Sedimentary Analysis of the New Ulm Till and its Importance for Understanding Ice Flow on a Deforming Bed on the Des Moines Lobe of the Laurentide Ice Sheet

By

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A thesis submitted In partial fulfillment of the requirements for the degree of

Bachelor of Arts

(Geology)

at

GUSTAVUS ADOLPHUS COLLEGE

2008

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Under the supervision of Professor Laura Triplett

ABSTRACT

The nature and dynamics of the Des Moines lobe of the Laurentide Ice Sheet have been the subject of extensive research focused on better understanding ice flow mechanics. Some models have suggested that a deforming bed may have influenced the Des Moines lobe flow and geometry over a large region. The goal of this project was to determine if till composition is homogenous or if there are variations in composition that may have been the result of local differences in deformation of the Des Moines lobe bed. This research project focused on the striated and faceted boulder pavement that lies immediately below till deposited by the Des Moines lobe (New Ulm till), and on the composition of the lowermost layer of the New Ulm till.

Lithologies of the coarse sand size fraction were identified in the till samples from the study area along the axis of the Des Moines Lobe trough. Results show that the lithologic components vary between both a) samples from the same site and, b) samples from different sites. Thus it does not appear that the lowermost New Ulm till is homogeneous, and the possibility of local differences in deformation processes acting on the bed exist.

AKNOWLEDGEMENTS

I would like to thank Ben Laabs for introducing me to glacial geomorphology, preparing me for, and guiding me into my research program. I would also like to thank James Cotter at University of Minnesota Morris for his hard work developing and leading the Research Experience for Undergraduates program that produced this project. Along with much gratitude towards the National Science Foundation for funding the REU program. My research was enriched by the assistance of Laura Murphy (University of Wisconsin River Falls) and Kelly Gorz (North Dakota State University) both in the field and in the lab.

I would also like to thank Laura Triplett, Jim Welsh, and Alan Gishlick for their time and effort spent contributing to my project.

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INTRODUCTION

The Des Moines Lobe, named for its late Wisconsinian (15ka) terminus in Des Moines Iowa, was the last outlet glacier of the Laurentide Ice Sheet (Figure 1) to occupy southern Minnesota (Clayton et. al, 1985). As the lobe retreated, it deposited what is now known as New Ulm till which is easily accessible for study (Matsch,1972).

The style of sediment deposition can reflect the type of ice flow that occurred. There are two main ways that glacial ice flows: creep and basal sliding (Ritter et. al, 2002). Creep is a result of the internal deformation of the ice under its own weight. The rate of creep is a function of the shear stress (force applied by gravity), which is determined by ice thickness and surface slope. Ice flow by basal sliding occurs when ice at the glacier sole is under enough pressure to induce melting. Only a slight film of water is necessary to induce basal sliding, which can account for up to 90% of the total velocity (Bennett et. al, 1996). Basal sliding has been associated with the formation of streamlined landforms such as drumlins, which are absent from the modern Minnesota landscape (Jennings, 2005). This suggests either that subsequent glacial advances overprinted streamlined landforms, or that the lobe was moving via a different process; perhaps by deforming sediment.

Glaciers deposit till in a number of different ways resulting in numerous landforms being developed. Each landform is indicative of the depositional environment. The landscape created by a glacier tells a great deal about the paleoenvironment and the processes involved.

Hummocky topography dominates the landscape where the Des Moines lobe flowed, particularly at the lateral margins (Jennings, 2005). This topography is a result of stagnant debris rich ice that melts differentially due to insulation by the debris, and the uneven deposition of debris.

