UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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COUNTY ATLAS SERIES
ATLAS C-57, PART A
Dakota County
Plate 2—Bedrock Geology

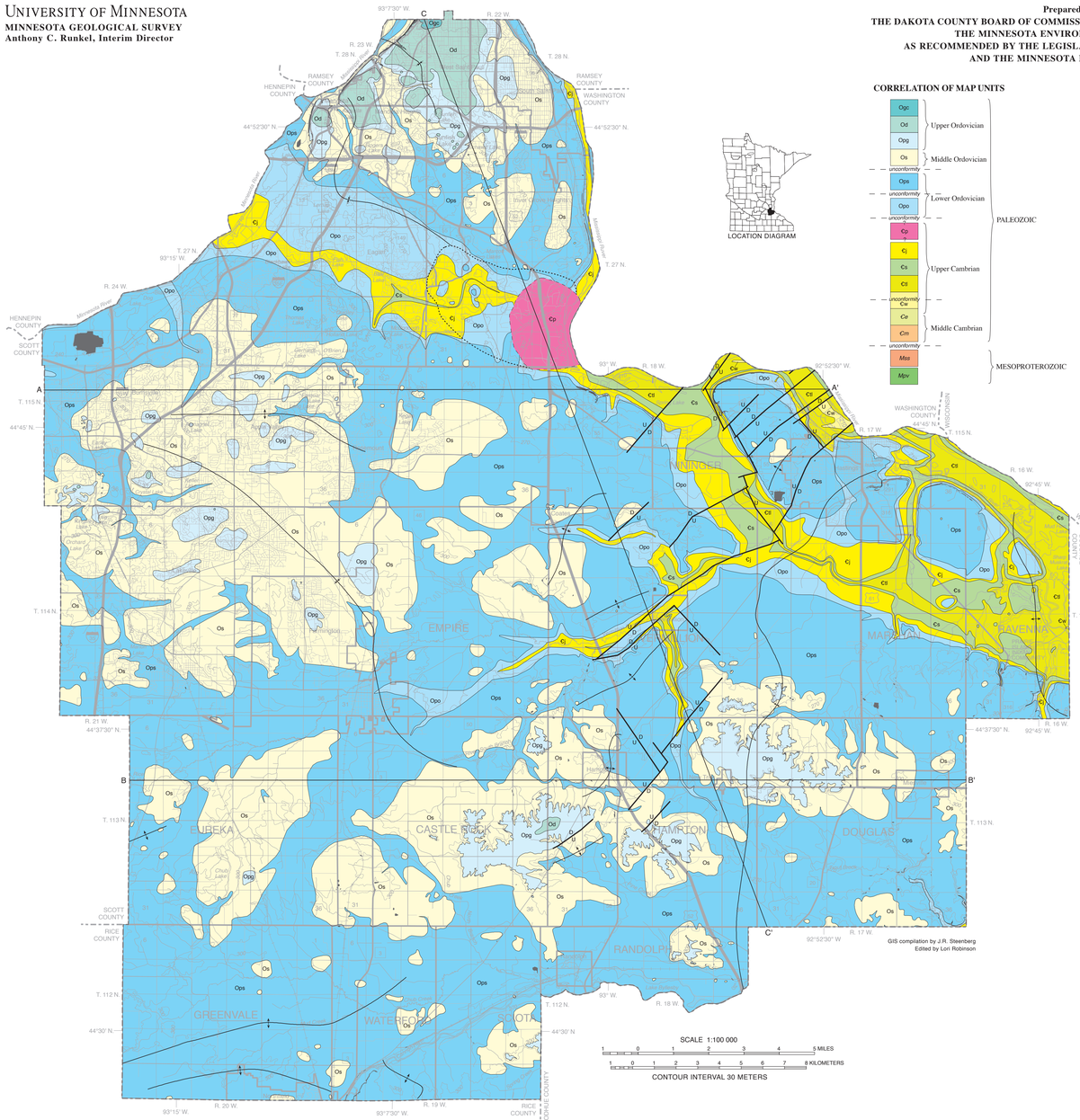
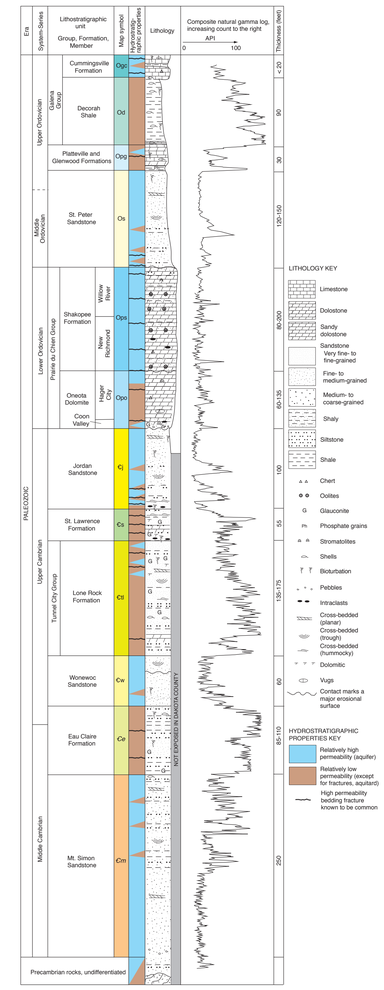


