Applied Quaternary research in the central part of glaciated terrain,
edited by *Peter Johansson and Pertti Sarala*.
Geological Survey of Finland, Special Paper 46, 69–78, 2007.

TUNNEL CHANNELS OF THE SAGINAW LOBE, MICHIGAN, USA

by

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Kehew, A. E. & Kozlowski, A. L. 2007. Tunnel Channels of the Saginaw Lobe, Michigan, USA. Applied Quaternary research in the central part of glaciated terrain. *Geological Survey of Finland, Special Paper 46*, 69–78, 10 figures.

During the last advance of the Laurentide Ice Sheet into southern Michigan, USA, the Saginaw Lobe advanced asynchronously with respect to the adjacent Lake Michigan and Huron-Erie Lobes, reaching its terminal position first, and then stagnating or retreating while the other lobes continued to advance.

A complex network of tunnel channels was formed in an intermittent and time-transgressive fashion beneath the Saginaw Lobe. One set of flow-parallel channels radiates from E-W to NE-SW to N-S orientations around the lobe. The channels typically exceed one kilometer in width and tens of meters in depth. In places, eskers occupy valley bottoms of the tunnel channels. Another set of channels cuts orthogonally across these channels at an approximate orientation of E-W to NW-SE.

Toward the southern limit of the Saginaw Lobe terrain, the channels were partially to nearly completely buried by ice and sediment deposited during collapse of the Saginaw Lobe and by sediment deposited during the overriding advances of the Lake Michigan and Huron-Erie Lobes. Relief in some channels subsequently increased as the buried ice melted. When the Lake Michigan Lobe began to retreat, the most recent set of tunnel channels, oriented trending westerly, were eroded by subglacial outbursts draining toward the former margin of the Saginaw Lobe.

Five genetic types of tunnel channels were identified in southern Michigan. These include: large, unburied channels (Type I), palimpsest channels partially buried by an end moraine formed by a readvance of the same lobe (Type II), palimpsest channels nearly completely buried by a readvance of the same lobe and not located near an end moraine (Type III), palimpsest channels partially buried by an advance of a different lobe than that under which the channels originally formed (Type IV), and unburied to partially buried channels that contain eskers (Type V).

Key words (GeoRef Thesaurus, AGI): glacial geology, glacial lobes, subglacial environment, meltwater channels, Pleistocene, Michigan, United States.

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INTRODUCTION

Recognition and descriptions of subglacially eroded channels formed beneath the former Laurentide and Scandinavian ice sheets have increased in recent years. These large, predominantly linear valleys are called tunnel channels when an origin by a single discharge of subglacial meltwater is inferred, or tunnel valleys when considered to form gradually or episodically, or when no genetic mechanism is implied (Clayton et al. 1999). Several defining characteristics of tunnel channels include: 1) dimensions reaching > 100 km in length, 4 km in width, and >3 m in depth, 2) generally straight reaches oriented parallel to the subglacial hydraulic gradient of the ice lobe, 3) undulating and adverse longitudinal gradients, and 4) irregular side slopes and valley bottoms (Kehew et al. 2007). The valleys appear to be most common near former ice margins, where they terminate at large glaciofluvial fans. They may be prominent topographic features or buried either partially or completely by younger glacial drift. Eskers may or may not be present on the valley bottoms.

Tunnel channels formed beneath the Scandinavian ice sheet have been described in German by Ehlers (1981), Grube (1983), and Piotrowski (1994). Jørgensen and Sanderson (2006) review the literature on Danish tunnel valleys. Most of the known tunnel channels associated with the Laurentide Ice Sheet are located in the glacial lobes of the Great Lakes region of North America. Wright (1973) first interpreted valleys in Minnesota as erosional forms of catastrophic subglacial discharges. Other studies have focused on tunnel channels in Minnesota (Mooers 1989, Patterson 1994, Hooke & Jennings 2006); Wisconsin (Attig et al. 1989, Clayton et al. 1999, Johnson 1999, Cutler et al. 2002); Michigan (Kehew et al. 1999, 2005, Fisher & Taylor 2002, Sjogren et al. 2002, Fisher et al. 2005, Kozlowski et al. 2005); and Ontario (Brennand & Shaw 1994).