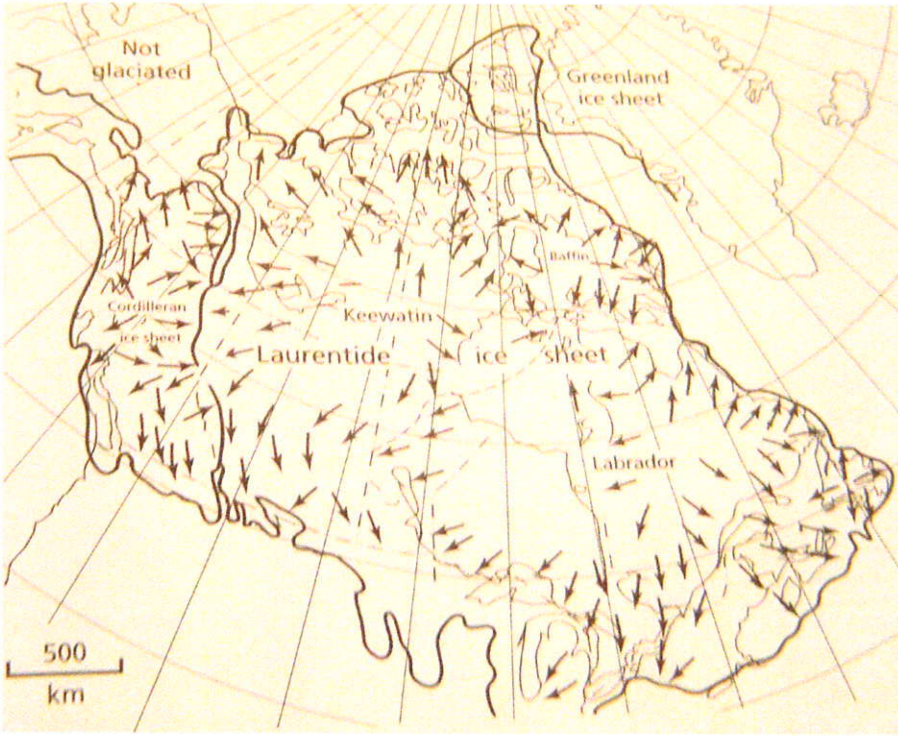

Figure 1: Map of the Laurentide Ice Sheet during the last glacial maximum. Arrows indicate ice flow direction. (Stern et. al. 1979)

Broad areas of hummocky topography may be the result of active ice overriding stagnant ice. Such an alternation in ice flow indicates glacial surging (Jennings, 2005). This conclusion was reached using observations of the landforms that are created by modern surging glaciers.

Jennings (2005) proposed that the Des Moines Lobe was an ice stream. An ice stream is a fast moving ice surrounded by slow moving ice. The middle of the glacier moves at a higher velocity than the lateral margins which are slowed by friction with the bed. The ice stream may deform the soft sediment underneath it that is saturated by basal melt-water rather than flowing by creep or basal sliding (Jennings, 2005; Rocha-Campos, 2005; Bennett et. al, 1996; Ehlers, 1996). Patterson (1996) suggested that the Des Moines lobe was a fast-moving ice stream draining the Laurentide ice sheet that had a land-based terminus that periodically stagnated once it had flowed beyond the main body of the ice sheet.

When a glacier moves over unfrozen, weak sediment the weight of the glacier may cause the sediment to start deforming. As the water seeps into the sediment it increases the pressure in the pore spaces and pushes grains apart. The forward movement is then produced by flow within the sediment; the sediment essentially carries the glacier (Bennett et. al, 1996). Speed is possible once the stress applied by the ice exceeds the shear strength of the bed causing it deform and behave as a liquid lubricating the ice rather than a solid applying friction on the ice (Patterson,1998). This was likely the case with the Des Moines Lobe. Jennings (2005) suggested that the Cretaceous shale beneath the Des Moines Lobe prevented subglacial drainage of the basal water, and that the overlying saturated sediment may have been a deforming bed. These models for a deforming bed are regional in extent and suggest that the entire bed is working as one. If deformational processes were uniform along the lobe the resulting till should be homogenous in composition. Alternatively local differences may be a function of local variation in the deformation process. The purpose of this study is to further investigate the Des Moines Lobe ice flow through Minnesota using till analysis.

GEOLOGIC SETTING

Matsch (1972) produced the seminal work in the Quaternary geology of southwestern Minnesota. The Minnesota River lowland is the southern continuation of a more extensive bedrock low that was the dominant control on ice flow as the Des Moines Lobe traveled southeast through this area (Figure 2). The three major lithologic groups that underlie southwestern Minnesota: high-grade metamorphic and igneous rocks of early Precambrian, Upper Precambrian Sioux quartzite, and poorly consolidated marine and continental Cretaceous shales and sandstones (Matsch, 1972; Jennings 2005).

