Glacial Lake Lind: Superior Lobe Retreat Rates Based on Varve Thickness Correlation and Identification of Trace Fossils

by
Kristin L. Addis

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Kristin L. Addis
under the supervision of Professor Mark D. Johnson

ABSTRACT

Glacial Lake Lind varved clay lies in the lowland region of the St. Croix River Valley in eastern Minnesota and western Wisconsin. The varves lie above the Superior Lobe till and underlie sands and gravels. Stratigraphic sections of the silt and clay varves were described and thicknesses measured at five sites. The clay layers were graphed and strong correlations were found at four of the five sections. By measuring distances between the sites with Superior Lobe till at the base of the varve sequence, glacial retreat rates were calculated to average about 200 m/yr. The longevity of the lake was estimated to be 1000 years based on varve counts from the North Branch site.

Glacial Lake Lind trace fossils are preserved at the interface of the clay and silt contact in a semi-relief, concave manner. There are three distinct types of trace fossils that are observed. The Type I trace fossil is a long continuous burrow made most likely by a "worm-like animal and/or possibly insect larvae" (Gibbard and Stuart, 1974). Type II is recognized as a crescent-moon shaped feature, possibly a burrow or resting trace. Type III trace fossils appear to be a resting trace of a bilobed organism. Possibilities include isopods, amphipods, nematodes, crustaceans and insect larva. Planolites-Palaeophycus-like and Taenidium-like traces described by Naldrett (1990) are similar to Glacial Lake Lind trace fossils Type I and II. These trace fossils are difficult to identify because of a lack of identification in North American trace fossil records.

ACKNOWLEDGMENTS

I would like to thank Gustavus Adolphus college for funding Mark Johnson through a creativity grant. I would also like to thank Lisa Ferber who endured two weeks of haunting field work to measure thickness' for this project. Lastly, Mark Johnson for introducing me to the glamorous world of varves, and giving me a sense of direction throughout this project.

CONTENTS

FIGURES AND TABLES

INTRODUCTION

The glacial history of eastern Minnesota and western Wisconsin has been studied for many years which consists of the following. The Superior Lobe extended from the Lake Superior Basin southwest to the Minneapolis Lowland during the St. Croix Phase (Wright and others, 1973). As the Superior Lobe retreated, Glacial Lake Lind was formed in the former St. Croix River valley (Johnson, 1992). As glacial retreat continued, Glacial Lake Lind expanded and eventually began to fill with deltaic sand. After the Superior Lobe retreated from the St. Croix River Valley and Glacial Lake Lind filled, the Grantsburg sublobe advanced (an offshoot of the Des Moines Lobe) to the northeast over the St. Croix Moraine (Superior Lobe remnant), and dammed the St. Croix River creating Glacial Lake Grantsburg (Cooper, 1935).

Glacial Lake Lind sediment occurs in couplets of silt and clay that represent one year of deposition. This idea was first introduced by Upham (1883) who suggests that the clay represents the winter months when the lake freezes over. This enables the clay particles to settle to the bottom of the glacial lake. The silt represents deposition during the spring and summer months when the glacier is melting producing coarser material than in the winter months. Because the varves are annual, the duration of the lake can be determined by counting the number of couplets present within the basin. The thickness of the varves is dependent upon the closeness of the sediment source. The closer an area is to the glacier or a prograding delta, the thicker the varves will be (Ashley, 1975).

Over the past few decades there has been an increase of research among geologists concerning trace fossils within proglacial lake sediment. Moussa (1970), Banerjee (1973), Gibbard and Stuart (1974), Ashley (1975), Gibbard and Dremanis (1978), and Naldrett (1990) have described trace fossils in proglacial lakes but have not been able to confidently identified them. Naldrett (1990) has identified trace fossils in the Champlain Sea, but these are marine traces and it is unknown if these organisms were able to live in a fresh water environment. Trace fossil records for North America are very limited, in fact the International Code of Zoological Nomenclature does not even recognize trace fossils within Pleistocene-age sediment (Naldrett, 1990). There is a great uncertainty in the North American proglacial lake trace fossil record which makes identifying trace fossils in Glacial Lake Lind challenging.

PREVIOUS WORK ON LAKE LIND VARVED CLAYS

Varved sediment in the St. Croix River Valley was first described by Berkey, (1905). He described the sediment as laminated reddish-brown (5 YR 4/4) clay and dark reddish-gray (5 YR 4/2) silt layer that is overlying Superior Lobe Till. By counting the number of varves and using drill hole logs he estimated that the glacial lake existed for approximately 1700 years. He interpreted this period to be an inter-glacial period between the advance of the Des Moines Lobe and the advance of the Superior Lobe.

Cooper (1935) described red clay similar to Berkey's description as being red in color and resting stratigraphically above the Superior Lobe Till. A second clay he discusses as massive and brown in color has been consistent of Glacial Lake Grantsburg clays residing in the Barron's lowland. Cooper interprets the red clays as a previous phase of Glacial Lake Grantsburg that received a supply of sediment from the streams originating the Superior Lobe when the Grantsburg Sublobe was advancing.

Wright (1972) also described both of these distinct lake sediments and concluded that both varve units were deposited in Glacial Lake Grantsburg. Wright explains that the portion of Glacial Lake Grantsburg that lies near the St. Croix River Valley is red in color because the lake was supplied by tributaries that extended from the Superior Lobe. He interpreted both red and brown varve units as sediment of Glacial Lake Grantsburg.

Johnson (1992) described a distinction between the two distinct varve units. He describes the stratigraphy in western Wisconsin and eastern Minnesota as Superior Lobe

Till underlying red clay that grades into deltaic sediment. Certain portions of Glacial Lake Lind are overlain by Glacial Lake Grantsburg varves and Grantsburg Sublobe till (Johnson, 1994). Therefore he concluded that the two clay units were deposited in two different lakes.

Based on subsurface information described by Helgesen and Lindholm (1977), Johnson (1992) expanded the extent of Glacial Lake Lind southwest to the Anoka Sandplains. Helgesen and Lindholm (1977) describe the sediment as "red and brown laminated lacustrine clay." Johnson interprets this description as the same unit observed in the St. Croix River Valley. Johnson also notes some general characteristics within the laminated sediment. He describes that the silt and clay couplets are gradational in character with occasional erosional surfaces.