Ó Cofaigh (1996) grouped the hypotheses for formation of tunnel channels into three main categories: (1) formation by subglacial sediment deformation, (2) gradual or time transgressive formation near ice margins, and (3) catastrophic subglacial sheet floods. The sediment deformation hypothesis is based on the work of Boulton and Hindmarsh (1987), who proposed that shallow channels carrying subglacial meltwater are initiated by piping from the ice margin and would gradually be enlarged by the creep of deformable sediment toward the channel and the subsequent removal of the sediment by meltwater flow. Opposition to this hypothesis is based upon arguments questioning the existence of a fluid-pressure gradient toward the channels and the occurrence of tunnel channels in bedrock lithologies, in which sediment deformation would not be possible (Ó Cofaigh 1996).

Time transgressive formation near ice margins is a hypothesis advocated by many authors. Formation was suggested by Mooers (1989) to be a more gradual, steady process, in which subglacial meltwater was augmented by diversion of supraglacial meltwater to the base of the glacier. On the other hand, most hypotheses invoke a sudden or catastrophic release of channelized subglacial meltwater because of the large clast size deposited in ice-marginal fans located at the termination of the channels (Piotrowski 1994, Cutler et al. 2002) and the size and dimensions of the channels (Kozlowski et al. 2005). The sudden release of subglacial reservoirs is often attributed to failure of a permafrost seal at the margin (Piotrowski 1994, 1997, Cutler et al. 2002, Jørgensen & Sanderson 2006, Hooke & Jennings, 2006). Piotrowski (1997) and Hooke & Jennings (2006) suggest a cyclical process in which a seal is punctured and leads to a catastrophic release of an impoundment, followed by the reestablishment of the seal and the refilling of the impoundment. Hooke & Jennings (2006) propose that piping and headward erosion back to meltwater impoundment initiate the outburst.

The catastrophic subglacial meltwater hypothesis for tunnel channels is one component of a complicated hypothesis for the origin of drumlins, Rogen moraine, megaflutes and other glacial landforms by broad subglacial sheetfloods (Shaw 2002). To account for the formation of landforms such as drumlins during the same megaflood that produced tunnel channels, advocates suggest the transition from sheetflow to channelized flow as the event progresses (Fisher et al. 2005). The sheetflood hypothesis is controversial, however, and has been challenged on various grounds (Clarke et al. 2005, Evans et al. 2006).

The presence of eskers in tunnel channels suggests that a depositional phase follows the erosional phase of channel formation, implying that the subglacial channel persists for a relatively long period of time. During deglaciation, collapse of ice and sediment into the channel may fill the channel for some period of time (Kehew et al. 1999, 2005, Kozlowski et al. 2005, Jørgensen & Sanderson 2006). Sediment from more recent glacial events may be deposited over the filled channel, leading to cross-cutting relationships that would be hard to explain without the presence of buried ice (Kehew et al. 1999). Gradual melting of the buried ice creates the final valley form, destroying the sharp, channel-like characteristics of the original valley.

GLACIAL LOBES IN MICHIGAN

The topography of southern Michigan, also known as the Lower Peninsula, is strongly controlled by the three lobes of the Laurentide Ice Sheet that occupied the area during the last (Wisconsin) glaciation. Ice advanced into Michigan around 26,000 ^{14}C yr BP and retreated for the last time around 11,000 ^{14}C yr BP (Larson & Schaetzl 2001). From west to east, the lobes include the Lake Michigan, the Saginaw, and the Huron-Erie Lobes (Figure 1). Both the Lake Michigan and Huron-Erie Lobes eroded deep troughs, now occupied by Lakes Michigan, Huron, and Erie. The Saginaw Lobe flowed southwesterly across the interior of the Peninsula, eroding Saginaw Bay of Lake Huron, which only extends partially along the flow path. Kehew et al. (2005) suggested that the Lake Michigan and Huron-Erie Lobes developed rapid, streaming flow, accounting for the size and depth of the troughs they created. By contrast, the central Saginaw Lobe advanced earlier into the area, but weakened or stagnated, as the flanking lobes grew stronger and encroached upon the recently deglaciated Saginaw Lobe terrain (Kehew et al. 1999, 2005).

