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GEOLOGIC INVESTIGATIONS APPLICABLE TO GROUND-WATER MANAGEMENT, ROCHESTER METROPOLITAN AREA, MINNESOTA

By

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January 19, 1996

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Open-File Report 96-1

Funding for this project was provided by

Rochester Public Utilities
400 East River Road Northeast
Rochester, Minnesota 55906-2813

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Scale 1:24,000

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INTRODUCTION

In recent years, metropolitan Rochester's projected water demands have increased to the point that detailed studies of geologic and hydrologic conditions within the Rochester-Zumbro ground-water basin are necessary for effective water management and long-term water planning. In 1988, the Minnesota Geological Survey published a geologic atlas for Olmsted County (Balaban, 1988). The atlas has helped local water managers by describing the regional geologic and hydrologic framework of Rochester's ground-water system; however, it does not provide, and was not intended to provide, the level of detail that water managers now require.

Since 1988, much potential new information on the subsurface geology within the Rochester-Zumbro ground-water basin has become available from well-drilling and construction activity associated with Rochester's rapid growth. Moreover, the geologic concepts within which the data are interpreted have advanced substantially. Of special importance in this regard is the recognition that the Jordan Sandstone is not hydraulically homogeneous, as it was formerly assumed to be; rather, it varies significantly from place to place in its permeability and its performance as an aquifer (Setterholm and others, 1991; Runkel, 1994a, 1994b). This finding has strong implications for the Rochester area, and an assessment of such variability should aid the city in construction of wells in the Jordan Sandstone that will deliver adequate yields. For these reasons and others, the Minnesota Geological Survey studied the bedrock geology of the Rochester metropolitan area in greater detail than was done for the county geologic atlas.

Objectives of this Study

This investigation has two objectives. One is to provide the city of Rochester, Minnesota, with bedrock geologic, bedrock topographic, and data-base maps suitable in scale, format, and data quality for use as a planning and environmental-management tool. These maps, produced in GIS (Geographic Information System) digital coverage at 1:24,000 scale, are described in Part I of this report. The second objective, discussed in Part II of this report, is to provide a better understanding of hydrogeologically important attributes of the Paleozoic strata and, in particular, the St. Peter–Prairie du Chien–Jordan aquifer, which supplies most of the potable water to the city of Rochester.

Description of the Study Area

This investigation was confined to the southern two-thirds of the Rochester-Zumbro ground-water basin, which is defined as the area bounded by Olmsted County highway 14 on the north and by the divides on the potentiometric-surface map for the St. Peter–Prairie du Chien–Jordan aquifer that circumscribe metropolitan Rochester on the west, south, and east (Kanivetsky, 1988; Delin, 1991). This irregular area is entirely within Olmsted County and includes the greater parts of Marion, Rochester, Haverhill, and Cascade townships, plus fractions of adjoining townships.

Acknowledgments

The work was performed by staff members of the Minnesota Geological Survey. Anthony C. Runkel, geologist, was the principal investigator and project manager. He was supported by G.B. Morey, geologist, Robert Tipping, hydrogeologist, Emily Bauer, data-base manager, and Joyce Meints, GIS specialist.

Part 1

Description of the Data-Base, Bedrock Geologic, and Bedrock Topographic Maps

THE DATA-BASE MAP

The data-base map (Plate 1) shows the location of all water wells, engineering borings, outcrops, and ephemeral excavations that were used to create the geologic maps and cross section. All of the information was compiled on parts of ten 7.5-minute topographic maps (scale 1:24,000, or 1 inch = 2000 feet). The data-base map shows where data are sparse or lacking, and where interpretation and extrapolation were required to prepare a map. Because geologic maps are largely interpretive, the data-base map is a guide to reliability. The data are described below to aid the map user in understanding the basis for the geologic interpretations, and for assessing which types of information may be useful for subsequent studies in the Rochester area.

Types of Data

Drill-hole information is found on a record of water-well construction, or well-driller's log, which is a water-well contractor's description of the geologic strata penetrated during drilling and the construction materials used to complete the well. Hydrologic data, such as the static water level and test-pumping results, are commonly included. Before any driller's log can be used, the location of the well must be verified, and a geologist must interpret the log. Drillers' logs are the primary source of subsurface geologic data in the Rochester area and about 1632 logs were used for this project. This data base includes standard water wells, as well as monitor wells that are used in environmental assessments. Monitor wells less than 25 feet deep were not included for areas where other sources of data are abundant.

Cutting samples collected during drilling provide physical evidence of subsurface geologic materials, and are the principal means of establishing the characteristics of bedrock that is not exposed at the surface. They are collected at fixed depth intervals (typically every 5 feet) during well drilling. There are cuttings from 23 wells in the Rochester study area.

Borehole geophysical logs are made by lowering instruments down the well or drill hole and measuring the physical and chemical properties of the geologic materials that the hole penetrates. Different logging techniques measure naturally occurring gamma radiation, spontaneous potential, and resistivity. Gamma logs, in graphic form, characterize the geologic formations penetrated. Spontaneous potential and resistivity are used mainly to locate water levels in wells and the depth of the well casing. The geophysical log can be used—along with cuttings samples from the same hole, information obtained from nearby outcrops, or the geophysical log from a nearby well—to recognize different rock types. Many rock units encountered in the subsurface have a characteristic geophysical "signature" that facilitates these correlations. Geophysical logs provide high-quality subsurface geologic and hydrologic information from wells for which little or no other information is available. There are borehole geophysical logs for 28 water wells within the study area.

Soil borings are test holes drilled to obtain information about the physical properties of subsurface materials for engineering, mapping, or exploration purposes. Most soil borings terminate at shallow depths, or where bedrock is encountered. They are logged by a geologist or an engineer using a variety of classification schemes based upon particle size, penetration rate, moisture content, and color. Soil borings data are most useful in determining the composition of unconsolidated deposits. Some logs include the depth to bedrock and the lithology of the first bedrock encountered. Soil borings are drilled using a variety of methods such as Giddings probe, auger-split spoon, and rotary drill. A data base of 429 borings was assembled from several sources that include the U.S. Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service), Minnesota Department of Transportation bridge borings, and the U.S. Army Corps of Engineers.

Bedrock outcrops are exposures of solid rock at the land surface. Most outcrops are naturally occurring; however, some exposures are created during construction. Outcrops in the Rochester area are common except in the western part of the study area where bedrock is covered by thick glacial drift. Outcrops serve as the principal reference points for mapping and for checking the accuracy of subsurface data. Bedrock at or near the surface must be considered in land-use planning decisions such as pipeline routing, sewage-system design, and excavations.

Data-Base Management

All of the data used in the Rochester study were plotted on 7.5-minute topographic quadrangles, half-section maps, or highway-alignment maps. Inventory numbers were assigned to all data except bedrock exposures. Manual files and automated data bases, County Well Index (CWI) and Test-Borings Data Base (TESTHOLE), were developed to provide easy access and rapid retrieval of these site-specific data. Both data bases utilize Public Land Survey descriptions and/or Universal Transverse Mercator (UTM) coordinates as location criteria, and are compatible with the natural-resource data bases housed at the Minnesota Land Management Information Center (LMIC). The data files may be obtained from the Minnesota Geological Survey.

County Well Index. The County Well Index is a PC-compatible data base of information related to water wells. Each well is assigned a six-digit unique number that is used to reference all data concerning the well. The unique number is used by local, state, and federal agencies, as well as drillers and consultants, to refer unambiguously to a specific well. The location of each well was digitized from topographic maps. Elevation of the land surface at well sites, expressed in feet above sea level, were also determined from the topographic maps. In addition, a street address, driller's log, and geologist's interpretation are included in CWI for each well. Additional information regarding CWI can be found in Appendix A of this report.

Test Borings Data Base (TESTHOLE). Information such as depth to bedrock, depth drilled, and the interpretation of first bedrock from soil borings and engineering test holes is stored in this data base. Each test hole is assigned a unique number, and the location is digitized from the site plan or from a quadrangle location that is based on a site description.

Digital Map Data

GIS (Geographical Information System) technology played an important role in the development and production of the maps included with this report. Point data from CWI and other sources were incorporated into the Minnesota Geological Survey GIS. Preliminary data maps were produced to aid geologic interpretation and mapping. The stable-base versions of the bedrock geologic and topographic maps, compiled by the geologists, were digitized using ARC/INFO® software. The coverages in the GIS format (digital map layers) are the final map products delivered to the city of Rochester. Details describing the GIS products and how to use them are appended as part of this report.