The distinction between the two separate glacial lakes is crucial to understand the glacial history of the area. Glacial Lake Grantsburg has been approximated to have existed for less than 100 years (Johnson, 1994). Johnson (1992) suggests that Glacial Lake Lind existed for nearly 1500 years and covered approximately 2500 sq. km. (Fig. 1).

MEASURED SECTIONS

There are five sites described in this study, North Branch, Ken Iverson, St. Croix, Ravine and Sandrock . The varves were counted and thickness of the silt and clay layers were described and measured. Stratigraphic columns were constructed of the generalized sedimentology (Fig. 2). Numbering of the varves in the stratigraphic column began at the contact between Glacial Lake Lind varves and Superior Lobe till or the first varve above river level.

The North Branch site located in the NW1/4, SE 1/4, SE 1/4, sec.15, R.18 W, T.40 N, (Fig. 2b) contains the thickest varve sequence ranging in elevation of 250 m (822 ft.) to 260 m (854 ft. at the top of varve sequence) along the North Branch Sunrise River. It is the most distal site from the retreating Superior Lobe. There are 9.8 m (32 ft.) of Glacial Lake Lind varves present with at least another foot below the river level which is very difficult to measure but it is important to note their presence. At the top of the varve sequence appears to be an erosional surface indicating an absence varve layers. Overlying the North Branch varves is 5.5 m (18 ft.) of sand. There is some contortion of beds in the middle region of the column. Complications arose in measuring the thickness' at the North Branch site because of extensive slumping of the outcrop. A 3 to 4 m (5 to 10 ft.) section of varves, probably about 100 varve years, are missing from the thickness measurements Fig. 3). Because of the slumping, the North Branch site was separated into three different columns to assure the most accurate thickness measurements and correlation. There are 811 varve years counted at this site. Since the varves extend further down past the river level, and extend up into the soil horizon it is estimated that Glacial Lake Lind most likely existed for approximately 1000 years.

The Ken Iverson site (Fig. 2, 3) is located at an outside meander of the Trade River, just southwest of Grantsburg, Wisconsin (NE1/4, SE 1/4, NE 1/4, sec. 18, R. 19 W, T. 36 N). The Ken Iverson site is one of the three sites with Superior Lobe till exposed beneath Glacial Lake Lind varves. The Trade River, which has eroded through the varves and till, has an elevation of 245 m (802 ft.) above sea level. The varves begin at 256 m (818 ft.) and continue for approximately 4.5 m (15 ft.) until the sand is observed. There are 501 varve years counted with an additional 7 to 8 cm of varves at the top of the sequence that were too water saturated to measure.

The Ravine site (located at NE 1/4, SE 1/4, NW 1/4, sec. 29, R. 20 W, T. 37 N) also exposes Superior Lobe till with approximately 3.7 m (12 ft.) of varves and a thin layer of pebbles at the top of the varve sequence underlying 6 m (20 ft.) of sand (Fig. 2, 3). These elevations are estimated from a topographic map .

The Sandrock site (Fig. 2, 3) is a roadcut which exposes the varves just east of the St. Croix River (NW 1/4, NE 1/4, SE 1/4, sec. 7, R. 19 W, T. 38 N). The contact between the Superior Lobe till and the varves is about 260 m (852 ft.) above sea level. It contains 8 m (26 ft.) of Glacial Lake Lind varves which are overlain by .6 m (2 ft.) of gravel (elevation

270 m.) similar to the pebble layer observed at the Ravine site (elevation of 256 m). Overlying the pebble layer is 4.9 m (16 ft.) of sands with the top at 274 m above sea level.

The site that is farthest to the north is the St. Croix site (NE 1/4, SE 1/4, SE 1/4, Sec. 15, R. 18 W, T. 40 N) and exposes the shortest varve sequence of the sites measured (Fig. 2b, 3). It is the highest observed varve outcrop occurring approximately between 263 to 270 m (864-884 ft.) above sea level. The varves coarsen upward and also increase in thickness as the elevation increases.

VARVE-THICKNESS CORRELATION

Each silt and clay layer at the five sites were measured and recorded. The silt and clay thicknesses were plotted on a graph against varve years in an attempt to correlate distinct layers (Fig. 3). No correlations within the silt thickness were seen. It is possible that the silt is too dependent on the location of the glacier and fluctuations within the lake (such as sediment flows) during the summer months to use it to correlate varve thickness. The clay thicknesses are much more constant because in the winter the lake has frozen over and the clay distribution is more constant throughout the lake than the silt distribution in the spring and summer. A distinct pattern of clay thickness is seen on 4 out of the 5 sites. The varve-thickness curves are placed in Fig. 3 to show the correlation peaks.

The clay thicknesses can be correlated through three strong peaks that occur in the middle of the varve sequences. Fig. 3 shows the gradual increase in the clay thickness producing the first peak at approximately varve #120 (North Branch). The clay thickness decreases for about 25 varve years until a rapid increase in the clay thickness is represented by the second prominent peak. Again, the thickness of the clay decreases for approximately 60 years until another pulse of clay appears for the third time at varve #150. By matching these patterns, it is clear that the lake existed at the North Branch, Ken Iverson, Ravine and Sandrock site at the same time because they all show the same distinct patterns in clay thickness. It is likely that Glacial Lake Lind also existed at the St. Croix site at the same time as the other four, but the St. Croix River has not had enough time to erode through the varve sequence to expose those varve years.

The fluctuations in the clay thickness are difficult to explain. A simple explanation would be that the winter was much longer than previous warmer years when the lake was frozen over for a shorter amount of time. Although it is possible, it seems unlikely that the winter would be able to deposit clays of that thickness in one year from the same source. Glacial ablation does indeed fluctuate, but a fluctuation as large as those seen in Fig. 3 would be extremely rare. It seems logical that there would have to be a second source for the clay thickness to increase as significantly as it does, especially in the Ravine and Sandrock sites (Fig. 3). The favored hypothesis consists of the following. The outlet of Glacial Lake Lind, located in the southwestern portion of the lake (Johnson, 1992) began to downcut. As the level of the lake dropped shoreline erosion would cause clays to be eroded and redeposited in the lake basin resulting in the thick clay layers that are observed. This systematic fluctuation apparently occurred over an interval of approximately 100 varve years (Fig. 3). It is possible that the lake underwent another period of outlet downcutting events 150 varve years after the first apparent downcutting event.