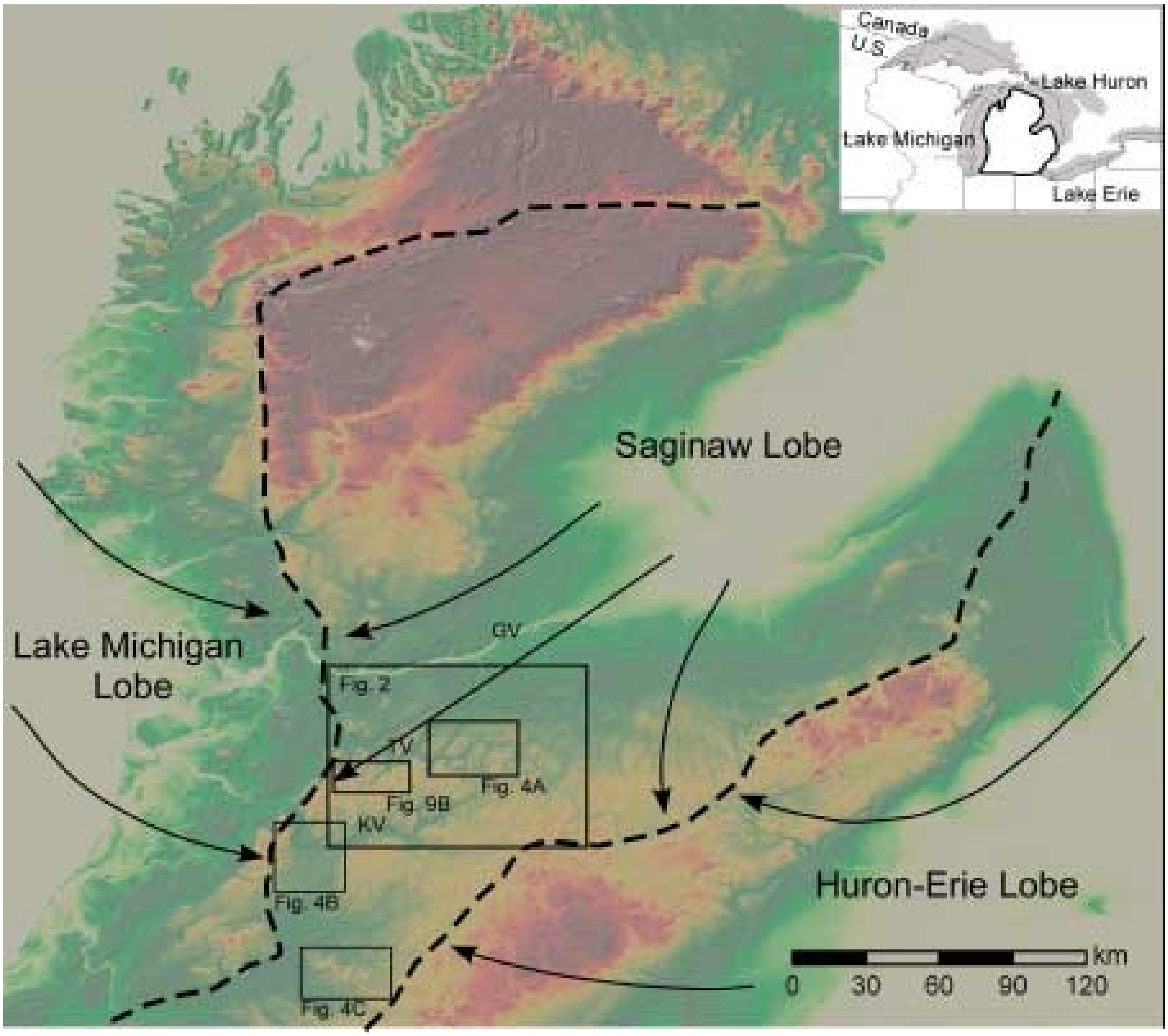


Fig. 1. Hillshade DEM of the Lower Peninsula of Michigan showing approximate extent of Lake Michigan, Saginaw, and Huron-Erie Lobes of the Laurentide Ice Sheet. Boxes show locations of other figures. GV: Grand Valley. TV: Thornapple Valley. KV: Kalamazoo Valley.

