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SINKHOLE DISTRIBUTION

By

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INTRODUCTION TO THE SINKHOLE DISTRIBUTION MAPS

Sinkholes are closed depressions (holes) in the landscape that act as direct conduits for surface water to enter the subsurface. Many sinkholes form when shallowly buried bedrock, through dissolution or mechanical erosion, develops openings of sufficient size to allow surface materials to collapse or be washed downward into the openings. Although sinkholes traditionally occur in areas of a karst landscape underlain by carbonate bedrock, they can also form over quartzite or quartz arenite sandstone (Wray, 1997). In Pine County, the sinkholes have formed above the Hinckley Sandstone. These sinkholes range from less than one meter to more than 100 meters in diameter.

Sinkholes present two types of challenges to environmental managers. First, sinkholes represent a direct connection between surface water and ground water, and they bypass the normal cleansing process of flow through the unsaturated zone. Consequently, water from shallow wells near sinkholes commonly shows evidence of surface contaminants. Second, sinkholes raise stability concerns, particularly for water impoundment structures on the land surface near sinkholes.

The Superior lobe of the most recent glacial advance produced the current landscape in north-central Pine County. Because a variety of glacial processes can produce closed depressions on the landscape, special effort was made to distinguish glacial features from karst features. Despite this scrutiny, some of the features shown as sinkholes on this map may prove to have other origins.

With the assistance of local residents, 245 sinkholes have been mapped in north-central Pine County. This project began as a survey of the sinkholes in Partridge Township, but the study soon expanded northeast into Bruno Township and southwest into Sandstone Township. The full subcrop of the Hinckley Sandstone has not been searched; every sinkhole in the area has not been located, and it is probable that sinkholes may be discovered in other areas of Pine County. The sharp boundary along the southeast side of the sinkhole array appears to be an actual boundary of sinkhole occurrence. The distribution of sinkholes in other directions remains undetermined. Mapping shows that sinkholes tend to form in clusters. One cluster, a single linear array along a northeast-trending ridge east of the Kettle River in Banning State Park, contains almost 20 percent of the 245 mapped sinkholes. This group of sinkholes aligns with Robinson's Ice Cave and adjacent small caves on the west side of the Kettle River, which are thought to have formed by the weathering and erosion of sandstone along fracture sets. The correlation of these caves with the linear array of sinkholes to the northeast provides support for the interpretation of open fractures as significant factors in sinkhole development.

The sinkholes in Pine County are believed to have been formed by turbulent surface water sinking through the overburden and transporting fine-grained sediment into an underlying system of open joints in the Hinckley Sandstone, eventually causing the land surface to subside. Once formed, sinkholes that are fed by large surface runoff areas can drain huge volumes of water during spring snowmelt and after heavy rain, at which time large whirlpools form and water can be heard running underground. Several of the sinkholes serve as the terminal sinks of perennial or ephemeral surface streams. The seasonal high water table, particularly in the northeastern part of the array, is in or above some of the sinkholes, and they are drowned during periods of high water (Fig. 1). It is unknown whether the drowned sinkholes continue to accept water during these floods or if they act as springs and intensify local floods.

Sinkhole Distribution and Bedrock Geology Map— In outcrops along the Kettle River, the Hinckley Sandstone displays enlarged vertical joints, caves, and horizontal layers with small conduits. If these features persist in the subsurface for some distance away from the valley, they would provide ideal flow paths for the rapid movement of water from the surface into the subsurface, which could induce sinkhole formation. The Hinckley Sandstone underlies all of the mapped sinkholes, and all sinkholes occur northwest of the Hinckley fault. Most sinkholes lie within 5 kilometers of the fault, and none have been mapped more than 8 kilometers from it. Southeast of the Hinckley fault, the Hinckley Sandstone is thinner, and the underlying Fond du Lac Formation is closer to the surface. Because of this, the jointing or fracturing of the Hinckley Sandstone may not be as well developed as in the area northwest of the fault, where the sandstone is thicker. Additionally, the Fond du Lac Formation has a higher content of clay and silt that are more likely to clog a developing fracture system. In contrast, the Hinckley Sandstone is composed almost entirely of quartz, and hence, lacks clay or minerals that alter to clay. Sinkholes located immediately northwest of the Hinckley fault appear to drain to wetlands located on the southeast side of the fault, where the landscape is lower and wetter.

