UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director

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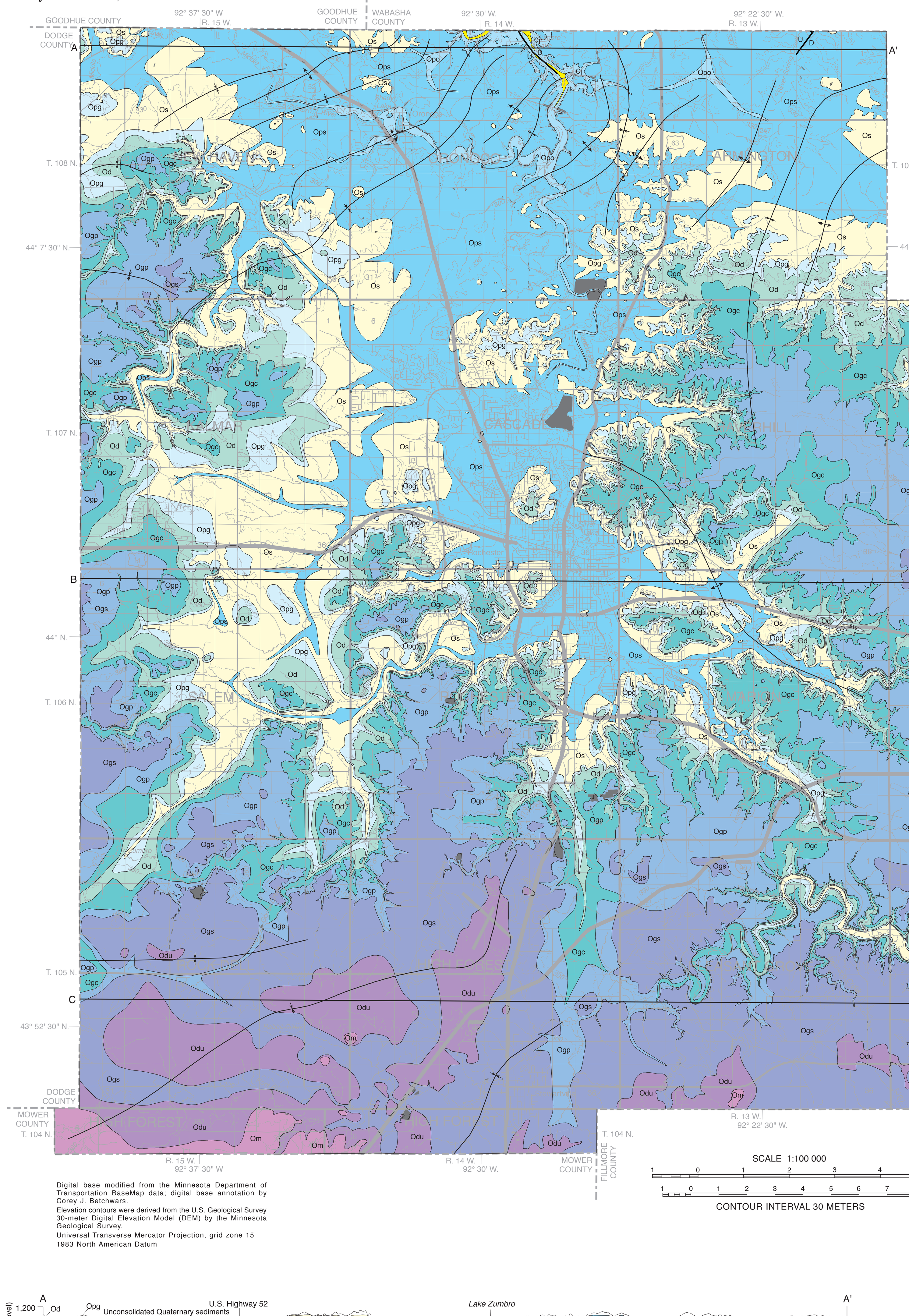
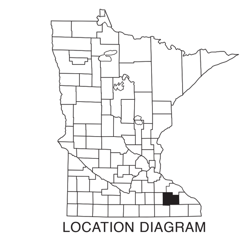


Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by Corey J. Betchwars.
Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.
Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