The data-base map is current as of June 1995. Considering that additional information is continually being generated as new water wells are drilled, as construction exposes more bedrock, or as more wells are tested for water quality, the library of geologic information prepared for the city of Rochester is flexible, so that new data can be added, and old data can be re-evaluated in light of new information or techniques.

BEDROCK TOPOGRAPHIC AND GEOLOGIC MAPS

A general description of the basic principles of map making and of the bedrock topography and geology of the Rochester area can be found in the Olmsted County geologic atlas (Balaban, 1988). The following discussion of the maps constructed for this investigation emphasizes the features that are most pertinent to ground-water issues and are different from the analogous bedrock maps of the atlas.

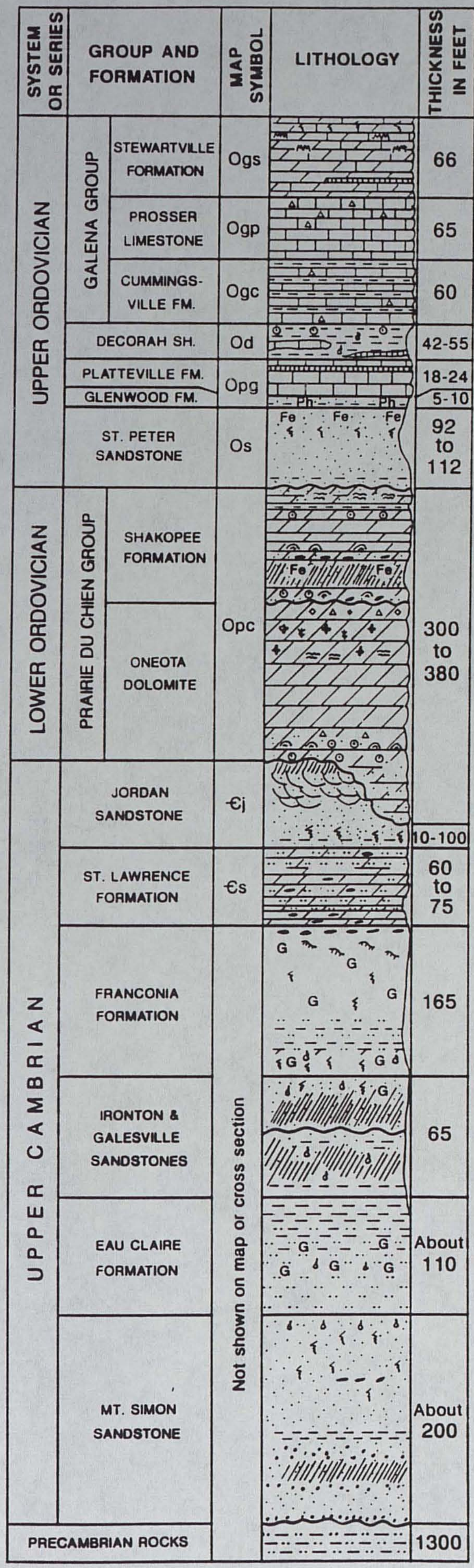
Bedrock Topographic Map

The bedrock topographic map (Plate 2) shows the shape of the bedrock surface exposed or buried beneath unconsolidated deposits. Depth to bedrock can be determined in any given area by subtracting the bedrock-surface elevation shown on the map from the land surface elevation shown on a standard topographic map. The thickness of unconsolidated deposits covering the bedrock varies. Across most of the study area the overlying deposits are very thin and the surface topography more or less reflects the bedrock topography. However, in the western part of the study area, in parts of Salem, Cascade, and Kalmar townships, the drift is much thicker, and the shape of the land surface does not reflect the bedrock topography.

The bedrock topographic map produced for this study differs from that in the Olmsted County geologic atlas (Plate 4 *in* Balaban, 1988) in that there is greater topographic resolution owing to the expanded data base and larger scale mapping. In addition, the interpretation of bedrock topography in areas of thick drift in the western part of the study area is substantially different from that shown in the atlas. The bedrock topographic plate in the atlas (Plate 4 *in* Balaban, 1988) shows a deeply buried, roughly north-south–trending valley in the western part of the county, which was interpreted as the master valley for pre-Quaternary drainage. New data gathered for this study indicate instead that the pre-Quaternary master valley approximates the position of the course of the South Fork of the Zumbro River. Buried valleys in the western part of the study area are east-west–trending tributaries to this master valley.

Bedrock Geologic Map and Cross Section

The bedrock geologic map (Plate 3) shows the distribution of Paleozoic bedrock units that are exposed or covered only by unconsolidated deposits. The division of bedrock strata into mappable units, shown on the stratigraphic column in Figure 1, generally conforms to the regional stratigraphic nomenclature developed in previous Minnesota Geological Survey investigations (Mossler, 1987; Runkel, 1994a). Descriptions of these units in the Rochester area can be found in Appendix B of this report and on the accompanying bedrock geologic map (Plate 3).



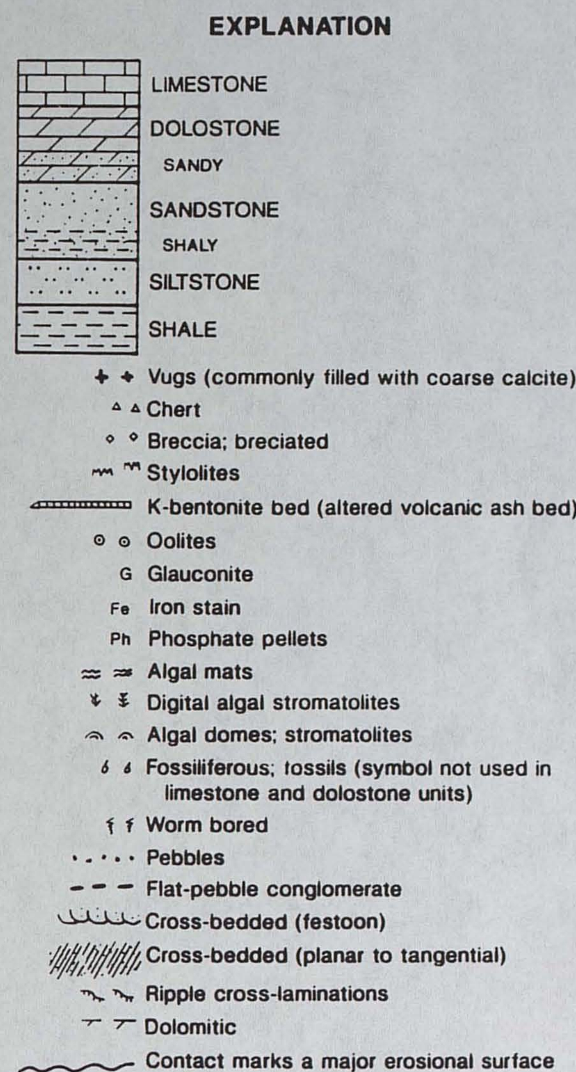


FIGURE 1. *Stratigraphic column showing bedrock geologic units in the Rochester metropolitan area. Descriptions of the units are given in Appendix B of this report and on the accompanying bedrock geologic map (Plate 3). See Figure 2 for a listing of the lithic components of the Prairie du Chien Group and Jordan Sandstone .*

Paleozoic strata in the Rochester area are nearly flat lying and have been eroded to form an upper and lower plateau. The resistant limestone and dolostone formations of the Galena Group form an upper plateau that skirts the perimeter of the southern, western, and eastern parts of the study area. The mostly carbonate rocks of the Prairie du Chien Group form a lower plateau in the central part of the study area, along the South Fork of the Zumbro River and the lower ends of its tributaries, in and around the city of Rochester. These two plateaus are separated by an escarpment, composed of Decorah Shale, Platteville Formation, Glenwood Formation, and St. Peter Sandstone, which is exposed on steep bluffs within and around the city. Locally, the Platteville Formation caps small buttes and narrow ridges between stream valleys or forms flat-topped hills isolated from the main body of the escarpment. In the western part of the study area, a lower plateaulike area is composed mostly of St. Peter Sandstone rather than Prairie du Chien Group.