On the west side of the sinkhole array, the numerous springs shown along the Kettle River are probably fed by water from the sinkholes which has flowed through enlarged joints in the Hinckley Sandstone; however, the connection between the feeder sinkholes and the springs remains to be demonstrated. Two distinct types of springs exist along the Kettle River: those which are clear and those which are rusty orange in color. The clear and orange springs can emerge a few centimeters from each other. The clear springs contain oxygenated water and probably represent shallower, shorter residence-time portions of the flow systems. The orange springs contain water with no oxygen that is enriched in iron; they probably represent deep-flowing, longer residence-time portions of the aquifers.

Sinkhole Distribution and Depth to Bedrock Map— The thickness and composition of glacial drift are also important in determining where sinkholes are likely to form. In places where the glacial drift is thin, surface water is able to move relatively quickly into the underlying bedrock. Areas of high transmissivity within the glacial drift, such as sand lenses, gravel lenses, or boulder concentrations, also permit the surface water to move downward rapidly. Thus, areas with thin and highly permeable drift underlain by fractured bedrock are most favorable for sinkhole development. In the area where the sinkholes have been mapped, the glacial drift also contains an abundance of large boulders and slabs of locally-derived Hinckley Sandstone. In many places these are piled on top of one another in a fashion that produces many large openings through which surface water can rapidly move. These scenarios could promote periodic flushing of fine-grained sediment and the development and maintenance of sinkholes. In this way, piles of boulders near joint openings may act as filters that allow fast moving water and its sediment load to pass through at some points, and block passage at others. The process may prevent clay and other fine-grained till transported by water from uniformly clogging the joints.

The sinkholes generally lie along a glacial readvancement moraine, but the causal relationship between the moraine and sinkhole distribution is uncertain. Discharge of glacial meltwater off the front of the moraine may have cleared fine-grained sediment from joints in the underlying bedrock, allowing them to act as subsurface conduits over which the sinkholes could form. The movement of surface sediment into the underlying fractures is an ongoing process.

Figures 2 and 3—Although the sinkholes in Pine County occur in a variety of shapes and sizes, a common morphology is a sinkhole a few meters in diameter and less than two meters deep that is a concave downward funnel. Figure 2 is a cross section resulting from the excavation of one small funnel sinkhole (MN58:D0144). This sinkhole is located near Log Drive Creek in Banning State Park. The subsurface funnel is larger and deeper than the surface sinkhole. In this funnel, dark, organic-rich topsoil is transported into an underlying open drain. The sinkhole was developed through dark-red till. This excavation did not reach bedrock.

A second morphology is a shallow, concave upward, bowl-shaped sinkhole, about 10 meters in diameter and a few meters deep. The morphology may or may not have a smaller diameter drain within the bowl. Figure 3 is a cross section resulting from a backhoe excavation of one of these bowl-shaped sinkholes (MN58:D0355). This sinkhole is located south of the Askov municipal sewage lagoons. Note the change in scales between Figures 2 and 3. In this case, organic topsoil is being transported down through laminated lake sediments and underlying dark-red till, into joints in the underlying Hinckley Sandstone. The movement of water follows lenses of till with a higher amount of gravel, which increases their transmissivity. The high transmissivity of these gravel lenses is demonstrated by the presence of ground water flowing through the till and into a bedrock fracture.

Small funnels and medium-sized bowls are two common morphologies in Pine County sinkholes. Other sinkhole varieties are discussed further in the accompanying text supplement.