GIS compilation by J.R. Steenberg
Edited by Lori Robinson



MAP SYMBOLS

Geologic contact, approximately located

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

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

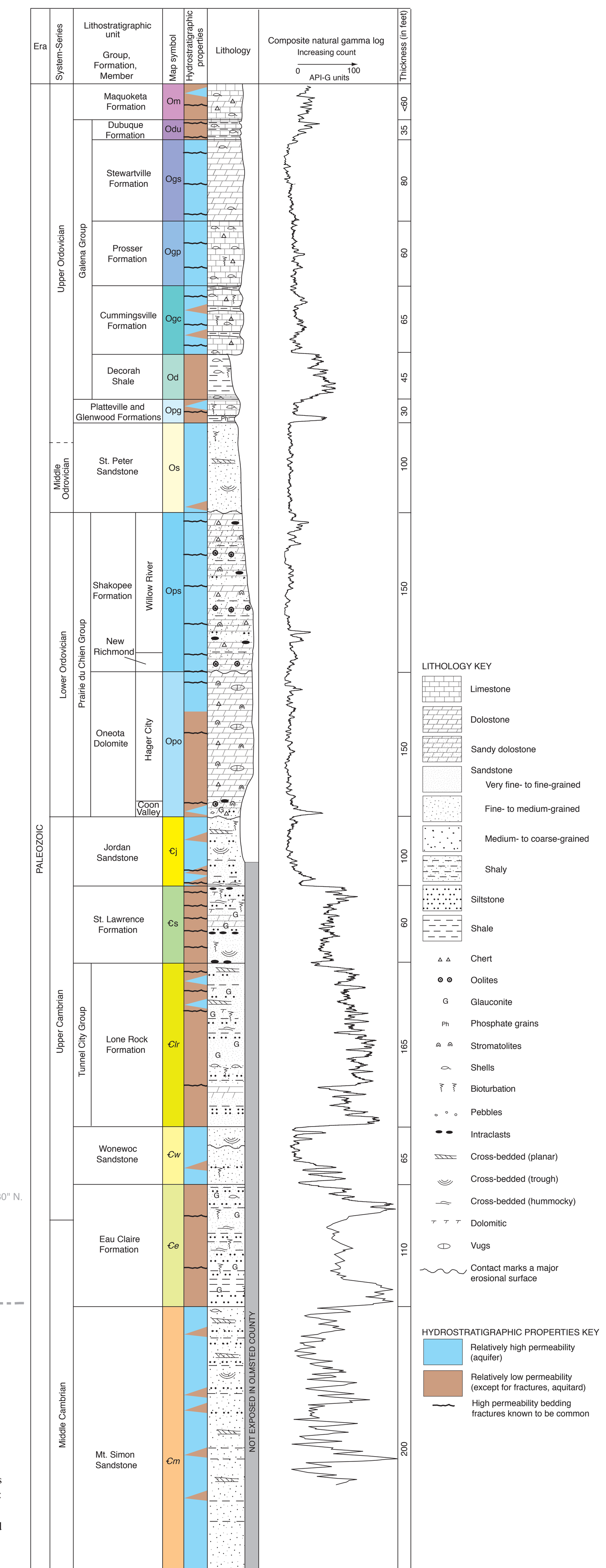


Figure 1. Generalized stratigraphic column depicting the lithology, thickness, vertical succession, age, and hydrostratigraphic properties for all units shown on the map, as well as the schematic depiction of relative competence in outcrop where exposed. Units below the St. Lawrence Formation are not present on the map surface and are only present at depths, 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 Olmsted and surrounding counties on file at the Minnesota Geological Survey: County Well Index unique numbers 580301 (Mt. Simon Sandstone to Eau Claire Formation), 220827 (Wonewoc Sandstone to Shakopee Formation), 658967 (Shakopee Formation to Prosser Formation), and 613709 (Stewartville Formation to Maquoketa Formation).