The expanded data base and larger scale mapping have allowed the construction of a bedrock map that shows greater detail than the county geologic atlas (Plate 2 *in* Balaban, 1988). For example, the Decorah Shale was mapped separately from the Platteville and Glenwood Formations. In addition, the map provides greater resolution in mapping areas of potential ground-water recharge to the St. Peter–Prairie du Chien–Jordan aquifer, such as the subcrop distribution of the St. Peter Sandstone and the Prairie du Chien Group, within which recharge occurs as infiltration through thin drift. The location of the eroded edge of the Glenwood Formation, where discharged water from the upper carbonate aquifer enters the St. Peter–Prairie du Chien–Jordan aquifer (Delin and Almendinger, 1993), is also better established. Such improvements will provide a more accurate geologic framework for making decisions concerning the management of ground-water resources.

The accompanying bedrock geologic cross section (Plate 4) shows the stratigraphy and structure of the bedrock units from a third dimension, as they would appear on the side of a trench cut vertically into the land surface. The geologic formations are thin in relation to their areal extent and have been greatly exaggerated vertically by a factor of 9.6. The section differs from those in the published atlas of Olmsted County (Plate 2 *in* Balaban, 1988) primarily by showing substantial variability in the thickness of the Jordan Sandstone. This variability is discussed in greater detail in Part II of this report.

Part 2

HYDROSTRATIGRAPHIC INVESTIGATION

INTRODUCTION

This part of the investigation focuses on the hydrostratigraphic properties of the St. Peter–Prairie du Chien–Jordan aquifer to determine the parameters that influence productivity of municipal wells, and to suggest guidelines for future construction of high-capacity wells. Previous investigations in the Rochester area have provided a general description of its aquifers and confining beds (Balaban, 1988; Delin, 1991). Those studies suggested that the bedrock aquifers, such as the St. Peter–Prairie du Chien–Jordan aquifer, have more or less laterally homogeneous hydrogeologic characteristics that are typical of the southeastern Minnesota region. However, the city has recently recognized substantial variability in the productivity of municipal wells that draw water from the St. Peter–Prairie du Chien–Jordan aquifer. Some recently developed municipal wells have a relatively low specific capacity compared to other wells constructed in a similar manner elsewhere in the Rochester area. This investigation shows that parts of the aquifer have considerable heterogeneity across relatively short distances, and that such heterogeneity accounts for the variability in well productivity.

Overview

In much of southeastern Minnesota, including the Rochester area, the St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone (Figs. 1 and 2) are grouped together as a single aquifer system on the basis of potentiometric data and the apparent absence of intervening confining units (Delin and Woodward, 1984; Kanivetsky and Walton, 1979). The aquifer is bounded by the Decorah-Platteville-Glenwood confining unit above, and the St. Lawrence confining unit below. The upper and lower parts of the aquifer, assigned to the St. Peter Sandstone and Jordan Sandstone, respectively, are very fine grained to coarse-grained, mostly friable sandstone and only minor shale. Ground-water flow is predominantly intergranular, although fractures are common in some outcrops and could be a potentially important pathway for ground-water movement. The main part of the aquifer is assigned to the Prairie du Chien Group and is composed predominantly of dolostone in which ground water travels through fractures and solution features and, subordinately, of sandstone in which flow is intergranular.

Most municipal wells in Rochester draw water from the St. Peter–Prairie du Chien–Jordan aquifer because of its position relatively close to the surface, its clean water, and its

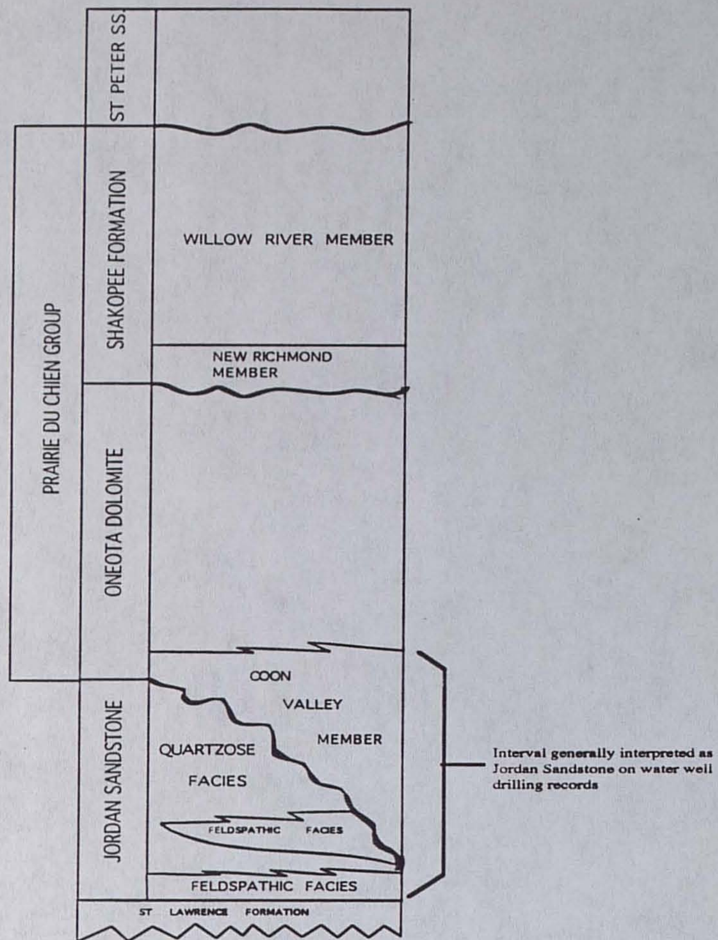


FIGURE 2. *Formal and informal litho-stratigraphic units within the St. Peter–Prairie du Chien–Jordan aquifer in the Rochester area.*

generally high transmissivity. State regulatory codes now require that where the Prairie du Chien is the first bedrock encountered, and the thickness of unconsolidated deposits is less than 50 feet within a one mile radius from the well site, new wells must be constructed so that most of the Prairie du Chien is cased and grouted (Minnesota Department of Health, 1994). As a result, since 1979 municipal wells drilled in the Rochester area that have the Prairie du Chien Group as the first bedrock are constructed so that only the Jordan Sandstone and lowermost part of the Prairie du Chien Group are exposed in the open-hole (uncased) interval of the well. This investigation focused on the hydrostratigraphic properties of this lowermost interval of the aquifer (Fig. 2) in an effort to better understand the cause of the variable well productivity.

DESCRIPTION OF LITHIC COMPONENTS

In the Rochester metropolitan area, the Jordan Sandstone and lower part of the Prairie du Chien Group contain three distinct formal and informal lithic components; a quartzose facies and a feldspathic facies of the Jordan Sandstone, and the Coon Valley Member of the Oneota Dolomite (Fig. 2). These components have previously been defined and characterized as part of regional investigations of this interval elsewhere in southeastern Minnesota and southwestern Wisconsin (Setterholm and others, 1991; Runkel, 1994a, 1994b). The quartzose facies is a trough-cross-bedded, moderately sorted to well-sorted, fine- to coarse-grained sandstone composed of about 98 percent quartz. It typically is friable except locally where the uppermost five feet of the Jordan Sandstone is strongly cemented with carbonate. The feldspathic facies is moderately sorted, structureless or faintly stratified, very fine grained sandstone, siltstone, and shale. It is typically strongly to weakly cemented. The cement is chiefly carbonate but silica and feldspar cements have also been reported (Dott, 1978; Odom, 1978). The Coon Valley Member is a heterolithic unit composed of medium to thin beds of interbedded siltstone, very fine to very coarse grained sandstone, sandy dolostone, and shale (Setterholm and others, 1991; Runkel, 1994a, 1994b). Cementation in the Coon Valley Member is variable; beds of medium- to coarse-grained sandstone are often friable, but very fine to fine-grained sandstone and siltstone are commonly strongly cemented. Field observations by the author elsewhere in southeastern Minnesota indicate that open fractures are less common in the Coon Valley Member than in the pure dolostone of the Oneota above.