ACKNOWLEDGMENTS

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REFERENCE

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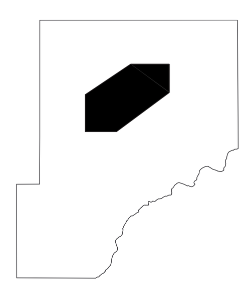
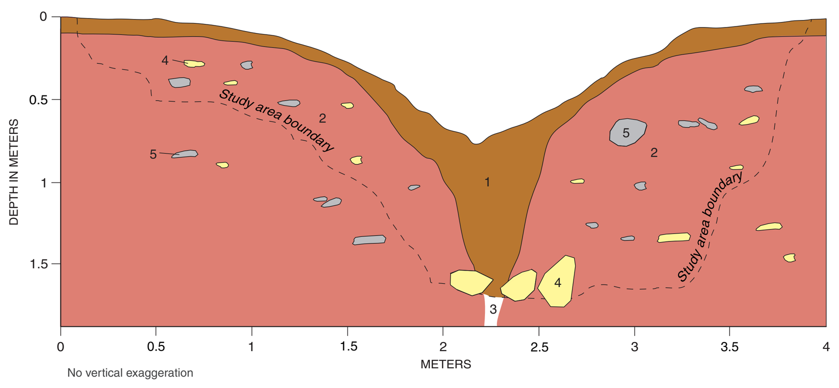


LOCATION DIAGRAM

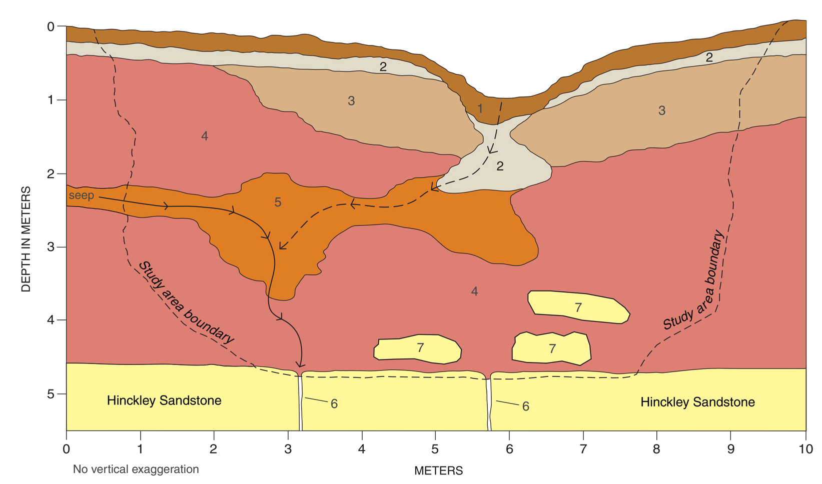
Figure 1. Three sinkholes in section 1, Partridge Township. The sinkholes formed behind a beaver dam (not pictured), and the area floods in the spring. The ponded water then drains through the sinkholes. The pond in the upper left drains into the sinkhole directly in front of it. Photo from May, 1998.



EXPLANATION

1. Organic-rich soil
2. Till
3. Open drain out of sinkhole
4. Boulders of Hinckley Sandstone
5. Glacial erratic

Figure 2. Subsurface profile of sinkhole D144, excavated in Banning State Park, north-central Pine County. This sinkhole is small in size and funnel-shaped.