SAGINAW LOBE TUNNEL CHANNELS

The most distinctive feature of the Saginaw Lobe terrain is the network of sub-parallel channels that radiate outward from the center of the lobe. These channels are best developed down stream from the Saginaw Bay lowland, where they range in orientation from north-south in eastern part of the area, to northeast-southwest in the western part of the area (Fig. 2). These channels are interpreted as tunnel channels because of their orientation (parallel to the subglacial hydraulic gradient of the lobe), their undulating to adverse longitudinal profiles (Kozlowski et al. 2005) and the presence of eskers in some of the channels. The network of channels is cross cut by channels oriented nearly perpendicular to them (east-west), the largest of which are (from north to south), the Grand Valley, the Thornapple Valley, and the Kalamazoo Valley (Fig. 1). These channels are deeper and are interpreted as younger tunnel channels, although the Grand Valley was utilized as a proglacial lake spillway and enlarged from its presumed original size (Kehew 1993). The east-west reach of the Kalamazoo Valley, which was probably eroded subaerially, appears to have been fed by an anastomosing network of southwest-trending tributary tunnel valleys (Fig. 3) that conveyed meltwater to an ice margin. (Kozlowski et al. 2005).

South of the Kalamazoo Valley, the southwest-trending tunnel channels are much less distinct than the channels north of the valley. A major reason for this is that the channels appear to have been initially eroded when the Saginaw Lobe was at or near its Late Glacial Maximum (LGM) position, and then partially buried by sediment from later advances of the Saginaw Lobe or by sediment from the Lake

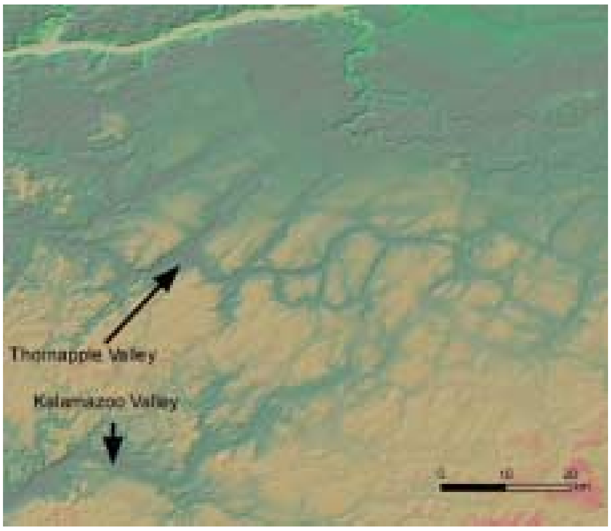


Fig. 2. Closeup view of tunnel channel networks of the central Saginaw Lobe.

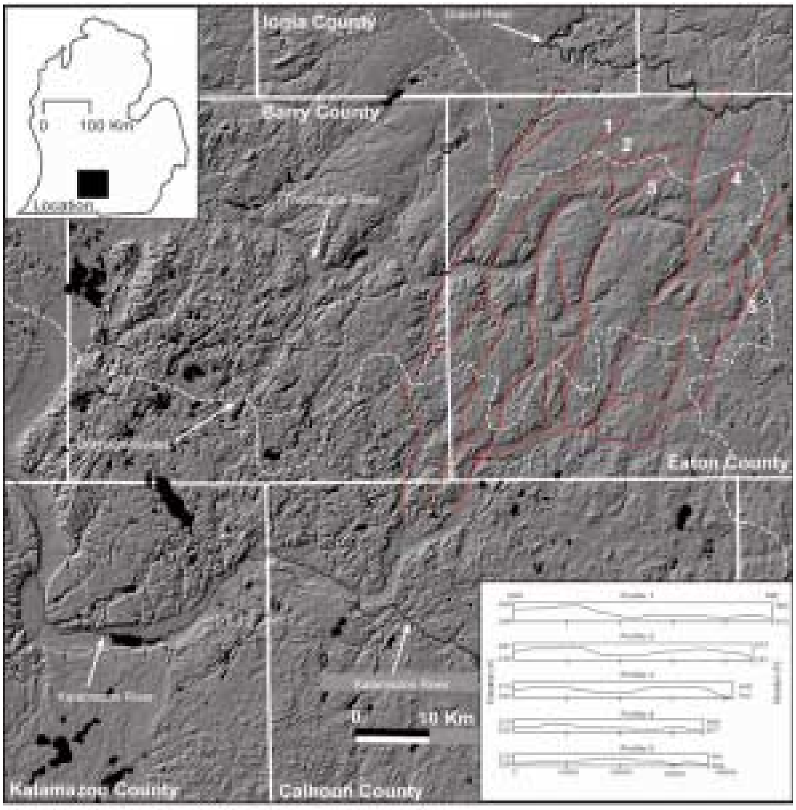


Fig. 3. Hillshade DEM displaying network of channels coalescing into the head of the central Kalamazoo Valley. Channels (black lines) interpreted as Saginaw Lobe tunnel channels. Dashed white lines are present day drainage divides. (From Kehew et al. 2007).