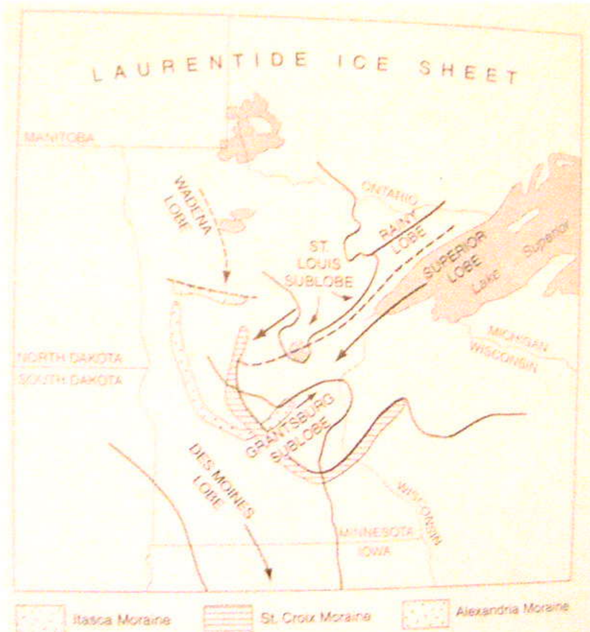

Figure 2: Map displaying the location of the Des Moines Lobe, along with other lobes of the Late Wisconsinan as they traveled through Minnesota. (Wright, 1972)

Matsch distinguished between two till units that are present in this area and produced preliminary mapping of them. They include the Granite Falls till which is usually dry, oxidized, and pale yellow. This till is low in shale content, contains mainly caorse sand, and is associated with the till sheet from the neighboring Wadena lobe (Figure 2). Above this layer is the New Ulm till which is yellow to olive brown or dark grey, calcareous, and contains abundant shale, carbonates, and granitic rocks. These two till sheets are regionally separated by a one-stone thick faceted and striated boulder pavement shown in Figure 3.

Gilbertson (1990) was the first to extensively map out the New Ulm till finding that it rarely exceeds 20ft in total thickness and in places has been completely removed by erosion. In that study area, the till had a quite variable lithologic composition: 21-77% Precambrian bedrock, 11-32% Paleozoic rocks, and 5-60% Cretaceous material. Gilbertson concluded that the high percentage of the cretaceous Pierre Shale in the New Ulm Till is the diagnostic feature of the unit.

Figure 3: Photograph taken at site 6, Big Stone Lake, South Dakota that shows a large boulder pavement separating the two tills present in the study area. The top layer is more clayey while the lower layer is visibly sandier.

APPROACH

The erosional and depositional processes of a glacier vary with respect to elevation within the trough. For this reason all samples of till were collected along the axis of the Des Moines Lobe trough to insure consistency. The till here would be subject to similar processes and yield more controlled results than if we had sampled at various positions within the trough.

Two criteria were used to determine site suitability before sampling was performed. First, boulder pavement must be present and in its original position. This ensures that the sediment directly above the pavement was the last till deposited by the glacier. This was established by taking a GPS reading for multiple boulders found at the site in order to gain an accurate elevation. By noting their positions in relation to the till layers and surrounding geology this could be correlated to the preliminary boulder pavement mapping by previous students (unpublished). Second, the sediment above the pavement must conform to our expectations for New Ulm till in terms of color and texture. After both governing criteria had been satisfied samples were collected by trenching to uncover a fresh till horizon and separate it from organic material and alluvium. A total of eleven samples were collected from nine sites along a 70 mile axis from Browns Valley, North Dakota to Granite Falls, Minnesota (Figure 4).

Figure 4: Map of Northeastern South Dakota and Western Minnesota encompassing the study area. The nine sample sites are highlighted. Sites follow the axis of the Des Moines lobe trough from Big Stone Lake, South Dakota to Granite Falls, Minnesota.

After collection, samples were air-dried and particles were broken apart using a blunt object in order to isolate individual grains. Samples were dry-sieved to further separate individual grains. However, cementation was so severe in some tills that a second sieving was performed. Once sieving was complete each phi (ϕ) size was then weighed and recorded to determine grain size distribution. Phi numbers represent -2log (d) where d=diameter of a grain. In most sedimentary environments the +1ϕ size (coarse-medium sand) will yeild a good representation of component lithology. In his formative studies of the Des Moines Lobe, Matsch

(1972) reasoned that this size is the most representative of till lithology because at larger sizes shale was over-represented and smaller sizes left shale under-represented. The +1ϕ was sub sampled to visually identify mineralogy and lithology of at least 100 grains in each sample. Each subsample was then weighed and a point count was performed using a microscope to identify different minerals and rock fragments from three geologic time periods: Paleozoic, Precambrian, and the Cretaceous.