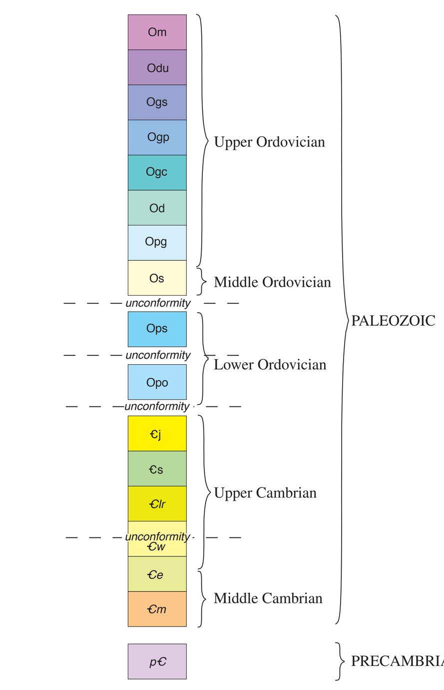
BEDROCK GEOLOGY

By

Julia R. Steenberg

2020

CORRELATION OF MAP UNITS



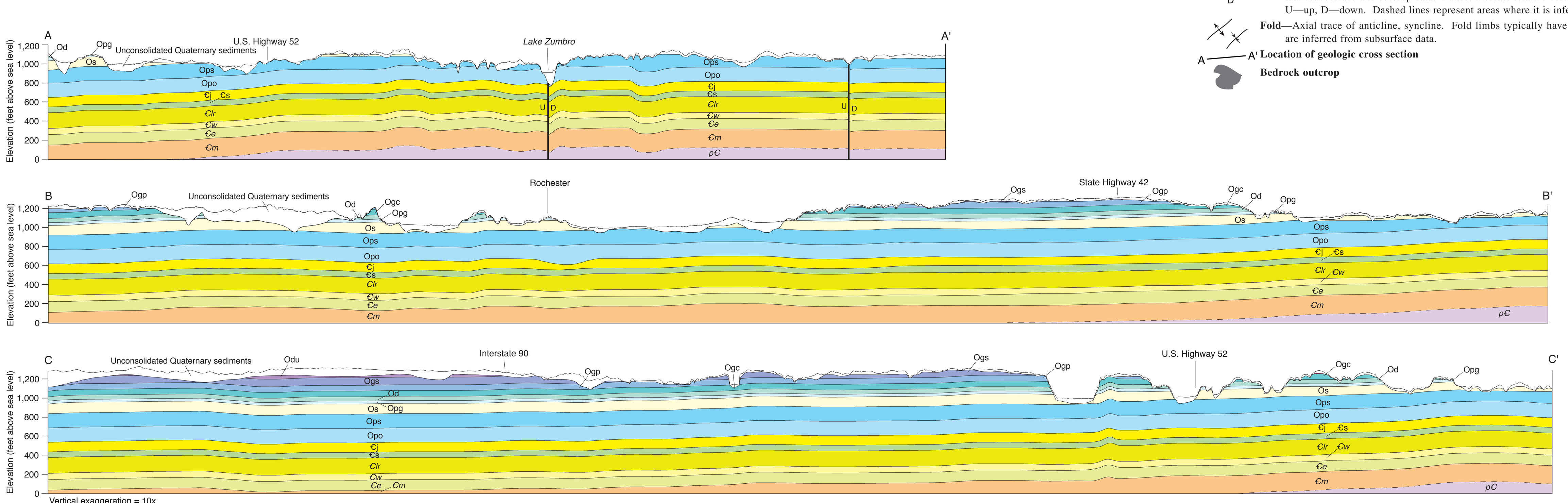


Figure 2. Cross sections—Every attempt has been made for the cross sections to match all geologic interpretations made from County Well Index data. Symbology is the same as on the bedrock map. Only one drill hole intersects Precambrian bedrock in the county, thus the relief is generalized on this surface and inferred from the thickness of the Mt. Simon Sandstone.

DESCRIPTION OF MAP UNITS

Om **Maquoketa Formation (Upper Ordovician)**—Fine-grained, fossiliferous limestone with shaley dolostone interbeds. Brachiopods, crinoids, and chert nodules are common. The Maquoketa Formation has a maximum preserved thicknesses of 60 feet (18 meters) in the southwest part of Olmsted County.

Galena Group (Upper Ordovician)

Odu ***Dubuque Formation***—Gray limestone with alternating thinner layers of olive-gray, calcareous shale. Unit is rich in crinoid and brachiopod fossils and may also include bryozoans, trilobites, and bivalves. Limited to the southwest part of the county. The Dubuque Formation is 25 to 35 feet (8 to 11 meters) thick.

Ogs ***Stewartville Formation***—Yellowish-gray, dolomitic limestone and dolostone. Thin, crinkly bedding. Fossiliferous in the lower and upper parts near contacts with the underlying Prosser Formation and overlying Dubuque Formation. Fossils include brachiopods, gastropods, horn corals, and cephalopods. Unit is highly bioturbated, giving it a burrow mottled appearance. Differential weathering on the mottled texture causes a "swiss cheese" appearance. The Stewartville Formation is generally 80 feet (24 meters) thick.

Ogp ***Prosser Formation***—Light tan to grayish-brown, very fine-grained, thin bedded limestone. Fossil-rich; fossils form thin coquina layers and are dominated by brachiopods, gastropods, bivalves, echinoderms, bryozoans, trilobites, horn corals, and cephalopods. Distinguished from the Cummingsville Formation by the lack of shale. The Prosser Formation is generally 60 to 65 feet (18 to 20 meters) thick.