Michigan Lobe as it advanced into terrain vacated by the Saginaw Lobe. Because of their modification by subsequent advances, these tunnel channels have been described as palimpsest tunnel channels (Kehew et al. 1999). Cross-cutting relationships to be discussed below indicate that after formation, ice collapsed into the tunnel channel and became buried by debris, similar to tunnel channels in Denmark (Jørgensen & Sanderson 2006). This burial probably delayed melt out of the collapsed ice and formation of the valley for a period of hundreds to thousands of years.

EXAMPLES OF TUNNEL CHANNEL MORPHOLOGY AND INFERRED FORMATION

In this section, five examples of tunnel channels will be presented to illustrate the range in topography and post-erosional modification.

Type I Tunnel channels

Type I tunnel channels are generally large and display the least degree of burial (Figs. 4 and 5). They are interpreted to form by a subglacial burst of drainage to an ice margin followed by subsequent deglaciation without extensive collapse and filling with sediment. As a result, they are very distinct topographic features. Type I tunnel channels in the study area include both southwest and east-west orientations. The east-west channels cross cut the southwest trending channels and are interpreted to be younger.

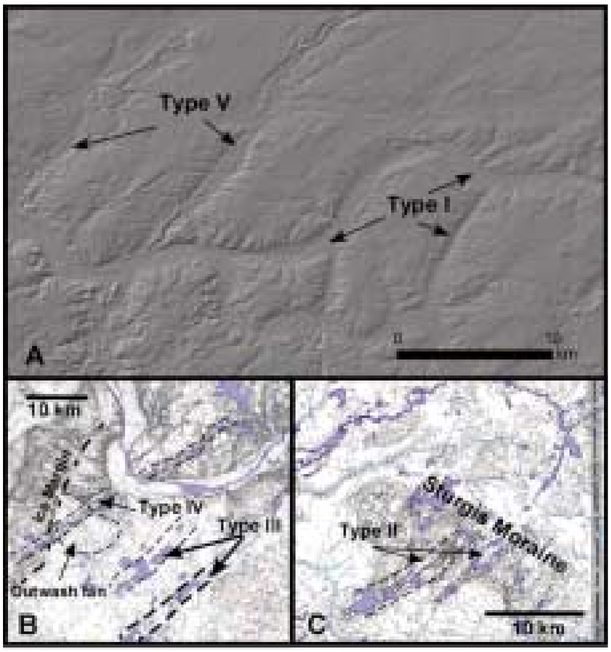


Fig. 4. Locations of types of tunnel channels discussed in text. Locations shown on Fig. 1. A. Hillshade DEM of Thornapple Valley. B. Contour map made from DEM (countour interval approximately 3 m.) Kalamazoo Valley is large valley in upper part of diagram. Ice margin is the Kalamazoo Moraine of the Lake Michigan Lobe. C. Contour map made from DEM.