Figure 1. Generalized stratigraphic column depicting the lithology, thickness, vertical succession, age, and hydrostratigraphic properties for all units shown on the map and in cross sections, as well as a schematic depiction of relative competence in outcrop where exposed. Units below the Wonewoc Sandstone are not present on the map surface and are shown only on the cross sections and within the supplementary GIS data. The gamma log is a compilation of the following borehole geophysical logs from Dakota County on file at the Minnesota Geological Survey: County Well Index unique numbers 783608 (Precambrian to Shakopee Formation), 127263 (Shakopee Formation to St. Peter Sandstone) and 250765 (St. Peter Sandstone to Cummingsville Formation).



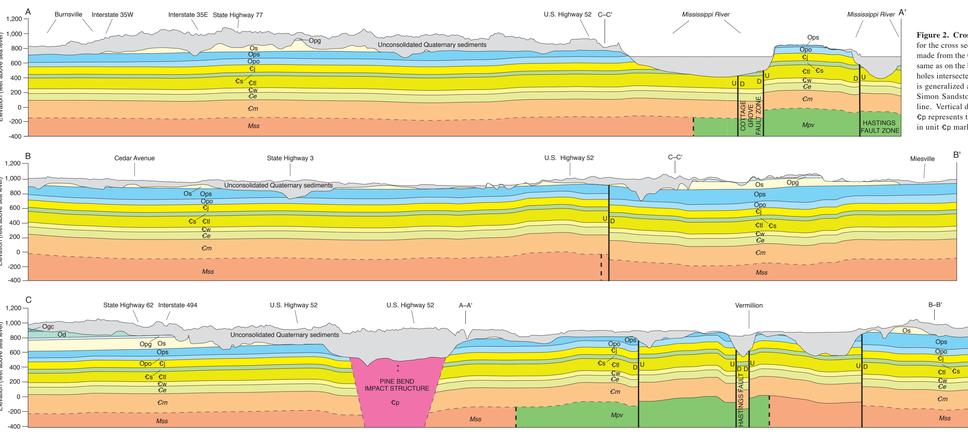


Figure 2. Cross sections—Every attempt has been made for the cross sections to match all geologic interpretations made from the County Well Index data. Symbology is the same as on the bedrock map. Only a small number of drill holes intersected Mesoproterozoic bedrock, thus the relief is generalized and inferred from the thickness of the Mt. Simon Sandstone and marked with a horizontal dashed line. Vertical dashed lines represent inferred faults. Unit Cp represents the Pine Bend Impact Structure. Asterisks in unit Cp mark the location of shocked quartz.

MAP SYMBOLS

Geologic contact—Approximately located. Dashed where inferred.

Fault—Faults are documented from abrupt changes in the elevation of stratigraphic units from subsurface and outcrop data. Letters indicate relative vertical displacement: U—up, D—down. Dashed where inferred.

Possible extent of disturbed strata related to the impact event.

Fold—Axial trace of anticline, syncline. Fold limbs typically have shallow dips and are inferred from subsurface data.

Location of geologic cross section.

Bedrock outcrop.

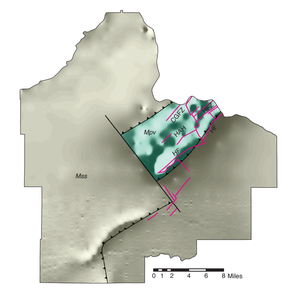


Figure 3. Faults that displace Paleozoic bedrock in Dakota County superimposed on a map of the first vertical derivative aeromagnetic data (Chandler, 1991) and the underlying Mesoproterozoic rock units (Jirsa and others, 2012). Paleozoic faults (magenta lines) and fault zones (CGFZ—Cottage Grove fault zone, HF—Hastings fault, HFZ—Hastings fault zone) are subparallel to strong, abrupt, linearly extensive contrasts in magnetic intensity in the underlying Mesoproterozoic rocks associated with the Midcontinent Rift. The aeromagnetic data display where a great thickness of magnetic Mesoproterozoic rift basalts (unit *Mpv*) have been brought near the surface in an inverted graben known as the Hudson–Afton horst (HAH), bounded by thrust faults, shown by black lines with teeth. Due to their similar trends and proximity, all Paleozoic faults are interpreted to have originated from reactivation of deep Mesoproterozoic structures (black lines). Abrupt thickness changes in the Prairie du Chien Group across the Hudson–Afton horst indicate that some faults were reactivated during Early Paleozoic (Early to Middle Ordovician) time.

