Looking into the Past with Lacustrine Sediment Sequences

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A thesis submitted in partial fulfillment of the requirement of the Bachelor of Arts

At Gustavus Adolphus College

2017

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Abstract

Glacial sediments can present a confusing sequence of lacustrine sediments and glacial till, and can make interpreting past ice dynamics and environments difficult. One example of this is in Becker County, where three cores were collected by the Minnesota Geological Survey (MGS), and the lacustrine sediments in them represent sediment deposited in at least one ancient proglacial lake. Being able to discern between the lacustrine sediments in each core to determine how many proglacial lakes are represented can help understand the ice dynamics involved. A mineralogical analysis by XRD and grain size and organic matter analysis by light microscope suggests that the analyzed samples are broadly similar, except for a sample from the base of the lacustrine interval in the northwest core in grain size, organic matter content, and mineralogy. Combined with stratigraphic data, this suggests two retreat cycles. First the lacustrine sediments of core one and two were deposited in an older lake in the west, which evolved in two stages, expanding in a southerly direction. This was followed by the creation of a younger lake to the east. Taken together, retreat cycles of at least two glacial advances can be identified in Becker County. In the first, it is possible to discern depositional facies in the resulting proglacial lake, and the second resulting in another proglacial lake.

Acknowledgements

Advisors

Julie K Bartley

Laura Triplett

Core Retrieval and Data Sharing

Katie Marshall of Minnesota Geologic Society

Facility Use

Gustavus Adolphus College

Hibbing Core Library

Transportation

Jim Welsh

Gustavus Adolphus College

XRD Collection and Analysis

Chad Wittkop

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Introduction

Glaciers have left their mark all over the world in many forms. One of these forms is proglacial lakes and glacial moraines that riddle the landscape. This hummocky topography is common all over middle North America, because of the retreat of the Laurentide Ice Sheet (Clayton et al., 2007). Even more so than a surficial record, glaciers have also left their mark on the geologic record in many ways, including the presence of glacial till, and lacustrine sediments from ancient proglacial lakes in the stratigraphic record. Lacustrine sediments are sediments that filled in lakes, and are commonly found in the geologic records in areas like the glaciated

Figure 1 - Core locations, Minnesota County Map with Becker County Highlighted, and Glaciation Map

portions of Minnesota. They are usually sorted clay, and frequently varved. Proglacial lakes can form at the tail end of retreating glaciers, and the sediments that fill in these lakes become lacustrine sediments. When glaciers advance through the area again, the previous proglacial lake sediments can be left in the geologic record. The re-advancing glacier will deposit glacial till, and the sequence can repeat, causing sequences of glacial till and lacustrine sediments to be left behind. These sequences in the stratigraphic record can reveal the glacial activity that resulted in their deposition, providing another method of uncovering the sequence of glaciations of the world.

The stratigraphic record that glaciers leave behind not only leave clues as to how they moved through the landscape, but is also important in understanding the environment the glaciers existed in, and other aspects of the landscape left behind, such as its hydrogeology, geochemistry, and viability for agriculture. However, these sequences do not usually provide a clear history, and more work needs to be done to interpret them. Previously, lacustrine sediments were used to reconstruct paleoclimate through their geochemistry and microfossil content. For example, Li, et al. (2008) used geochemistry and mineralogy of lacustrine sediments from Tibet to determine the source of the minerals and a depositional environment that correlated with a shift from a fresh water environment to an evaporative one.

Determining source and depositional environment of lacustrine sediments can reveal distinct differences, which can be used to discern between ancient proglacial lakes. Increases and decreases in grain size, and increases and decreases in organic matter content can be used to determine sedimentation rates of each sediment (Karlén, 1981), which can indicate changes in environmental conditions like major shifts in climate. Taking this even further, the mineralogy of lacustrine sediments has been used to reconstruct glacial history more accurately than the previously used moraine dating method (Leonard and Reasoner, 1998).

Geologic Setting

Minnesota has an extensive history of glacial activity. The most recent glacial activity came in the form of the Wisconsin Ice Sheet, which advanced through the area in multiple lobes. These lobes changed over time and are given different names that represent different phases of the lobes. During the last glacial maximum, there were three lobes defined in Minnesota: The Des Moines in the west, and the Superior and Wadena Lobes in the east. As the Wisconsin Ice sheet retreated, the Wadena lobe split up into the Itasca, Rainy, and Brainerd Lobes in Northeastern Minnesota. Finally, in the most recent glaciation, the Northern Half of the Des Moines Lobe became the Red River Lobe. The Koochiching Lobe and Grantsburg (sub lobe of the Des Moines Lobe) replaced the Itasca and Brainerd Lobes (Figure 1) (Johnson et al., 2016). In Becker County, the primary lobe during the latest glacial phase was the Red River Lobe, which is the uppermost part of Des Moines Lobe (Johnson et al., 2016).

The bedrock in Becker County is composed of crystalline rocks – mostly felsic intrusive high grade metamorphic and dark metasedimentary and metavolcanic rocks (Johnson, et al., 2016). The stratigraphy of Becker County comprises primarily of glacial till deposited by the Wisconsin Glaciation and proglacial lakes pockmark most of Becker County.

Johnson et al., (2016) describes 80 different sedimentary units of Quaternary age in Minnesota in his ongoing "Quaternary Lithostratigraphic Units of Minnesota" report. For purposes of this study, only the tills associated with this area of Minnesota will be described.

The till formations of Becky county are, in descending stratigraphic order: Red Lake Falls, Goose River (St. Hilaire Member), New Ulm (Heiberg Member), Otter Tail (New York Mills Member), Hewitt, Lake Henry (Meyer Lake Member), Eagle Bend, Elmdale, and Mulligan. At the surface, the till formations are: Red Lake Falls formation in the west of Becker County, Goose River and Villard are at the surface in the middle, and the Hewitt formation in the east. These include, moving down-core in stratigraphic order, the Red Lake Falls Formation, the St. Hilaire Member of the Goose River Formation, the Heiberg Member of the New Ulm Formation and the Hewitt Formation. The till of the Red Lake Falls Formation is a loamy, calcareous till made up of 33% sand, 44% silt and 23% clay (Thorleifson, 2005). The St. Hilaire Member is dark, pebble-loam, clayey and calcareous with coarse sand lithology (Thorleifson, 2005) with some shale picked up from the shale bedrock by the Des Moines Lobe. The Heiberg Member is similar to the St. Hilaire, but browner and with more shale content. The Hewitt formation is light olive brown, sandy loam textured (Johnson, 2016). The lacustrine sediment is silt and clay, calcareous, and has intermittent sandy zones.

Each core was logged by Katie Marshal at MGS. These core logs (Figures 2-4) show these till-lacustrine sequences; all lacustrine layers are highlighted, but the confusing sequences are located only in the upper two lacustrine layers of Core 1, and the upper lacustrine layers of Cores 2 and 3. The locations of each core are provided in Figure 1 for spatial reference.

