UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director

Prepared and Published with the Support of
THE U.S. GEOLOGICAL SURVEY AS PART OF THE 2008 STATE GEOLOGIC MAPPING PROGRAM ELEMENT (STATEMAP) OF THE NATIONAL GEOLOGIC MAPPING PROGRAM, THE CHISAGO COUNTY BOARD OF COMMISSIONERS, AND THE MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND AS RECOMMENDED BY THE LEGISLATIVE-CITIZEN COMMISSION ON MINNESOTA RESOURCES

COUNTY ATLAS SERIES
ATLAS C-22, PART A
Plate 2—Bedrock Geology

BEDROCK GEOLOGY

By

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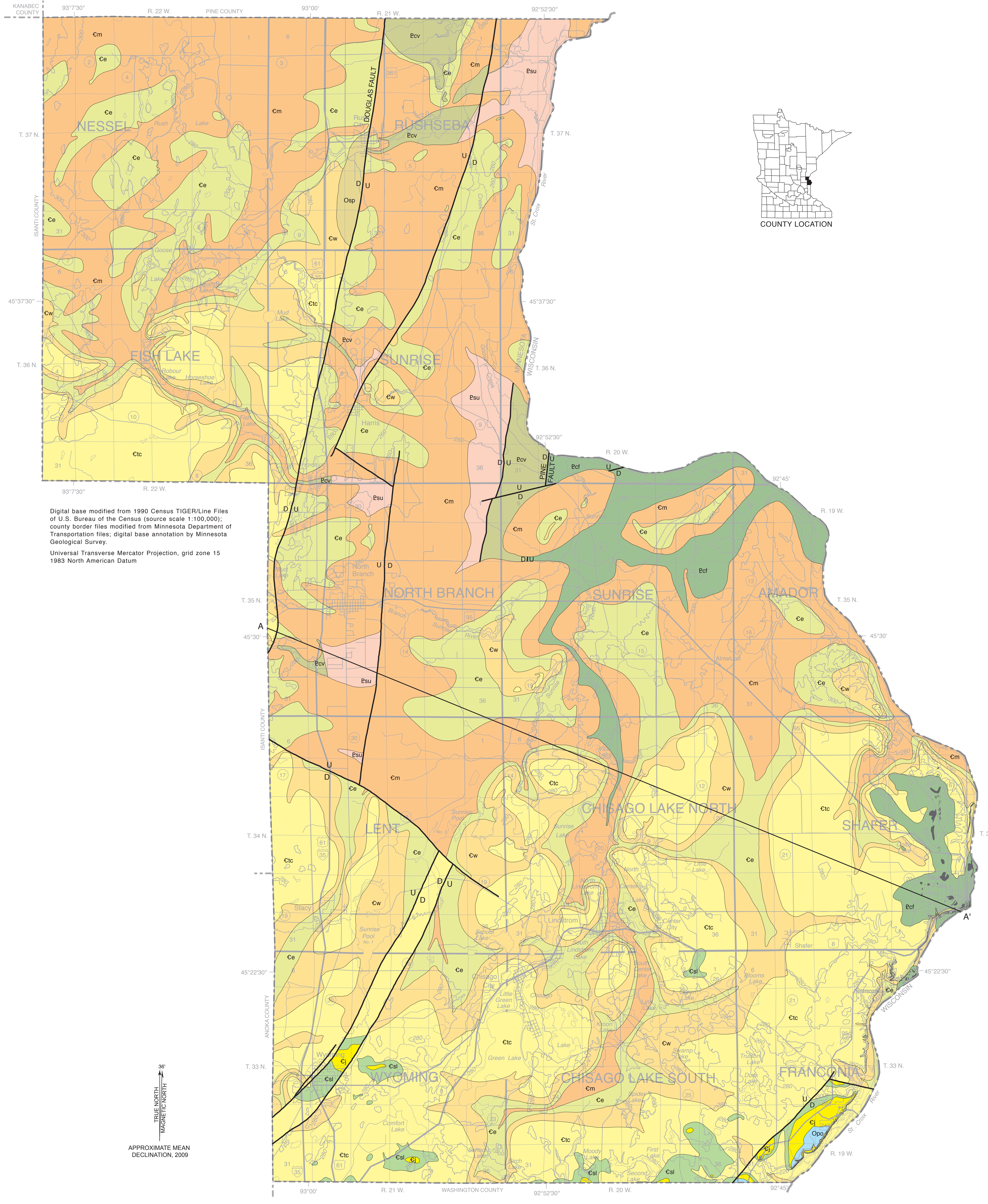
2010