ICE-RETREAT RATES

Varve correlation enable us to estimate a range in varve years where the lake existed concurrently at each site. Glacial margins were drawn on a map as seen in Fig. 4 (Johnson, in press). These are hypothetical glacial ice-marginal positions which applied geomorphic features to estimate ice margin configurations at each site. The ice margin lines were drawn through the sites with Superior Lobe till exposed at the base (Ken Iverson, Ravine and Sandrock). The distances between the hypothetical ice-margin positions were measured at two different locations along the ice-marginal position. Then the distance was divided by how much time it took the glacier to retreat between the sites. This is accomplished by using the correlations between the sites with till beneath the varves. The difference of the number of varves between the till bases of both sites is then divided into the distance. Fig. 5 shows the calculations of the three sites that overlie Superior Lobe till.

Comparing Superior Lobe retreat rates to Brunnberg (1995), Donner (1995), and Ridge (1990) shows that the Superior Lobe retreated at a similar rate (Fig. 6). The overall average retreat rate of the Superior Lobe in the Glacial Lake Lind region is approximately 200 m/yr. This fits about in the upper middle range with those referred to above. This increases the confidence of the correlation between the clay layers.

DESCRIPTION AND CLASSIFICATION OF TRACE FOSSILS

There are an abundance of trace fossils in Glacial Lake Lind varved sediment. It is common for the trace fossils to be consistently present throughout the samples that were collected from the North Branch, Ken Iverson and Sandrock sites. The samples were split along the contact between the silt and clay. The fossils appear to be fairly consistent throughout Glacial Lake Lind with exception of the first few years of deposition at the front of the glacier. The absence of trace fossils is most likely due to coarse sediment in the melt water coming off the glacier.

The trace fossils are most easily preserved on the top layer of the clay. The sediment has been compressed or eroded, and the void fills with silt settling through the water column. The fossils were observed by viewing the bottom side of the silt layer because the trace fossils are more easily observed in comparison to the top of the clay layer.

There is an absence of trace fossils in the clay layer. This could be due to a number of things. Naldrett (1990) suggests that the preservation within the fine-grained sediment is not preserved as well as in the fine sediment but more visible at the contact between the annual layers. If this is true it would be reasonable to assume that some sort of disturbance would be seen in thin section. Thin section descriptions of Glacial Lake Lind varves suggests a different explanation. The traces do not cut across bedding planes. There appears to be no bioturbation features within the winter (clay) layers unlike the summer (silt) layers. Thin sections do reveal some disruption in the clay but it is most likely due to sediment flows and load structures because of their irregular, inconsistent shapes (Fig. 7). This suggests that the organisms were dormant during the winter.

Three possible kinds of traces resided in the Glacial Lake Lind sediment (Fig. 8). Type I trace fossils are characterized by branching burrows (1-3 mm width) with trails that are straight with occasional wave-like movements (Fig. 9). Comparison of the evidence found in Glacial Lake Lind with that of Gibbard and Dreimanis (1978), and Gibbard and Stuart (1974), suggests that these are the tracks of insect larva or other "worm-like animal burrows." The fossils Gibbard and Stuart (1974) observed closely resemble the fossils found in Lake Lind. Gibbard and Dreimanis' trace fossils seemed to be a bit more sinusoidal than the fossils found in Glacial Lake Lind. The occasional waviness present in Glacial Lake Lind traces is not confined to insect larva (Ekdale, 1984) suggesting the possibility of other organisms. Organisms of the nematode group can form wavy trails also but there is no possibility of distinguishing separate genus or species just from viewing the trails alone.

Trace fossils in the shape of a crescent moon are characteristic of Type II traces as seen in Fig. 10. Some of the crescent-moon traces end in a elliptical or circular depression. Many were no larger than 15 mm in length. These features are similar to those observed by Gibbard and Dreimanis (1978) although not all of the Type II trace fossils observed in Glacial Lake Lind end in a circular depression. It is difficult to classify these trace fossils with Gibbard and Dremanis, (1978) insect larva because these features described by Gibbard and Dremanis were smaller, more continuous and less distinct than the Glacial Lake Lind features.

Type III trace fossils are a small scoop-like feature with a ridge going down the center of the trace fossil suggesting that it was created by a bilobed organism (Fig. 11). Single resting trace fossils has been observed in other glacial lake sediments in north America which are very similar to the trace fossils contained within the Glacial Lake Lind sediment. These possible trace fossils include isopods, amphipods, nematodes, crustaceans and insect larva.

Naldrett (1990) describes traces that are "cylindrical with circular cross section, smooth sided, unlined, sinuous, sometimes branching, and sometimes meniscate" found in the Champlain Sea in a subaqueous outwash deposit near Ottawa, Canada. Naldrett classifies these as "Planolites-Palaeophycus-like and Taenidium-like" trace fossils. These also have a striking resemblance to the trace fossils found within Glacial Lake Lind varved sediment. It is possible that these may be very similar to the organisms that represent Types I and II of the trace fossils described, but further investigation is needed

Thin section descriptions reveal a cross sectional view of the features observed at the bedding planes of Glacial Lake Lind varves. These have been interpreted as trace fossils. Nonbiogenic origins such as load structures, erosional markings and flute casts have been ruled out. For instance, load structures would not be as continuous as the features within the sediment. Some load structures are present within the sediment as seen in thin section (Fig. 7), but the structures occur within the clay layer and not at the contact. The shape of the load structures are not as circular as the trace fossils appear. Erosional markings have been documented to show branching (Potter and Pettijohn, 1963) but branching is highly unlikely. It is also unlikely if these were erosional markings that they would occur as frequent as they do in Glacial Lake Lind sediment. Other markings such as flute casts are usually regularly spaced and do not overlap one another as observed in Lind traces (Naldrett, 1990). None of the characteristics stated above describe features seen within the varved sediment of Glacial Lake Lind. Therefore it is reasonable to conclude that the features seen in Glacial Lake Lind are indeed trace fossils.