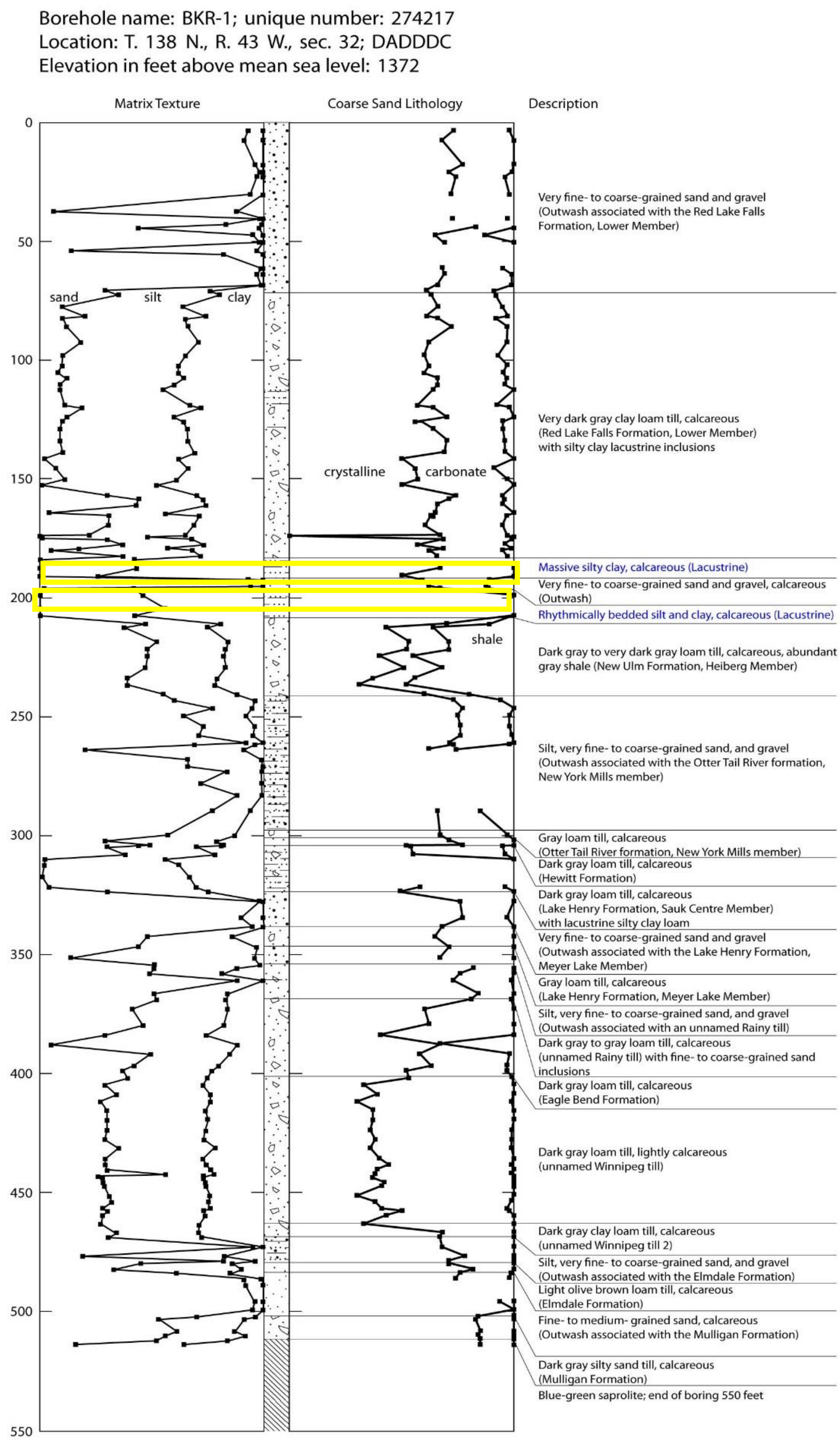

Figure 2 - Core One Log, done by Katie Marshal at MGS

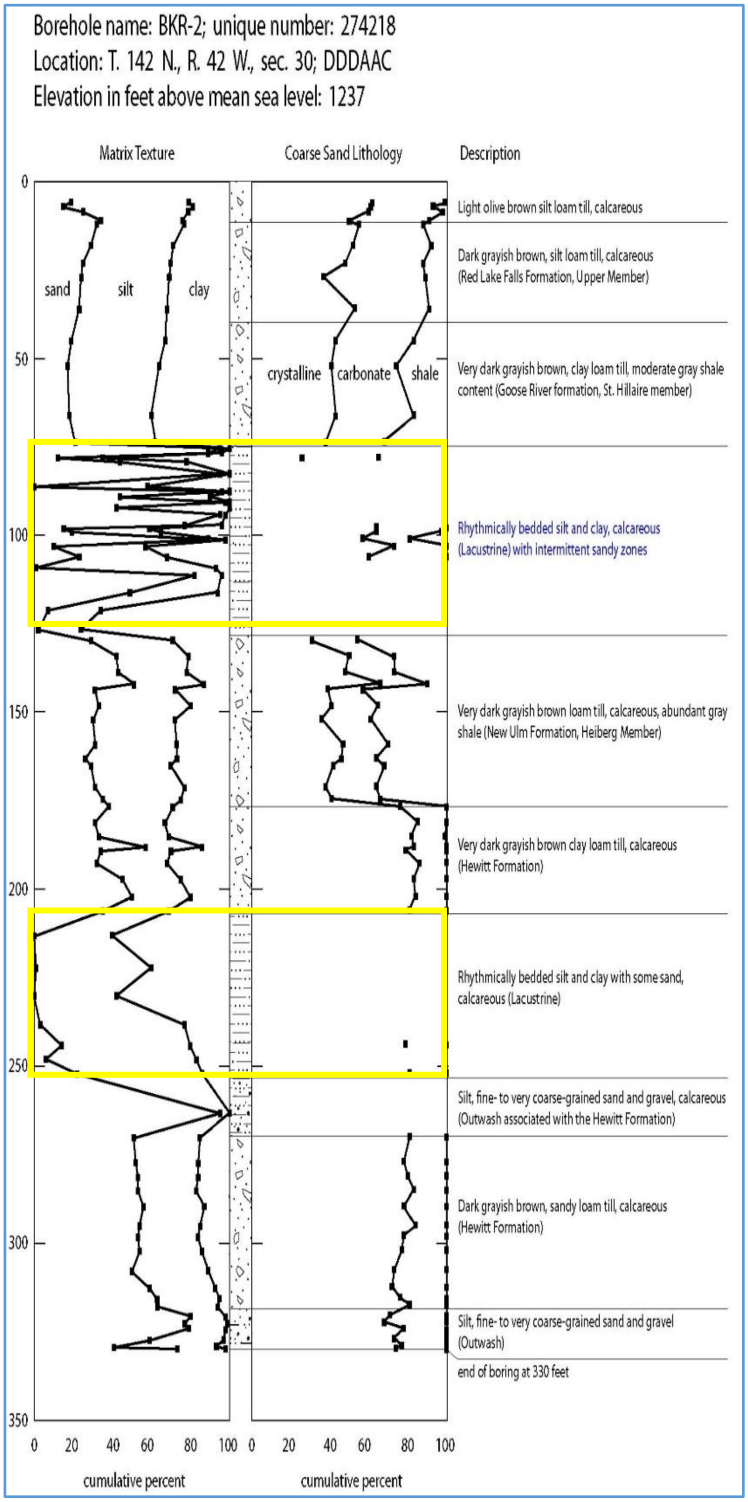

Figure 3 - Core Two Log, done by Katie Marshal at MGS

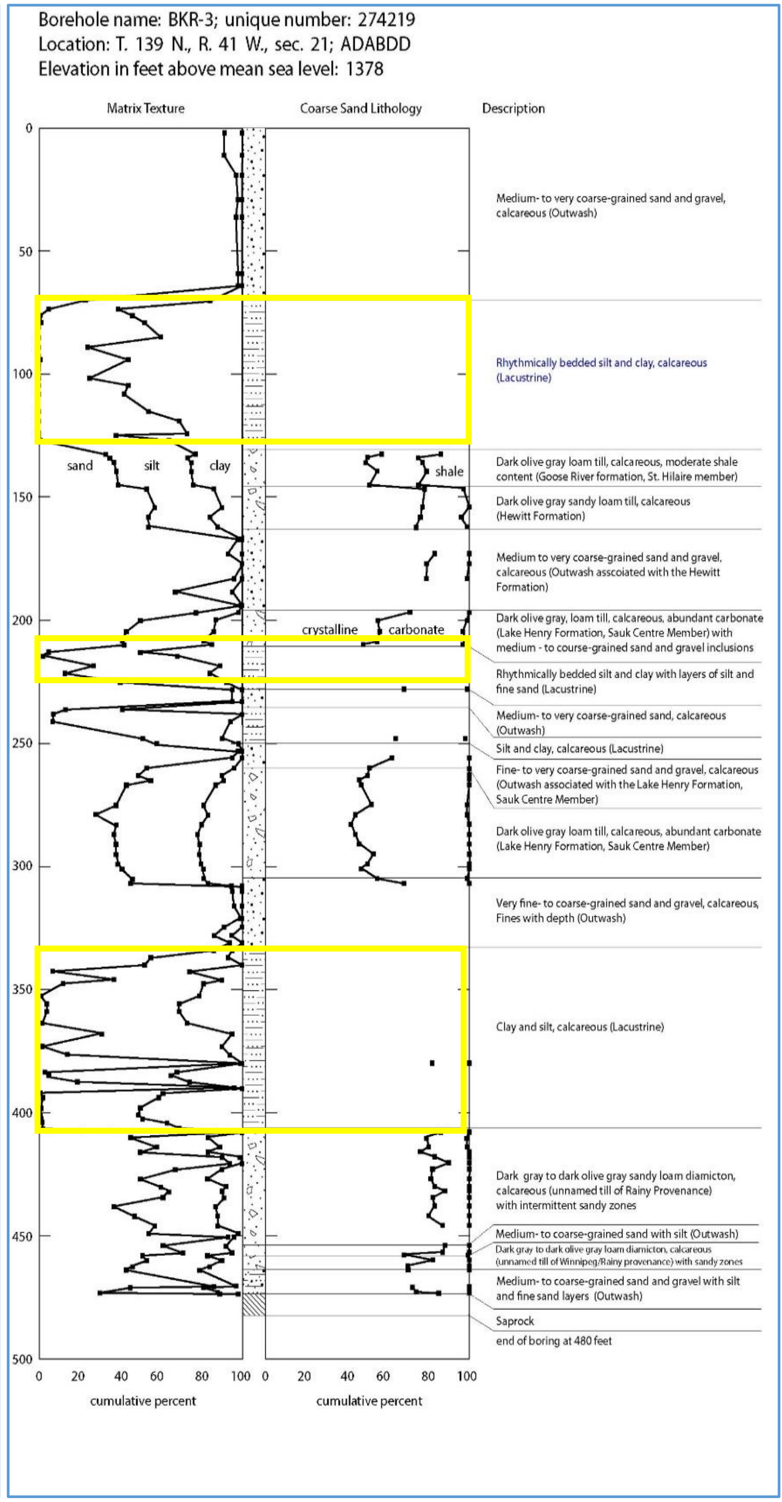

Figure 4 - Core Three Log, done by Katie Marshal at MGS

Research Question

In Becker County, which lies in Northwest Minnesota (Figure 1) and was most recently glaciated by the Des Moines lobe during the Wisconsin glaciation (Figure 1), the Minnesota Geologic Survey (MGS) collected three sediment cores which showed interbedding of till and lacustrine sediments. These interbedded sediments are not entirely unexpected due to the nature of proglacial lake formation described earlier, but the stratigraphic relationship of the lacustrine sediments to surrounding till are. These relationships are shown in generalized cross sections

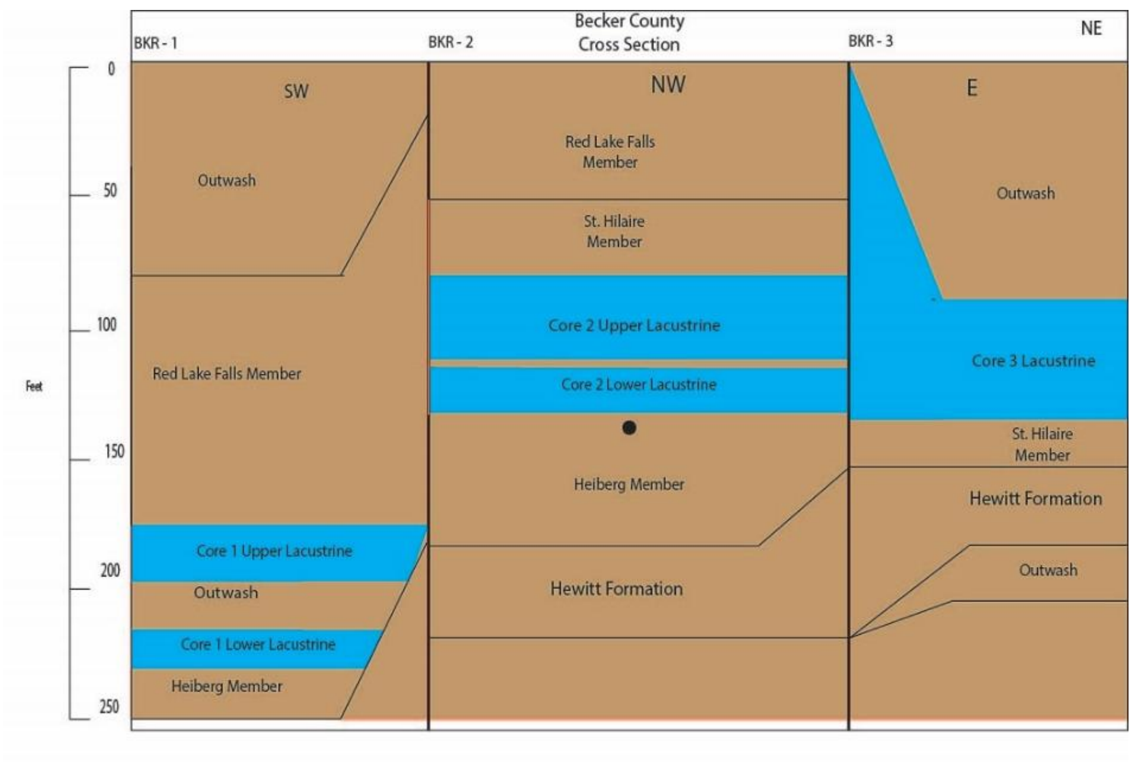

Figure 5 - Initial Cross Section created from MGS core logs

(Figure 5). Each labeled lacustrine layer is a potential lake. The difference between upper and lower lacustrine layers in core 1 in the figure is unclear because of the outwash between them. They could be the same lake, whose formation was interrupted by outwash from the glacial lobe, or separate lakes. Similarly, lacustrine layers from Cores 2 and 3 could all be the same or different, or all five lacustrine layers could represent the same lake. Minnesota's extensive glacial history and its importance in modern farming practices as well as understanding how it responded to paleoenvironments makes it an important focus of study. Being able to differentiate between these lakes can straighten out the geologic history of glacial activity, and to some extent, reconstruct glacial movements and lake formation in Becker County, Minnesota. This study will attempt to differentiate between lacustrine sediments in the three different cores logged by MGS and reconstruct, to some degree, the process that resulted in their depositions (Figures 3-5).

Methods

The cores were stored in the Hibbing Core Library, which was visited to obtain the samples. Cores were previously logged by Katie Marshall at the Minnesota Geologic Society (Figures 2-4). For this study, samples were taken from the cores in the varves of lacustrine layers in Figure 5, and from the till above and below each lacustrine layer. During sampling, no large organic matter was found that could have been used for C^{14} dating. This was done to provide more detailed information of the lacustrine sediment in question.

