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BEDROCK GEOLOGIC MAP AND SECTIONS

By

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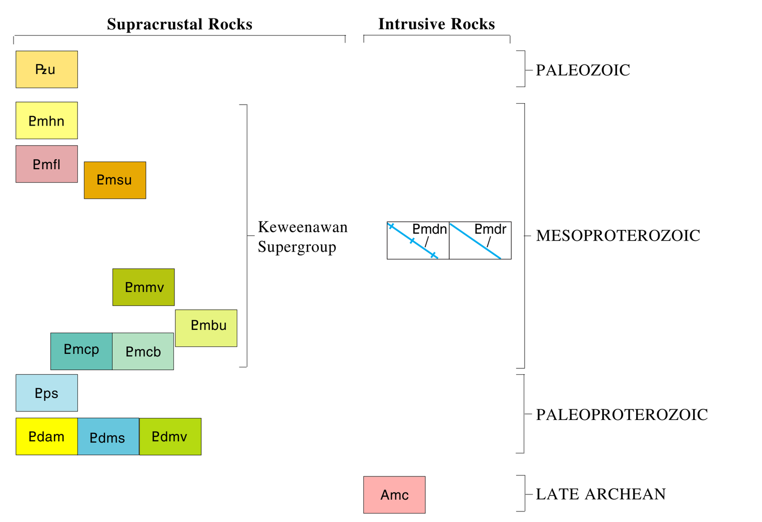
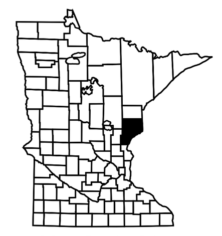
2001

CORRELATION OF MAP UNITS





DESCRIPTION OF MAP UNITS

PALEOZOIC ROCKS

Pzu **Paleozoic rocks, undifferentiated**—Sandstone, tan to white, friable, cross-stratified; minor shale interbeds. Medium- to coarse-grained sandstone is composed of more than 98 percent moderate to well-rounded grains of quartz, whereas finer grained sandstone and siltstone are feldspathic. Scattered pebbles of vein quartz and pink quartzite as large as several centimeters in diameter are common. Red and green shale is present as thin laminae separating cross-strata sets or is draped on foresets. Fine-grained, disseminated glauconite, and bioturbated mottling are rare features of some strata.

Collectively, the rocks mapped as Paleozoic probably include equivalents to units ranging in age from Late Cambrian Mt. Simon Sandstone to Middle Ordovician St. Peter Sandstone (Mossler, 1987). The unit is not shown on the cross sections owing to its thinness.

KEWEENAWAN SUPERGROUP
MESOPROTEROZOIC ROCKS

Ᵽmhn **Hinckley Sandstone**—Quartz arenite, tan to orange, fine- to medium-grained, well-sorted and well-rounded; composed of about 96 percent quartz (Tryhorn and Ojakangas, 1972). It is characterized by trough cross-beds and thin layers of ripple-marked, fine-grained sandstone indicative of deposition in an aqueous environment, and by planar, low-angle cross-beds, possibly indicative of deposition in an eolian environment (Beaster and others, 2000).

Adjacent to the Douglas Fault the sandstone contains scattered cobbles of maroon quartzite and rare pebbles of felsite and agate. Between the Hinckley and Douglas faults, the Hinckley Sandstone contains 10 percent or more of weathered, kaolinitic feldspar. This part of the Hinckley is interpreted as the lowermost part of the formation, in fault contact with the upper part of the Hinckley to the west and basalt to the east.

Ᵽmfl **Fond du Lac Formation**—Quartzose to subarkosic sandstone, pale-orange to dusky-red, medium- to coarse-grained; interbeds of dark-brownish-red siltstone and minor shale. Based on drill-core, the Fond du Lac Formation is at least 650 meters (2,100 feet) thick. Mooney and others (1970) and Allen (1994) estimate a thickness of two to three kilometers for the Fond du Lac Formation adjacent to the Douglas Fault, based on geophysical data.

Outcrops along tributaries to the Kettle River south of the city of Sandstone are trough-cross-bedded, medium-grained, quartz-rich sandstone that contains a significant fraction of weathered detrital feldspar, lithic grains, and detrital mica flakes. Layers of conglomerate commonly define bottoms of troughs; conglomerate clasts are dominantly basalt, with minor felsite and jasper. The contact between the upper Fond du Lac Formation and the overlying basal Hinckley Sandstone is exposed in a single outcrop along a tributary to the Kettle River, where it is a sharp erosional unconformity.