Ogc ***Cummingsville Formation***—Limestone interbedded with shale. The limestone is yellowish-gray, shaly, fossiliferous, and fine-grained with thin and crinkly bedding. Fossils mainly include brachiopods, bryozoans, trilobites, horn corals, gastropods, and crinoids. The shale is green to gray and calcareous. Exposures weather to a serrated profile because of the alternating shale beds. The Cummingsville Formation is generally 60 to 65 feet (18 to 20 meters) thick.

Od ***Decorah Shale***—Fossiliferous, green-gray shale with thin interbeds of blue-gray, densely fossiliferous limestone. Fossils include brachiopods, bryozoans, trilobites, cephalopods, crinoids, gastropods, and bivalves. Ferruginous oolites of a brassy color are common in the upper half. The Decorah Shale is 45 to 50 feet (14 to 15 meters) thick.

Opg **Platteville and Glenwood Formations, undivided (Upper Ordovician)**

Platteville Formation—Tan to gray limestone and dolostone. Commonly burrowed, mottled, and fossiliferous. Unit contains fine- to coarse-grained quartz sand and phosphate grains in the lowermost 2 feet (0.6 meter). Fossils include bryozoans, brachiopods, echinoderms, horn corals, and gastropods. The Platteville Formation is generally 20 to 25 feet (6 to 8 meters) thick.

Glenwood Formation—Grayish-green to brownish-gray, calcareous, sandy, and phosphatic shale. The Glenwood Formation is 5 to 10 feet (2 to 3 meters) thick.

Os **St. Peter Sandstone (Middle to Lower Ordovician)**—Fine- to medium-grained, whitish-tan, quartzose sandstone. The sandstone is generally structureless, and less commonly, shows subtle cross stratification. The uppermost few feet are commonly iron-crusted and burrowed. The St. Peter Sandstone is generally 80 to 100 feet (24 to 30 meters) thick.

Prairie du Chien Group

Ops ***Shakopee Formation*** **(Lower Ordovician)**—Tan to gray dolostone, sandy dolostone, and sandstone divided into two members. The Willow River Member is composed of thin- to medium-bedded dolomite, sandy dolomite, and thin quartz sandstone and minor shale beds. The dolostone and sandy dolostone beds contain an oomoldic texture as well as oolites and stromatolite fossils. Chert nodules are common. The Willow River Member is generally 120 to 150 feet (36 to 46 meters) thick. The New Richmond Member is composed of fine- to medium-grained quartzose sandstone as well as oolitic sandy dolostone and only reaches thicknesses of 25 feet (8 meters) or less in Olmsted County. The uppermost New Richmond Member, known as the Root Valley facies, is composed entirely of quartz sandstone and commonly exhibits low-angle cross bedding. The Root Valley facies is typically less than 10 feet (3 meters) thick in Olmsted County but is still commonly picked out by water-well drillers in their descriptions of geologic materials and can be used as an estimate for the contact between the Oneota Dolomite and the Shakopee Formation. However, 10-foot (3-meter) beds of sandstone and sandy dolomite are common in the overlying Willow River Member, so it is best to use additional evidence such as geophysical logs, core, or cuttings to distinguish the precise contact. The lowermost New Richmond Member may locally contain oolitic sandy dolostone and sandstone beds known as the Prairie Island facies. Where present, these beds are generally 15 feet (4 meters) or less in Olmsted County (Squillace, 1979). The total thickness of the Shakopee Formation is 150 feet (46 meters).

Opo ***Oneota Dolomite*** **(Lower Ordovician)**—The Oneota Dolomite is divided into two members. The Hager City Member is composed of medium to thick, irregular tabular beds of dolostone and silty dolostone. The dolostone is light tan to light gray and fine-grained crystalline, contains stromatolitic and thrombolytic microbial textures, and may be intraclastic. It contains white to gray chert nodules and calcite-filled vugs throughout, though they are more common in the upper and lowermost parts. The thickness of the Hager City Member is generally 125 feet (38 meters). The underlying Coon Valley Member consists of interbedded sandstone, sandy dolostone, dolostone, and minor shale. It commonly contains stromatolites, oolites, and an oomoldic texture. The thickness of the Coon Valley Member is generally 20 to 30 feet (6 to 9 meters) thick. However, it can vary significantly from 20 to 75 feet (6 to 23 meters) in the Rochester area where the underlying Jordan Sandstone has been partially eroded. Detailed stratigraphic analysis based on gamma logs and cuttings samples show areas where the Jordan Sandstone is eroded and a more poorly sorted, sandstone to sandy dolostone of the Coon Valley Member is deposited (Runkel, 1996). The total thickness of the Oneota Dolomite is 150 feet (46 meters).