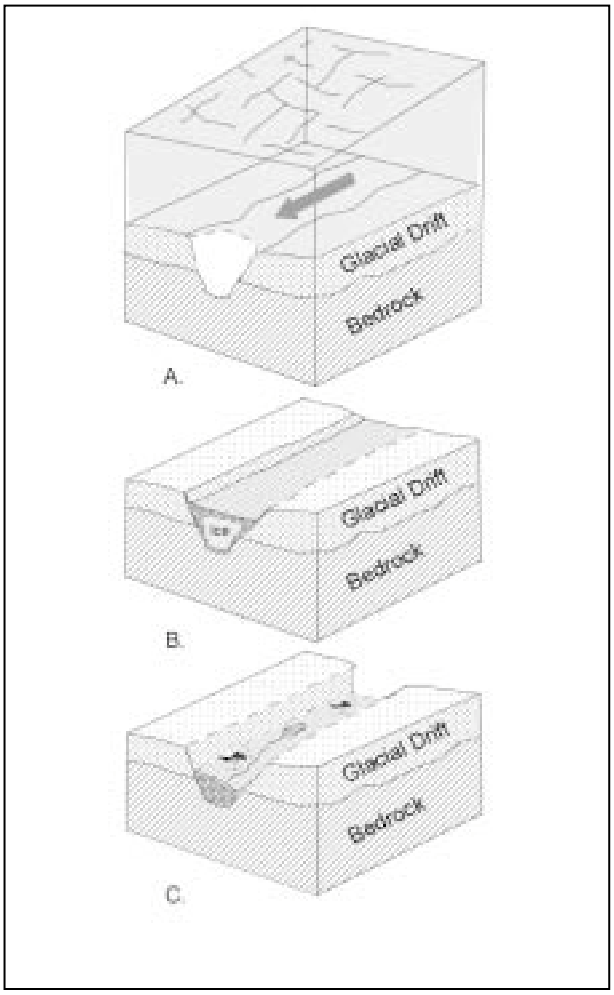


Fig. 5. Origin of Type I tunnel channels. A. Subglacial erosion of tunnel channel into bedrock. B. Remnants of collapsed ice and debris in channel after deglaciation. The amount of ice is relatively small in this case. C. Valley after meltout of buried ice. Valley walls are relatively straight and smooth.

Type II Tunnel channels

Type II tunnel channels (Figs. 4C and 6) are palimpsest channels that cut through terminal moraines of a more recent advance than the advance in which the channels were formed. The Sturgis Moraine of the Saginaw Lobe (Figs. 1 and 4C) is a good example of this type of tunnel channel. After erosion of the subglacial channel, it was likely filled to the top with collapsed ice and debris. Collapsed ice in the channel was still present at the time of the subsequent advance of the Saginaw Lobe to the position at which it formed the Sturgis Moraine. Melting of the buried, stagnant ice after formation of the moraine resulted in the development of indistinct valleys cutting through the moraine.

Type III Tunnel channels

The Type III tunnel channel (Fig. 4B and 7) represents another type of palimpsest tunnel channel. Here, after filling of the valley by collapsed ice, a subsequent advance of the Saginaw Lobe completely overrode the channel, probably the same advance that formed the Sturgis Moraine. A more complex fill, involving a diamicton from the later advance, and surficial outwash, comprises the stratigraphy of the channel. Because of the degree of post-erosional filling of the channel, channels of this type are very subtle features on the modern landscape. The two Type III tunnel channels shown on Fig. 4B are recognizable only by an alignment of lake basins and no valley exits at land surface.

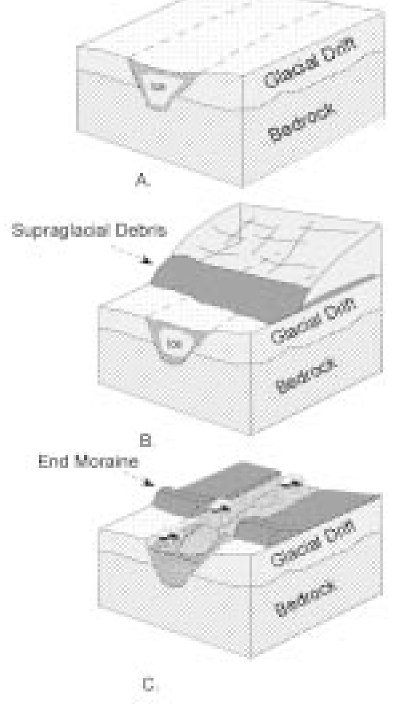
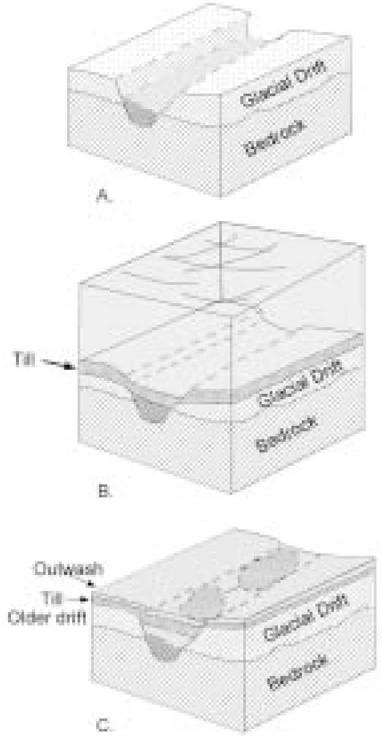


Fig. 6. Origin of Type II tunnel channels. A. Channel eroded as in Fig. 5A by early advance of Saginaw Lobe, filled with thick buried ice and debris, and deglaciated by retreat of lobe. B. Readvance of the Saginaw Lobe to form Sturgis Moraine at terminal position of readvance (Figs. 4C and 1). C. Gradual meltout and collapse of buried ice to form present-day valley, which cuts through the moraine.