EXPLANATION

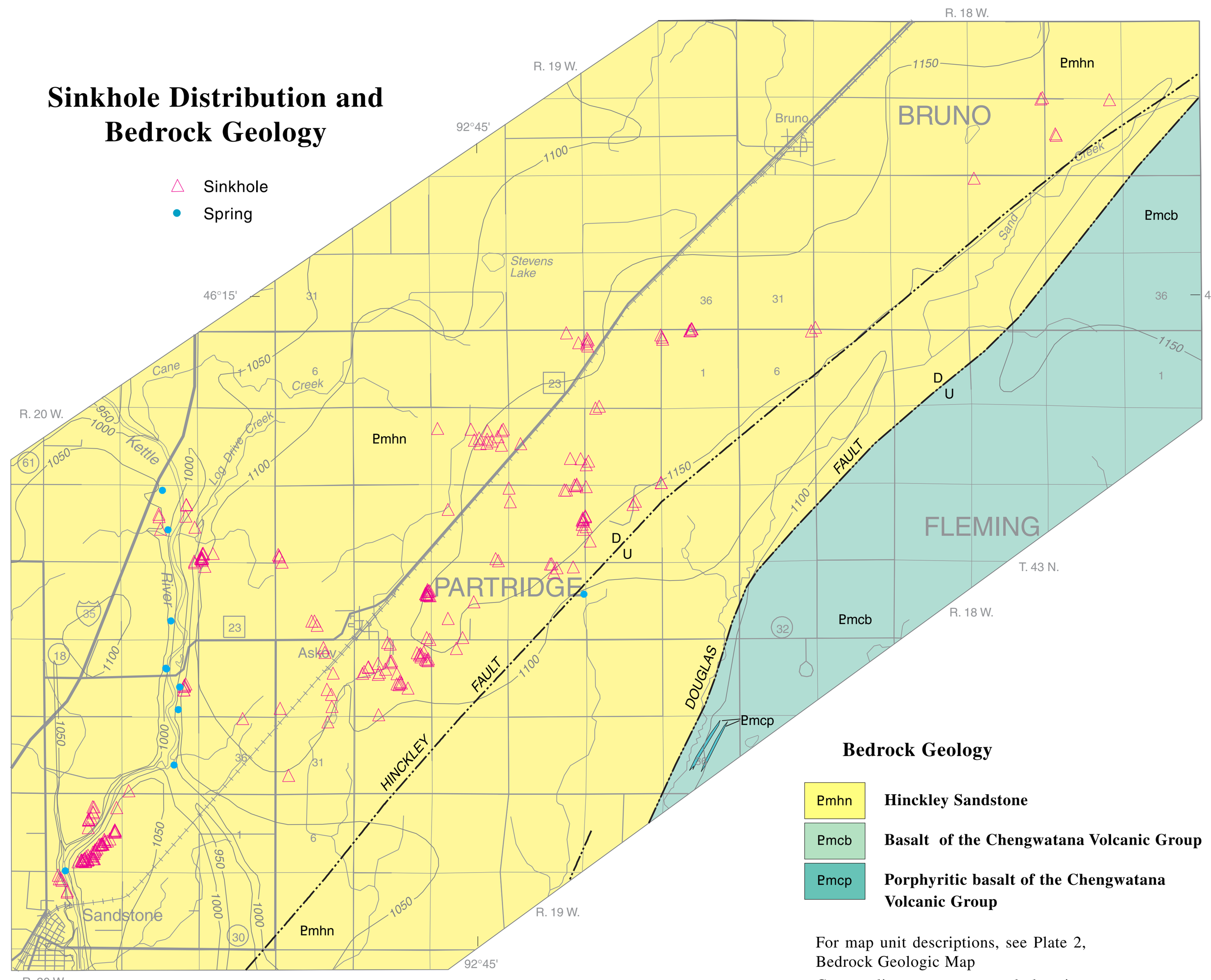
1. Organic-rich soil
2. Leached organic material
3. Laminated lake sediments
4. Till
5. Till with organic material (inferred)
6. Joints in sandstone bedrock
7. Sandstone boulders

→ Observed ground-water flow path
← – Postulated surface-water flow path

Figure 3. Subsurface profile of the central portion of sinkhole D355, excavated in the city of Askov, north-central Pine County. This sinkhole is medium-sized, bowl-shaped, and has an active drain. The sinkhole is about three times wider than the section shown.

Sinkhole Distribution and Bedrock Geology

△ Sinkhole
● Spring



Bedrock Geology

Emhn	**Hinckley Sandstone**
Emcb	**Basalt of the Chengwatana Volcanic Group**
Emcp	**Porphyritic basalt of the Chengwatana Volcanic Group**

For map unit descriptions, see Plate 2, Bedrock Geologic Map

Contour lines represent equal elevation of the uppermost bedrock surface.