CONCLUSIONS

The calculation of glacial retreat rates is a useful tool in determining the nature of the glacier and the surrounding area. By measuring and correlating the thickness' of the clay layer leads us to conclude the following:

1. Glacial Lake Lind existed for approximately 1000 years based on the North Branch varve column.
2. The three distinct peaks seen within the clay layer of the varve sequence show excellent correlations which indicate that Glacial Lake Lind existed at the North Branch, Ken Iverson, Ravine and Sandrock sites simultaneously.
3. The variation in clay thickness is most likely due to a drop in lake level caused by a downcutting of the outlet of the lake. This is thought to be responsible for the increase in clay thickness because of erosion from the edge of the lake which added to the amount of clay deposited as seen in four of the five sites measured.
4. The Superior Lobe retreated at an average rate of 200 m/yr from the Glacial Lake Lind region.

Biological activity in proglacial lakes has been previously thought to be nonexistent, but descriptions of the structures present within Glacial Lake Lind lead us to conclude the following:

5. It is clear that proglacial lakes are capable of supporting benthic organisms.
6. The features observed in the varved sediment are bioturbation structure burrows (Ekdale, 1984). They have been preserved at the interface of the clay and silt in a semi-relief, concave (negative) manner.
7. Based on Naldrett (1990), type I and II trace fossils present within Glacial

Lake Lind show some similarity to Planolites-Palaeophycus-like and Taenidium-like trace fossils from the Champlain Sea.

8. Type III trace fossils are mostly resting traces which are defined as the impression of an organism's body that has fallen to the bottom of the lake. Possible type III trace fossils include isopods, amphipods, nematodes, crustaceans and insect larva (Ekdale, 1984).

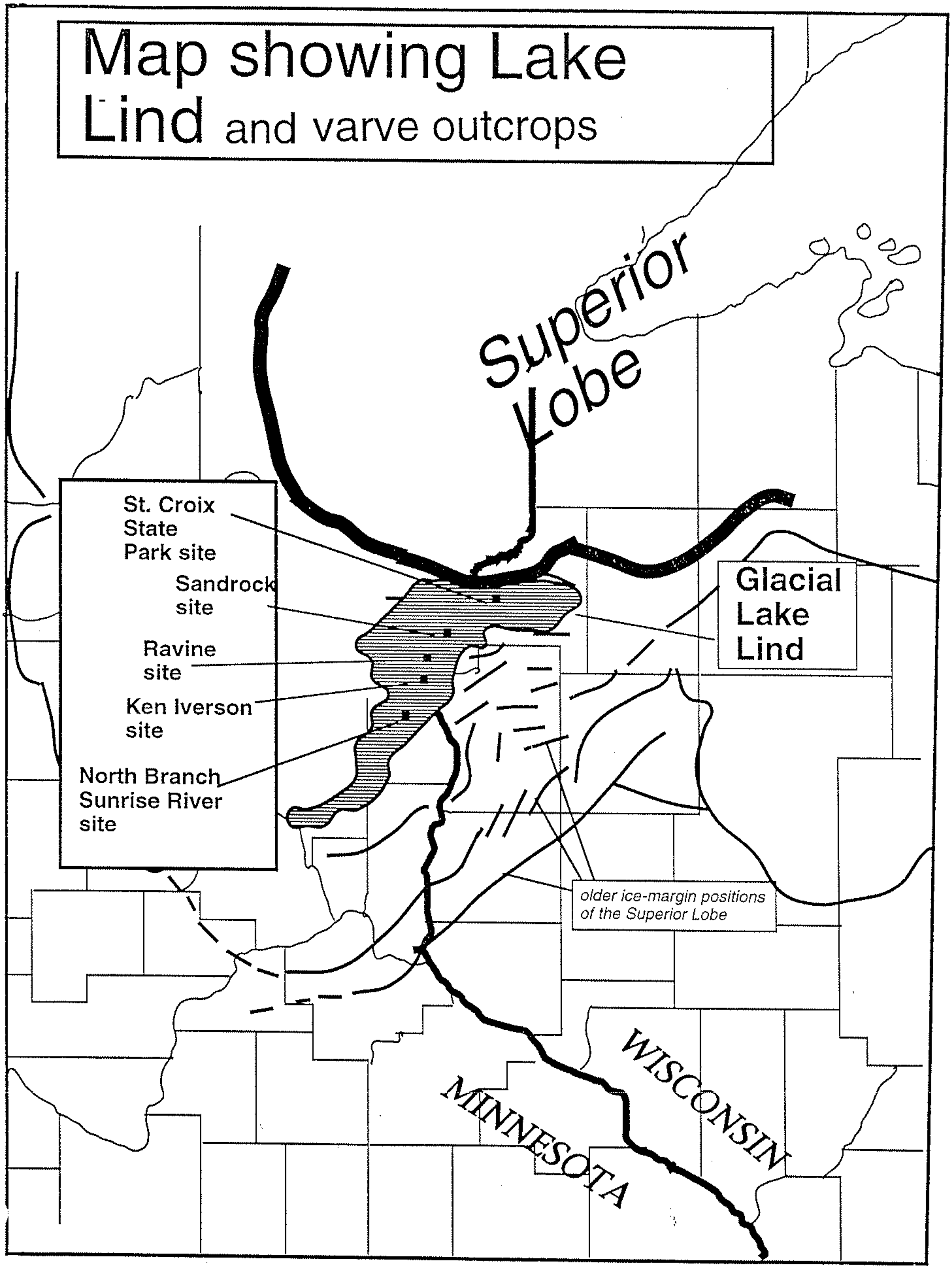

Figure 1. A map of eastern Minnesota and western Wisconsin showing Glacial Lake Lind and the locations of the varve sites where thickness measurements were taken. Also shown are ice-margin positions of the Superior Lobe.