In western Pine County about 15 exploratory drill holes penetrate the contact of the Fond du Lac Formation and underlying pre-Keweenawan bedrock. Here the Fond du Lac consists of coarse-grained, pale-orange sandstone interbedded with dark-brownish-red siltstone and minor shale. Basal conglomerate is common in the drill cores; it is composed of angular cobbles that are mainly derived from the underlying rock units.

Ᵽmsu **Sandstone, siltstone, and minor shale**—Predominantly lithic subarkosic sandstone, light-greenish-tan to dark-maroon-brown, medium- to coarse-grained; cemented by ankeritic carbonate. Lithologically similar to and possibly correlative with the Fond du Lac Formation, but correlation is uncertain. Aeromagnetic and water-well data indicate that the northwestern margin of this basin may be a shallow east-dipping unconformity; however, Mooney (1970) suggested on the basis of seismic velocities inter–mediate between basalt and sedimentary rocks that the sedimentary strata are interbedded with mafic volcanic rocks.

Diabase dikes—Inferred from aeromagnetic maps. Dikes are not portrayed on the cross sections.

Ᵽmdn *Normal magnetic polarity dike*

Ᵽmdr *Reverse magnetic polarity dike*

Ᵽmmv **Minong volcanic sequence**—Basalt, dark-gray (fresh) to maroon-brown (weathered), fine- to medium-grained. Dominantly ophitic to locally intergranular; locally weakly porphyritic. Small amygdules are filled with quartz, chlorite, calcite, epidote, and zeolite minerals of undetermined composition. Epidote may be a secondary replacement within amygdules. Individual flow thicknesses are unknown due to poor exposure. Aeromagnetic data show this unit to be continuous with similar rocks in Wisconsin, where they are informally termed the Minong volcanics (Cannon and others, 2001). A rhyolite flow at the base of the Minong volcanics has been dated at 1094 Ma (Zartman and others, 1997).

Ᵽmbu **Basalt**—Dark-gray to maroon-brown, fine- to medium-grained; ophitic to intergranular and locally weakly porphyritic. Amygdules are filled mainly with chlorite; chalcedony, quartz, calcite, epidote, and zeolite-group minerals are less common, and native copper is rare. Inferred from aeromagnetic data to be in fault contact with unit Ᵽmcb, and to be unconformably overlain by unit Ᵽmmv. Aeromagnetic data (see Plate 3) indicate that the flows within this sequence are broadly folded.

Chengwatana Volcanic Group—The term Chengwatana has been applied by various workers to all the volcanic rocks in the St. Croix horst, which extends from eastern Pine County into Wisconsin (Craddock, 1972). However, recent aeromagnetic data (Cannon and others, 2001) indicate that the St. Croix horst consists of several distinct sequences of volcanic rocks that include units Ᵽmmv, Ᵽmbu, Ᵽmcb, and Ᵽmcp. Here, the term Chengwatana is reserved for the thin panel of volcanic rocks located between the Pine and Douglas faults (units Ᵽmcb and Ᵽmcp).

Ᵽmcb **Basalt**—Gray to brown, fine- to medium-grained. Ophitic to intergranular, locally flow banded into alternating centimeter-scale dark-green and maroon layers. Some flows are weakly porphyritic. Amygdaloidal flow tops contain zeolites, chlorite, calcite, quartz, and, rarely, epidote. Zones of weak to intense epidote alteration are present and range from secondary epidote-filling amygdules to complete replacement of basalt by epidote and quartz. Copper mineralization is present in variable but generally minor proportions. Where present, it occurs as finely disseminated specks throughout the basalt and in amygdules. Rare coarse native copper was observed within late, brittle veins of coarse prehnite. This unit also includes interflow conglomerates (unit Ᵽmcs in inset map A on Plate 3).

Ᵽmcp **Porphyritic basalt**—Local flows or packets of flows within unit Ᵽmcb. Rock consists of a fine-grained groundmass that is dark gray when fresh or red brown when weathered and abundant phenocrysts of plagioclase as long as five centimeters.