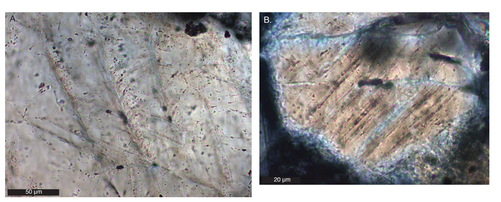


Figure 6. Photomicrographs of shocked quartz from drill cuttings within the Pine Bend Impact Structure.

A. Two sets of planar features (PFs), including feather features. PFs are planar, thin, parallel-walled fractures that are generally spaced more than 15 to 20 µm apart. Feather features are linked to shearing along the PFs during deformation.

B. One set of decorated planar deformation features (PDFs). PDFs are typically composed of narrow, individual planes of amorphous material that are less than 5 µm thick, comprising straight, parallel sets of features that are spaced 2 to 10 µm apart. PDFs that are decorated have fluid inclusions. Decorations are generally less than 2 µm in size; their presence greatly facilitates detection of PDFs at the scale of the optical microscope. Photos by L. Ferrière at Vienna Museum of Natural History.

BEDROCK GEOLOGY

By

Julia R. Steenberg

2023

INTRODUCTION

The geologic map, cross sections, and stratigraphic column on this plate depict the type, distribution, and structure of the bedrock units in Dakota County that are either exposed at the land surface or lie directly beneath unconsolidated Quaternary sediments of variable thickness (Figs. 1, 2; Plate 3, *Surficial Geology*; Plate 4, *Quaternary Stratigraphy*; Plate 6, *Depth to Bedrock and Bedrock Topography*). The map shows how the bedrock surface would appear if it was viewed from an aerial perspective and the overlying Quaternary sediments were stripped away. The bedrock units near the land surface in Dakota County consist of sedimentary rocks of Paleozoic age that form distinguishable and mappable layers designated as formations. These units are commonly exposed along the Mississippi and Minnesota River bluffs, along roadcuts, within rock quarries, and in bedrock buttes and river valleys in the southern portion of the county. Some of the Paleozoic bedrock formations are major reservoirs for the water supply in Dakota County and some provide a source of crushed carbonate rock.

Lithologic and hydrostratigraphic characteristics of each formation are given in the stratigraphic column (Fig. 1) and in the description of map units. The accompanying bedrock geologic cross sections (Fig. 2) add the dimension of depth and illustrate the stratigraphic, structural, and topographic relationships of the bedrock units, as well as the variable thickness of the overlying Quaternary sediments. The geologic formations are thin in relation to their aerial extent and would only be one tenth as thick as shown on the cross sections if no vertical exaggeration was used. The exaggeration is necessary to show the thin rock formations and gives the appearance of steeper slopes on bedrock unit contacts, the land surface, and bedrock topography. Surfaces representative of the elevation of the tops of the mapped formations are also available as raster grids for use in GIS programs within the supplementary digital and GIS files for this atlas (https://conservancy.umn.edu/handle/11299/57196).

Production of the map and associated products relied on several data sources, including outcrops, water-well and scientific drilling records, rock core, drill-cutting samples, borehole geophysical logs, seismic soundings, geophysical images, and previously published geologic maps of and within Dakota and adjacent counties (Mossler and Tipping, 2000; Mossler, 2006a, b, c, d, 2013; Steenberg and Retzler, 2016; Retzler, 2018). The data sources and their irregular distribution and density can be seen on Plate 1, *Database Map*, and this should be considered when assessing the reliability of the map at any location. Areas with a high density of bedrock control points are more likely to have an accurate interpretation of the bedrock geology, whereas areas with widely spaced control points may have less reliable interpretation and be inappropriate for site-specific needs. During production of this map, the records of 7,952 located boreholes with stratigraphic information existed within Dakota County in the County Well Index and nearly 6,142 of those reached bedrock. Geologic interpretations of subsurface material described by drillers or gathered from other data sources were updated by the author and are available in the County Well Index. Every reasonable effort has been made for the geologic interpretations in the County Well Index to correspond to the map.

This map supersedes the previous bedrock geology map of Dakota County (Mossler, 1990). Significant improvements and modifications were made to the previous map based on additional water-well records, rock core, drill-cutting samples, borehole geophysics, and refined geophysical images. In contrast to the previous map, most of the formations are now mapped separately, including the Oneota Dolomite, Shakopee Formation, St. Lawrence Formation, and Tunnel City Group (previously the Franconia Formation). Formal groups, formations and members are defined in Mossler (2008). The position of faults and folds in the county were updated to reflect new data showing significant offset and structural dip in the Paleozoic formations. This new level of detail for the subsurface geologic conditions will improve models of groundwater flow.