Strew slides, which can be used to look for biological indicators in the form of diatoms, pollen, or loose organic matter, were made of samples from each core. Strew slides can also show any obvious variation in grain size. This process involved diluting the sediment from each sample with DI water in a ratio of 1:4. The diluted samples were mounted on microscope slides and analyzed under 400x power magnification in plane polarized light and cross polarized light.

X-Ray Diffraction (XRD) was used to acquire mineralogical data on the samples. Mankato State University's XRD was used with the assistance of Chad Wittkop. Preparation for XRD analysis involves powdering the samples in a mortar and pestle, then sieving 2-3 grams down to a fraction size of 63 microns. The XRD machine batters the sample with X-rays and the software records the frequency and angle of the returning X-rays. It then interprets how many times the characteristic 2-theta angle (each mineral has a unique mineralogical structure that diffracts rays consistently at angles unique to each mineral) of each mineral was returned. This provides the analyst with the composition of the samples and relative concentrations of each mineral. Mineralogy can highlight key differences or similarities in each sample by showing concentrations of each mineral in the sample. By comparing these results to the descriptions of the glacial till above and below, in a method like that of the study done by Leonard and Reasoner (1998), a more complicated glacial activity record can be reconstructed.

These methods produced results that can be compared stratigraphically, spatially, and temporally to reveal a more complicated glacial history, which can increase our understanding of proglacial lakes, and the glacial history of Becker County. Finally, the results of the XRD test and strew slides were used to finalize the stratigraphic cross section in Figure 2. This can illustrate the stratigraphic relationship of the sediments, and then be compared spatially as well.

Results

All graphs are labeled by type of sediment, and whether it was taken from the upper portion of lacustrine sediment or lower portion of lacustrine sediment. Key trends are described below each graph.

Strew Slides

Observations from strew slides include both grain size observations (Figure 5) and organic matter content observations (Figure 6). Both show values from all three cores, split up into till and lacustrine sediments to highlight differences between lacustrine sediments.