Natural gamma logs are particularly useful to distinguish the quartzose facies, feldspathic facies, and Coon Valley Member in the subsurface (Fig. 3) (Setterholm and others, 1991; Runkel, 1994a, 1994b). The feldspathic facies has a high potassium content and therefore causes a strong positive deflection on the gamma logs. The quartzose facies has a low potassium content and therefore corresponds to low readings on the gamma logs. Gamma values for the Coon Valley Member are moderate to high, in contrast to the low constant signature of the

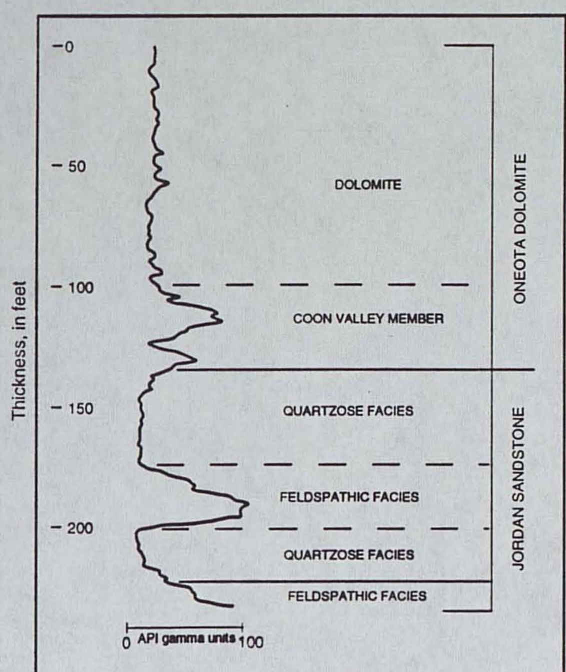


FIGURE 3. ***Representative natural gamma signature for the Oneota Dolomite and Jordan Sandstone.***

quartzose facies of the Jordan Sandstone below, and the low to moderate, variable signature of the middle to upper Oneota Dolomite above. These characteristics, in conjunction with cuttings samples, were used to determine the thickness of these components in the subsurface (Fig. 4).

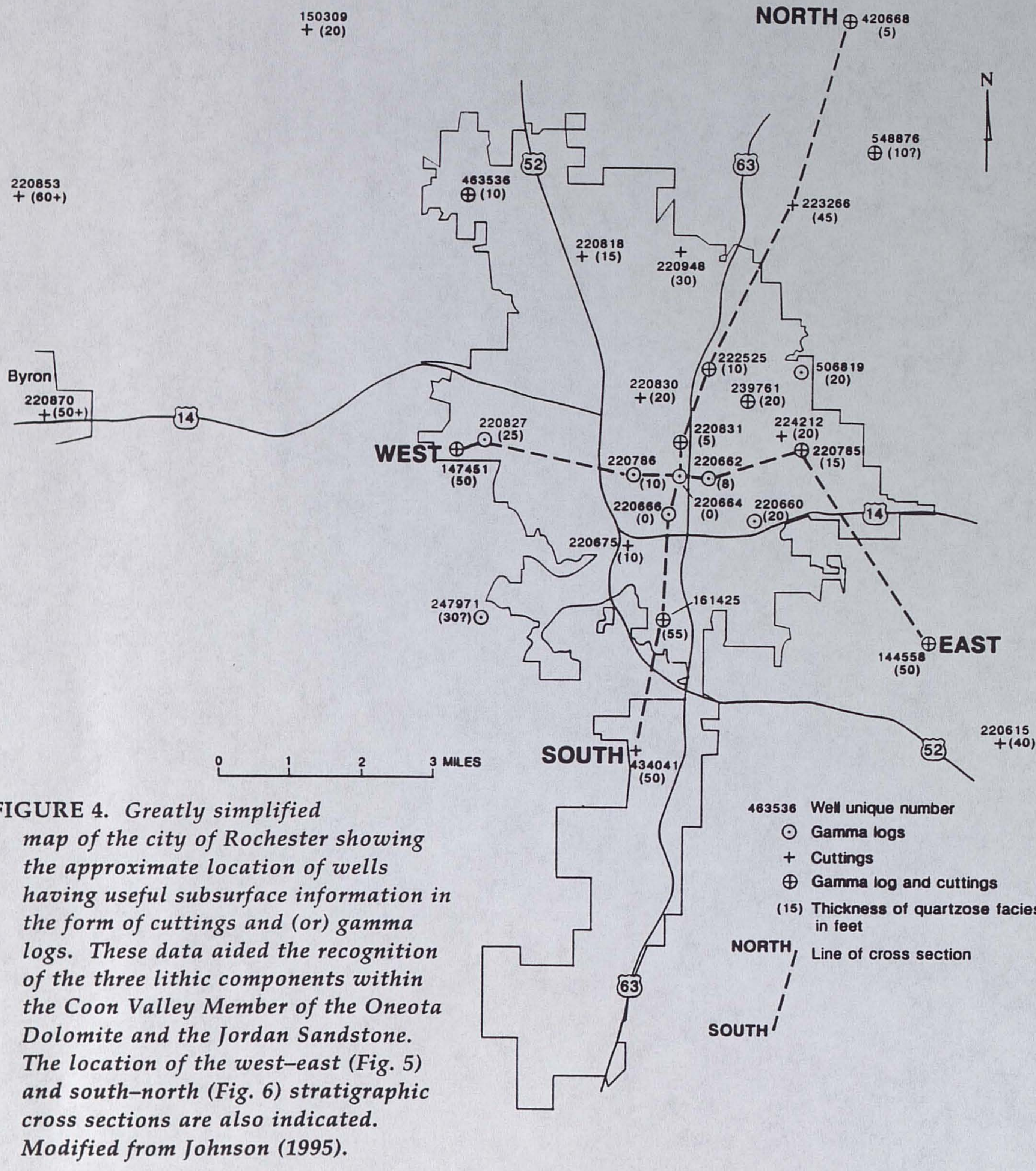


FIGURE 4. *Greatly simplified map of the city of Rochester showing the approximate location of wells having useful subsurface information in the form of cuttings and (or) gamma logs. These data aided the recognition of the three lithic components within the Coon Valley Member of the Oneota Dolomite and the Jordan Sandstone. The location of the west–east (Fig. 5) and south–north (Fig. 6) stratigraphic cross sections are also indicated. Modified from Johnson (1995).*