Fig. 7. Origin of Type III tunnel channels. A. Erosion of tunnel channel by Saginaw Lobe as in Fig. 5A and meltout of most or all of buried ice as in Fig. 5C. B. Readvance of Saginaw Lobe over site with deposition of diamicton (till). C. Outwash deposited during retreat of Saginaw Lobe or advance of Lake Michigan Lobe from west. Final valley is subtle, low relief topographic feature identified by linear chain of lakes on landscape.



Type IV Tunnel channels

The Type IV tunnel channel model is shown in Figs. 4B, 8 and 9A. This type of palimpsest tunnel channel forms when sediment from a different lobe than the lobe of origin partially buries the channel. The example in Figs. 4B and 9A was previously described by Kehew et al. (1999, 2005). As the Lake Michigan Lobe advanced into terrain that had been recently deglaciated by the Saginaw Lobe, large glaciofluvial fans were deposited from the ice margin shown in Figs. 4B and 9A. These fans slope toward the large Saginaw Lobe tunnel channel and continue with exactly the same slope on southeast side of the channel. The best way to explain this cross cutting relationship is that the tunnel channel was completely filled with ice and debris at the time of fan deposition. After the fans were deposited, the buried ice gradually melted and the modern valley formed.

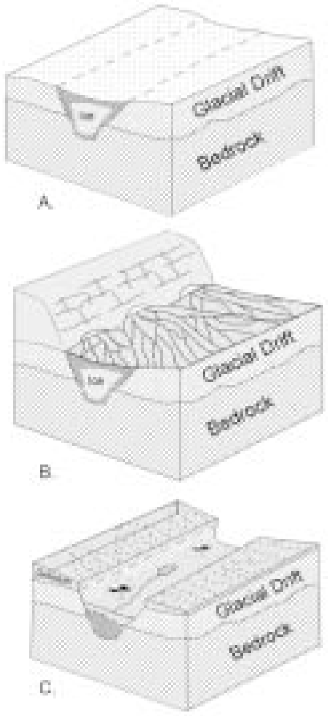


Fig. 8. Origin of Type IV tunnel channels. A. Tunnel channel is subglacially eroded and completely filled with ice and debris. B. Lake Michigan Lobe advances from west and deposits outwash fans over buried tunnel channel. C. Buried ice melts to form present-day valley. Slope of fan remnants west of valley slope is identical to slope of fan remnants east of valley.