GEOLOGIC HISTORY

The oldest known bedrock in the county, which is Precambrian in age, lies unconformably beneath the Paleozoic sequence at great depths and is only inferred on the cross sections and shown in Figure 3. Geologic interpretations of the Precambrian bedrock where deeply buried rely significantly on aeromagnetic and gravity data. These data suggest the county is underlain by Mesoproterozoic (approximately 1,100-million-year-old [Ma]) rocks of the Keweenawan Supergroup associated with the Midcontinent Rift, including sandstone, siltstone, and shale of the Hinckley Sandstone and Solor Church and Fond du Lac Formations (unit *Mss*). The northeastern area of Dakota County is underlain by the Powder Mill volcanic rocks (unit *Mpv*) and bounded by thrust faults. Due to their deep burial and limited subsurface data, the distribution of these individual units is less certain than for the Paleozoic units. Therefore, the contact between the top of these units and the overlying base of the Mt. Simon Sandstone is dashed on the cross sections. No new mapping of these units was done for this project. Instead, the Precambrian bedrock geology of Minnesota is depicted from the most recent compilation map (Fig. 3; Jirsa and others, 2012).

Paleozoic rocks unconformably overlie the Precambrian bedrock. They are characterized by relatively thin, widespread layers of sandstone, shale, and carbonate deposited in shallow seas during the Cambrian and Ordovician Periods of the Paleozoic Era, from about 500 to 450 million years ago (Mossler, 2008). The older, Cambrian-age formations are dominated by siliciclastic sedimentary rock including sandstone and siltstone with minor shale, such as the Jordan Sandstone. Carbonate rock is present only as relatively thin layers within these units. Ordovician-age formations, in contrast, are dominated by thicker units of carbonate rock with less sandstone and shale, such as the Oneota Dolomite and Shakopee Formation of the Prairie du Chien Group. The sedimentary rocks differ in their resistance to weathering and erosion, as indicated by the weathering profile on the lithology column of Figure 1. The units that cover the largest areas of the map are the most resistant to weathering, and generally form plateaus composed of carbonate rock (limestone and dolostone). The soft sandstone and shale formations are easily eroded and occur within the walls of valleys and plateau slopes.

Where carbonate rock and silica-rich (quartzose) sandstone are near the land surface (within 50 feet [15 meters]), they are considered an economically viable geologic resource. The silica-rich sandstone is texturally mature and well-rounded and has a variety of industrial uses, such as for oil and gas production, glass making, foundry operations, ceramics, filtration, and agriculture. Carbonate rock products are crushed, sorted, and used as construction material for roads and buildings, and in concrete operations. Viability of extraction is dependent on many factors, including detailed geologic conditions at individual sites, proximity to bulk transportation, current land ownership and use, regulatory requirements, rock properties, and many others. Figure 4 depicts where carbonate rock or quartzose sandstone is within 50 feet (15 meters) of the land surface and highlights the active quarry operations at the time this map was created. The southern half of Dakota County and areas adjacent to the Minnesota and Mississippi River valleys have the most significant areas of aggregate resources.

Across western Dakota County the Paleozoic strata dip (less than 1°) in a crescent shape to the northwest towards Minneapolis and St. Paul as part of the southern margin of a shallow structural depression known as the Twin Cities basin. As a result, progressively younger bedrock formations subcrop into northwest Dakota County towards the Twin Cities metropolitan area. In eastern Dakota County the strata dip west (less than 1°) following a regional trend seen to the south in Goodhue County. These two broad areas are separated by a series of faults that outline a significant uplift of Paleozoic bedrock. A fault is recognized where changes in the elevation of a bedrock contact occur within a very short distance, generally elevation changes of 50 feet (15 meters) or more within a distance of 1,000 feet (305 meters). The faults mapped in Dakota County are all inferred from drill-hole data, none are exposed in outcrop. Displacement along these faults in Dakota County is as much as 200 feet (61 meters), which is sufficient in many places to juxtapose different formations along the inferred fault. Bedrock that has dropped alongside a fault preserves relatively younger formations (shown with a D on the map) at the surface and bedrock that has been uplifted brings older formations closer to the surface (shown with a U on the map). A fold is inferred where these elevation changes indicate more gradual slopes. Fold axes are shown as a line and symbolized to indicate whether it is an anticline or syncline. Folds are oriented northeast–southwest and northwest–southeast. The stratigraphic top of the Jordan Sandstone was contoured at 25-foot (8-meter) intervals (Fig. 5A). This unit was selected to portray these structures because it has an easily recognized contact established at numerous and evenly distributed outcrop and drill-hole control points.