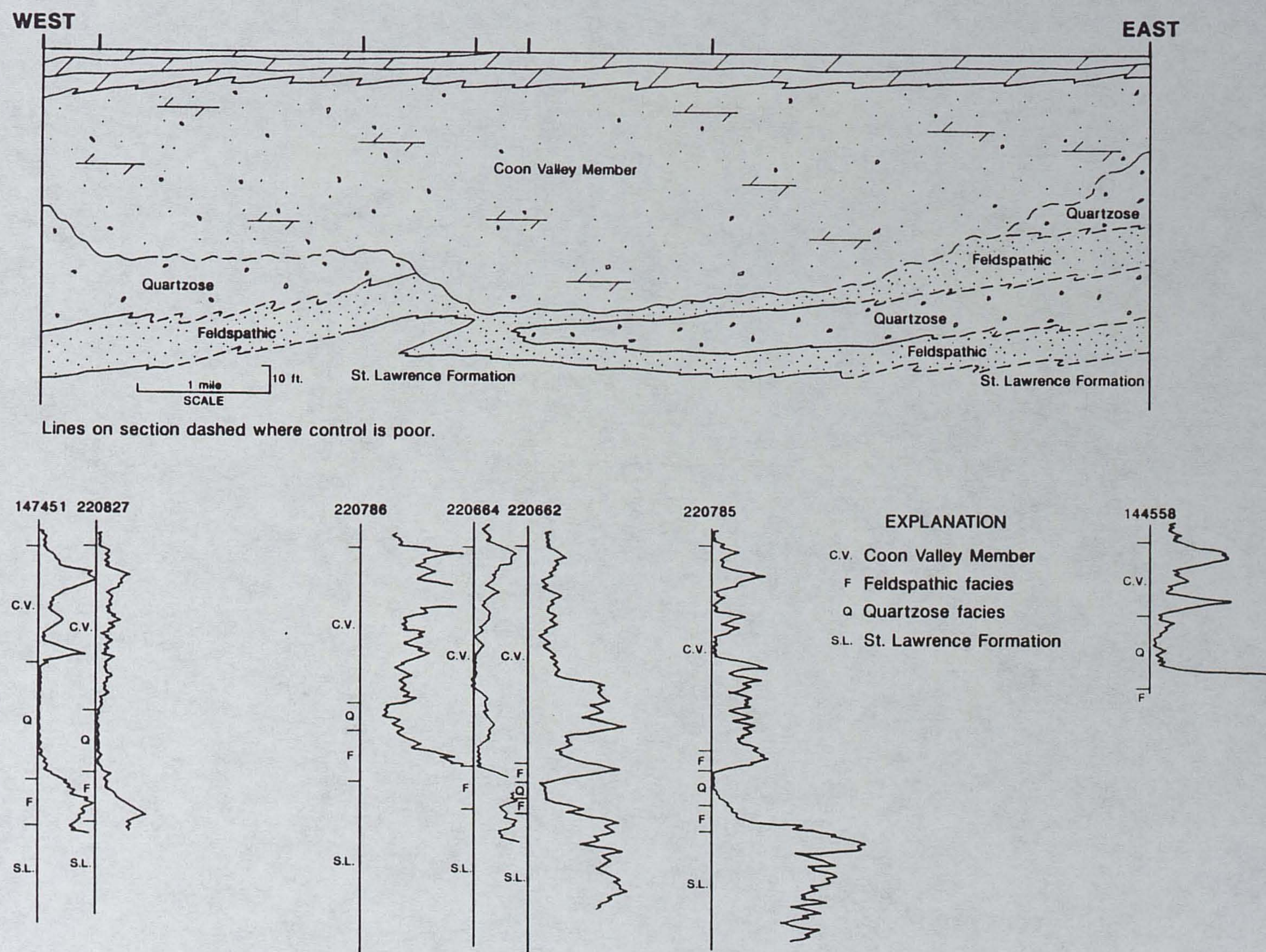


FIGURE 5. *West-east stratigraphic cross section (top) of the Jordan Sandstone and the lower part of the Oneota Dolomite in the Rochester metropolitan area, showing the variable thickness of the Jordan beneath the Coon Valley Member. The cross section was constructed on the basis of interpretations made from gamma logs and cutting samples (bottom). See Figure 4 for the location of the section and data sources.*

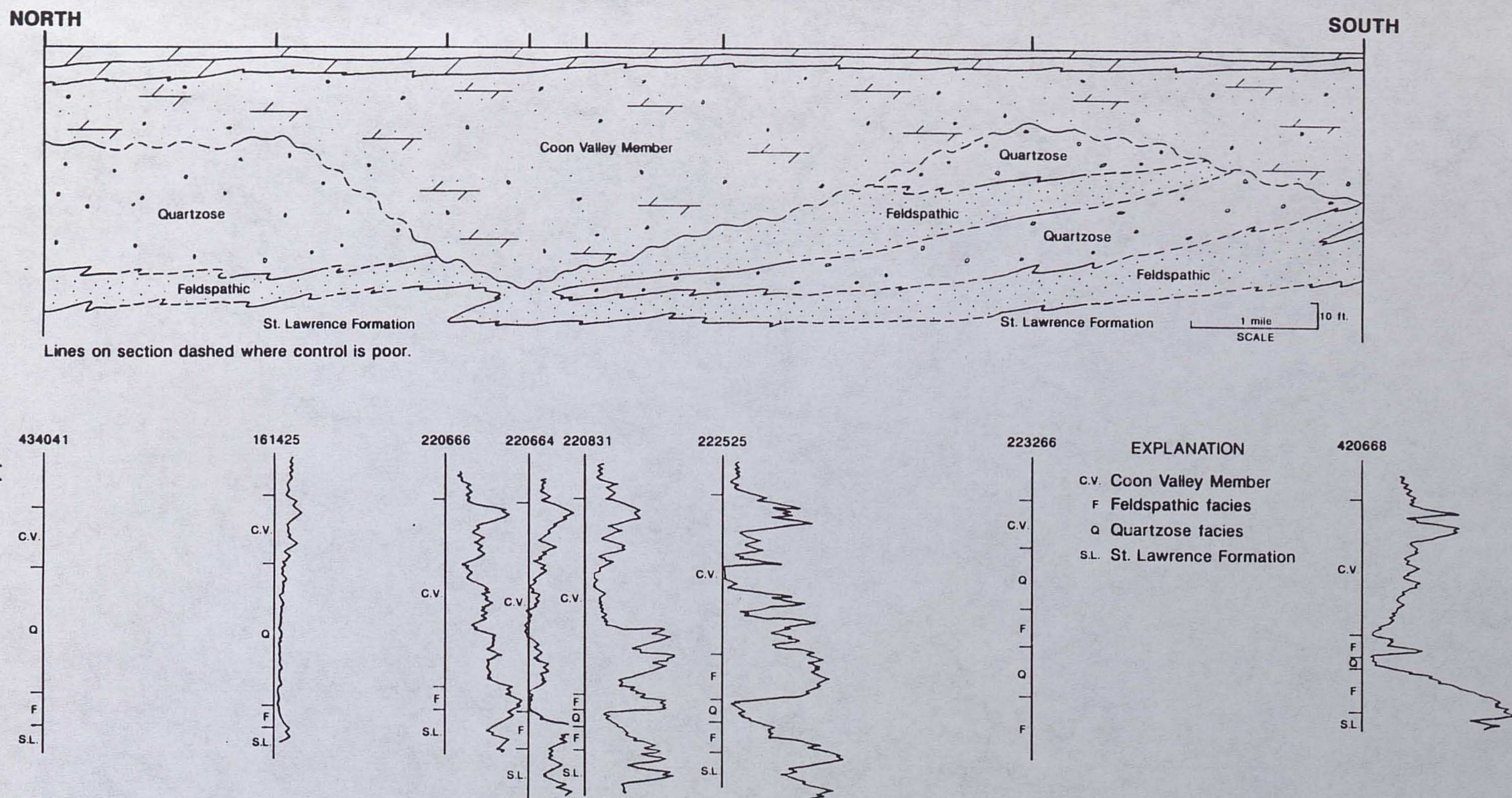


FIGURE 6. *South–north stratigraphic cross section (top) of the Jordan Sandstone and the lower part of the Oneota Dolomite in the Rochester metropolitan area, showing the variable thickness of the Jordan beneath the Coon Valley Member. The cross section was constructed on the basis of interpretations made from gamma logs and cutting samples (bottom). See Figure 4 for the location of the section and data sources.*

Cross sections based on correlated natural gamma logs and cuttings samples show that the stratigraphic setting of the Jordan Sandstone and Coon Valley Member in the Rochester area is complex (Figs. 5 and 6). Across the entire study area, the quartzose and feldspathic facies of the Jordan Sandstone, and the Coon Valley Member of the Oneota Dolomite, together form a mostly clastic interval of relatively uniform thickness, generally from 90 to 110 feet thick, that lies between the pure dolostone of the Oneota above, and the dolomitic siltstone of the St. Lawrence Formation below. However, within this interval the thickness of the Jordan Sandstone varies substantially, which results in a large variation in the relative proportions of the three lithic components of this interval. For example, in some places the Jordan Sandstone is 80 to 90 feet thick and is internally composed of 50 to 60 feet of the quartzose facies, and 20 to 40 feet of the feldspathic facies. The Coon Valley Member is 20 to 30 feet thick in these areas. Elsewhere, the Jordan Sandstone is only 10 feet thick and consists entirely of the feldspathic facies. The Coon Valley Member is as much as 90 feet thick in these areas and composes most of the interval between the St. Lawrence Formation and the dolomite of the Oneota.

HYDROSTRATIGRAPHIC PROPERTIES OF LITHIC COMPONENTS

Intergranular flow in the Jordan Sandstone and the Coon Valley Member of the Prairie du Chien Group is largely controlled by porosity and permeability, which are functions of grain size, sorting, and cementation. Such features cannot be measured directly from these strata in the Rochester area because they are not exposed at the surface, and there are no suitable samples from the subsurface. However, the porosity and permeability (hydrostratigraphic character) of the quartzose facies, feldspathic facies, and Coon Valley Member in the Rochester area can be inferred from the results of previous regional investigations. Recent studies by the Minnesota Geological Survey (Setterholm and others, 1991; Runkel, 1994a, 1994b) reveal that these three components vary substantially in porosity and permeability (Table 1). Plug tests of outcrop samples vary in permeability over four orders of magnitude. The values range from 1905 millidarcies to greater than 3000 millidarcies for the quartzose facies, 0.126 to 107 millidarcies for the feldspathic facies, and 4.59 to 97.5 millidarcies for the Coon Valley Member. Measurements like these do not precisely represent large-scale field conditions of hydrogeologic units, but they can show relative differences in hydrostratigraphic properties. The results of similar plug tests have been shown to be reasonable estimates of the relative transmissivity of clastic aquifers and confining beds in Minnesota (e.g., Miller 1984; Norvitch and others, 1974).