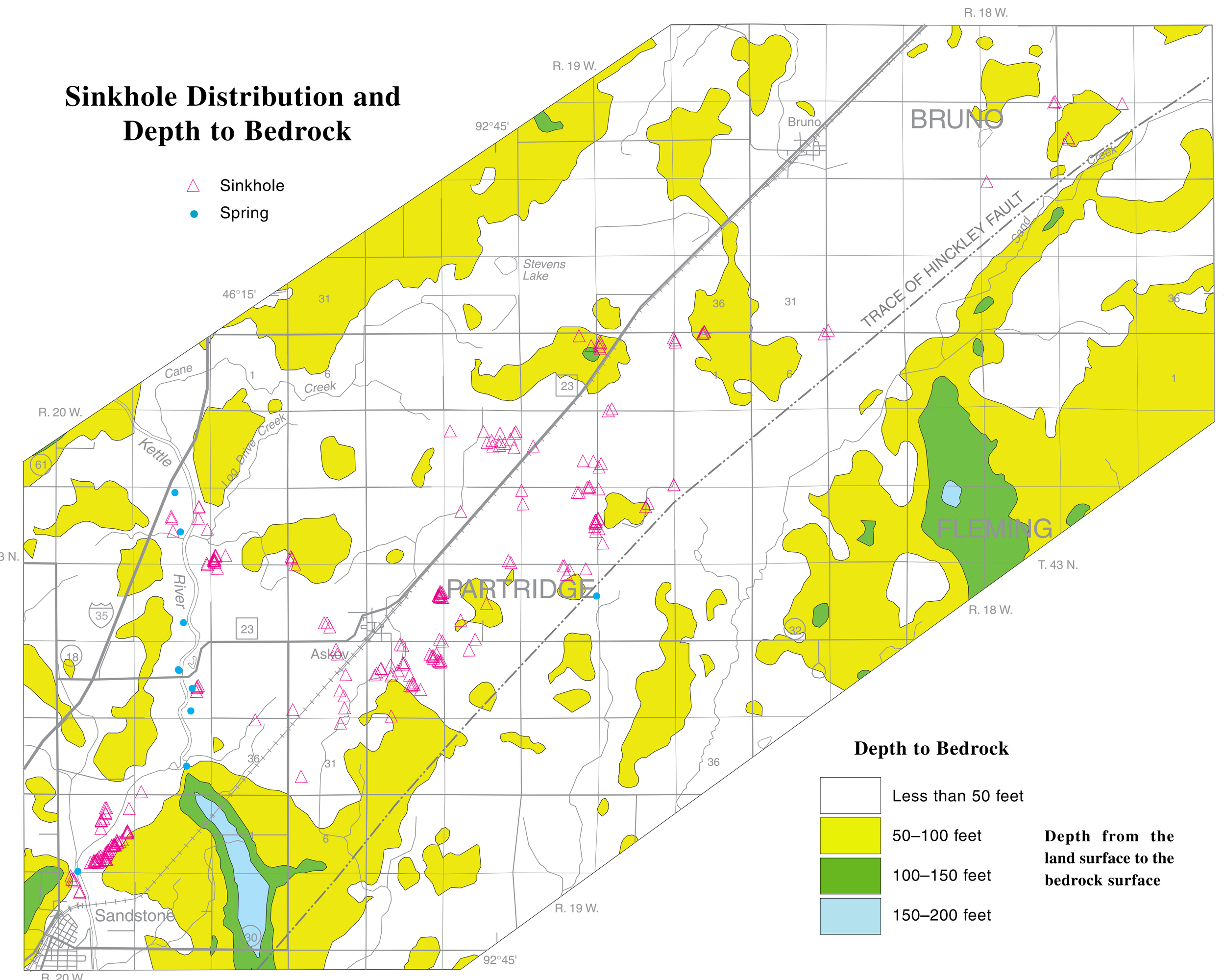
SCALE 1:100 000

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 KILOMETERS

Sinkhole Distribution and Depth to Bedrock

△ Sinkhole
● Spring



Depth to Bedrock

Less than 50 feet	**Depth from the land surface to the bedrock surface**
50–100 feet	
100–150 feet	
150–200 feet	