Several of the faults in Paleozoic strata are subparallel to faults in the underlying Mesoproterozoic Midcontinent Rift rocks, as inferred from geophysical imagery, and are therefore interpreted to represent reactivation of these older structures (Fig. 3). The aeromagnetic and gravity data show where a great thickness of dense and magnetic basalt has been brought near the surface in an inverted graben known as the Hudson–Afton horst (Sims and Zeitz, 1967; Cannon and others, 2001). Paleozoic rocks overlying the Hudson–Afton horst in Dakota County are also uplifted relative to the rocks on either side, although the displacement is less than that in the underlying Mesoproterozoic bedrock.

Reactivation of Midcontinent Rift faults can be documented to have occurred in Ordovician time. The Lower Ordovician Prairie du Chien Group is thinner (as thin as 130 feet [40 meters]) within the uplifted horst region and thickens to the east of the horst (as much as 320 feet [98 meters]; Fig. 5B). The thickness of the overlying St. Peter Sandstone does not show a similar trend, suggesting some displacement was during Early to Middle Ordovician time while the Oneota Dolomite and Shakopee Formation were being deposited, but had ceased while the St. Peter Sandstone was deposited later in the Ordovician Period. Additional displacement occurred sometime after the St. Peter Sandstone was deposited, because faults also continue through units as young as the Platteville Formation. This is similar to findings from mapping in adjacent Washington (Steenberg and others, 2015; Steenberg and Retzler, 2016) and Hennepin (Retzler and others, 2016; Retzler, 2018) Counties.

A geologically-disturbed area was discovered south of Inver Grove Heights and adjacent to the Mississippi River valley while producing this geologic map. Stratigraphic layers of the Jordan Sandstone and underlying units are out of place, or in some cases, completely overturned, as supported by several borehole geophysical logs paired with drill-cutting samples. Detailed examination of the drill-cutting samples within this area has revealed cloudy and fractured quartz sand grains (Fig. 6). Through microscopic analysis, these grains have been confirmed to be shocked quartz and known to only be produced by extreme shock compressions caused by meteorite impact (U. Reimold, written commun.). As such, this area (unit Cp) is referred to as the Pine Bend Impact Structure (Fig. 2, cross section C–C'). Further examination is needed to better understand the Pine Bend Impact Structure and the geology of its infill. Based on the limited drill-cutting samples and borehole geophysical logs, we estimate the size of the crater to be approximately 5 square miles (13 square kilometers), and the size of the meteor to have been several hundred meters in diameter, given what is known about crater-to-meteor size ratios (Grieve and Pilkington, 1996). Due to its location within a buried bedrock valley, the upper sequence of this structure has been eroded away and it is difficult to predict the timing of this event with such limited data. It may be as old as Late Cambrian, having occurred during or after deposition of the Jordan Sandstone. As much as 520 feet (158 meters) of overlying glacial sediments are above this structure within the deepest part of the buried valley, to as little as 155 feet (47 meters) where bedrock is closer to the land surface northeast of the structure.

HYDROSTRATIGRAPHY

The Paleozoic bedrock formations are significant sources of groundwater that provide the water supply for Dakota County. This map and associated products, such as the bedrock surfaces, provide a three-dimensional depiction of the rock properties that control flow in these water-bearing layers. Such rock properties are called hydrostratigraphic properties. The hydrostratigraphic classification, shown by brown and blue colors on the hydrostratigraphic column of Figure 1, distinguishes layers that are dominated by relatively high permeability (easily transmitting water) material versus layers dominated by lower permeability (relatively more difficult to transmit water) material. This generalized characterization for Dakota County is based on hydrogeologic reports by Runkel and others (2003, 2018, and references therein) and unpublished borehole and core data collected by the Minnesota Geological Survey. The high-permeability layers are potential aquifers, able to yield economic quantities of water in most places. The low permeability layers are potential aquitards that vertically retard flow, hydraulically separating the aquifer layers from one another in many places, and protecting water resources in the underlying layers. High-permeability bedding fractures are likely to be present, at least locally, in all formations in Dakota County, but are placed on the column where the hydrogeologic reports cited above indicate they are most common. The Precambrian bedrock does not directly supply water to Dakota County largely because sufficient water resources are available at shallower depths in the Paleozoic rocks. However, groundwater within the Precambrian units may be connected to the Mt. Simon Sandstone aquifer.