The values for the quartzose facies indicate that it is a moderately to highly permeable unit, with increased cementation causing a decrease in conductivity. It is by far the most

TABLE 1. ***Porosity and permeability values for samples of the quartzose facies, the feldspathic facies, and the Coon Valley Member.***

[Data from Setterholm and others, 1991. Samples were collected from selected exposures in southeastern Minnesota. Q, quartzose facies; F, feldspathic facies; CV, Coon Valley Member of the Oneota Dolomite. Permeability is measured in millidarcies (md), hydraulic conductivity in meters per day (m/day), and porosity in percent (%).]

Sample	B-1	J-1	F-1	S-1	M-1	N-1
Lithofacies	Q	Q	F	F	CV	CV
Permeability (md)	3000	1905	107	0.126	97.5	4.59
Hydraulic conductivity (m/day)	2.22E + 00	1.41E + 00	7.93E - 02	9.34E - 05	7.22E-02	3.40E - 03
Porosity (%)	26.0	35.1	28.1	14.6	20.6	15.0
Cementation	moderate	moderate to strong	moderate	strong	moderate	moderate to strong

permeable of the three components, and it likely contributes the high yields reported across much of southeastern Minnesota for wells that draw water from the Jordan Sandstone.

The feldspathic facies has low to very low relative permeability. Its very fine grain size and increased cementation results in a markedly lower permeability compared to the quartzose facies. The feldspathic facies is similar in grain size and cementation to much of Eau Claire Formation, a regional confining unit in Minnesota, and its conductivity values are within the range of values calculated for other confining units in Minnesota (e.g., Miller 1984).

The plug tests of the Coon Valley Member indicate a low relative permeability. The Coon Valley Member is generally more tightly cemented and, overall, finer grained than the quartzose facies. Although the plug samples that were tested are representative of the bulk of the Coon Valley Member, as a heterolithic unit it varies markedly in permeability from bed to bed. Coarse-grained sandstone beds that are too friable to provide coherent samples are likely to be highly permeable.

Several studies indicate that the Coon Valley Member functions as a leaky confining bed, although it apparently does not everywhere effectively hydraulically separate the Jordan Sandstone from stratigraphically higher parts of the Prairie du Chien Group. Nitrate concentrations in the aquifer show a clear and strong correlation between the thickness of the Coon Valley Member and the nitrate concentration above and below it (Setterholm and others, 1991). In areas where the Coon Valley Member is greater than 10 feet thick, nitrate concentrations in the Jordan Sandstone are substantially lower than those in the carbonate portion of the Prairie du Chien Group. Other studies show similarly distinct hydrogeochemical facies separated by the Coon Valley Member in areas where it is greater than 10 feet thick (Alexander, 1990; Donahue and Associates, 1991; Wall and Regan, 1994). In addition, unpublished local studies of potentiometric levels show that the Coon Valley may in places hydraulically separate the Jordan from the Prairie du Chien Group (Donahue and Associates, 1991; Norvitch and others, 1974; N.O. Janick, Winona State University, oral commun., 1994).

IMPLICATIONS FOR WELL PRODUCTIVITY

The quartzose facies, feldspathic facies, and Coon Valley Member possess distinct and variable hydrogeologic properties; therefore, the relative proportions of these components can have a major influence on the productivity of wells that draw water from the Jordan Sandstone and lower part of the Prairie du Chien Group. The thickness of the highly permeable quartzose facies varies substantially from place to place (Fig. 4), largely because of the variable thickness of the Jordan Sandstone beneath the Coon Valley Member (Figs. 5 and 6). Many wells draw water from open-hole (uncased) intervals having quartzose facies thicknesses of less that 20 feet; other wells draw from open-hole intervals having quartzose facies thicknesses greater than 50 feet (Fig. 7). Therefore, the permeability of the strata exposed in open-hole intervals of these wells will vary dramatically, which may explain the great variability in well productivity (Johnson, 1995) in the study area.

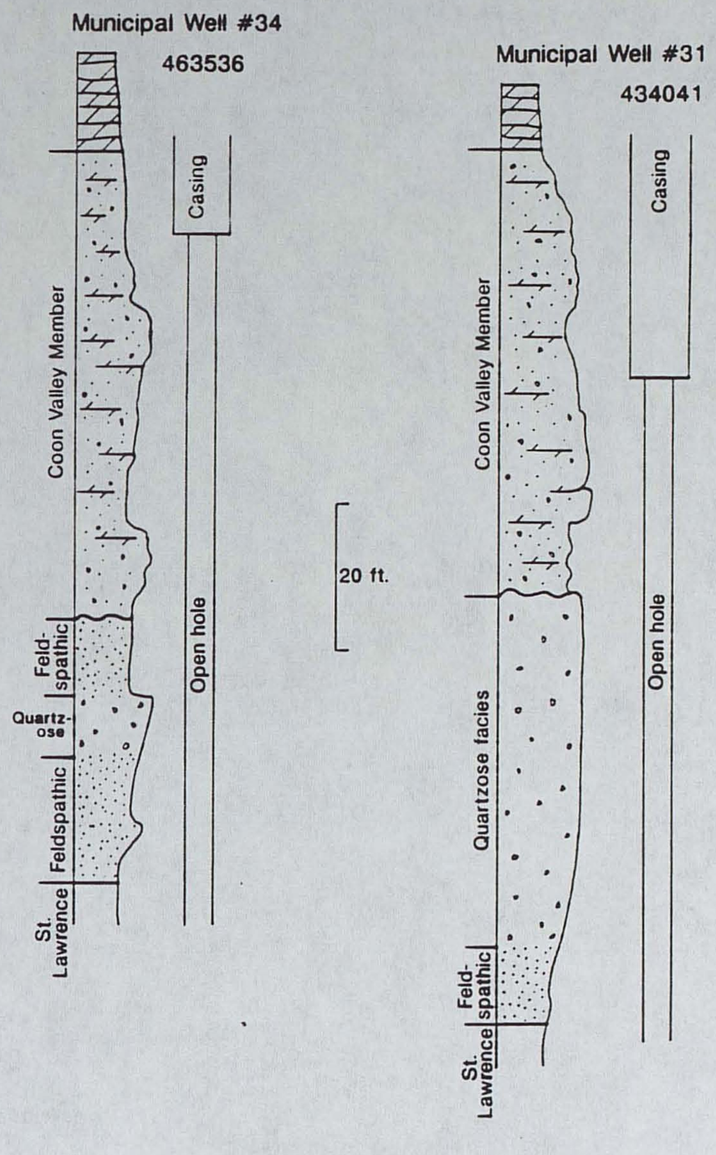


FIGURE 7. *Variation in thickness of the quartzose facies where exposed in the open-hole (uncased) interval of two Rochester municipal wells. See Figure 4 for the location of the holes.*

The geologic controls on productivity of individual wells can be evaluated by comparing pumping data to the hydrostratigraphy of the open-hole (uncased) intervals of municipal wells constructed to draw water from the Coon Valley Member and Jordan Sandstone (Table 2; Fig. 8). Such a comparison suggests that well productivity is directly proportional to the thickness of the quartzose sandstone facies in the open-hole interval. Municipal wells 29 and 31 have a substantially higher specific capacity than any of the other municipal wells. These wells have 55 and 50 feet, respectively, of the quartzose facies exposed in the open-hole interval. In contrast, other wells have 20 feet or less of exposed quartzose sandstone .

TABLE 2. Productivity compared with thickness of the quartzose facies in wells having open-hole intervals across *only* the Coon Valley Member and (or) Jordan Sandstone.