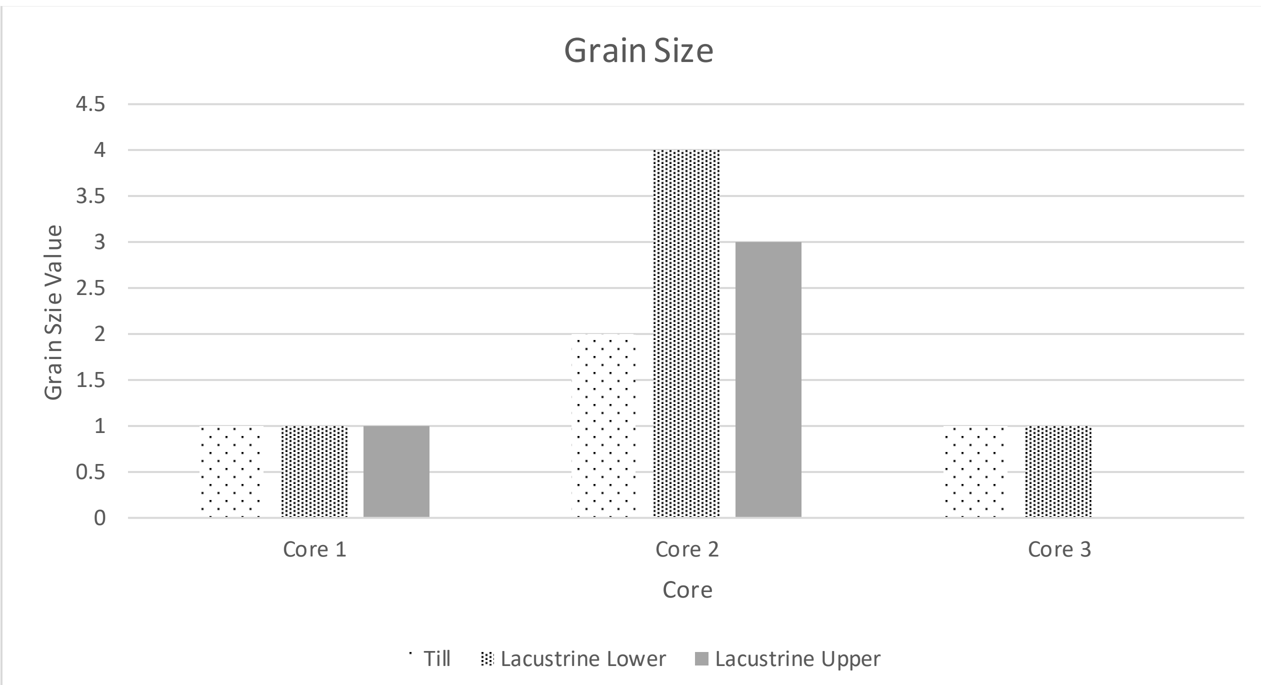

Figure 6 - Grain size graph comparing grain sizes through all samples. Lower values represent finer grain sizes and larger values represent coarser grain sizes.

Cores 1 and 3 both showed finer grain sizes compared to Core 2 samples. In Core 2, the till had slightly coarser grains than Cores 1 and 2, while the lacustrine sediment had much coarser grain sizes than all other samples. Upper lacustrine samples from Core 3 are missing because only one sample was collected from the lacustrine sediment in Core 3.

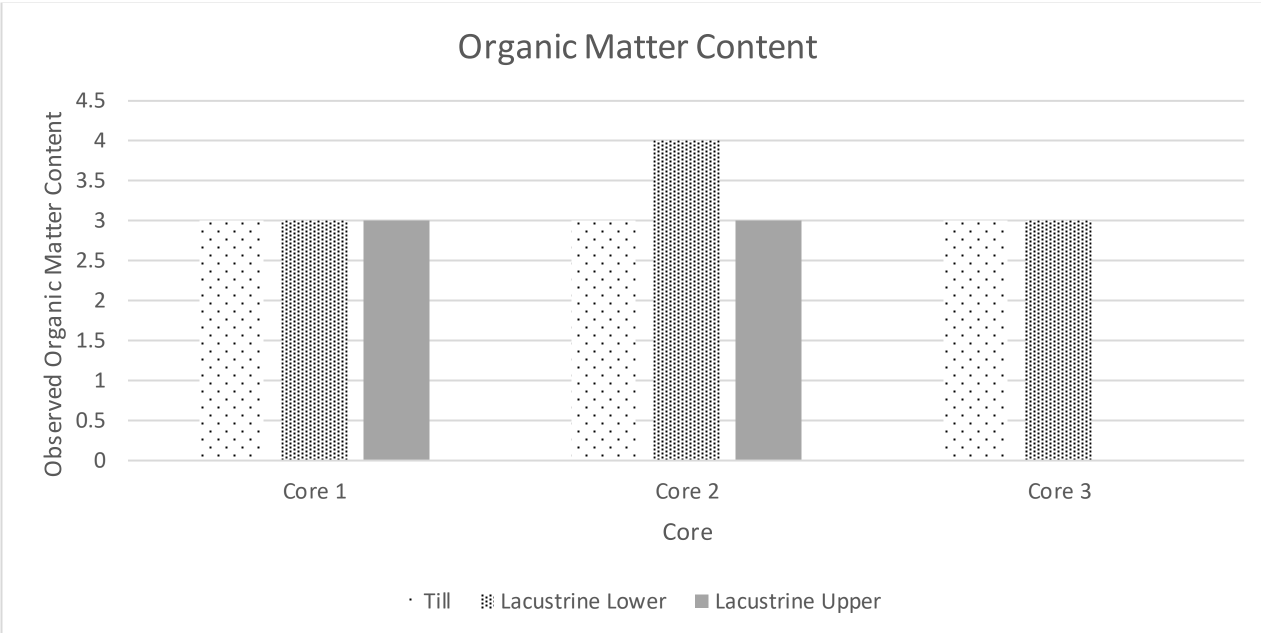

Figure 7 – Observed Organic matter content graph comparing organic matter content through all samples. Lower values represent less organic matter and larger values representing more organic matter observed.

Cores 1 and 3 also had organic matter content, with moderate amounts of organic matter in both the till and lacustrine sediments in both cores. Core 2 shows higher organic matter content in the lower lacustrine sample.

XRD

Individual results from XRD tests are graphed separately for each sample (figures 7-12). Due to time constraints, only till from Core 1 was analyzed by XRD. The important trends are the relationships of feldspar, calcite, and dolomite concentrations in all of the lacustrine samples.

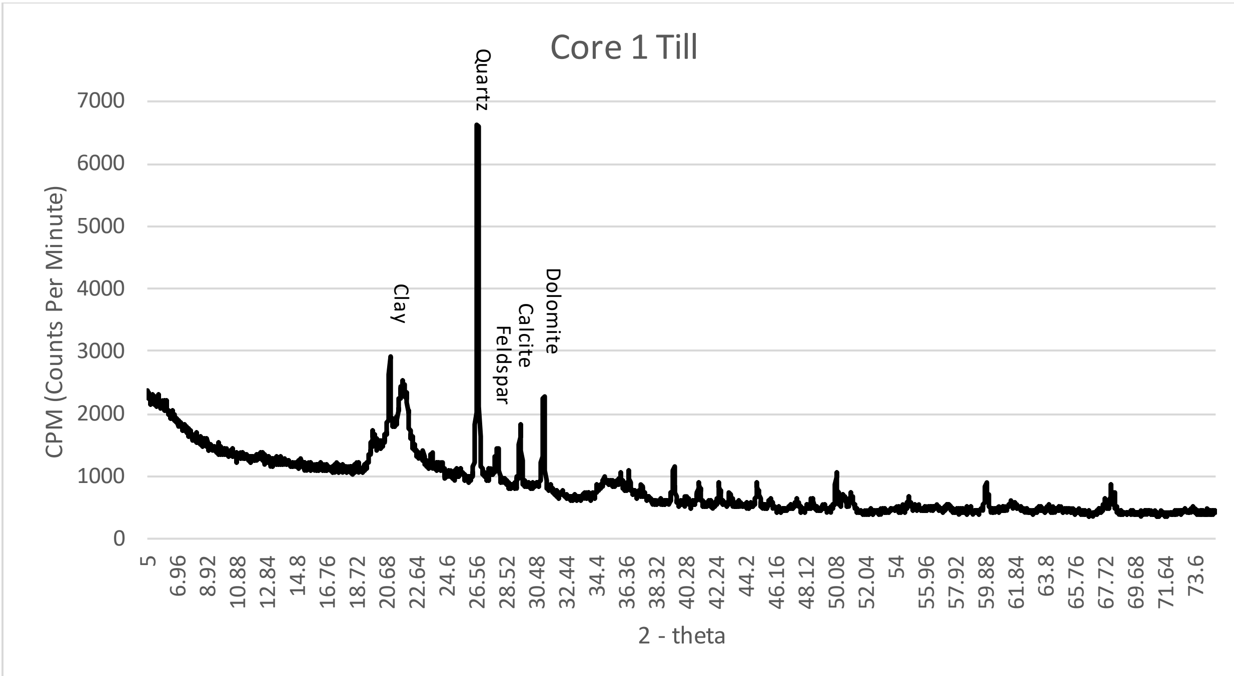

Figure 8 - Till from core 1 (Red Lake Falls member). Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

The only till sample with XRD data. Till shows strong peaks for clay minerals, and quartz. Feldspar, calcite, and dolomite also have strong peaks. The relative concentration feldspar is less than that of calcite, which is in turn less than dolomite.