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

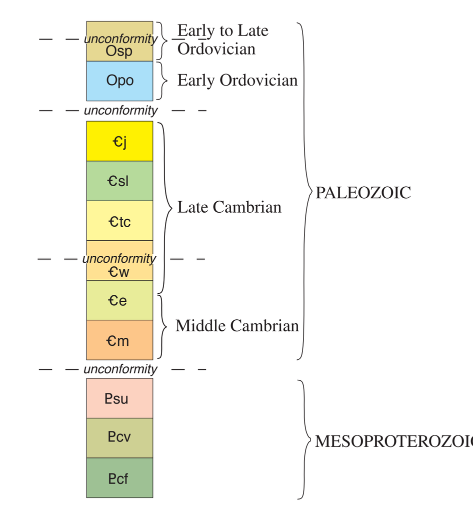
SCALE 1:100 000

CONTOUR INTERVAL 20 METERS

GIS compilation by R.S. Lively
Edited by Lori Robinson

COUNTY LOCATION

CORRELATION OF MAP UNITS



MAP SYMBOLS

Geologic contact—Approximately located.

Fault—Faults in Paleozoic rocks are interpreted to be dip-slip. Letters indicate what is inferred to be the most recent relative vertical displacement: U, up; D, down. Faults are concealed by Quaternary sediments and recent alluvium and are inferred from subsurface geologic data supplemented by aeromagnetic and gravity data. Contrasts in magnetic intensity on the aeromagnetic map are inferred to be largely the expression of faults in the underlying Mesoproterozoic volcanic and sedimentary rocks. Offsets of Paleozoic strata indicate that some of these faults were rejuvenated during and after Early Paleozoic time.

Bedrock outcrop

INTRODUCTION

This geologic map, cross section, and stratigraphic column depict the bedrock formations exposed at the land surface or lying directly beneath unconsolidated Quaternary deposits of variable thickness across Chisago County. The map shows how the bedrock would appear if it were viewed from an aerial perspective, as if all the overlying unconsolidated material was stripped away. Quaternary glacial till, lake sediments, outwash, and river alluvium cover the bedrock across most areas (Meyer and Lusardi, 2001). The unconsolidated deposits reach a maximum thickness of about 500 feet (152 meters). Bedrock exposures are limited to the eastern part of the county, mostly along the St. Croix River and its tributaries near Taylors Falls.

There are two fundamental kinds of bedrock mapped across Chisago County. Mesoproterozoic bedrock of the Keweenawan Supergroup is about 1.1 billion years old, and consists of reddish-brown mudstone and siltstone, lithic and feldspathic sandstone, and volcanic rocks such as basalt. The Keweenawan Supergroup accumulated as part of the development of the Midcontinent Rift System (for example Cannon and others, 2001), a large tear in the crust of North America. A second type of bedrock consists of relatively thin layers of sandstone, siltstone, dolostone, and shale deposited in shallow seas during the Paleozoic Era, about 500 million years ago (for example Mossler, 2008). These bedrock layers eventually buried the Keweenawan Supergroup across nearly all the county. An exception was at Taylors Falls, where resistant knobs of Keweenawan basalt stood as topographic highs, emergent as islands in the Paleozoic seas (Fig. 1). This setting also led to local deposition of unusual Paleozoic bedrock that includes boulders and cobbles of basalt that were shed from these islands into the shallow sea. These deposits have been informally called the "Mill Street conglomerate" (Berkey, 1897).

The most prominent feature of the bedrock topography (Plate 6) is an anomalously deep and linearly extensive buried valley in the southern half of the county that approximates the position of the modern Sunrise River system and chain of lakes around the cities of Lindstrom and Chisago (see cross section). The buried valley deepens to the north, and crosses the St. Croix River into Wisconsin near the town of Sunrise, where the base of the valley reaches an elevation of less than 400 feet (122 meters). Other highlights of the bedrock topography are the knobs of relatively hard, resistant Mesoproterozoic basalt (Clam Falls Volcanics, unit Pcf) that stand at high elevation near Taylors Falls. The tops of some of the highest knobs exceed 1,050 feet (320 meters), about 300 feet (91 meters) above the bedrock surface across most of the rest of the county.