[All wells are Rochester municipal wells; see Figure 4 for locations. Unique numbers are assigned to water wells and test holes with stratigraphic information. Leader (--), not tested for; ft, feet; gpm/ft, gallons per minute per foot of drawdown; ft/d, feet per day; ft^2/day, feet squared per day.]

				Aquifer Tests	
Unique No.	Well No.	Thickness (ft)	Specific Capacity[1] (range in gpm/ft)	Hydraulic Conductivity (ft/d) 1980–1981[2]	Transmissivity (ft^2/day) 1995[3]
220660	23	20	3.77–4.16	8.9	--
224212	27	20	9.35–10.3	--	--
161425	29	55	22.2–29.6	17.0	--
239761	30	20	9.36–10.1	10.6	--
434041	31	50	20.5–24.9	--	3209
463536	34	10	4.6–4.97	--	936
506819	32	20	4.37[3]	--	--

[1]Data from Johnson (1995), except for well 32.

[2]Data from the U.S. Geological Survey.

[3]Data obtained by Leisch and Associates for Rochester Public Utilities.

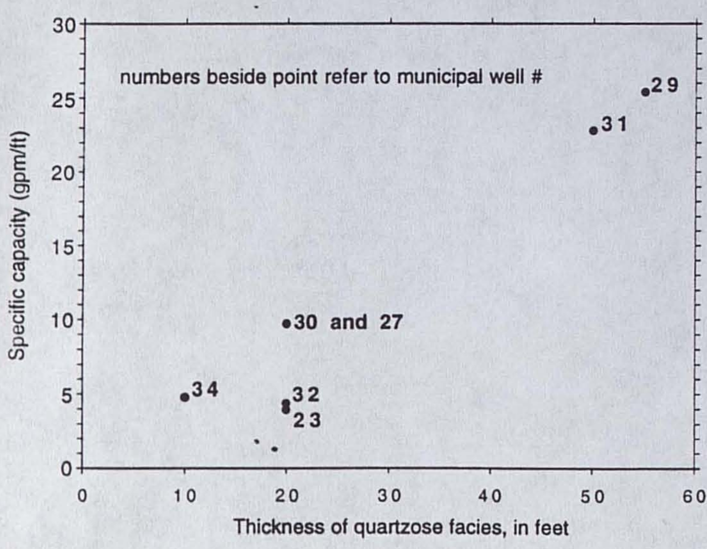


FIGURE 8. *Specific capacity of selected Rochester municipal wells versus the thickness of the quartzose facies in he open-hole (uncased) interval of wells. Gpm/ft, gallons per meter per foot.*

A comparison of municipal wells 31 and 34 exemplifies the correlation between well productivity and thickness of quartzose facies in the open-hole interval (Fig. 7). Good stratigraphic control in the form of cuttings and (or) gamma logs is available for these wells, and the wells have also been subjected to controlled pumping tests. The open-hole (uncased) interval in well 31 includes about 50 feet of quartzose sandstone. In contrast, well 34 has only about 10 feet of quartzose sandstone in the open-hole interval. Pumping data shows that the specific capacity and transmissivity are about three to five times greater for well 31 compared to well 34, even though the latter has a longer open-hole interval and has been chemically treated to enhance productivity.

SUGGESTIONS FOR FUTURE MUNICIPAL WELL CONSTRUCTION

This investigation has established for the first time stratigraphic parameters that influence the productivity of wells constructed to draw water from the lower part of the St. Peter–Prairie du Chien–Jordan aquifer in the Rochester area. Productivity is dependent largely on the thickness of the quartzose facies of the Jordan Sandstone exposed across the open-hole (uncased) interval of individual wells. Subsurface data are sufficient to predict that within about a one-mile radius from downtown Rochester, near the intersection of the west–east and south–north cross sections (Fig. 4), the quartzose facies is 20 feet thick or less. Therefore, a municipal well constructed in this area that is open hole (uncased) across only the lower part of the St. Peter–Prairie du Chien–Jordan aquifer is likely to have a low specific capacity.

The thickness of the quartzose facies cannot be confidently mapped outside of a one-mile radius from the downtown Rochester area with reasonable certainty because subsurface data are too sparse relative to the abrupt lateral changes in stratigraphic setting. Therefore, it is not possible to confidently predict where high capacity wells can be successfully constructed in the lower part of the St. Peter–Prairie du Chien–Jordan aquifer. Ideally, new municipal wells intended to draw water from the lower part of the St. Peter–Prairie du Chien–Jordan aquifer would be constructed within tens of feet distance from existing wells with a high specific capacity. However, the location of new municipal wells is largely determined by the location of demand within the city, and future wells will therefore be drilled in areas where the subsurface knowledge of the aquifer is scant. In such situations well construction should be preceded by drilling a small-diameter test hole to estimate the thickness of the highly permeable quartzose facies of the Jordan Sandstone, thereby determining whether construction of a high-capacity municipal well is possible. The following procedures and suggestions can be used in such test drilling.

Test holes should be drilled entirely through the Jordan Sandstone, penetrating the uppermost St. Lawrence Formation. Cuttings should be collected at depth intervals of five feet or less. As the Coon Valley Member and Jordan Sandstone are drilled, the mud thickness and circulation in the well should be controlled to minimize recirculation of cuttings, so that the samples are representative of the interval drilled. Drilling speed and relative hardness of the rock should be carefully noted, as this information can be useful in estimating the degree of cementation. A natural gamma log should be collected when the drilling is completed.

The cuttings, gamma log, and driller's record can be used to estimate the thickness of the quartzose facies in the test hole. If as much as 50 to 60 feet of quartzose sandstone is present, a municipal well constructed to draw water from this interval can reasonably be expected to have a high specific capacity, similar to current municipal wells 29 or 31. If the interval contains less than 20 feet of quartzose facies, the specific capacity will likely be relatively low, perhaps as poor as municipal wells 32 and 34. Test pumping of the interval intended to be open hole (uncased) in the finished well should be conducted to estimate well productivity in conjunction with the estimates based on stratigraphic data.

If test-hole data indicate that the lower part of the St. Peter–Prairie du Chien–Jordan aquifer will likely produce a poor yield, an alternate site can be chosen and test drilled according to the above procedures in an attempt to locate a site with greater potential for a high-capacity well. The thickness of the quartzose facies can potentially change tens of feet over lateral distances of a few city blocks. However, it is possible that a substantial thickness of quartzose facies does not exist within the area in which the new well must be constructed.

If the well site is not changed from the location of the test hole, there are four options to consider in the construction of the well, each utilizing a different stratigraphic interval. These options include construction of a well that draws water from (1) the Coon Valley Member and Jordan Sandstone; (2) stratigraphically higher parts of the Prairie du Chien Group, in addition to the Coon Valley and Jordan Sandstone; (3) the Franconia-Ironton-Galesville aquifer; or (4) the Mt. Simon Sandstone.

If the well is constructed according to option one, its productivity is expected to be roughly proportional to the thickness of the quartzose facies. The well should be constructed so that as much of the Coon Valley Member and Jordan Sandstone are exposed as open hole as is legally permitted. The open-hole interval may be treated or blasted to enhance the productivity. Even with such procedures, productivity as low as municipal wells 32 and 34 should be expected for wells that have less than 20 feet of the quartzose facies exposed across the open-hole interval.

The second option involves constructing a well that draws water from the Prairie du Chien Group above the Coon Valley Member. This interval is well known regionally for producing locally high yields from fractures and solution features, and some active Rochester municipal wells draw water from this interval. This type of well construction is illegal where the Prairie du Chien Group is overlain by less than 50 feet of unconsolidated deposits or sandstone bedrock within a one mile radius from the well site (Minnesota Department of Health, 1994). Therefore, a variance would have to be granted by the Minnesota Department of Health to construct this type of well in most of the Rochester area. Such wells are more susceptible to contamination from land-surface sources than wells that draw water only from the underlying Jordan Sandstone.

The third option is to construct a well that draws water from the Franconia-Ironton-Galesville aquifer, which is utilized by other cities in southeastern Minnesota for their municipal supply. In the Rochester area it currently is not used by itself to supply water to any one well, although it is exposed across the open-hole interval of some multi-aquifer wells. Based on a regional stratigraphic study by Runkel now in progress and on pumping tests elsewhere in Minnesota (Woodward, 1986; Norvitch and others, 1974), this aquifer commonly produces only moderate to low yields. Such a well is more expensive to construct than wells that draw water from the St. Peter–Prairie du Chien–Jordan aquifer because of the aquifer's greater depth.