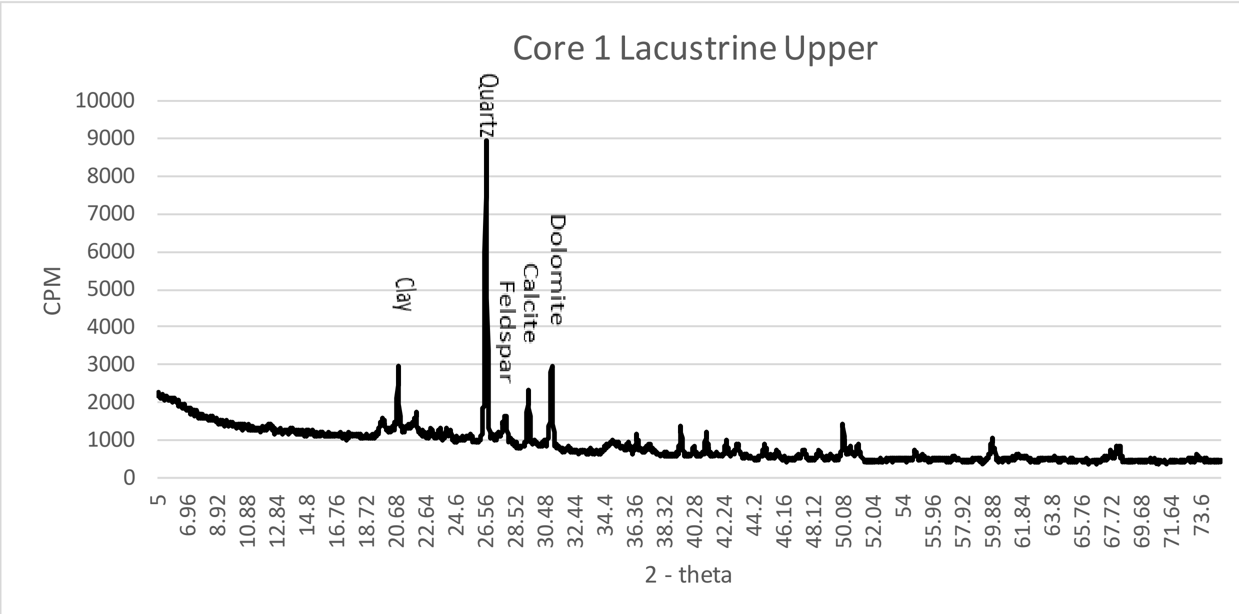

Figure 9 - Lacustrine sediments from upper portion of lacustrine layer in core 1. Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

Upper lacustrine sample from Core 1 show an expected smaller clay peak than the till. The feldspar, calcite and dolomite concentrations all have the same relationship as in the till sample.

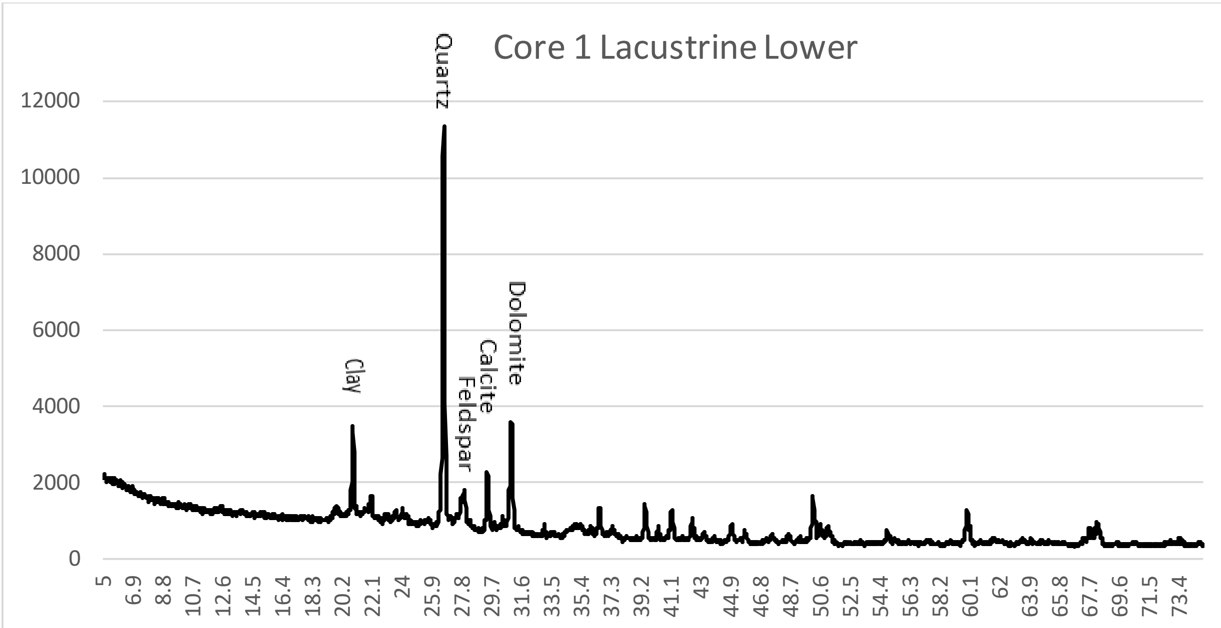

Figure 10 - Lacustrine sediment from lower portion of lacustrine layer in core 1. Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

Lower lacustrine sediment showed similar trends as the upper portion of the lacustrine layer in Core 1.

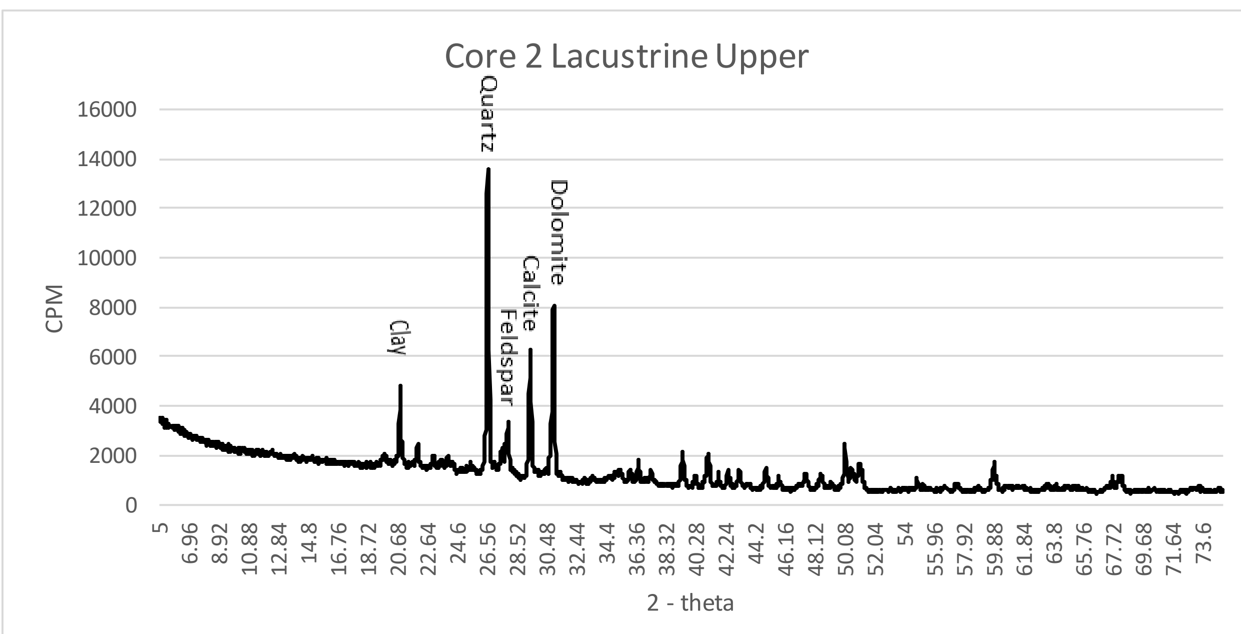

Figure 11 - Lacustrine sediment from upper portion of lacustrine layer in core 2. Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

Lacustrine sediment from upper portion of core two showed similar trends to lacustrine sediment from Core 1.