€j **Jordan Sandstone (Upper Cambrian)**—Sandstone. Characterized by coarsening-upward sequences of two distinct facies: a quartzose facies of mostly friable, yellow to white sandstone, and a feldspathic facies of very fine-grained sandstone, siltstone, and shale (Runkel, 1994). The Jordan Sandstone is generally 80 to 100 feet (24 to 30 meters) thick, but can be much thinner where partially eroded within the Rochester area (Runkel, 1996).

€s **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, but more common in the lower 30 feet (9 meters) of the formation. Intraclastic beds are present near the top and at the base of the unit. The St. Lawrence Formation is generally 60 to 75 feet (18 to 23 meters) thick. The St. Lawrence Formation is the uppermost bedrock within the North Fork of the Whitewater River in northeast Olmsted County.

Tunnel City Group (Upper Cambrian; shown only on cross sections)

€lr ***Lone Rock Formation***—Sandstone, siltstone, and shale. Sandstone is pale yellowish-green, fine- to very fine-grained, glauconite-rich, and feldspathic. Shale is green and gray. 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 is generally 165 feet (50 meters).

€w **Wonewoc Sandstone (Upper Cambrian; shown only on cross sections)**—Fine- to coarse-grained, quartzose sandstone. 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 is typically 65 feet (20 meters) thick.

€e **Eau Claire Formation (Middle to Upper Cambrian; shown only on cross sections)**—Siltstone, shale, and minor fine- to very fine-grained sandstone. The siltstone and shale are generally dark gray and the sandstone is tan to gray. Limited subsurface data indicate the Eau Claire Formation is approximately 110 feet (34 meters) thick.

€m **Mt. Simon Sandstone (Middle Cambrian; shown only on cross sections)**—Medium- to coarse-grained quartzose sandstone. Interbeds of shale, siltstone, and very fine-grained feldspathic sandstone are common in the upper half. The basal contact is a major erosional surface. There is only one drill hole known in Olmsted County that penetrates the entire thickness of the Mt. Simon Sandstone. According to the driller's log there are about 200 feet (61 meters) of sandstone above Precambrian rocks (Stauffer and Thiel, 1941).

p€ **Precambrian rocks, undifferentiated (shown only on cross sections)**—Precambrian rocks were not differentiated in Olmsted County due to the lack of deep subsurface information. The one drill hole that is known to intersect Precambrian rock, noted above, describes approximately 1,900 feet (579 meters) of red, shale-rich sandstone interpreted to be part of the Mesoproterozoic Keweenawan Supergroup of the Midcontinent Rift overlying Archean granite (Stauffer and Thiel, 1941).

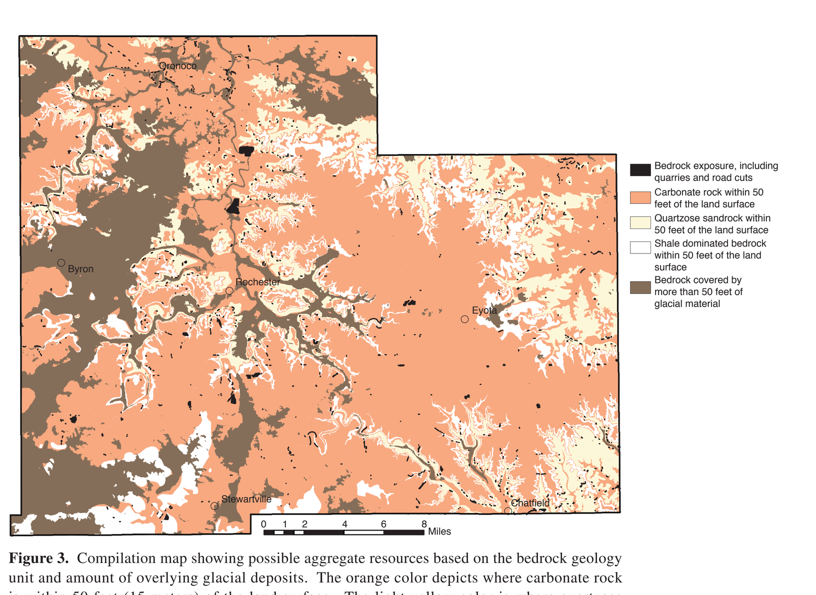


Figure 3. Compilation map showing possible aggregate resources based on the bedrock geology unit and amount of overlying glacial deposits. The orange color depicts where carbonate rock is within 50 feet (15 meters) of the land surface. The light yellow color is where quartzose sandrock is within 50 feet (15 meters) of the land surface. Brown areas show where there are more than 50 feet (15 meters) of glacial deposits. White areas show where shale is within 50 feet (15 meters) of the land surface. Outcrops and quarries that show where rock is exposed directly at the land surface are shown in black.