Buried stream channels incised into bedrock, in combination with faults with up to about 200 feet (61 meters) of displacement, and a gentle, overall southward dip of Paleozoic bedrock (Fig. 2), are a primary influence on the map distribution of bedrock geologic units. Across much of the county the uppermost bedrock consists principally of moderately consolidated layers of sandstone, siltstone, and shale of Cambrian age. The southward dip of the Paleozoic strata is reflected on the map by a pattern of progressively older formations northward across the county. Mesoproterozoic rocks of the Midcontinent Rift System are the uppermost bedrock largely where deep buried valleys were incised entirely through Cambrian strata, and where resistant knobs of basalt stood as topographic highs when Paleozoic strata were deposited. This general distribution of bedrock units is interrupted by faults such as those along the Douglas fault zone on the western boundary of the Mesoproterozoic Midcontinent Rift (Sims and Zeitz, 1967), which were reactivated during and after early Paleozoic time (Figs. 2, 3; cross section). As a result, Mesoproterozoic sedimentary and volcanic rocks are the uppermost bedrock in some areas where they have been displaced upward between faults. Conversely, down-dropped blocks of bedrock have preserved relatively young formations such as the Early Ordovician Oneota Dolomite in a small area in the extreme southeastern part of the County.

The production of this map and cross section relied on a number of sources of information, including water-well and scientific drilling records (including holes drilled for this project), outcrop mapping, geophysical surveys, and published geologic maps of parts of Chisago and adjacent counties (Berkey, 1897; Cordua, 1989; Mossler and Bloomgren, 1990; Johnson, 2000; Boerboom, 2001). The location of faults is inferred from borehole data, with additional constraints provided by patterns in aeromagnetic anomalies (Fig. 3). Seismic-refraction techniques were used to determine the elevation of the bedrock surface in some areas, and linear, sinuous, aeromagnetic anomalies (Fig. 4) were used to constrain the position of channels on the bedrock surface in the northwestern part of the county (Fig. 4). The geophysical data were collected by the Minnesota Geological Survey (Chandler and others, 2004), the Minnesota Department of Natural Resources, and the Geology and Geophysics Department of the University of Minnesota. The distribution of all these data is shown on the map. Because the bedrock is concealed by Quaternary sediments across most of the county, the distribution of bedrock units and the pattern of faults are strongly dependent on borehole records. The depiction of uppermost bedrock units in the northern approximately one-half of the county is more tenuous than in the southern half. Borehole data are relatively sparse in the north, and the lithic differences between the Cambrian formations are so subtle that they are unresolvable on many drilling records. For example, parts of the Eau Claire Formation and Tunnel City Group are dominated by beds of tan, white, or brown sandstone that on the basis of drilling records alone commonly cannot be distinguished from the Mt. Simon and Wonewoc Sandstones. Many driller's logs of bedrock wells describe such units only as tan or white sandstone, which is a substantial component of all the Cambrian formations below the St. Lawrence Formation.

DESCRIPTION OF MAP UNITS

PALEOZOIC ROCKS

Nomenclature has been revised for some Paleozoic formations in Minnesota, and some formation names formerly in use at the Minnesota Geological Survey have been replaced by names widely accepted elsewhere in the region (Mossler, 2008). Rocks formerly included in the Franconia Formation are now assigned to the Tunnel City Group, which is subdivided into the Mazomanie Formation and the Lone Rock Formation. The interval formerly referred to as the Ironton-Galesville Sandstone is now named the Wonewoc Sandstone. More detailed discussion of these revisions is given in Mossler (2008).

Osp **St. Peter Sandstone and Prairie du Chien Group (Early to Middle Ordovician)**—Limited information (one set of borehole cuttings and one natural gamma log) indicates that the St. Peter Sandstone and Prairie du Chien Group locally unconformably overlie the Eau Claire Formation and Wonewoc Sandstone west of the Douglas fault at Rush City. The St. Peter Sandstone consists largely of fine- to medium-grained, quartzose sandstone, with interbeds of very fine-grained, feldspathic sandstone that may be the Pigs Eye Member (Mossler, 2008). Strata beneath the St. Peter Sandstone in this area are largely fine- to coarse-grained quartzose sandstone, with interbeds of sandy, oolitic dolostone. They most likely correlate to the Shakopee Formation, but could instead be equivalent to the lowest part of the Oneota Dolomite (Coon Valley Member) of the Prairie du Chien Group. The maximum thickness of this map unit is about 70 feet (21 meters).