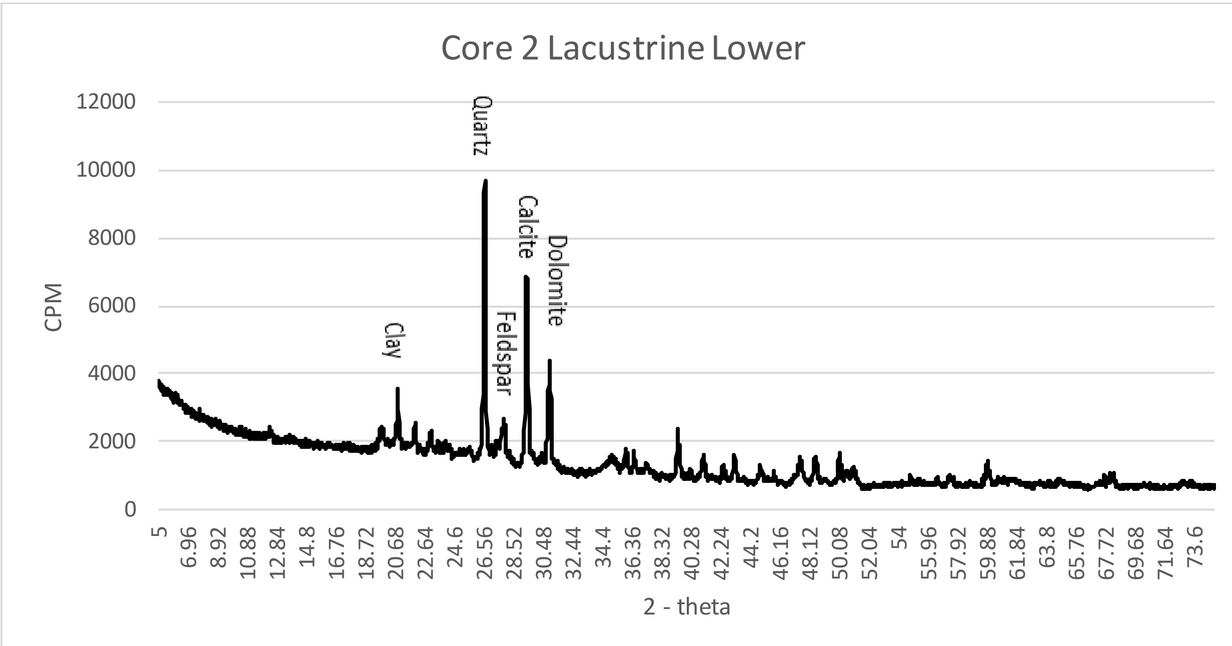

Figure 12 - Lacustrine sediment from lower portion of lacustrine layer in core 2. Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

Sediment from the lower portion of the lacustrine layer in Core 2 showed a different mineralogical trend as the rest of the data. Calcite:dolomite ratio is opposite from the rest of the data, represented by the stronger calcite than dolomite peak. This trend is opposite of the rest of the samples, which showed higher concentrations of dolomite than calcite.

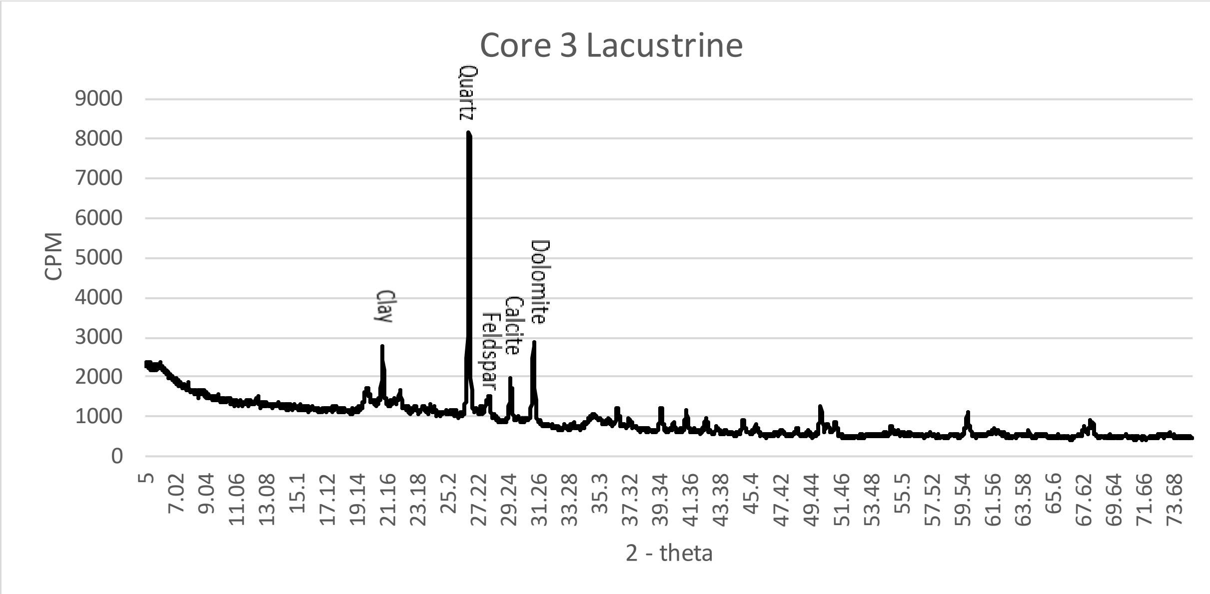

Figure 13 - Lacustrine sediment from core 3. Relative concentrations are shown by the CPM, and each significant minerals 2-theta value is labeled.

Lacustrine sediment from Core 3 shows similar trends to the rest of the lacustrine samples. Trends in significant mineral concentrations are consistent in both lacustrine samples of Core 1, and the lacustrine sample from Core 3. The lower sample from Core 2 shows different calcite:dolomite ratios in the lacustrine sediment, with higher concentrations of calcite than dolomite.

Discussion

This study attempts to differentiate between ancient proglacial lakes by testing the lacustrine sediment in three separate cores. Samples were taken from the lacustrine sediments in these cores and analyzed for their mineralogical content and sediment descriptions. Previous studies that analyzed lacustrine sediment mineralogy with XRD have shown that mineralogical tests can reveal a more detailed glacial history of an area (Leonard and Reasoner, 1999). In that study, the authors correlated mineralogical data with organic material data to reconstruct the environments in which the sediment was deposited, and the glacial activity that created the studied lakes. Strew slide analysis can give an idea of grain size, and show any organic matter content in the sampled sediment, both of which are important features that vary within a lake, and between lakes. Dramatic differences in the character of strew slide data could permit differentiation among lacustrine sediments in this study, and help determine whether they formed in one or many proglacial lakes. To discern whether lacustrine sediments in the three cores represented one or multiple lakes, the mineralogical data and sediment descriptions must show differing trends. The conclusions made from these analyses can then be examined in space to reconstruct glacial movements, by comparing the data from the lacustrine sediments in each core to where the core was pulled in relation to the others.

The results of the XRD tests show similar mineralogical compositions in all the lacustrine samples, except for in the lower lacustrine sample from Core 2. The XRD data shows a greater concentration of calcite than dolomite in the lower lacustrine sediment from Core 2, but higher concentrations of dolomite than calcite in the rest of the samples (strew slide observations also show similar trends in the lacustrine samples from Cores 1 and 3, but different trends in Core 2). If the samples were from separate lakes, more extreme differences in their mineralogy would be expected. However, the calcite:dolomite ratio in the bottom of the lacustrine horizon in Core 2 does show change of some sort. The strew slide observations show finer grain sizes throughout the lacustrine sediment in Cores 1 and 3, but coarser grain sizes in Core 2. Changes in grain size can indicate deposition in different lakes if significant, or in different facies of the lakes. The organic matter content in Cores 1 and 3 are similar, and there is more organic matter content shown in Core 2. Changes in organic matter can represent changes in depositional environment, or again they can represent different facies of the lakes, such as shallower near shore facies, or deeper facies near the center. These differences are minor, and do not show significant enough change from one lacustrine sample to another to clearly indicate different lakes. However, coarser grains, higher organic matter content, and stronger dolomite concentrations are all consistent with sediments in near shore lake environments. All three samples come from sediment of Riding Mountain provenance, so the source should not cause changes in the lacustrine sediment.