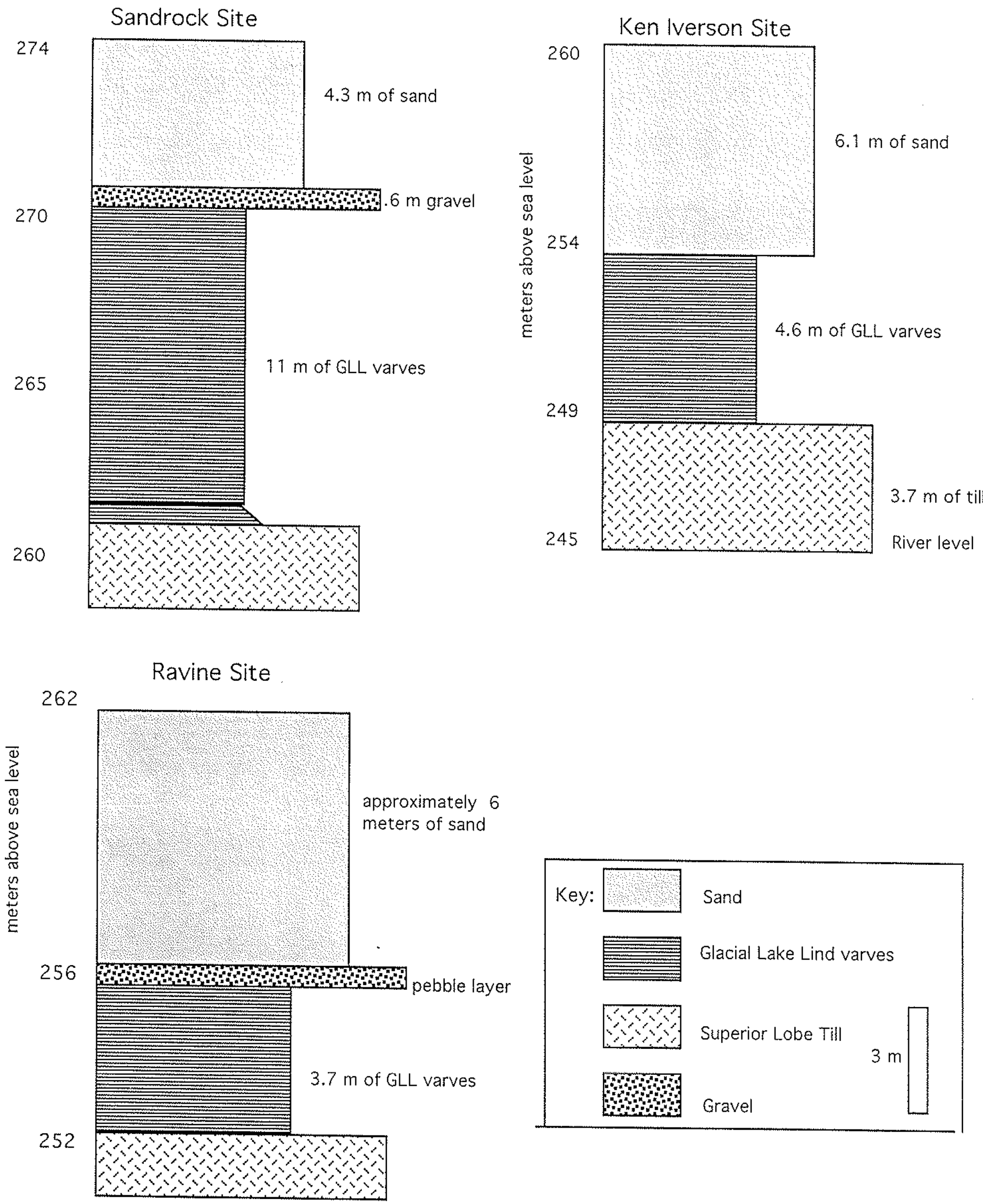

Figure 2a. Stratigraphic columns of varve sites with Superior Lobe till at the base. These three sites were used in the calculation of ice retreat rate of the Superior Lobe from Glacial Lake Lind region.

