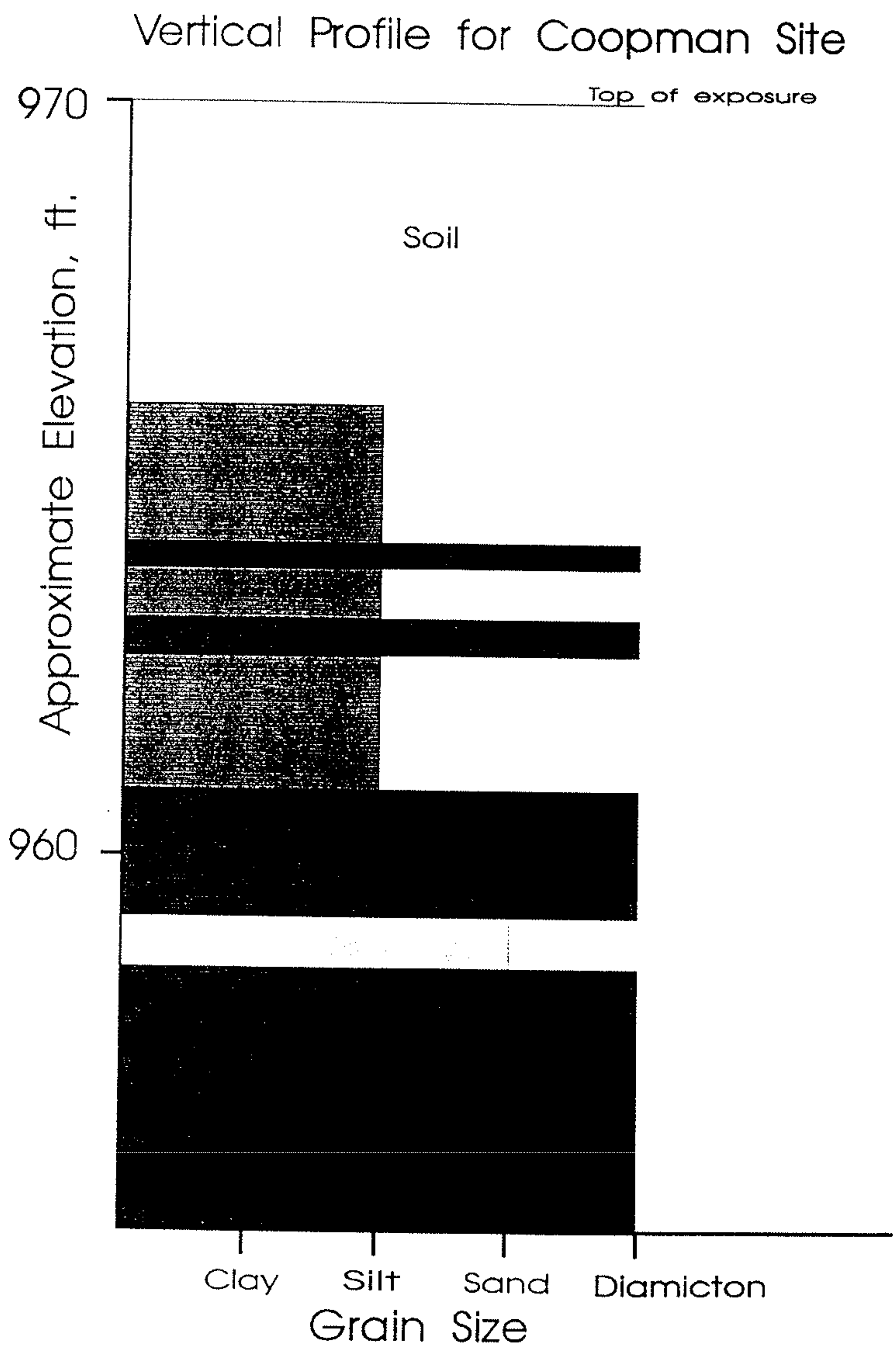
Table 1

Data from Glacial Lakes Minnesota Sites

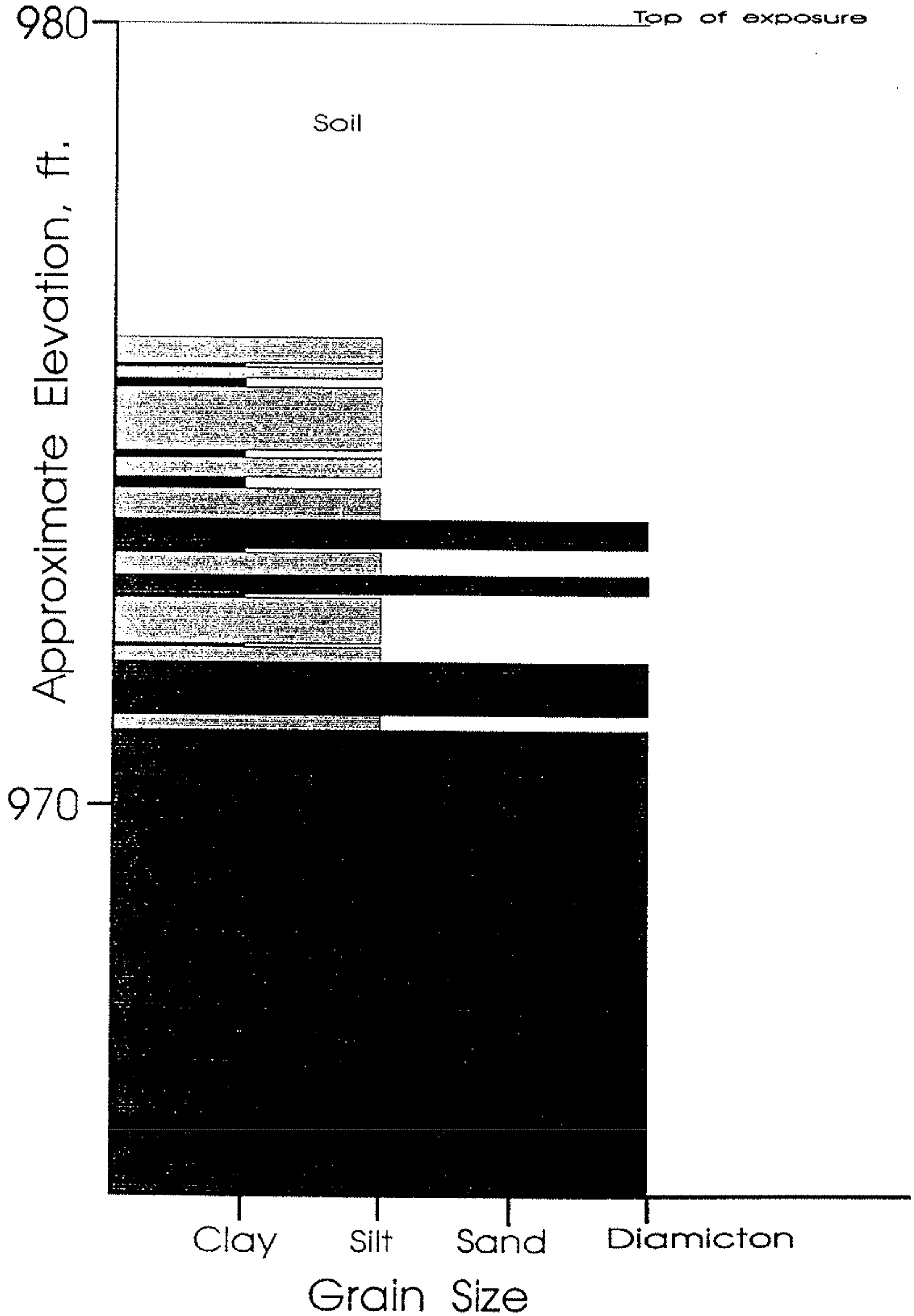
Sample	Material	% clay	% silt	% sand	# grains, 0phi	% shale	% crystalline	% carbonate	color
MF-7-98	silt	55	39	6	46	45.65	43.48	10.87	2.5Y 5/4
MF-13-98	silt	26	73	1	2	50	50	0	2.5Y 5/4
MF-20-98	silt	19	79	2	6	0	0	100	2.5Y 6/4
MF-3-98	clay	74	23	3	16	50	25	25	5Y 5/3
MF-6-98	clay	64	32	4	16	63	25	12	2.5Y 6/2
MF-8-98	clay	72	27	1	4	0	50	50	2.5Y 5/4
MF-37-98	ditch	60	31	9	157	38.22	15.92	45.86	5Y 5/2
MF-1-98	N.U.T	38	39	23	153	43.79	24.18	32.03	2.5Y 5/4
MF-22-98	N.U.T	48	28	24	145	49.65	24.83	25.52	2.5Y 5/4
MF-29-98	till	3	55	42	111	39.64	45.95	14.41	5Y 5/3
MF-31-98	till	4	35	61	277	22.38	59.57	18.05	2.5Y 5/4
MF-34-98	till	6	33	61	343	23.9	46.36	29.74	2.5Y 5/4
MF-10-98	clay								2.5Y 6/2
MF-16-98	clay								2.5Y 6/2
MF-24-98	clay								2.5Y 5/2
MF-15-98	silt								2.5Y 5/4
MF-23-98	silt								2.5Y 5/4