In Dakota County, some aquifers are layers dominated by coarse-grained sandstone, such as the St. Peter or Jordan Sandstone, in which water can be relatively easily transmitted in both horizontal and vertical directions through the pore spaces between sand grains, as well as through fractures. Parts of these aquifers, including the lower Jordan Sandstone, can locally contain low permeability strata that serve as small, internal aquitards (see Fig. 1). Other aquifers are composed mostly of carbonate rock (limestone or dolostone), such as the Shakopee Formation, in which water is transmitted mostly through a relatively dense network of fractures and other voids. Many of the voids in the carbonate bedrock are quite large, including cave networks. Their sizes and connectivity have been enhanced as a result of solution in a karst system. The Prairie du Chien Group is considered a karst system in Dakota County. The St. Peter Sandstone is also known to contain karst features in Dakota County. Karst features may be expressed at the land surface by springs and sinkholes in areas with only a thin cover of unconsolidated material, but the same aquifer properties commonly exist in areas with greater cover and with few, if any, obvious surface karst features.

Most layers designated as aquitards in the county have a much lower permeability in a vertical direction than do aquifers. Examples in Dakota County include the St. Lawrence and Eau Claire Formations. These rocks are composed mostly of very fine-grained sand, silt, and shale with small, poorly connected pore spaces. Carbonate rock with relatively sparse fractures, such as the lower part of the Oneota Dolomite, are also aquitards. However, layers designated as aquitards with very low permeability in a vertical direction may contain horizontal fractures that are conductive enough to yield large quantities of water. Horizontal and vertical fractures are also more common where bedrock layers are at or near the bedrock surface. As a result, aquitards in such conditions are likely to have higher permeability compared to deeper conditions of burial and may have a diminished ability to retard water flow to underlying aquifers. There is no precise boundary between shallow and deep conditions of burial, but in most areas of southeastern Minnesota about 50 feet (15 meters) of depth below the bedrock surface is considered a best approximation (Runkel and others, 2006). In addition to this hydrostratigraphic classification, the Minnesota Department of Natural Resources, as Part B of the Dakota County atlas, will conduct a thorough hydrogeologic study of the groundwater flow system, groundwater chemistry, aquifer capacity, and aquifer sensitivity, which may or may not result in modifications or additions to this classification. Furthermore, designations of aquifers versus aquitards made here may not correspond precisely with those made for regulatory purposes by the Minnesota Department of Health.

ACKNOWLEDGEMENT

The Minnesota Geological Survey gratefully acknowledges permission granted by the Prairie Island Indian Community for geologic mapping on tribal land within Dakota County.

DESCRIPTION OF MAP UNITS

PALEOZOIC

Galena Group (Upper Ordovician)

Ogc — ***Cummingsville Formation***—Limestone interbedded with shale. Limestone is yellowish-gray, shaly, fossiliferous, and fine-grained. The Cummingsville Formation has a maximum preserved thickness of 20 feet (6 meters) in the northernmost portion of Dakota County. Interpreted from geophysical logs and previous stratigraphic studies of the Decorah Shale in Lilydale, Minnesota (Rice, 1985).

Od — ***Decorah Shale***—Dominantly grayish-green, calcareous shale interbedded with thin beds of fossiliferous limestone. Fossiliferous, yellowish-brown limestone beds are most common at the base of the Decorah Shale, as part of the basal Carimona Member. The Decorah Shale is present mainly in the northern portion of Dakota County with some small erosional remnants in the south. The Decorah Shale has a thickness of 90 feet (27 meters) where fully present near the Mississippi River bluffs. Formerly mined near Lilydale for clay to make brick and tile.

Opg — **Platteville and Glenwood Formations, undivided (Upper Ordovician)**—The Platteville Formation is tan to gray, fossiliferous limestone and dolostone. The underlying Glenwood Formation is dominantly a green-gray, sandy shale. The Platteville Formation is present in the northern portion of Dakota County; small erosional remnants in the west-central and southern areas of the county cap bedrock cored buttes. The combined thickness of the formations is 30 feet (9 meters).

Platteville Formation—The Platteville Formation is generally 25 feet (8 meters) thick. It is composed of tan to gray limestone and dolostone. It is commonly burrowed, mottled, and fossiliferous. It contains fine- to coarse-grained quartz sand and phosphate grains in the lowermost 2 feet (0.6 meter). Formerly quarried for rock aggregate and building stone near south St. Paul. It may be as thick as 30 feet (9 meters) in the northernmost part of the county and thins to 18 feet (5 meters) in the southeastern part of the county.

Glenwood Formation—The Glenwood Formation is composed of green to brownish-gray shale. It is calcareous and contains phosphatic grains. The lower half contains significant fine- to medium-grained quartz sand grains. The Glenwood Formation is 3 to 5 feet (1 to 1.5 meters) thick in northern Dakota County and reaches a thickness of 10 feet (3 meters) farther south.