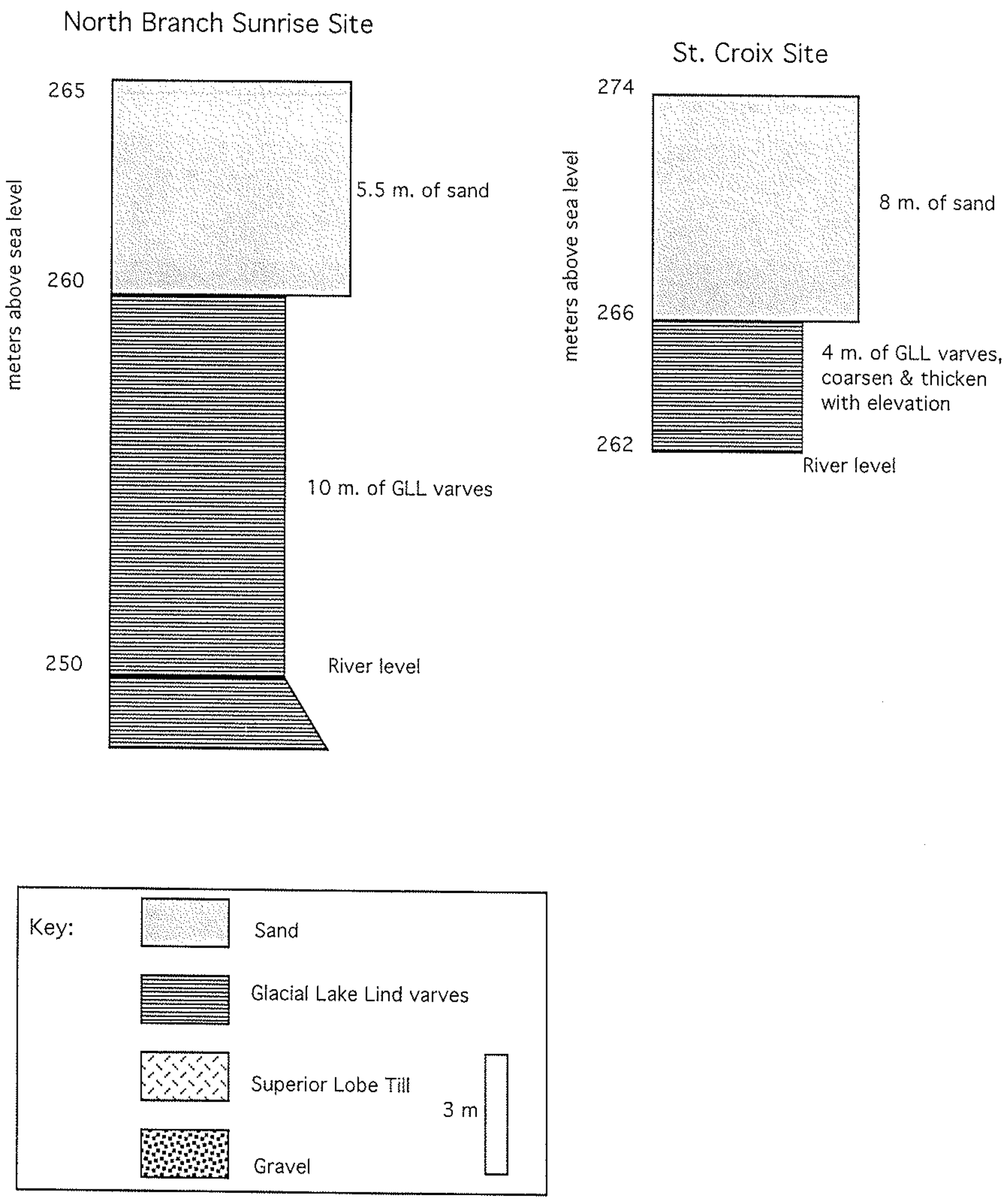

Figure 2b. Stratigraphic columns of Glacial Lake Lind varves without Superior Lobe till exposed at the base of the varve sequence.

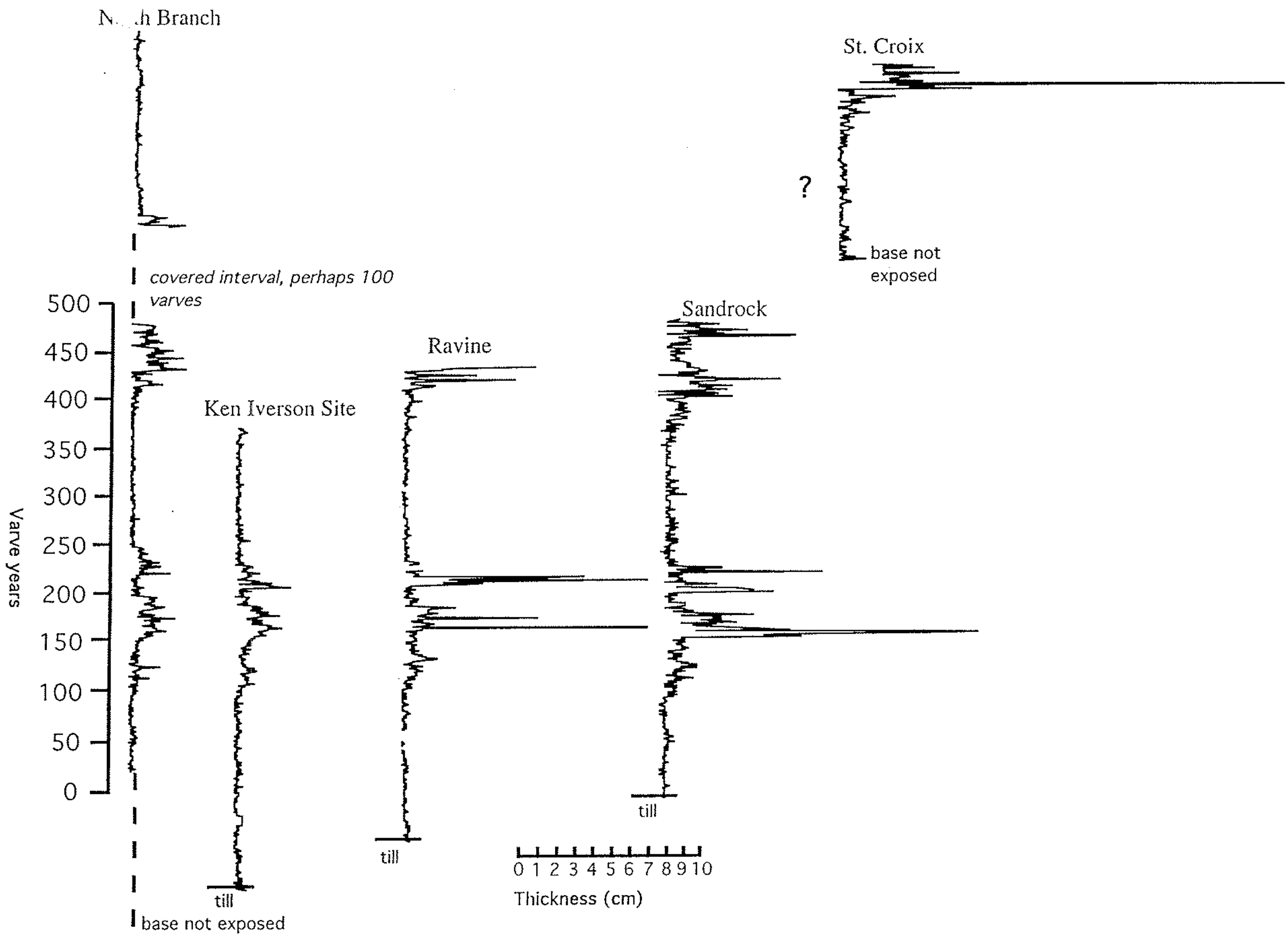

Figure 3. Varve correlation graph showing the relationship between the clay thickness' that are easily correlated to one another with exception of the St. Croix site that is located the furthest north of all of the sites.