RESULTS

The grain size analysis (Figure 5) found that clasts within the +1ϕ size category were usually well-rounded to slightly angular with the exception of shale clasts that had a more elongated shape. In the lab the tills were found to be heavily weathered and they were largely cemented together into clumps that were resistant to sieving.

The point count results show a strong component of Precambrian material (Figure 6) due to the high abundance of resistant quartzite, granite, gneiss, and other metamorphic rocks found along the glacier's path. The Paleozoic was mostly represented by carbonates, chert, sandstone, and some shale. Lastly, the Cretaceous was identified through the presence of grey shale and in some cases limestone. Though one of the main diagnostic features of the New Ulm till is the presence of Cretaceous Shale, these samples lack a significant amount of shale.

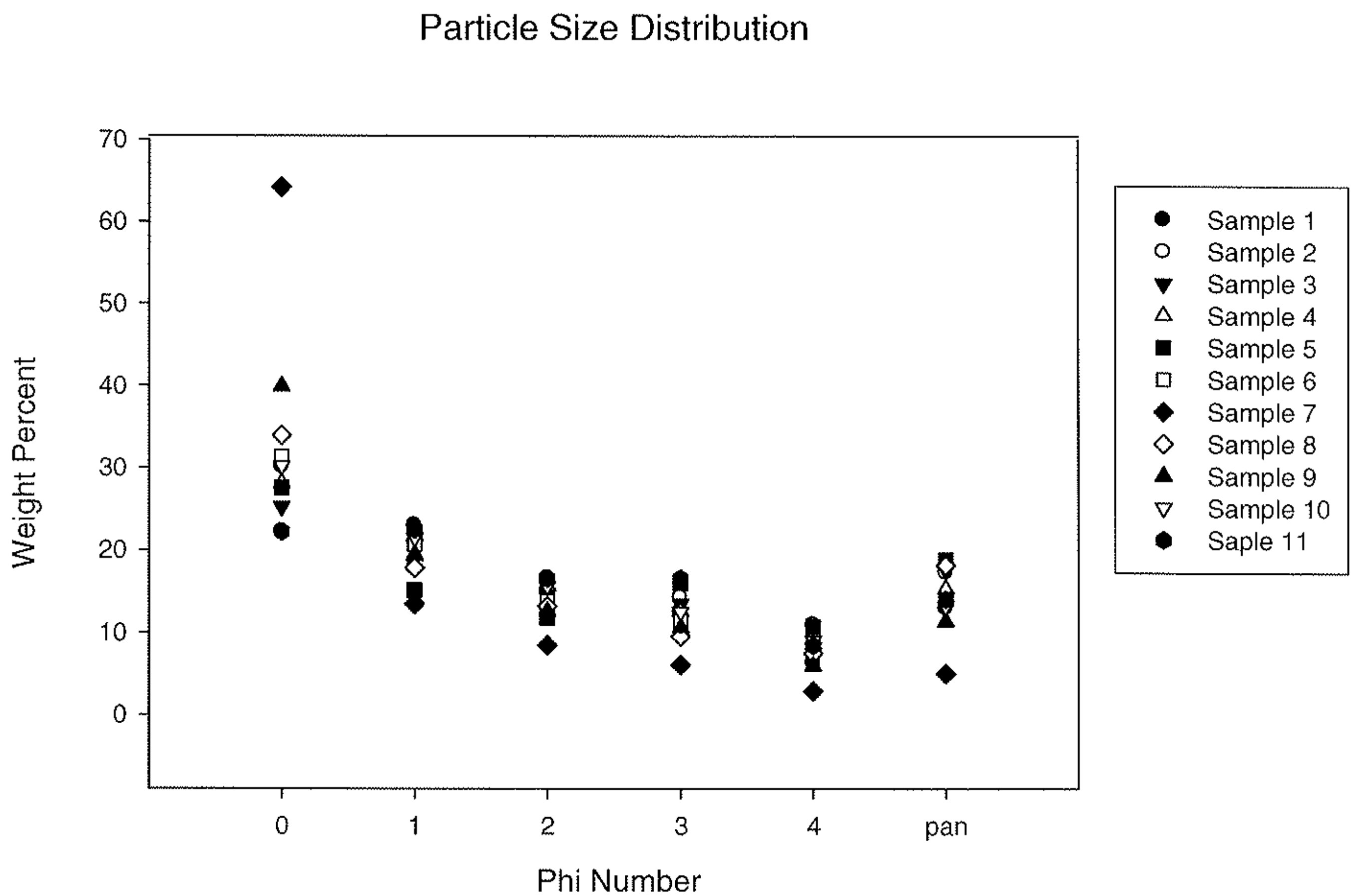

Figure 5: Scatter plot showing the different weight percentages of each phi number for each sample taken. The 0ϕ size is consistently larger in weight percent see discussion. All samples show a similar weight distribution by particle size.