Os — **St. Peter Sandstone (Middle to Lower Ordovician)**—The upper half to two-thirds of the St. Peter Sandstone is mostly a white to tan, fine- to medium-grained, friable quartzose sandstone and referred to as the Tonti Member. Bedding and other sedimentary structures are generally absent. It is exposed along the Mississippi and Minnesota River valleys and in the southern half of the county along the sides of the bedrock buttes. The lower portion, referred to as the Pigs Eye Member, includes white to gray feldspathic shale and siltstone interbedded with coarser-grained sandstone. The Pigs Eye Member is not exposed in Dakota County. The thickness of the St. Peter Sandstone varies from about 120 to 150 feet (37 to 46 meters), thickening towards the northwest within the Twin Cities basin. The basal contact of the formation with the underlying Shakopee Formation (unit Ops) is a major erosional unconformity (Smith and others, 1993). Natural and human-made caves occur in the St. Peter Sandstone along the Mississippi River bluffs and have been used for a variety of purposes over the years, including for glass making.

Prairie du Chien Group (Lower Ordovician)—Dominated by dolostone interlayered with lesser amounts of quartz sandstone. Outcrops are common in Dakota County including along the Mississippi, Minnesota, Cannon, Vermillion, and Trout Brook River valleys. Small, patchy outcrops are common throughout southern Dakota County where the Quaternary sediments are thin. The Prairie du Chien Group is a significant source of rock aggregate in the county with several large quarries. The Prairie du Chien Group is formally divided into two formations: the Shakopee Formation and underlying Oneota Dolomite. The full thickness of the Prairie du Chien Group varies across Dakota County, from 130 feet (40 meters) in the northwest to over 300 feet (91 meters; Fig. 5B) in the southeast. Faulting along the Hudson–Afton horst shows thinning of the Prairie du Chien Group where there is uplift, and thickening to the east where there has been downward movement. This is consistent with relationships to the north in Washington County, providing further evidence for syndepositional faulting along the Hudson–Afton horst (Steenberg and Retzler, 2016).

Ops — ***Shakopee Formation***—A heterolithic unit composed of tan- to orangish-brown dolostone, sandy dolostone, sandstone, and shale. It may contain oolites, intraclasts, fossilized microbial mats (stromatolites), and chert nodules. Thickness of the Shakopee Formation beneath the St. Peter Sandstone varies across the county ranging from 80 feet to slightly over 200 feet (24 to 70 meters). It is thickest along and east of the Hudson–Afton horst. The Shakopee Formation thins on the west side of the Hudson–Afton horst and farther northwest into the Twin Cities basin. There are two members of the Shakopee Formation recognized in Minnesota, the Willow River and the New Richmond Members. The New Richmond Member is the lower part of the Shakopee Formation and is composed of fine- to medium-grained quartz sandstone as well as oolitic sandy dolostone. It is generally less than 10 feet (3 meters) thick in Dakota County and can be difficult to discern from the overlying Willow River Member (Squillace, 1979).

Opo — ***Oneota Dolomite***—A yellowish-gray to light brown, medium- to thick-bedded dolostone that generally lacks sedimentary features such as oolites and quartz sand characteristic of the Shakopee Formation, except in its lowermost part. The Oneota Dolomite ranges from 55 feet (17 meters) thick in the northwesternmost part of the county and thickens to 130 feet (40 meters) thick in the southeasternmost part of the county near Miesville. The formation contains two members: the Hager City and the Coon Valley. The basal Coon Valley Member is heterolithic, composed of thinly bedded dolostone, sandy dolostone, and beds of fine- to coarse-grained, poorly sorted quartz sandstone. The thickness of the Coon Valley Member is generally 5 to 20 feet (1.5 to 6 meters) but can reach thicknesses of 40 feet (12 meters) in the southeasternmost part of the county near Miesville. The Hager City Member is primarily very finely crystalline dolostone, with microbial textures. Its thickness follows a similar trend as the Coon Valley Member in being thicker to the east of the Hudson–Afton horst and is thickest in the southeasternmost part of the county near Miesville, where it may reach thicknesses over 100 feet (30 meters).

Cp — **Pine Bend Impact Structure (informal, Upper Cambrian or younger)**—As much as 575 feet (175 meters) of mixed sandstone, siltstone, and shale (Fig. 2, cross section C–C'). Interpreted from drill-cutting samples and borehole geophysical logs. Parts of the sequence are similar to local Cambrian and Precambrian stratigraphic units, but are out of stratigraphic order, and in places are overturned. Included is glauconitic, very-fine-grained sandstone with dolomitic cement and phosphatic brachiopods similar to the Eau Claire Formation or Tunnel City Group, and quartzose sandstone similar to the Jordan, Wonewoc, and Mt. Simon Sandstones. Sediments similar to the Mesoproterozoic unit *Mss* include subrounded to angular, medium- to coarse-grained feldspathic sandstone with pebbles of rhyolite and basalt, micaceous green and red shale, and dark gray carbonate-rich shale and siltstone. An interval of about 85 feet (26 meters) that cannot be confidently assigned to a known formation is dominated by poorly sorted quartz and very coarse- to fine-grained feldspathic sandstone with cloudy and fractured quartz grains. Many of the quartz grains have planar deformation features, narrow planes of glassy material within the quartz grains, arranged in parallel sets that have distinct orientations with respect to the grain's crystal structure. Such grains are referred to as "shocked quartz" and are diagnostic of a meteorite impact site (for example French and Short, 1968; Fig. 6).