Opo **Prairie du Chien Group–Oneota Dolomite (Early Ordovician)**—Dominantly tan to gray, medium to thickly bedded, finely crystalline dolostone, present only in the extreme southeast corner of the county. Microbial build-ups (thrombolites) are common in some beds. The lowermost few feet include interbeds of fine- to coarse-grained, intraclastic, quartzose sandstone, very fine-grained, feldspathic sandstone and siltstone, shale, and sandy dolostone of the Coon Valley Member. The maximum preserved thickness of the Oneota Dolomite is about 30 feet (9 meters).

Cj **Jordan Sandstone (Late Cambrian)**—Dominantly tan to light gray sandstone characterized by coarsening-upward sequences consisting of two interlayered facies (Runkel, 1994), which are not separated on the map. They are medium- to coarse-grained, cross-stratified, generally friable, quartz sandstone; and very fine-grained, commonly bioturbated, feldspathic sandstone and lenses of siltstone and shale. The major part of the very fine-grained facies forms a regionally continuous interval that gradationally overlies the St. Lawrence Formation (unit Csl), although there are lithologically similar intervals intercalated with the medium- to coarse-grained facies at higher stratigraphic positions. The Jordan Sandstone is generally 60 to 80 feet (18 to 24 meters) thick where uneroded. An unconformity, locally marked by thin beds of quartz pebble conglomerate and silcrete-cemented sandstone clasts (Runkel and others, 2007), separates the Jordan Sandstone from the overlying Oneota Dolomite.

Csl **St. Lawrence Formation (Late Cambrian)**—The St. Lawrence Formation is principally light gray to yellowish-gray and pale yellowish-green, dolomitic, feldspathic siltstone with interbedded, very fine-grained sandstone and shale. Lenses and layers of light gray, finely crystalline, sandy dolostone occur locally, especially in the lowermost few feet of the formation (Runkel and others, 2006). The formation is 25 to 40 feet (8 to 12 meters) thick. The upper contact with the Jordan Sandstone is conformable and gradational. The gradational nature of the contact in well-cuttings and on natural gamma logs can make selecting a precise contact between these formations problematic.

Ctc **Tunnel City Group (Late Cambrian)**—The Tunnel City Group, formerly named the Franconia Formation (Berg, 1954), varies from about 150 to 180 feet (46 to 55 meters) in thickness in the map area, except where it pinches out in unconformable contact against knobs of Keweenawan basalt near Taylors Falls. It is divided into two formations: the Mazomanie Formation and the Lone Rock Formation (Mossler, 2008). The Mazomanie Formation is dominantly white to yellowish-gray, fine- to medium-grained, cross-stratified, generally friable, quartz sandstone. Glauconitic grains typically are absent and never exceed 5 percent (Berg, 1954). Some beds contain brown, intergranular dolomite as cement. *Skolithos* burrows and sandstone intraclasts are common along discrete horizons. Individual tongues of Mazomanie Formation are up to 50 feet (15 meters) thick. The Mazomanie Formation and the Jordan Sandstone are sometimes mistaken for one another in the southern Chisago County area because of their lithic similarities and similar thickness. The Lone Rock Formation underlies the Mazomanie Formation and intertongues with it. It consists of pale yellowish-green, very fine- to fine-grained glauconitic, feldspathic sandstone and siltstone, with thin, greenish-gray shale partings. Thin beds with dolomitic intraclasts are common. In the Taylors Falls area, the lower part of the Lone Rock Formation locally includes a basalt cobble to boulder conglomerate, informally named the "Mill Street conglomerate" (Berkey, 1897; Yochelson and Webers, 2006). Intervals of Lone Rock Formation are as much as 60 feet (18 meters) thick in Chisago County.

The upper contact of the Tunnel City Group with the St. Lawrence Formation is conformable. The contact is fairly sharp and the contrast between the siltstone and shale of the St. Lawrence Formation and underlying fine- to medium-grained, quartzose sandstone in the Mazomanie Formation of the Tunnel City Group is distinct.