SCALE 1:100 000

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 KILOMETERS

DEPTH TO BEDROCK

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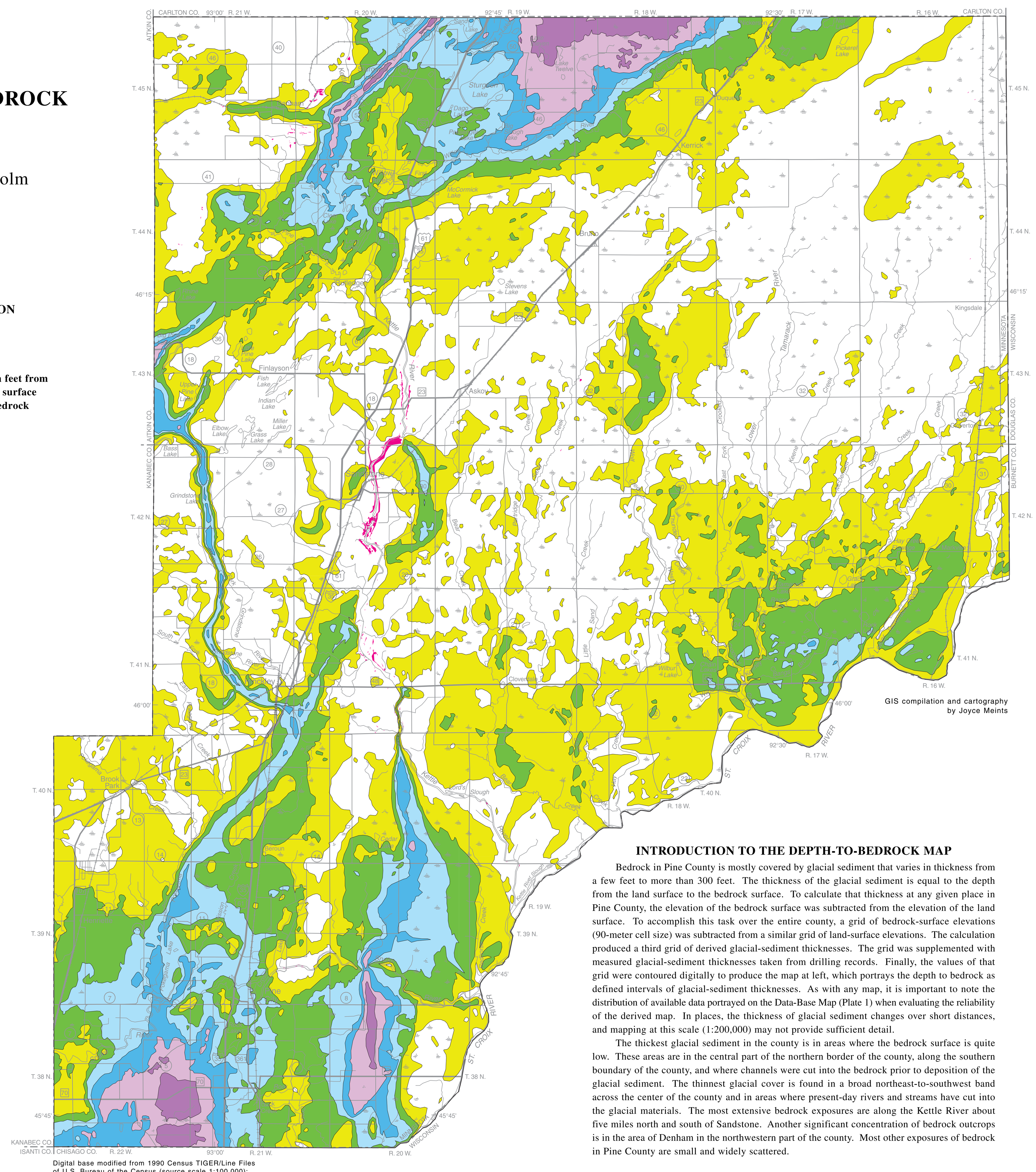
2001

MAP EXPLANATION

50 or less	**Depth in feet from the land surface to the bedrock surface**
50–100	
100–150	
150–200	
200–250	
250–300	
300–350	

Bedrock outcrop



GIS compilation and cartography by Joyce Meints

Digital base modified from 1990 Census TIGER/Line Files of U.S. Bureau of the Census (source scale 1:100,000); county border files modified from Minnesota Department of Transportation files; digital base annotation by Minnesota Geological Survey.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:200 000