The Mt. Simon Sandstone is widely used across southeastern Minnesota for municipal and commercial water supplies for which a high-capacity well is desired. It is a thick, generally friable, fine- to coarse-grained sandstone about 200 feet thick and composed mostly of a quartzose facies similar to that of the Jordan Sandstone. The aquifer is relatively little used in the Rochester area for commercial or domestic supplies, although some active multi-aquifer municipal wells have open-hole intervals across the Mt. Simon. Construction of a Mt. Simon well would require several hundred feet of additional drilling and well construction material compared to a St. Peter–Prairie du Chien–Jordan well.

CONCLUSIONS

The stratigraphic interval between the underlying St. Lawrence Formation and the overlying dolomite of the Oneota in the metropolitan Rochester area has generally been interpreted as the Jordan Sandstone on drilling records and has been considered relatively homogeneous and highly permeable. This investigation shows that this interval varies substantially in the amount of highly permeable, quartzose sandstone it contains, from more than 60 feet to less than 10 feet, and in many places it consists mostly of the Coon Valley Member of the Oneota Dolomite. As the primary water-producing facies, the thickness of quartzose sandstone is proportional to the productivity of individual wells. Recently constructed municipal wells with a low productivity draw water from intervals that consist of less than 20 feet of the quartzose facies. Future well construction may be aided by test drilling to determine the potential for development of high-capacity wells in the lowermost part of the St. Peter–Prairie du Chien–Jordan aquifer.

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APPENDIX A

Description of County Well Index

The County Well Index has the following three components: CWI, CWI/WL and CWI/WC.

CWI contains basic data on the well, such as location, owner's name, depth, and date drilled, as well as aquifer usage and basic ground-water quality data, and it serves as an index to data that is available in the other CWI components. Most of the information in CWI comes from well drillers' records. Some basic well data, however, originates from community testing programs and the Minnesota Department of Health data collections on ground-water quality (mostly nitrate measurements and coliform bacteria counts). These data, though very limited in subsurface information, are stored in CWI, as are historic static-water-level measurements.

CWI/WL, or County Well Index/Well Log, contains well-construction information, such as casing, screen, and pump installation, pumpage test data, and the driller's log of subsurface materials. It also contains the geologic interpretation of the materials described in the driller's logs.

CWI/WC, or County Well Index/Water Chemistry, provides storage for the results of analyses of water samples from wells. This component is intended for results from more detailed or rigorous sampling than the basic bacteria and nitrate data contained in the CWI component. Basic water-chemistry parameters recorded in CWI/WC include temperature, pH, conductivity, dissolved oxygen, alkalinity, major anions and cations, stable isotopes, and tritium. Additional parameters may be recorded as encountered.

APPENDIX B

Description of Map Units Used on the Bedrock Geologic Map of the Rochester Metropolitan Area

GALENA GROUP (Upper Ordovician).

Ogs *Stewartville Formation*—Dolomitic limestone and dolostone, fine-grained, mottled. Pitted, "swiss cheese" appearance caused by weathering. Thin, crinkly bedding. Fossiliferous, particularly in lower part. As much as 66 feet thick.

Ogp *Prosser Limestone*—Limestone, very fine grained, thin- and crinkly-bedded. Dolomitic near top. Fossils form thin coquina layers. Distinguished from Cummingsville Formation below by near absence of shale interbeds. About 65 feet thick.

Ogc *Cummingsville Formation*—Limestone and shale. Limestone, fine-grained, fossiliferous, thin- and crinkly-bedded. Interbedded with green-gray shale. Shale, calcareous; thick bedded in lower part. Weathering of soft, recessive shale alternating with hard limestone results in a sawtooth profile. About 60 feet thick.

Od **Decorah Shale (Upper Ordovician)**—Shale, green-gray. Thin interbeds of fossiliferous limestone. Ferruginous oolites at top. From 42 to 55 feet thick.

Opg **Platteville Formation (Upper Ordovician)**—Limestone, fine-grained, fossiliferous, thin- to medium-bedded. Sandy at base. Thin shale beds in upper part. Gradational contact with units above and below. Forms prominent ledge where it caps small plateaus. From 18 to 24 feet thick.

Opg **Glenwood Formation (Upper Ordovician)**—Shale, sandy, green-gray; contains phosphatic grains as much as one centimeter in diameter. Thin, quartzose, fine- to coarse-grained sandstone interbeds are common. From 5 to 10 feet thick.

Os **St. Peter Sandstone (Upper Ordovician)**—Sandstone, mostly fine- to medium-grained, poorly-cemented. Structureless or, less commonly, subtle cross-stratification. Some intensely burrowed, pale-green, shaly intervals. Progressively finer grained upward in lower half; coarsens upward in upper half. Unconformity at basal contact. Commonly exposed along steep hill slopes held in place by caps of Platteville Formation. From 92 to 112 feet thick.

Opc **PRAIRIE DU CHIEN GROUP (Lower Ordovician)**—Dolostone, sandy dolostone, and sandstone, tan to gray.

Shakopee Formation—Quartzose sandstone and minor sandy dolostone in lower part (New Richmond Member). Disconformity at base of New Richmond. Dolostone, sandstone, sandy dolostone, and minor shale in upper part (Willow River Member). Thin to medium beds.

Oneota Dolomite—Sandstone, sandy dolostone and minor shale in lower 20 to 85 feet (Coon Valley Member). Lower contact unconformable with Jordan Sandstone. Dolostone, thick- to medium-bedded; minor sandstone and sandy dolostone in upper part. Vuggy dolostone and calcite mineralization common in uppermost part.

Sandstone and sandy dolostone beds within the Oneota Dolomite in some areas make it difficult to distinguish the Oneota from the Shakopee Formation in cuttings samples. Therefore, these two formations are mapped as a single unit that ranges from 300 to 380 feet thick.

-Ꞓj **Jordan Sandstone (Upper Cambrian)**—Sandstone; coarsening-upward sequence consists of two distinct facies; quartzose facies of mostly friable, yellow to white sandstone, and feldspathic facies of very fine grained sandstone, siltstone, and shale. From 10 to 100 feet thick. Shown on cross section only.

-Ꞓs **St. Lawrence Formation (Upper Cambrian)**—Silty dolostone and siltstone, tan to gray, well-cemented, thin- to medium-bedded. Thin shale beds. Dolostone contains variable amounts of clay, silt, sand, and glauconite. Thin to medium beds of very fine grained sandstone common, particularly in upper 20 feet. From 60 to 75 feet thick. Shown on cross section only.

Franconia Formation (Upper Cambrian)—Sandstone, siltstone, and shale. Sandstone, mostly glauconitic, feldspathic, very fine to fine-grained. Shale, green and gray. Dolostone, pink or tan, sandy, glauconitic. Generally coarser grained and more poorly cemented than St. Lawrence. About 165 feet thick. Not shown on map or section.

Ironton and Galesville Sandstones (Upper Cambrian)—Sandstone, quartzose, fine- to very coarse grained. Lowermost part (Galesville): well to moderately sorted; with minor shale, siltstone, and very fine grained sandstone. Upper part (Ironton): moderately to poorly sorted; substantial shale and siltstone form interbeds or are found within sandstone matrix. About 65 feet thick. Not shown on map or section.

Eau Claire Formation (Upper Cambrian)—Shale, siltstone, and sandstone. Shale, gray to greenish-gray. Siltstone, tan to gray. Sandstone, tan to gray, very fine to fine-grained, glauconitic. Unit coarsens upward; shale and siltstone most abundant in lower part, sandstone in upper part. About 110 feet thick. Not shown on map or section.

Mt. Simon Sandstone (Upper Cambrian)—Sandstone, quartzose, fine- to coarse-grained, friable. Poorly known in Rochester area. Elsewhere in southeastern Minnesota shale, siltstone, very fine-grained sandstone common in upper two-thirds of unit and pebbly sandstone in the lowermost one-third. About 200 feet thick. Not shown on map or section.

Precambrian rocks, undifferentiated—Only one drill hole in the Rochester metropolitan area is known to intersect Precambrian rocks. According to a driller's log of this wildcat oil well, 1300 feet of siltstone and shale overlie "granite." Not shown on map or section.