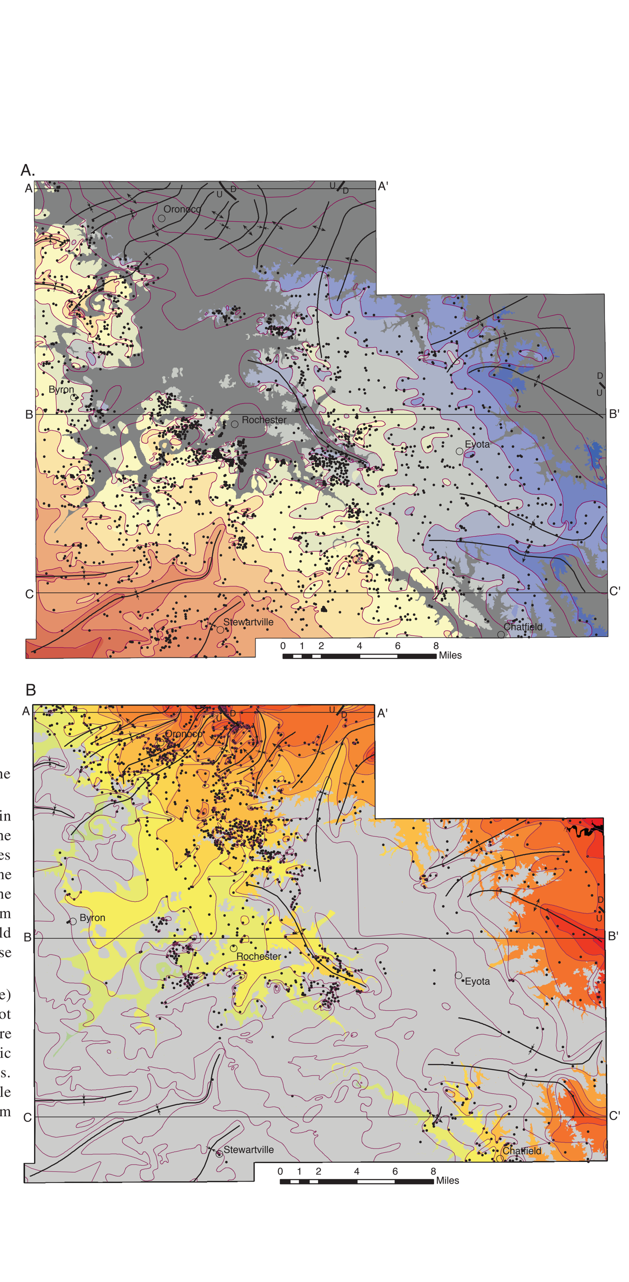


Figure 4. Map of Olmsted County depicting the structural relationships for the St. Peter Sandstone (A) and the Jordan Sandstone (B).

A. The elevation of the top of the St. Peter Sandstone is shaded from lower (red) to higher (blue) in elevation where it exists below the Glenwood Formation. The structure contour lines of the top of the St. Peter Sandstone are depicted in 25-foot (8-meter) intervals. Fold axes of the synclines and anticlines are drawn as a thin black line. Water wells that penetrate the stratigraphic top of the St. Peter Sandstone where it underlies the Glenwood Formation are shown as black dots. Gray depicts areas where the St. Peter Sandstone is partially or completely eroded and contours are only generally inferred from projection vertically from the top of the Jordan Sandstone. The Jordan Sandstone may have older fold and fault structures that are not present in the overlying St. Peter Sandstone and younger strata because some deformation occurred prior to deposition of those units.