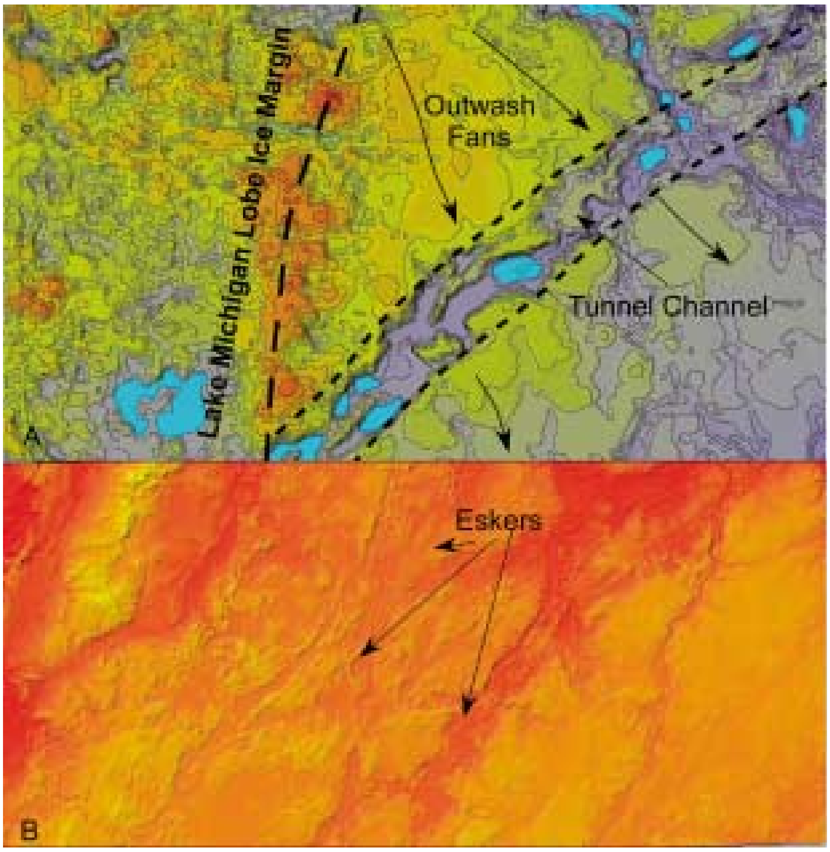


Fig. 9. A. Digital elevation model of Type IV tunnel channel. Origin of channel conforms to model shown in Fig. 8. B. Digital elevation model of Type V tunnel channels containing eskers. Origin shown in Fig. 10.

Type V Tunnel channels

The last type of tunnel channel to be described is shown in Figs. 4A, 9B and 10. The presence of eskers in the valley bottoms of these channels indicates that they were not filled with ice and debris after channel erosion. An esker in one of these valleys was drilled using rotasonic methods in the summer of 2006 (unpublished data). The stratigraphy of the esker consists of a fining upward sequence from gravel in the tunnel channel to interbedded fine sand and silt near the top of the esker. The base of the tunnel channel was not reached in the borehole. This stratigraphic sequence indicates that flow in the channel declined from high velocities at the base to intermittent, low-energy conditions at the top. The tunnel may have contained impounded to very slowly moving water at times. These conditions suggest that the tunnel was occupied continuously or intermittently over a relatively long period of time, perhaps during stagnation and/or deglaciation of the lobe.

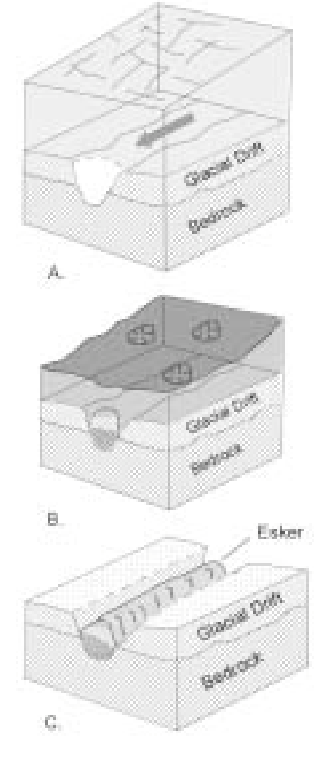


Fig. 10. Origin of Type V tunnel channels. A. Tunnel channel is subglacially eroded. B. Channel persists for long period of time during ice stagnation or retreat. Discharge and velocity through tunnel decreases through time. C. After retreat, esker with fining upward stratigraphic sequence remains in valley.

CONCLUSIONS

Tunnel channels of the Saginaw Lobe of the Laurentide Ice Sheet provide important clues to the subglacial hydrology of the lobe and the interaction of the lobe with its adjacent lobes. Five types of tunnel channels are recognized in this study:

- Type I–large, mostly unburied channels.
- Type II–partially buried palimpsest channels cutting an end moraine produced by readvance of same lobe.
- Type III–deeply buried palimpsest channels behind end moraines produced during readvance of same lobe.
- Type IV–palimpsest channels partially buried by deposits from a different lobe than the lobe under which they were formed.
- Type V–unburied to partially buried channels that contain eskers.

Two predominant sets of channels include southwesterly and westerly trending segments. The southwesterly channels appear to be the oldest, perhaps dating from the LGM or retreat of the lobe following the LGM. South of the Kalamazoo Valley, the tunnel channels are palimpsest features overridden or buried by sediment from more recent advances of the Saginaw or Lake Michigan Lobes. The presence of eskers in tunnel channels north of the Kalamazoo Valley suggests the persistence of these subglacial channels until late in the deglacial history of the lobe. Some of these channels were probably cut time-transgressively during the younger advance of the lobe to the Sturgis Moraine or more recent ice-marginal positions. The west-trending channels cross cut the southwesterly channels and are interpreted to represent the most recent episode of subglacial drainage. The change in orientation of these channels may be the result of retreat of the Lake Michigan Lobe, which was impinging upon the western margin of the Saginaw Lobe. Large, probably catastrophic subaerial meltwater flows can be traced from the west trending tunnel channels southward between the two lobes as the Lake Michigan lobe was retreating (Kozlowski et al. 2005). Further, more detailed study of these channels will be necessary to fully understand their origin and temporal relationships.

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