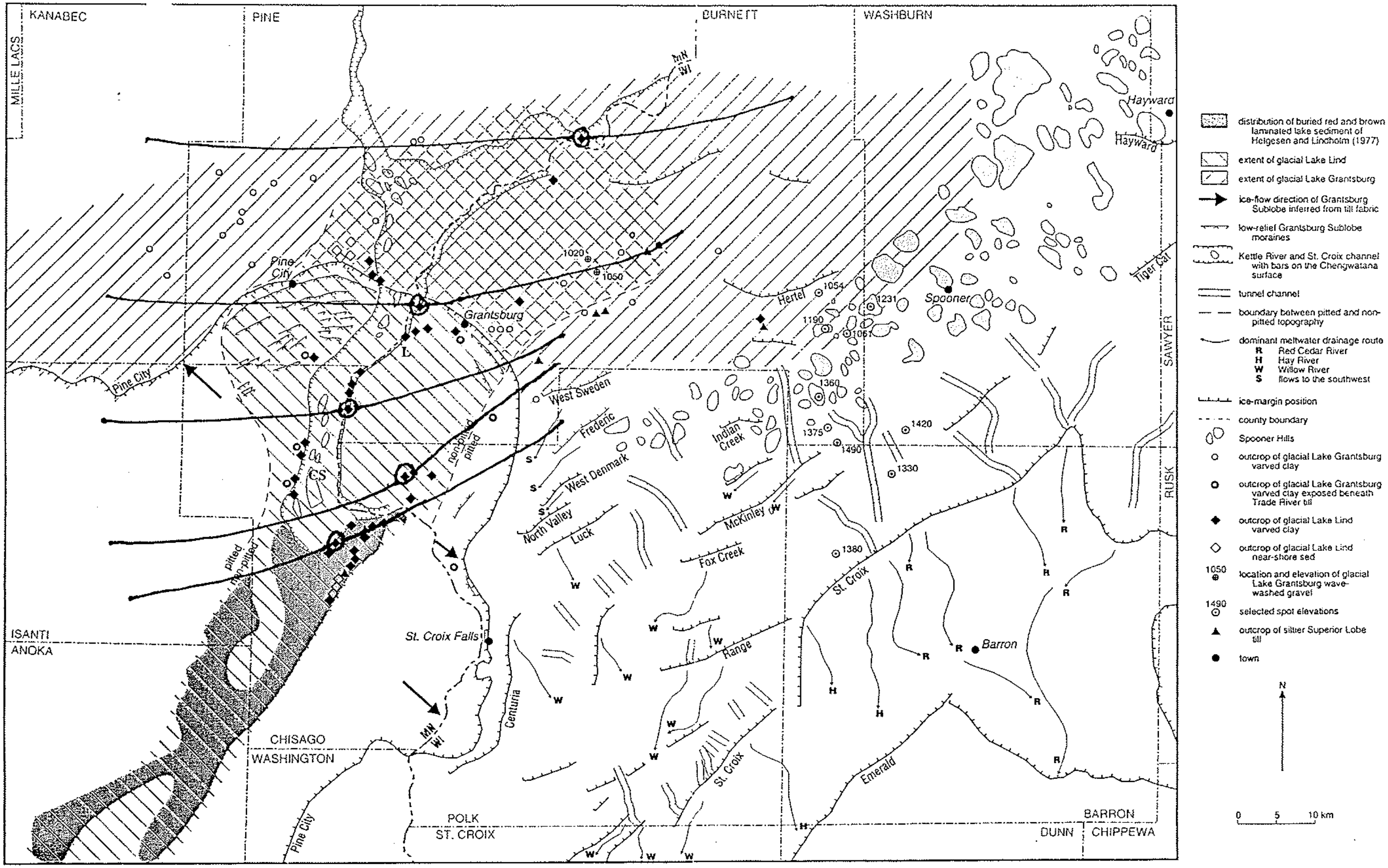

Figure 4. Hypothetical ice-margin positions are represented by long continuous lines drawn through the circled varve sites used in calculating ice-retreat rates drawn on a map (Johnson, in press) with other glacial features.

	Years	Distance (m)	Rate (m/yr)
Ken Iverson to Ravine	63-78	10200-11900	131-189
Ravine to Sandrock	30-38	8000-10200	211-340
Ken Iverson to Sandrock	90-110	17000-19800	180-220

Figure 5. Calculations of ice-retreat rates based on varve years and distances of the ice margins between the sites.

Author	Country	Location	Retreat rate (m/yr)
Brunnberg (1995)	Sweden	DeGeer varve 1400-1200	78-148
		DeGeer varve 1500-2200	17
		DeGeer varve 2400-2500	75
		DeGeer varve 2500- 3600	122
		DeGeer varve 1100-900	270
Donner, 1995	Finland	Pre-Salpausselka	55
Ridge and others, 1990	United States	Mohawk Valley, valley axis	327
		Mohawk Valley, edge	122
Addis and others, 1996	United States	Glacial Lake Lind, K. Iverson to Ravine	131-189
		Ravine to Sandrock	211-340
		K. Iverson to Sandrock	180-220

Figure 6. Ice retreat rates from varve sediment around the world. Used to compare Glacial Lake Lind retreat rates with others to give insight into the character of the glacier.