B. The elevation of the top of the Jordan Sandstone is shaded from lower (green) to higher (orange) in elevation. The structure contour lines of the top of the Jordan Sandstone are depicted at 25-foot (8-meter) intervals. Fold axes of the synclines and anticlines are drawn as thin black lines and faults are shown with thick black lines and displacement directions. Water wells that penetrate the stratigraphic top of the Jordan Sandstone where it underlies the Prairie du Chien Group are shown as black dots. Gray depicts the areas where a full thickness of St. Peter Sandstone is present and there is very little stratigraphic data for the Jordan Sandstone. In these areas, contours were projected downward from the top of the St. Peter Sandstone.

INTRODUCTION

The geologic map, cross sections, and stratigraphic column on this plate depict the type, distribution, and structure of the bedrock units in Olmsted County that are either exposed at the land surface or lie directly beneath unconsolidated Quaternary sediments of variable thickness (Fig. 2 and 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 Olmsted County consist of sedimentary rocks of Paleozoic age that form distinguishable and mappable layers designated as formations. These units are commonly exposed in bluffs, riverbanks, rock quarries, and roadcuts throughout the county. Some parts of the Paleozoic bedrock formations are major reservoirs for the water supply in Olmsted County and also provide a source of crushed carbonate rock and silica sand.

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 necessary to show the thin rock formations 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 Digital Elevation Models (DEMs) for use in GIS programs within the supplementary digital and GIS files for this atlas. All of the Paleozoic units that exist as first bedrock on the geology map, with the exception of the St. Lawrence Formation, can be seen at the land surface in outcrops in Olmsted County. 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.

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 Olmsted and adjacent counties (Olsen, 1988; Mossler, 1995, 1998, 2001; Runkel, 1996, 1998; Tipping and others, 2007; Steenberg, 2014; Retzler, 2019). The different data sources and their irregular distribution and density can be seen on Plate 1, *Data-Base Map*, and this should be considered when assessing the reliability of the map at any particular location. Areas with a high density of bedrock control points are more likely to have an accurate interpretation of the bedrock geology, whereas those areas with widely spaced control points may be less reliable and inappropriate for site-specific needs. During production of this map, the records of over 4,700 located boreholes with stratigraphic information existed within Olmsted County in the County Well Index and nearly 4,300 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 records. 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 Olmsted County (Olsen, 1988). Significant improvements and modifications were made to the previous map based on additional water-well records, rock core, drilling cuttings, 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, Tunnel City Group (previously the Franconia Formation), Decorah Shale, Maquoketa Formation, and Dubuque Formation. Faults and folds in the county were mapped to reflect significant offset and structure in the Paleozoic formations. This provides detail of the subsurface geologic conditions, which has implications for modeling groundwater flow.

The oldest known bedrock in the county, Precambrian in age, lies unconformably beneath the Paleozoic sequence at great depths and is only inferred on the cross sections. Little is known about these rocks due to their deep burial and scarcity of subsurface information. Geologic interpretations of the Precambrian bedrock where deeply buried rely significantly on aeromagnetic and gravity data. These data suggest the western half of Olmsted County is underlain by Mesoproterozoic (approximately 1,100 million-year-old [Ma]) rocks of the Keweenawan Supergroup, including sandstone, siltstone, and shale associated with the Midcontinent Rift. The eastern half of Olmsted County is underlain by Archean (about 3,600 to 2,500 Ma) granites and Mesoproterozoic mafic intrusions (Jirsa and others, 2012). One drill hole reaches Precambrian rock in the western part of the County. This borehole is described as having penetrated approximately 1,900 feet (579 meters) of red, shale-rich sandstone interpreted to be part of the Keweenawan Supergroup overlying Archean granite (Stauffer and Thiel, 1941).

The Paleozoic rocks of Olmsted County 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 445 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. 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. Much of Olmsted County has bedrock within 50 feet (15 meters) of the land surface, making it rich in aggregate resources (Fig. 3). Carbonate rock products are crushed, sorted, and used as construction material for roads and buildings, and in concrete operations. The silica-rich sandstone is texturally mature and well-rounded, which makes it a sought-after resource in the oil industry. It also has a wide variety of other uses including glassmaking, foundry operations, ceramics, filtration, and agriculture. However, viability of extraction is dependent on many other factors, including detailed geologic conditions at individual sites, proximity to bulk transportation, current land ownership and use, market prices, regulatory requirements, rock properties, and many others. Kostka and Ellingson (2010) have mapped the mineral potential in Olmsted County as part of the Aggregate Resources mapping program at the Minnesota Department of Natural Resources. These maps assess where there is high, moderate, and low resource potential based on several of these factors.