PALEOPROTEROZOIC ROCKS

Ᵽps **Pelitic schist and metagraywacke**—Staurolite- and garnet-bearing quartz-mica schist, gray, fine-grained, variably crenulated. Upright bedding is generally subhorizontal and subparallel to metamorphic foliation, both of which are gently folded by second-generation folds that have vertical axial surfaces and an associated subvertical crenulation cleavage. The crenulation cleavage is best developed in the more pelitic beds. Drill-core data show the widespread presence of a thin graphitic schist horizon at the base of this unit that is transitional into underlying dolomitic marble of the Denham Formation.

Denham Formation—The type locality for the Denham Formation is located about 2.5 kilometers (1.6 miles) southeast of the town of Denham (Morey, 1978). As originally defined, the Denham Formation consists of metamorphosed quartz-rich sedimentary rocks, marble, and mafic volcanic rocks. Detailed remapping of the outcrops at the Denham type locality (see inset map C on Plate 3) indicates the distribution and relationships among these diverse rock types. All the rock units in the Denham Formation have been metamorphosed to the amphibolite facies (Holm, 1986).

Ᵽdam **Arkose, gritstone, conglomerate, and dolomitic marble**—All metamorphosed under amphibolite-facies conditions. Interbedded micaceous rocks, derived from relatively minor shaly or silty protoliths, display layer-parallel schistosity and well-developed crenulation cleavage. Arkose and minor conglomerate contain detritus derived from the subjacent McGrath Gneiss (unit Amc). The dolomitic marble is tan and generally massive, but in places it contains thin beds of arkosic rocks. Drill-core data indicate that the arkosic component does not persist far away from the area of outcrop. To the north and northeast of the outcrop area, drill cores and cuttings show that the marble is at least 500 feet thick, very pure, and grades from pale gray to white in color with increasing depth.

Ᵽdms **Mica schist**—Gray, fine- to coarse-grained schist of pelitic protolith. Where between unit Ᵽdmv and Amc, this unit is a fine-grained, fairly massive biotite-quartz-feldspar schist with vague relict bedding. Where within unit Ᵽdmv, this unit is coarse-grained, tightly crenulated garnet- and staurolite-bearing biotite-muscovite schist. Bedding and early foliation in both occurrences are crenulated by later D2 deformation.

Ᵽdmv **Amphibolitic metabasalt**—Dark grayish-green, fine-grained, amygdaloidal. Southern belt is pillowed to fragmental, with at least two flow sequences exposed; the northern belt consists entirely of fragmental amphibolitic basalt, with relict amygdaloidal basalt clasts. Pillows and clasts are all strongly lineated.

LATE ARCHEAN ROCKS

Amc **McGrath Gneiss**—Augen gneiss and flaser gneiss developed from variably sheared, coarsely porphyritic, biotite granite protolith; medium to coarse grained, pinkish gray. Unit continues west to Mille Lacs Lake (Boerboom and others, 1999).

DESCRIPTION OF MAP SYMBOLS

Contacts.

Certain.

Approximately located.

Boundary between rock bodies located by aeromagnetic survey.

Thrust fault—Inferred; sawteeth on upthrown side.

Dip-slip faults—U, upthrown side, D, downthrown side.

Approximately located.

Concealed beneath Paleozoic strata.

Located from aeromagnetic survey.

12 **Attitude of flow-parallel sheet joints in volcanic flows as determined from outcrop**—Approximates the attitude of flow layering; angle in degrees from horizontal.

20 **Attitude of inclined sedimentary bedding and volcanic flow layering as determined from outcrop**—Angle in degrees from horizontal.

78 **Attitude of inclined sedimentary bedding as determined from outcrop**—Angle in degrees from horizontal; ball indicates direction of younging.

25 **Attitude of M1 metamorphic foliation**—Inclined.

950 **Line of equal elevation on the bedrock surface**—Contour interval 50 feet. See also Plate 6 for a 1:200,000-scale map that portrays bedrock topography as color intervals representing defined elevation ranges.

Anticline—Showing trace of nearly vertical axial plane and plunge of fold.

Syncline—Showing trace of nearly vertical axial plane and plunge of fold.

Minor anticline—Showing trace of nearly vertical axial plane.

Minor syncline—Showing trace of nearly vertical axial plane.

Crest of linear aeromagnetic anomaly—Inferred to represent bedding trends in basalt flows.