Cw **Wonewoc Sandstone (Late Cambrian)**—This sandstone unit, formerly referred to as the Ironton-Galesville Sandstone, is composed mostly of fine- to coarse-grained, moderately to well sorted, light gray, cross-stratified, quartz sandstone (Mossler, 2008). White, brown, and black linguliform brachiopod shells are locally abundant. The upper part is the coarsest-grained; the lower part is finer-grained, better sorted, and progressively finer-grained toward its base. The very fine-grained sandstone in the lower part is feldspathic. The thickness of the formation is 75 to 110 feet (23 to 34 meters), except where it pinches out in unconformable contact against knobs of Keweenawan basalt near Taylors Falls. The Wonewoc Sandstone is conformable with overlying and underlying formations; however, there is a subtle unconformity marked by a pebbly sandstone layer within the formation (Runkel and others, 1998).

Ce **Eau Claire Formation (Middle to Late Cambrian)**—The formation is composed of yellowish-gray to pale olive-gray, fine- to very fine-grained, feldspathic sandstone, siltstone, and shale. White and brown linguliform brachiopod shells are common. The Eau Claire Formation gradually coarsens to the north across Chisago County, and as a result is composed dominantly of very fine- to fine-grained sandstone in the northern one-half of the county. The formation ranges from 60 to 90 feet (18 to 27 meters) in thickness, except where it pinches out in unconformable contact against knobs of Keweenawan basalt near Taylors Falls. The contact with the Mt. Simon Sandstone is conformable.

Cm **Mt. Simon Sandstone (Middle Cambrian)**—The Mt. Simon Sandstone is pale yellowish-brown to grayish-orange-pink to light gray, medium- to coarse-grained, quartz sandstone. Interbeds of shale, siltstone, and very fine-grained, feldspathic sandstone are common, particularly in its upper half (Mossler, 1992), and in the lower several tens of feet of the Mt. Simon Sandstone in the North Branch area. Inarticulate brachiopod shells are locally common in the upper one-third of the formation. Thin beds of quartz-pebble conglomerate occur at several stratigraphic positions, and are especially abundant near the base of the formation. The Mt. Simon Sandstone unconformably overlies Mesoproterozoic rocks, burying a surface of erosion that had hundreds of feet of relief within the county. As a result, the thickness of the Mt. Simon Sandstone is markedly variable even within small areas such as near Taylors Falls. Based on a limited number of full penetrations of the formation, it appears to have a maximum thickness of about 250 feet (76 meters) across most of the county.

MESOPROTEROZOIC ROCKS

KEWEENAWAN SUPERGROUP

Psu **Sandstone, siltstone, and minor shale**—Sedimentary rocks consisting largely of reddish-brown mudstone and siltstone, and lithic and feldspathic sandstone (Morey, 1977). They are poorly known in Chisago County, represented only by a handful of borehole cuttings samples, gamma logs, and two video logs. Therefore they cannot be confidently assigned to individual formations, but likely correlate to parts of the Solar Church and/or Fond du Lac Formations. Mooney and others (1970) suggested that some parts of the sedimentary package may be interbedded with mafic volcanic rocks. Geophysical modeling implies that this unit is more than 0.6 mile (1 kilometer) thick in the area between the Pine and Douglas faults, and more than 2 miles (3 kilometers) thick to the west of the Douglas fault, beneath the Paleozoic rocks (Allen and others, 1997).

Pcv **Chengwatana Volcanic Group**—A thin panel of dominantly basaltic volcanic rocks located between the Pine and Douglas faults (Cannon and others, 2001). Rocks of the Chengwatana Group are not exposed in Chisago County, but likely are similar to exposures in nearby Pine County, which are composed of steeply east-dipping flows of basalt, porphyritic basalt, and interlayered conglomeratic sedimentary rocks (Boerboom, 2001).

Pcf **Clam Falls Volcanics**—A thick succession of largely mafic volcanic rocks between the Pine fault on the west and the Cottage Grove–Lake Owens fault on the east in Wisconsin (Cannon and others, 2001). Outcrops near Taylors Falls consist of thick, coarsely-grained, ophitic basalt flows with thick, fragmental flow tops, and thinner flows of fine-grained, intergranular basalt and porphyritic basalt. All the exposed flows contain abundant epidote and actinolite, which indicates that the flows were deeply buried (approximately 4.7 miles [7.5 kilometers]; Wirth and others, 1998) prior to uplift of the St. Croix Horst (see Plate 2, Fig. 2). Based on deep seismic profiles the thickness of the remaining volcanic rocks in the St. Croix Horst beneath the Clam Falls Volcanics is estimated to be approximately 5 miles (8 kilometers). The Clam Falls volcanics underlie Paleozoic bedrock across a large expanse of southeastern Chisago County. They subcrop beneath unconsolidated Quaternary material in deep bedrock valleys, and are exposed as the uppermost bedrock in the Taylors Falls area.