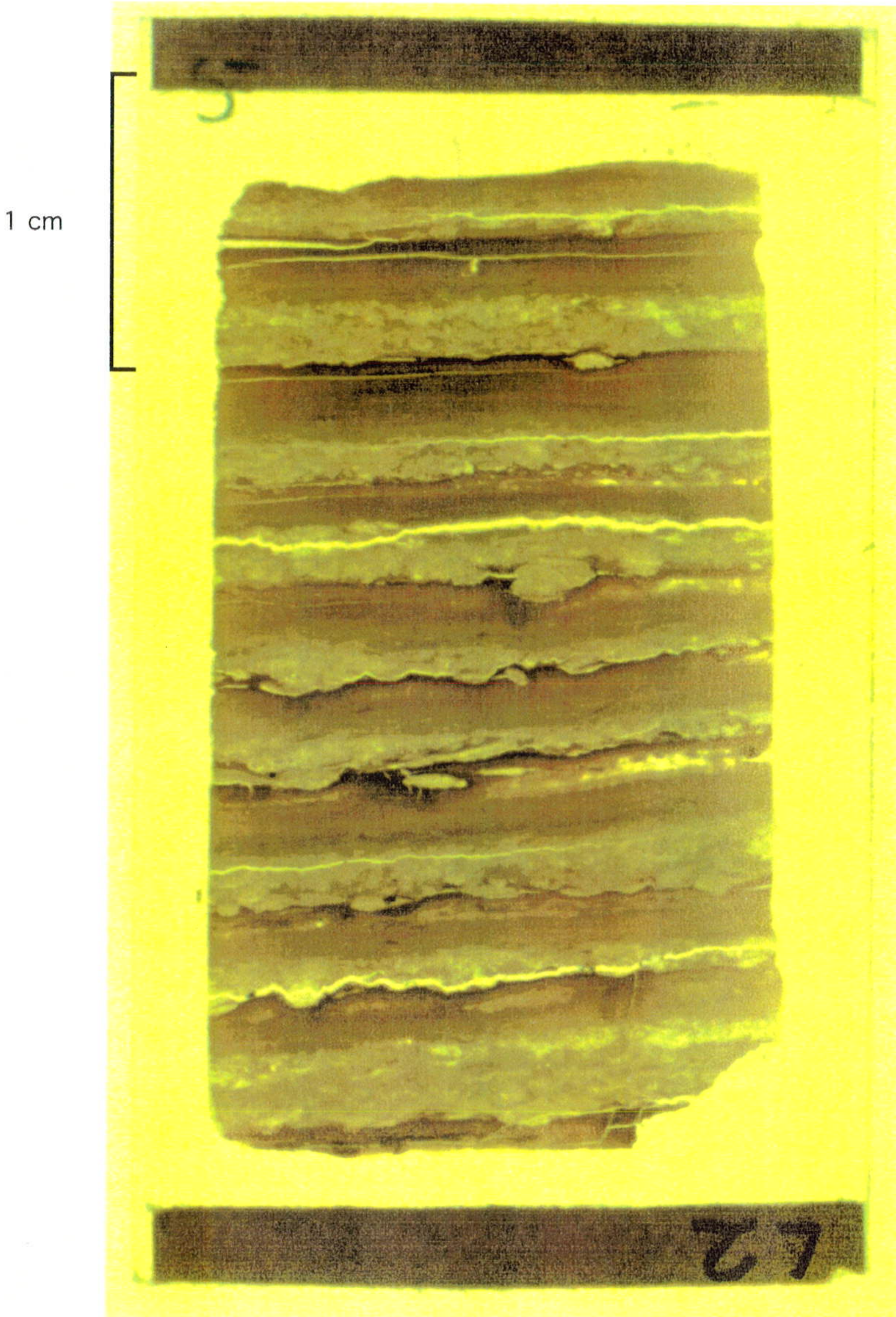

Figure 7. Thin section of varved sediment showing depression of the clay layer by the organism. Silt eventually fills the void left by the organism and the structure is preserved. Bioturbation is not observed within the clay layer.

	Shape	Burrowing or resting	Width	Length
Type I	long and continuous	burrowing	1-3 mm	various, extensive
Type II	Crescent-moon	both are a possibility	1-6 mm	maximum 40 mm
Type III	Single depression	most likely resting trace	1- 4 mm	maximum 5 mm

Figure 8. A table showing the classifications of the three types of trace fossils found in Glacial Lake Lind.

Figure 9. Cast of a long, contiuous burrow classified as a Type I trace fossil within Glacial Lake Lind varved sediment.

Figure 10. Cast of Type II trace fossils in Glacial Lake Lind varved clay with prominent crescent-moon shaped traces. Some ending in an elliptical shaped impression.

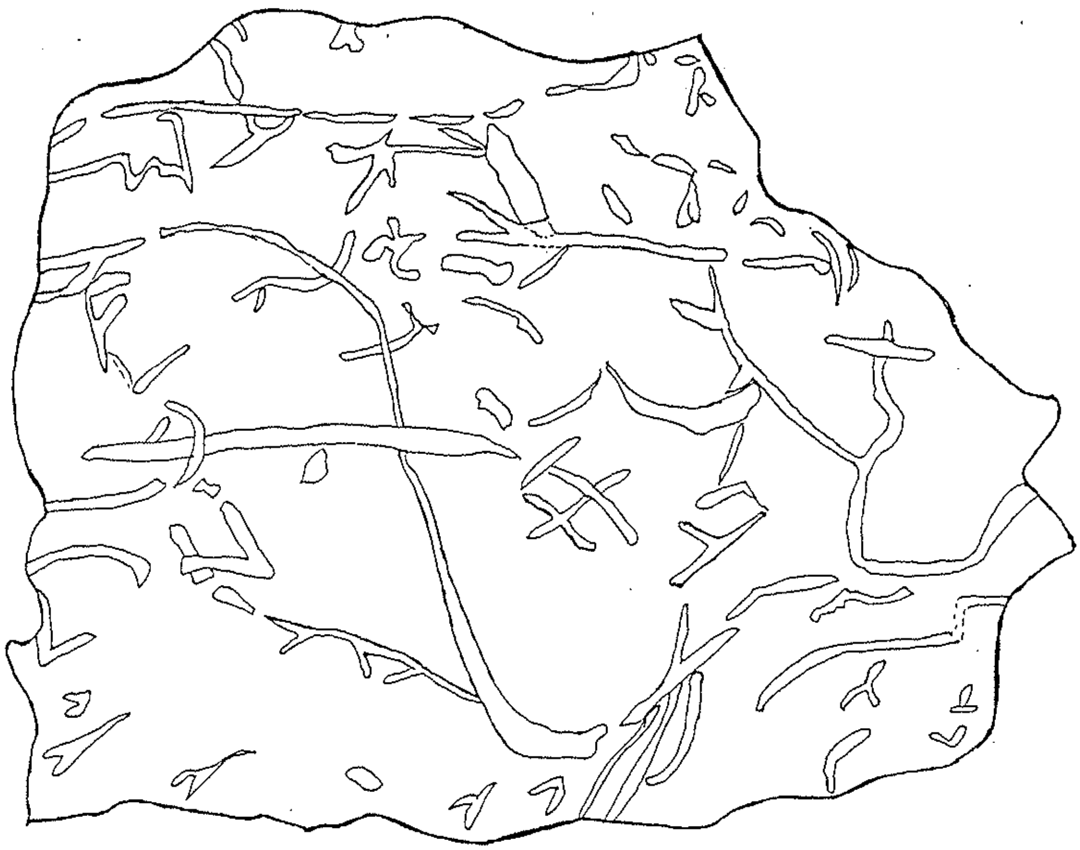

Figure 11. Sketch of trace fossils found at the Sandrock site. Type I, II, and III are shown in this sketch. Dotted lines represent areas where the impressions were disturbed.

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