Lithologic Compositions for +1ϕ Particle Size

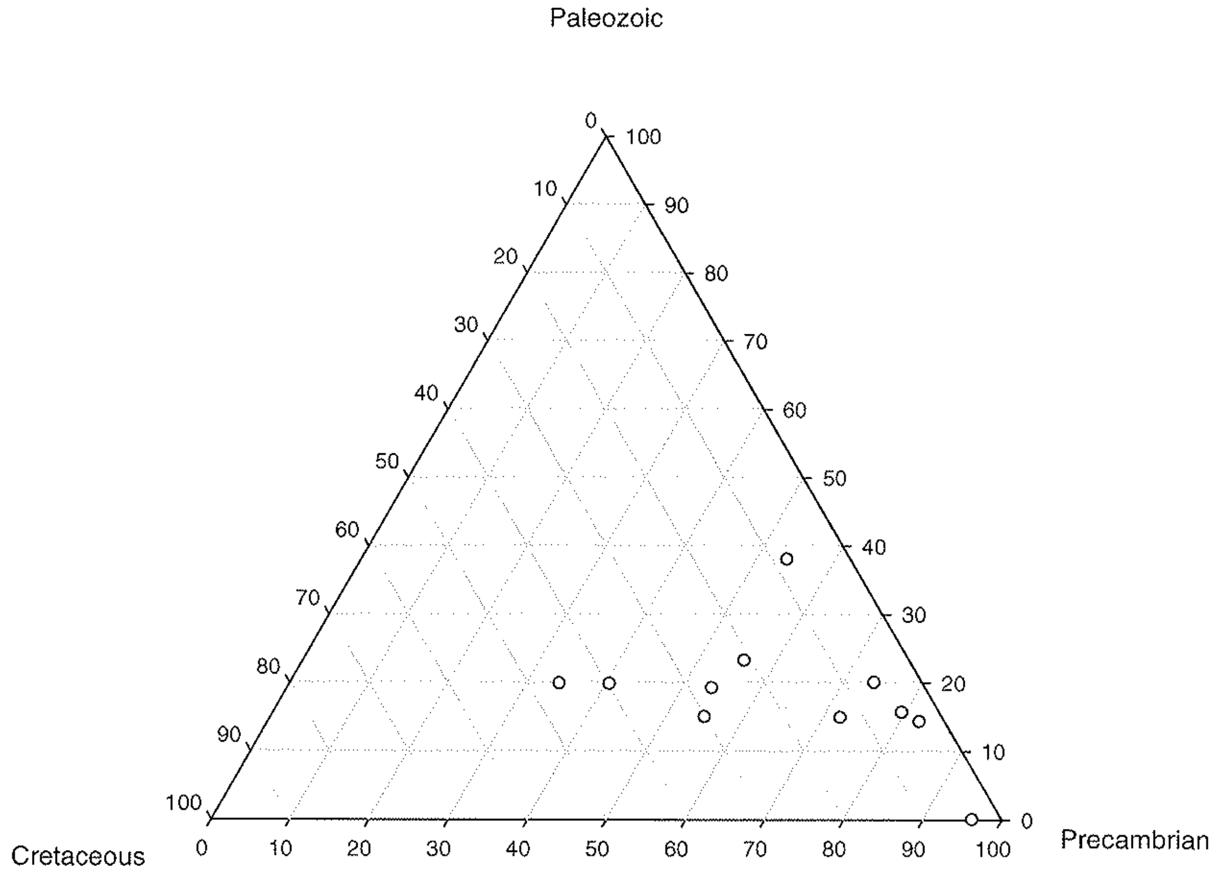

Figure 6: Ternary plot of the overall lithologic compositions for +1ϕ particle size for the eleven samples that were collected and analyzed among nine sample sights. The compositions plot strongly in the Precambrian age component, see results. This is due to a large presence of quartzite throughout the samples. Sample number two was lacking in Paleozoic material entirely, however this may be due to the extremely weathered nature of the sample.