The Paleozoic strata in Olmsted County lie on the eastern side of a broad cratonic depression known as the Hollandale embayment. Strata generally dip less than 1° to the southwest as part of the regional structural trend of the embayment. As a result, progressively younger bedrock formations subcrop from northeastern to southwestern Olmsted County. Smaller-scale structural features such as faults and folds are superimposed on this regional dip pattern and are recognized by changes in the elevation of key bedrock contacts. 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 three faults mapped in Olmsted County are all inferred from drill-hole data, none are exposed in outcrop. Displacement along these faults in Olmsted County is less than 100 feet (30 meters), which is sufficient in the fault near Zumbro Lake 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. Most folds are oriented northeast–southwest, but several others are northwest–southeast. The stratigraphic top of the St. Peter and Jordan Sandstones were contoured separately at 25-foot (8-meter) intervals (Fig. 4). These two units were selected to portray these structures because they have easily recognized contacts established at numerous outcrop and drill-hole control points. Drill holes that penetrate the top of the St. Peter Sandstone are numerous and fairly evenly distributed where the St. Peter Sandstone is present (Fig. 4A). Drill holes that penetrate the Jordan Sandstone are most common in areas where the Prairie du Chien Group is the uppermost bedrock (Fig. 4B). There are only a few drill holes that penetrate both the St. Peter and Jordan Sandstones.

The origin and timing of these fold and fault structures are difficult to discern. Folds in the St. Peter Sandstone had to occur after its deposition and had to also fold all underlying units (Fig. 4A). There are no apparent thickness changes near the folds in any of the younger units, suggesting folds occurred at least after the Maquoketa Formation was deposited (post latest Ordovician). Faults crosscut strata as young as Devonian in Mower County to the south, so movement in Olmsted County could be post Devonian as well (Mossler, 1998). Based on recent mapping further north in the Twin Cities metropolitan area (Washington and Hennepin Counties), evidence suggests faulting and folding also occurred as early as the Early Ordovician, while the Oneota Dolomite and Shakopee Formation were being deposited (Steenberg and others, 2015; Retzler and others, 2016; Steenberg and Retzler, 2016; Retzler, 2018). It is therefore possible that the Prairie du Chien Group and older units, including the Late Cambrian Jordan Sandstone, may have older fold and fault structures that are not present in the overlying St. Peter Sandstone and younger strata because deformation occurred prior to deposition of those units (Fig. 4B). For example, tightly mapped folds in northern Olmsted County in the top of the Jordan Sandstone may have also offset the St. Peter Sandstone and younger units that are no longer present, or they may be younger structures that occurred during Prairie du Chien Group deposition and are not present in the St. Peter Sandstone and younger units.

Late Cretaceous age sediments of the Windrow Formation are likely to be locally present in scattered locations across Olmsted County. However, subsurface data are insufficient to map this formation as a distinct unit. Sloan (1964) described two outcrops in the county, but they are no longer exposed. Two members of the Windrow Formation are known in the area, the Iron Hill and Ostrander. The Iron Hill Member is a weathering residuum of silt, clay, and chert fragments that may be seen locally on carbonate rock plateaus and filling enlarged joints and sinkholes in the county. The Ostrander Member is sandstone and conglomerate dominated by chert and quartz pebbles. One of the four rotary-sonic drill holes drilled for this project was interpreted to penetrate 6 feet (2 meters) of the Ostrander Member of the Windrow Formation (OLR-1, unique well number 340107, see Plate 4). The quartz sand is fine-to medium-grained, well rounded, and white to orange in color. Pebbles of well rounded, smooth chert and quartz are present.

HYDROSTRATIGRAPHY

The Paleozoic bedrock formations contain significant sources of groundwater that provide the water supply for Olmsted County. This map and associated products, such as the bedrock DEM 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 Olmsted County is based on hydrogeologic reports by Runkel (1996), Paillet and others (2000), Runkel and others (2003, 2006a, b, 2018), Tipping and others (2006), Luhmann and others (2011), Green and others (2012), 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 Olmsted County, but are placed on the column where the hydrogeologic reports cited above indicate they are most common. The Precambrian bedrock does not supply water to Olmsted County largely because sufficient water resources are available at shallower depths in the Paleozoic rocks.

In Olmsted 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. Both the Prairie du Chien Group and the upper carbonate units (Galena Group through Maquoketa Formation) are considered karst systems in Olmsted County. Karst features may be expressed at the land surface by caves, numerous springs, and many 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 Olmsted 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, as well as 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, 2006b). In addition to this hydrostratigraphic classification, the Minnesota Department of Natural Resources, as Part B of the Olmsted 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.

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