Because the lacustrine sediment from Core 3 lies above the St. Hilaire Member till, and the sediments from Cores 1 and 2 lie below it, it can be separated into one, younger lake to start.

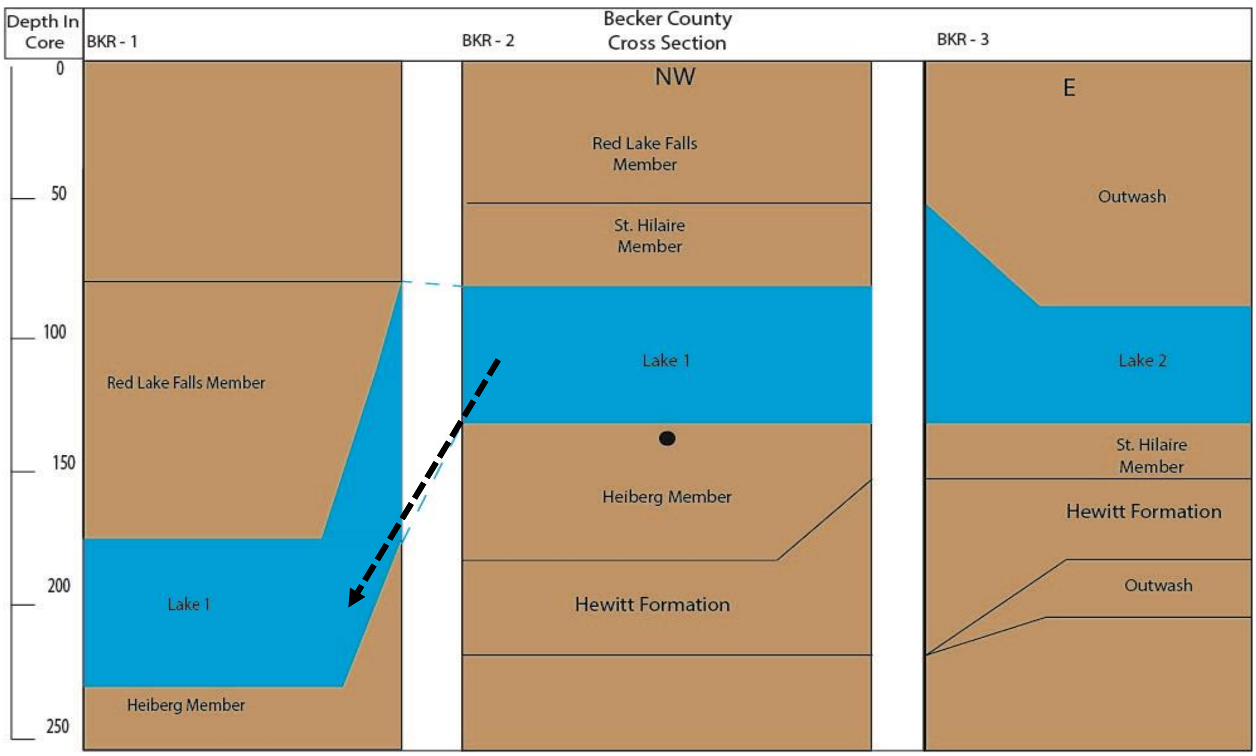

Figure 14 - Final cross section of all three cores showing relationships of ancient proglacial lakes, black arrow indicates that lake evolution started with lacustrine sediment in core 2.

The interpretation that the lacustrine sediment from Cores 1 and 2 are of different facies of the same lake results in a second lake being represented, older than the lake represented in Core 3 (Figure 15). When this interpretation is correlated spatially to the locations of the three cores, an evolution of the older lake can be roughly outlined (Figure 15).

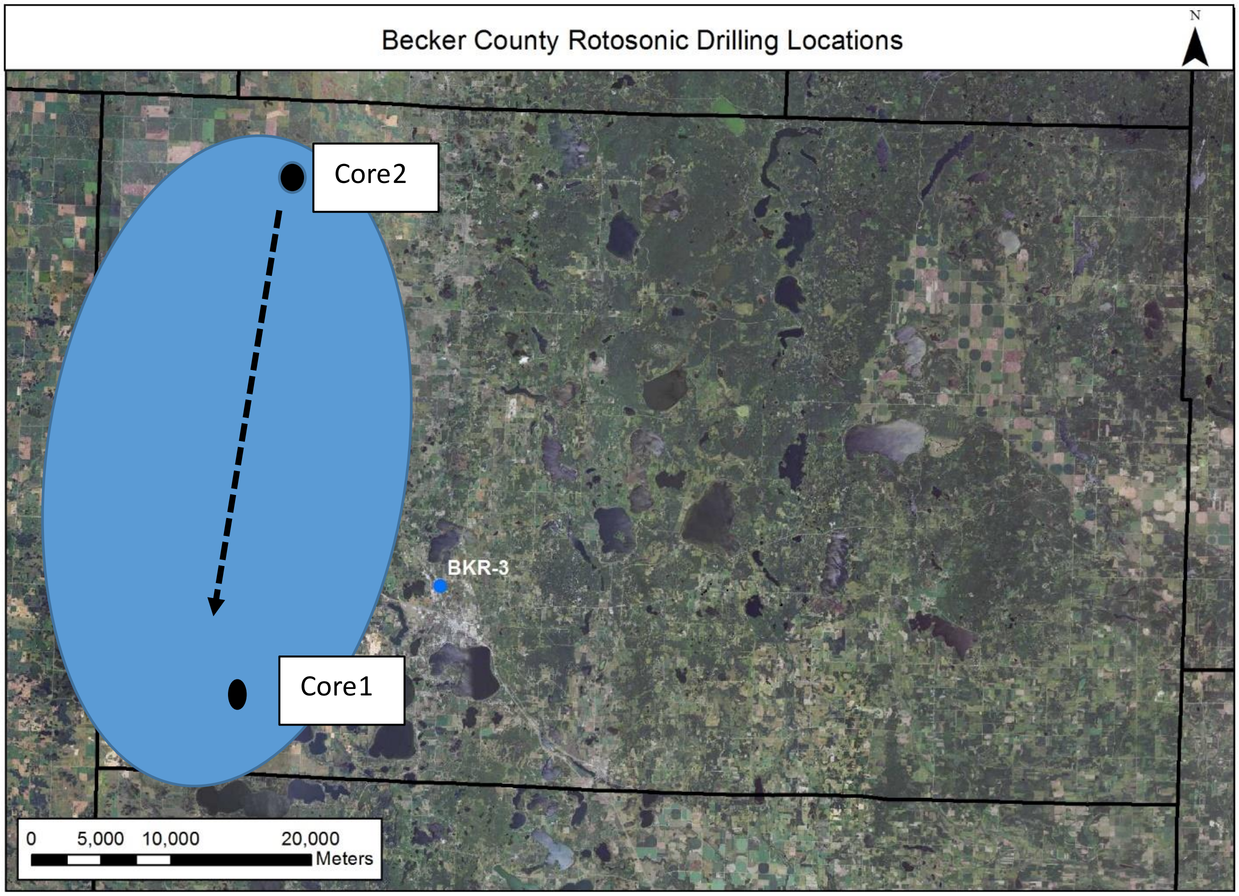

Figure 15 - Potential evolution of lake 1; Post deposition of Heiberg till, pre deposition of St. Hilaire till