ACKNOWLEDGMENTS

Funding was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR), and the U.S. Geological Survey as part of the 2008 State Geologic Survey Mapping Component (STATEMAP) of the National Geologic Mapping Program. Ted Starns assisted with field mapping. V.W. Chandler (Minnesota Geological Survey) compiled and in part revised seismic and airborne geophysical data. B.J. Bonin, WSB and Associates, provided data and insight into the interpretation of the geologic setting of the North Branch area.

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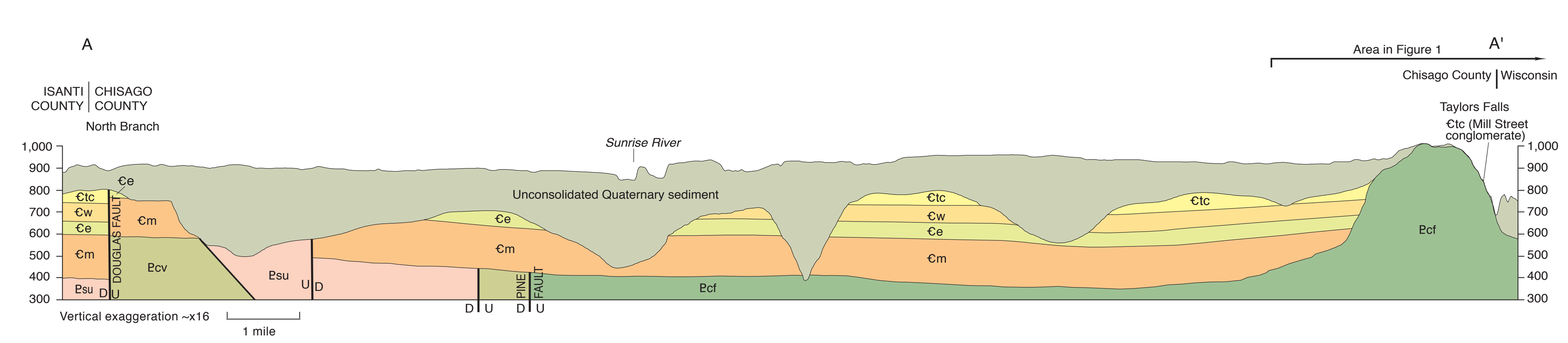


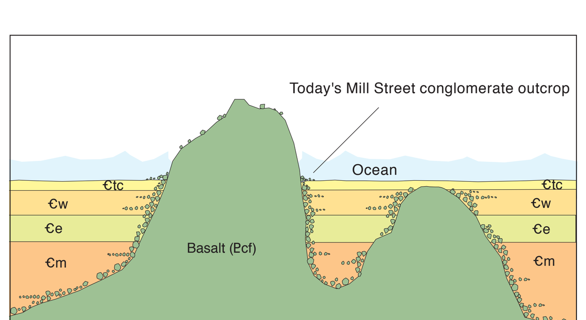


Figure 1. Schematic illustration of the depositional conditions about 490 million years ago in the area known today as Taylors Falls, Minnesota, and St. Croix Falls, Wisconsin. The Cambrian sedimentary bedrock present in the area today was deposited in a shallow sea, with resistant knobs of Proterozoic basalt (Pcf) emergent as islands. Very close to these islands, basalt boulders and cobbles were incorporated into the Cambrian deposits (Cm, Ce, Cw), locally forming conglomerate, such as the Mill Street conglomerate (Berkey, 1897) in Taylors Falls.