DISCUSSION

The most important control on ice flow is the type of bedrock over which it is traveling (Matsch 1972). If the Cretaceous shales and sandstones that the Des Moines lobe flowed over contributed to lower values of basal shear stress, then a large portion of the forward movement would have been accommodated by bed deformation (Bennett et. al, 1996). Patterson (1996) has suggested that the Des Moines lobe was an ice stream that surged, so the New Ulm till can be considered a hybrid till composed of both sub glacial sediment deformation and lodgement caused by active ice overriding stagnant ice (Nelson et. al, 2005, Jennings 2005). The shape of the clasts found in the study area also suggests that they were in active transport in the traction zone, and the high fissility in samples is further evidence of deformation (Nelson et. al, 2005).

The under-representation of shale in till at some of the sites can be interpreted in four different ways: (1) There exist discontinuous shale/clay lenses within the till implying that sub-glacial water pressures were spatially and temporally variable (Nelson et. al, 2005), such that at times the shale was not being eroded by the glacier. (2) The variation resulted from the migration and evolution of the source area of the ice stream (Jennings, 2005), (3) the shale was eroded prior to the Des Moines occupation of the low land valley, (4) the preparation process for the samples destroyed a large amount of the shale content.

If the first interpretation is accepted, then there were definitely local differences in the deformation of the bed causing the water pressures to vary and thus erosion potential to vary. If the second interpretation is accepted then perhaps tills without shale are from a subsequent lobe that occupied the same trough a little later and had a different tributary (Jennings, 2005); however this study yielded no evidence that would allow for such an assumption to be made.

It is possible that the shale was previously eroded in the area, yet the high amounts of shale found in previous studies have rendered it an accepted diagnostic characteristic of the New Ulm till. Finally, in regard to the last interpretation, the previously described cementation of the till made manual particle separation necessary and is believed to have caused an overrepresentation of the +0ϕ size as seen in Figure 5. If the under representation is due to the sampling process, then different methods that would reduce the potential for shale destruction, such as wet sieving, should be used in further research.

According to Matsch there should be less shale in the tills on either side of the topographic axis due to the amount of erosion taking place there. However, it is possible that there was little to no erosion occurring along the axis where the ice was the thickest because pressure melting may have occurred locally to allow the glacier to move over the bed with little disturbance of underlying shale. In constrast, the areas where the ice was flowing out towards the glacial margins there may have been more erosion of underlying material (including shale). This difference in erosion and flow is a result of the physics of the glacier changing in response to reaching the lowland of the Minnesota River Valley (Matsch, 1972).

The majority of the land use within the study area is for farming and agriculture so most of the land had been thoroughly disrupted. This made finding acceptable sample sites difficult. In most cases boulder pavement boulders, though definitely present, were no longer in their original positions. Boulder pavement boulders were taken to be in their original orientations if found along or near the 1100ft topographic contour and were accompanied by several other boulders at the same topographic level (Figure 7). Samples of till were only taken from areas that had a significant amount (at least 6 inches) of till between the boulder and the soil horizon in order to avoid collecting organic debris and soil. In most cases boulders were exposed on a hillside and required digging to expose a large enough till horizon to satisfy the sampling requirements (Figure 8). Additional sample sites would help confirm that the till is spatially heterogeneous as a result of differential ice flow and bed deformation.

Figure 7 A group of uncovered in place boulder pavement boulders at site 4 in Milbank, North Dakota.

Figure 8 Boulder pavement dug out of a hill side at site 7 in Browns Valley, South Dakota.

CONCLUSIONS

The New Ulm till appears a hybrid of till created by a deforming bed, which carried the Des Moines lobe, and an alternation between active and stagnant ice. This supports the results of previous works that suggest that the Des Moines Lobe was a surging outlet glacier of the Laurentide Ice Sheet. Lithologies vary in each sample, and from each site with a higher percentage of material from the Precambrian bedrock. The differences in lithologic composition suggest that spatial and temporal differences in deformation processes were taking place throughout the flow of the ice stream and depositon of the till. This research will help to further understanding of ice stream mechanics and may help with interpretation of paleo ice flow patterns of other outlet glaciers.

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