C——C' **Line of cross section.**

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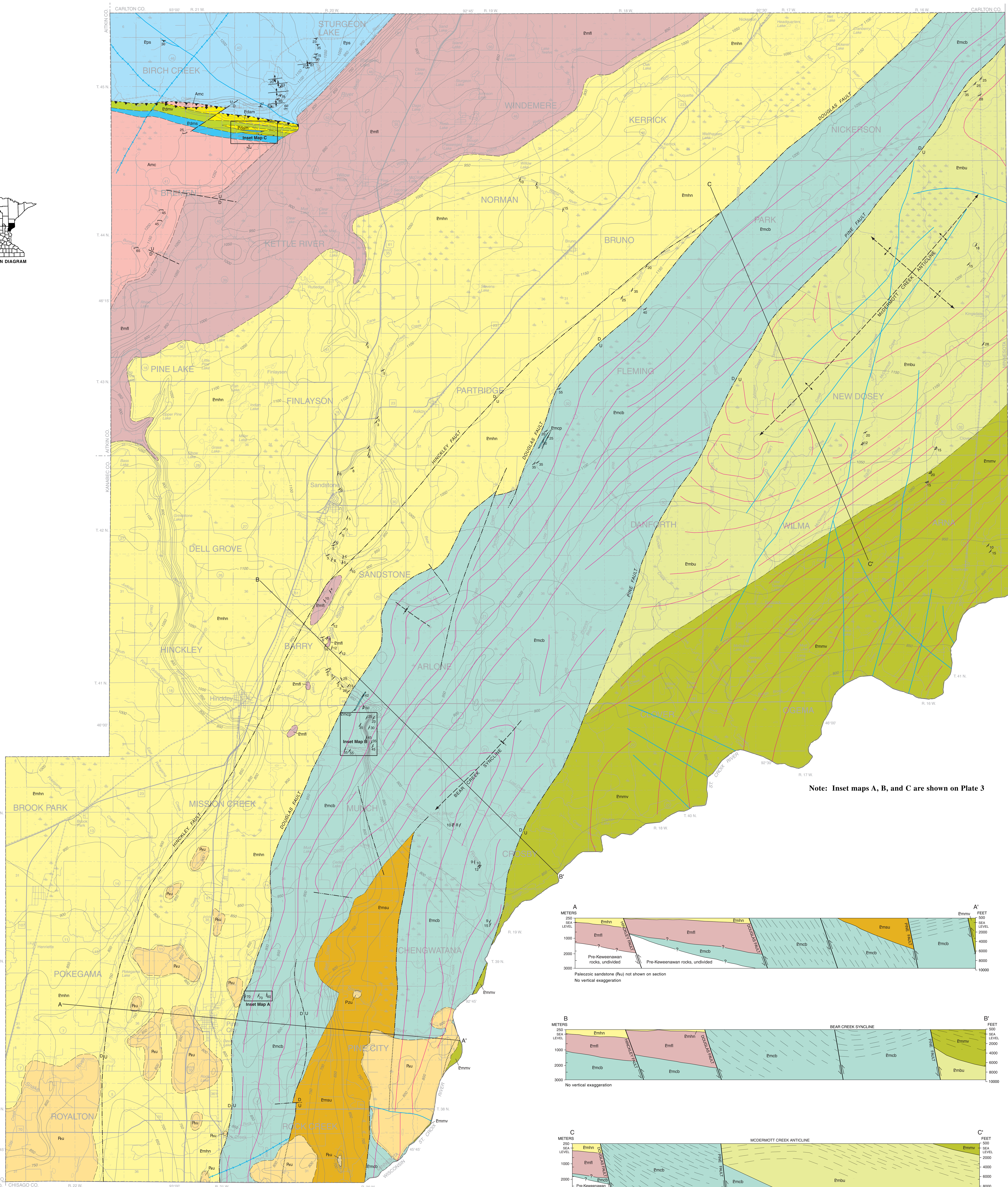
Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.



Note: Inset maps A, B, and C are shown on Plate 3

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

Geology compiled November 2000

GIS compilation and cartography by Joyce Meints and Philip Heywood

SCALE 1:100 000

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 KILOMETERS

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GEOLOGIC ATLAS OF PINE COUNTY, MINNESOTA