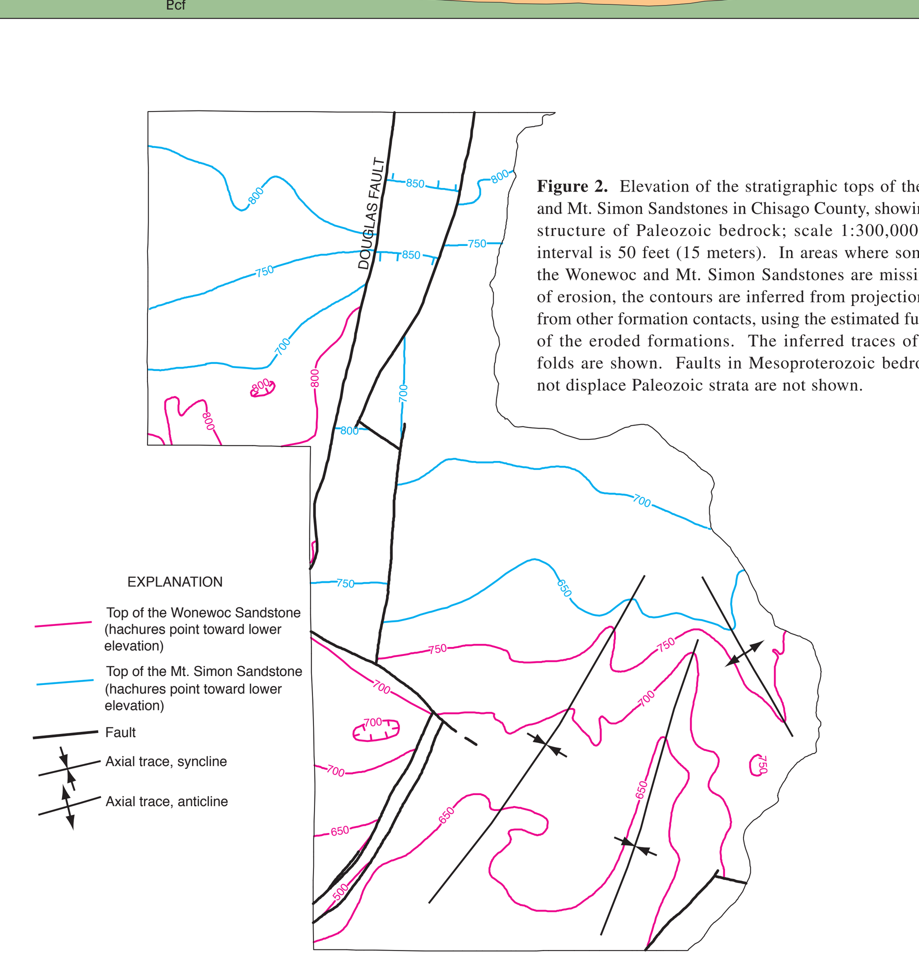


Figure 2. Elevation of the stratigraphic tops of the Wonewoc and Mt. Simon Sandstones in Chisago County, showing geologic structure of Paleozoic bedrock; scale 1:300,000. Contour interval is 50 feet (15 meters). In areas where some or all of the Wonewoc and Mt. Simon Sandstones are missing because of erosion, the contours are inferred from projection vertically from other formation contacts, using the estimated full thickness of the eroded formations. The inferred traces of faults and folds are shown. Faults in Mesoproterozoic bedrock that do not displace Paleozoic strata are not shown.

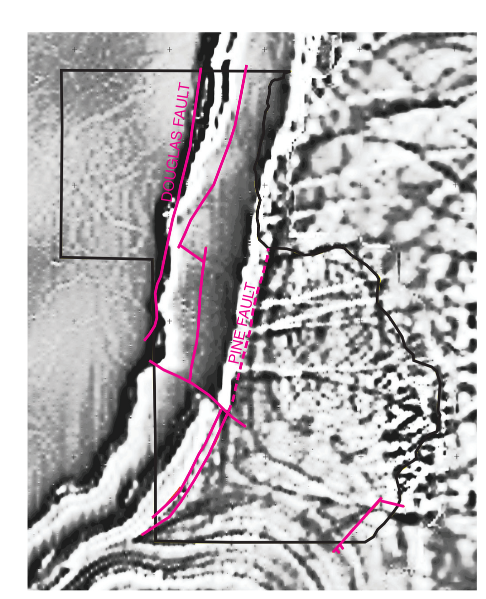


Figure 3. Faults mapped in Chisago County superimposed on first vertical derivative aeromagnetic data (Chandler and others, 2004). All faults except those in extreme southeastern Chisago County are part of major fault zones along the western side of the Midcontinent Rift System, recognizable by strong, abrupt, linearly extensive contrasts in magnetic intensity. The faults in the southeastern part of the county do not appear to correspond to distinct, linear anomalies. Faults that displace Paleozoic bedrock, shown as solid pink lines, were reactivated during and after Early Paleozoic time. Their position at the bedrock surface does not everywhere correspond to the magnetic anomaly that marks the position of the major faults in underlying Mesoproterozoic bedrock, but their similar trends and close proximity indicate they are related features. Dashed pink line shows another major Midcontinent Rift System fault that does not appear to displace Paleozoic bedrock.