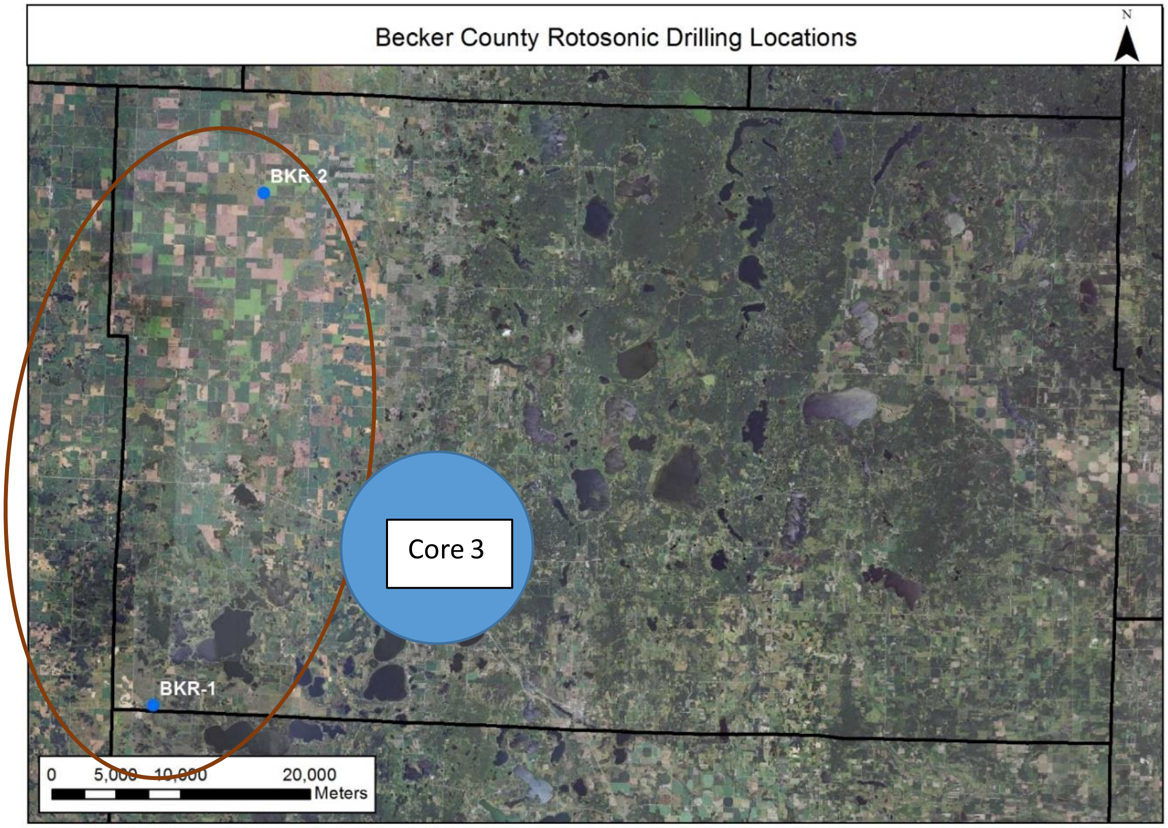

Figure 16 - Lake 2; created after deposition of St. Hilaire till

These conclusions show a more detailed glacial history in Becker County. First, the interpretation of one lake represented by the lacustrine sediments from Cores 1 and 2 indicates at least one glacial advance and retreat. This is based off of the model of proglacial lakes forming at the tail end of retreating glaciers, fill in from advances, and form again at retreat. Interpreting the lacustrine sediment from Core 3 as representing another, younger lake, another glacial advance and retreat is revealed. The extent of the first glacial advance can be placed between the two, since the glacier had to advance at least past Cores 1 and 2. When you compare these results to where the cores were pulled from, it easy to roughly draw in where these advances extended geographically (Figure 17).

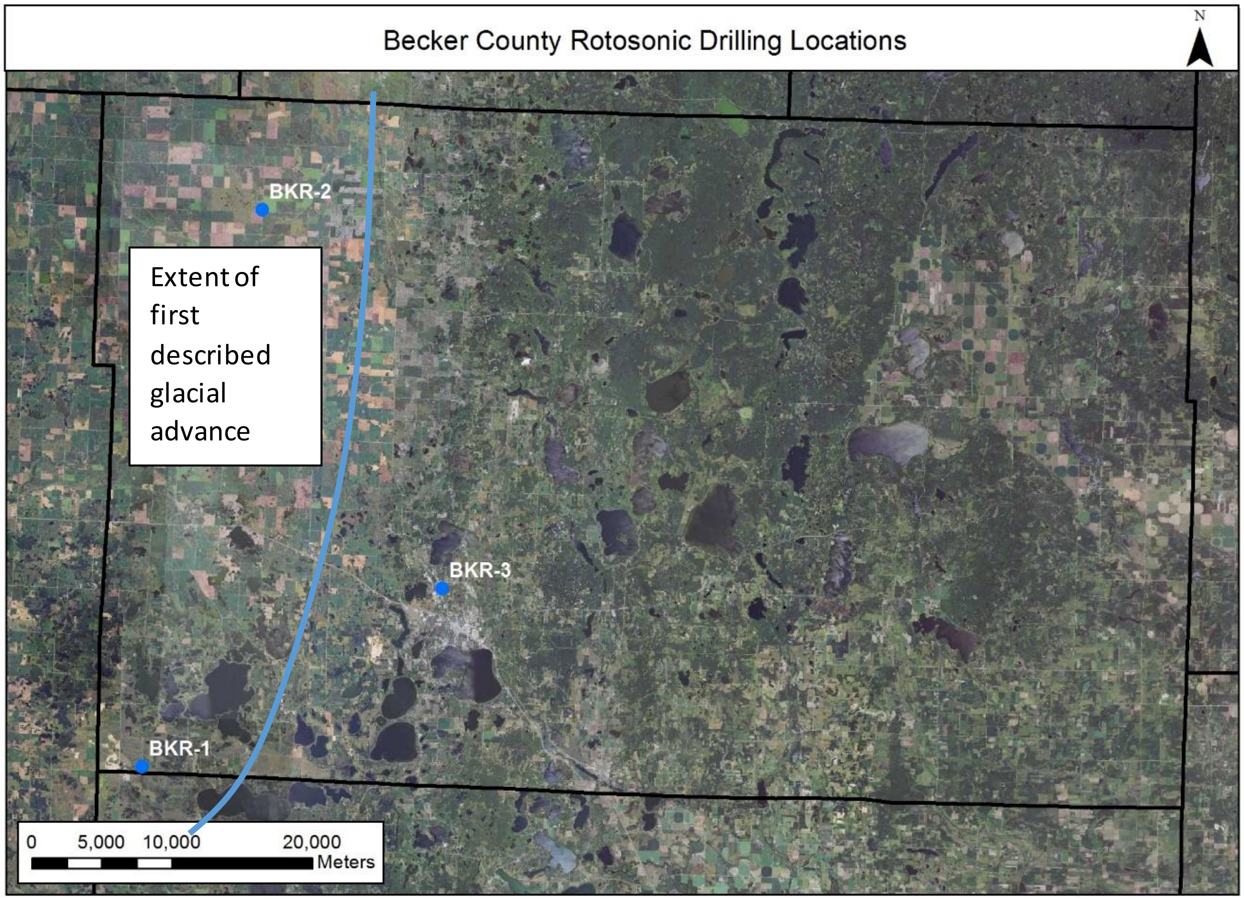

Figure 17 - Minimum extent of glacial movement that created lake 1

Weaknesses of this study begin with the storage of the cores. The cores were stored in a cool dry climate, which caused them to dry out. This made sample collection difficult in two ways: Collecting from the same specific depths in the core due to the difficulty to get any sample small enough to store and transport, and attempting to identify what was being sampled. This also led to some issues with time. The core was not stored nearby where the tests were being run, and as a result there was not enough time to collect as much sample as would be ideal. Because of this only one or two samples were used to represent large sections of core, giving some of the data a higher threshold of error if any of the XRD tests were run wrong or sample was contaminated at any point. Another difficulty was lack of macro-sized organic matter to carbon date in relevant areas. Moving forward in this project, more samples should be collected for testing, specifically in each varve of each lacustrine layer, and above and below each lacustrine layer should be sampled more thoroughly. All of these samples should be analyzed with the same methods done in this research. Other tests, such as a geochemical analysis should be done to ensure the data collected is representative of each section of the core they were representing in this work and provide more data on the depositional environments of each lacustrine sample, and its source.

To conclude, the analysis of lacustrine sediments through X-ray diffraction and strew slide data in the three Becker County cores shows two separate lakes, which indicate two separate glacial advances and retreats through Becker County. They also can show a rough model of proglacial lake evolution. These methods used to differentiate between lacustrine sediments allows for further, more precise reconstruction of glacial movements, which can be done in areas outside of Becker County as well. However, there is some uncertainty in the sample collection, and further data collection of the cores should be an important next step in confirming these findings. Because of this, it would be ideal to collect more samples and run more tests in the future.

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