APPENDICES

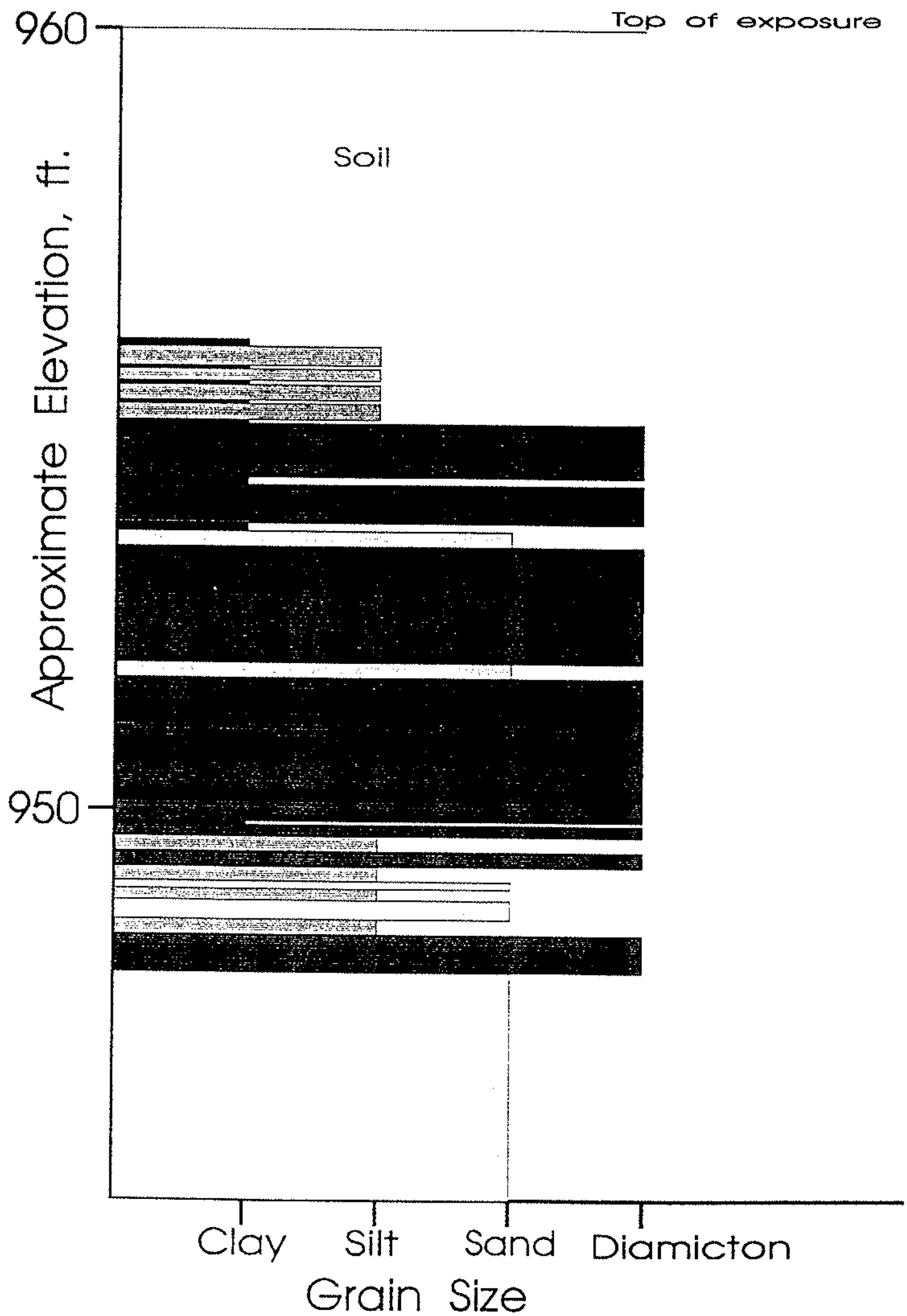

Vertical Profile for VernonCenter Site
Top of exposure
Soil
1010
1000
Approximate Elevation, ft.
Clay
Silt
Sand
Diamicton
Grain Size


Vertical Profile for Coopman Site
970
960
Top of exposure
Soil
Approximate Elevation, ft.
Clay
Silt
Sand
Diamicton
Grain Size

Vertical Profile for the Prange Pit



Vertical Profile for Dinosaur Pit



Data from Glacial Lake Minnesota Sites

Sample	Material	% clay	% silt	% sand	# grains, 0phi	% shale	% crystalline	% carbonate	Color
ER-7-98	clay	58.93	27.99	13.08	78	41.03	42.31	16.67	2.5Y 6/4
ER-13-98	clay	73.12	26.42	0.46	0	0	0	0	2.5Y 6/4
ER-15-98	clay	52.14	44.68	3.18	11	9.09	0	90.9	2.5Y 6/4
ER-19-98	clay	65.69	32.17	2.14	4	0	100	0	2.5Y 5/4
ER-29-98	clay	80.29	15.59	4.12	6	16.67	83.33	0	2.5Y 4/3
ER-2-98	silt	35.22	62.58	2.2	67	17.91	17.91	64.18	2.5Y 5/4
ER-6-98	silt	35.31	60.84	3.85	18	44.44	11.11	44.44	2.5Y 5/4
ER-20-98	silt	42.87	55.2	1.93	0	0	0	0	2.5Y 5/4
ER-1-98	NUT	26.54	44.05	29.41	240	51.67	36.67	11.67	2.5Y 5/4
ER-3-98	diamicton	43.68	46.44	9.88	93	37.63	36.56	25.81	5Y 5/4
ER-8-98	diamicton	28.92	36.59	34.49	265	58.49	27.17	14.34	2.5Y 5/4
ER-11-98	diamicton	38.41	32.55	29.04	238	64.71	12.61	22.69	2.5Y 4/3