Cj — **Jordan Sandstone (Upper Cambrian)**—Dominantly white to yellow, very fine- to coarse-grained, friable quartz sandstone characterized by coarsening-upward sequences consisting of two interlayered facies (Runkel, 1994); medium- to coarse-grained, cross-stratified, generally friable, quartz sandstone; and very fine-grained, commonly bioturbated, feldspathic sandstone with 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 Cs), although there are lithologically similar intervals intercalated with the medium- to coarse-grained facies at higher stratigraphic intervals. An unconformity, locally marked by thin beds of quartz pebble conglomerate and silcrete-cemented sandstone clasts (Runkel and others, 1999, 2007), separates the Jordan Sandstone from the overlying Oneota Dolomite. The Jordan Sandstone is exposed along the Mississippi River in Nininger township and ranges in thickness from 80 to 100 feet (24 to 30 meters).

Cs — **St. Lawrence Formation (Upper Cambrian)**—Mostly well-cemented, thin to medium beds of tan to gray siltstone, dolomitic siltstone, very fine-grained sandstone, and very thin shale. Glauconite is present throughout the formation. Intraclastic beds are present near the top and at the base of the unit. The St. Lawrence Formation is 45 to 55 feet (14 to 17 meters) thick.

Tunnel City Group (Upper Cambrian)

Csl — ***Lone Rock Formation***—Sandstone, siltstone, and shale. Sandstone is pale yellowish-green, fine- to very fine-grained, glauconite-rich, and feldspathic. Sandstone beds may be cross-bedded and bioturbated. Shale is green and gray. White, brown, and black linguliform brachiopod shells are locally abundant in the lower part of the formation. Pink dolostone beds are present near the base of the formation. Generally coarser-grained and more poorly cemented than the St. Lawrence Formation. Thickness of the Lone Rock Formation varies from 135 to 175 feet (41 to 53 meters).

Cw — **Wonewoc Sandstone (Upper Cambrian)**—Fine- to coarse-grained, quartzose sandstone. White, brown, and black linguliform brachiopod shells are locally abundant. The lower part is well- to moderately sorted, with minor shale, siltstone, and very-fine-grained sandstone. The upper part is moderately to poorly sorted, with substantial shale and siltstone interbeds. The Wonewoc Sandstone ranges from 55 to 70 feet (17 to 21 meters) thick.

Ce — **Eau Claire Formation (Middle to Upper Cambrian; shown only on cross sections)**—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. Glauconite is present throughout. The formation ranges from 85 to 110 feet (26 to 34 meters) in thickness. The contact with the Mt. Simon Sandstone is conformable.

Cm — **Mt. Simon Sandstone (Middle Cambrian; shown only on cross sections)**—Fine- to coarse-grained, quartzose, white to pale yellowish-brown sandstone. Interbeds of shale, siltstone, and very fine-grained feldspathic sandstone are common in the upper half. Inarticulate brachiopod shells are locally common in the upper third of the formation. Thin beds of quartz-pebble conglomerate occur at the base of the formation. The Mt. Simon Sandstone unconformably overlies Mesoproterozoic rocks. Based on a limited number of wells that fully penetrate the formation, its thickness ranges from 230 to 290 feet (70 to 88 meters).

MESOPROTEROZOIC

Keweenawan Supergroup

Mss — ***Sandstone, siltstone, and local conglomerate (shown on cross sections and Fig. 3)***—Includes the Hinckley Sandstone and the more feldspar- and lithic-rich sandstones and shales of the Fond du Lac (youngest detrital zircons approximately 1,000 Ma) and Solor Church Formations; deposited in eolian, fluvial, and lacustrine and marine environments. Previous investigations have noted there may be little to no Hinckley Sandstone in Dakota County. The reddish-brown, lithic, feldspathic sandstone and shale below the Mt. Simon Sandstone in western Dakota County is likely the Solor Church Formation. East of the Hudson–Afton horst in Dakota County is the light red to dark reddish-brown, poorly sorted feldspathic sandstones of the Fond du Lac Formation (Morey, 1977).

Mpv — **Powder Mill volcanic sequence (~1,099 Ma; shown on cross sections and Fig. 3)**—Part of the St. Croix horst.

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