5 0 5 10 MILES

5 0 5 10 15 KILOMETERS

INTRODUCTION TO THE DEPTH-TO-BEDROCK MAP

Bedrock in Pine County is mostly covered by glacial sediment that varies in thickness from a few feet to more than 300 feet. The thickness of the glacial sediment is equal to the depth from the land surface to the bedrock surface. To calculate that thickness at any given place in Pine County, the elevation of the bedrock surface was subtracted from the elevation of the land surface. To accomplish this task over the entire county, a grid of bedrock-surface elevations (90-meter cell size) was subtracted from a similar grid of land-surface elevations. The calculation produced a third grid of derived glacial-sediment thicknesses. The grid was supplemented with measured glacial-sediment thicknesses taken from drilling records. Finally, the values of that grid were contoured digitally to produce the map at left, which portrays the depth to bedrock as defined intervals of glacial-sediment thicknesses. As with any map, it is important to note the distribution of available data portrayed on the Data-Base Map (Plate 1) when evaluating the reliability of the derived map. In places, the thickness of glacial sediment changes over short distances, and mapping at this scale (1:200,000) may not provide sufficient detail.

The thickest glacial sediment in the county is in areas where the bedrock surface is quite low. These areas are in the central part of the northern border of the county, along the southern boundary of the county, and where channels were cut into the bedrock prior to deposition of the glacial sediment. The thinnest glacial cover is found in a broad northeast-to-southwest band across the center of the county and in areas where present-day rivers and streams have cut into the glacial materials. The most extensive bedrock exposures are along the Kettle River about five miles north and south of Sandstone. Another significant concentration of bedrock outcrops is in the area of Denham in the northwestern part of the county. Most other exposures of bedrock in Pine County are small and widely scattered.

BEDROCK TOPOGRAPHY

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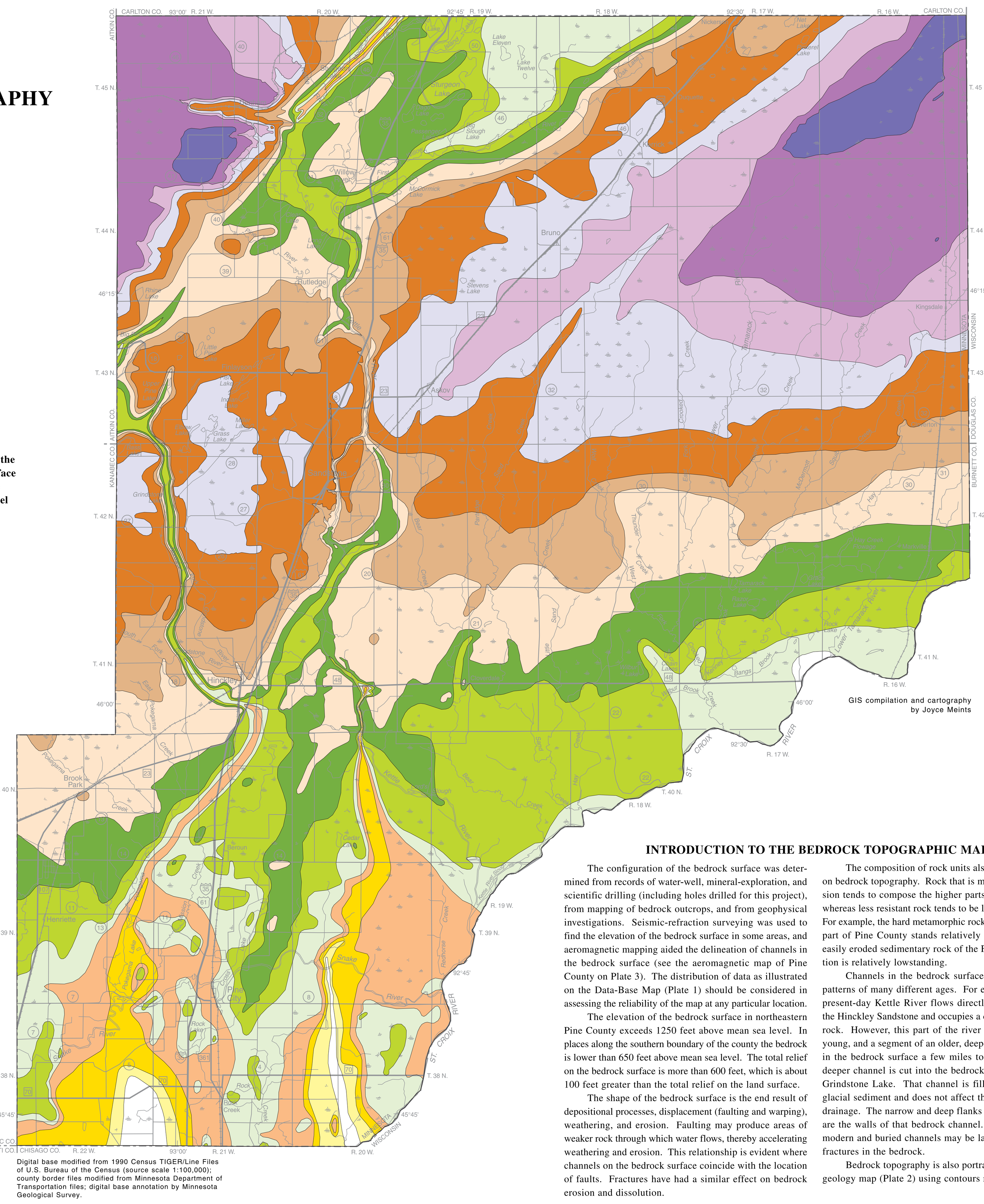
MAP EXPLANATION