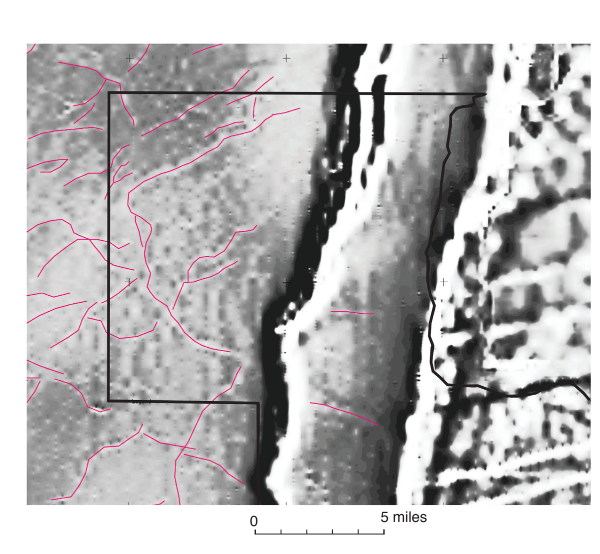
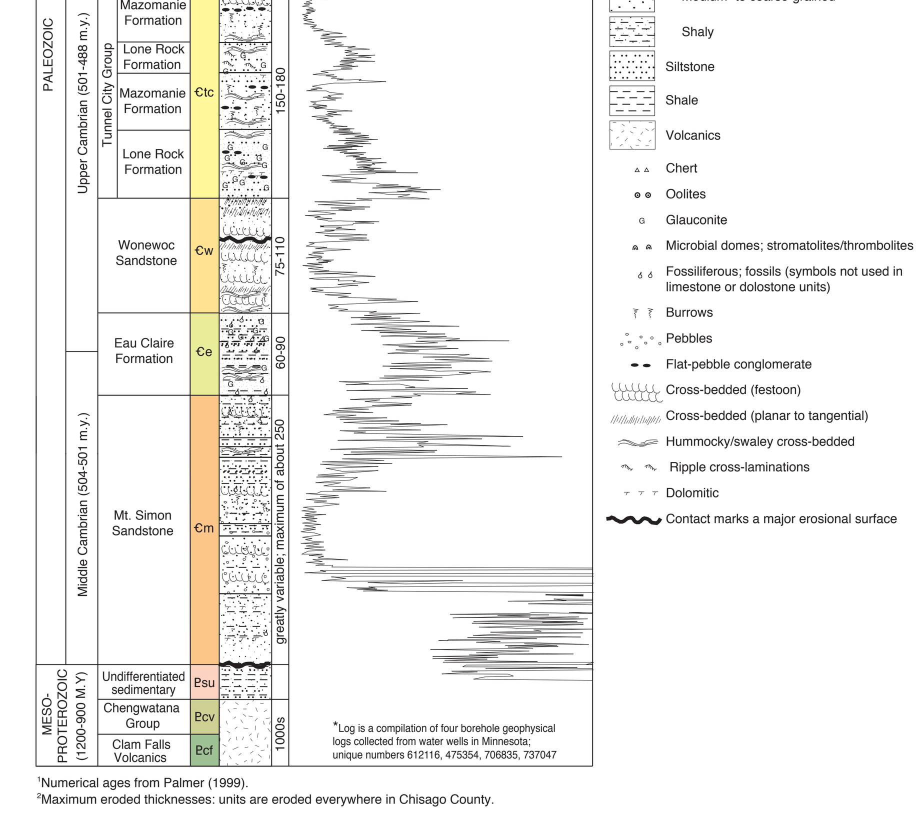


Figure 4. Map of second vertical derivative magnetic anomaly data in the northern part of Chisago County showing "stream-like" anomalies, traced with thin, magenta lines, that represent buried bedrock valleys. The buried valleys contain a relatively great thickness of moderately magnetic glacial deposits, which is visible as a magnetic anomaly in areas where the underlying regional bedrock is comparatively non-magnetic. Together with drillhole data, these anomalies were used to produce the bedrock topography contours shown on the geologic map in the northwestern part of the county. See Chandler and others (2002) for additional information on use of magnetic anomalies for buried valley delineation.

STRATIGRAPHIC COLUMN



[1]Numerical ages from Palmer (1999).
[2]Maximum eroded thicknesses: units are eroded everywhere in Chisago County.

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.

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