650 and fewer	**Elevation of the bedrock surface in feet above mean sea level**
650–700	
700–750	
750–800	
800–850	
850–900	
900–950	
950–1000	
1000–1050	
1050–1100	
1100–1150	
1150–1200	
1200–1250	
1250 or more	



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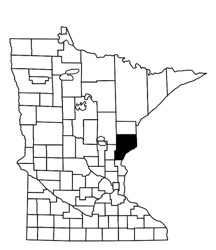

LOCATION DIAGRAM

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Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:200 000

5 0 5 10 MILES

5 0 5 10 15 KILOMETERS

INTRODUCTION TO THE BEDROCK TOPOGRAPHIC MAP

The configuration of the bedrock surface was determined from records of water-well, mineral-exploration, and scientific drilling (including holes drilled for this project), from mapping of bedrock outcrops, and from geophysical investigations. Seismic-refraction surveying was used to find the elevation of the bedrock surface in some areas, and aeromagnetic mapping aided the delineation of channels in the bedrock surface (see the aeromagnetic map of Pine County on Plate 3). The distribution of data as illustrated on the Data-Base Map (Plate 1) should be considered in assessing the reliability of the map at any particular location.

The elevation of the bedrock surface in northeastern Pine County exceeds 1250 feet above mean sea level. In places along the southern boundary of the county the bedrock is lower than 650 feet above mean sea level. The total relief on the bedrock surface is more than 600 feet, which is about 100 feet greater than the total relief on the land surface.

The shape of the bedrock surface is the end result of depositional processes, displacement (faulting and warping), weathering, and erosion. Faulting may produce areas of weaker rock through which water flows, thereby accelerating weathering and erosion. This relationship is evident where channels on the bedrock surface coincide with the location of faults. Fractures have had a similar effect on bedrock erosion and dissolution.

The composition of rock units also has a direct effect on bedrock topography. Rock that is more resistant to erosion tends to compose the higher parts of the topography, whereas less resistant rock tends to be located in low areas. For example, the hard metamorphic rock in the northwestern part of Pine County stands relatively high, and the more easily eroded sedimentary rock of the Fond du Lac Formation is relatively lowstanding.

Channels in the bedrock surface represent drainage patterns of many different ages. For example, part of the present-day Kettle River flows directly on the surface of the Hinckley Sandstone and occupies a channel cut into that rock. However, this part of the river course is relatively young, and a segment of an older, deeper route can be seen in the bedrock surface a few miles to the east. An even deeper channel is cut into the bedrock north and south of Grindstone Lake. That channel is filled and overlain by glacial sediment and does not affect the course of surface drainage. The narrow and deep flanks of Grindstone Lake are the walls of that bedrock channel. The paths of both modern and buried channels may be largely controlled by fractures in the bedrock.

Bedrock topography is also portrayed on the bedrock geology map (Plate 2) using contours rather than color.