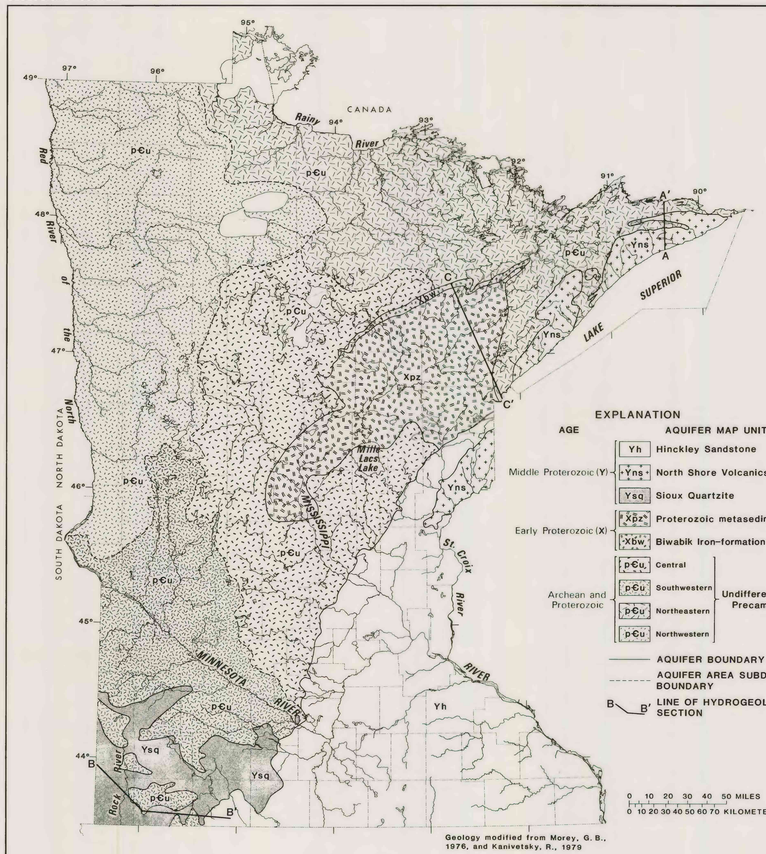
GEOLOGY AND GROUND WATER



Geology modified from Morey, G. B., 1976, and Kanivetsky, R., 1979

Figure 1.--Crystalline-rock aquifers of Archean and Proterozoic age

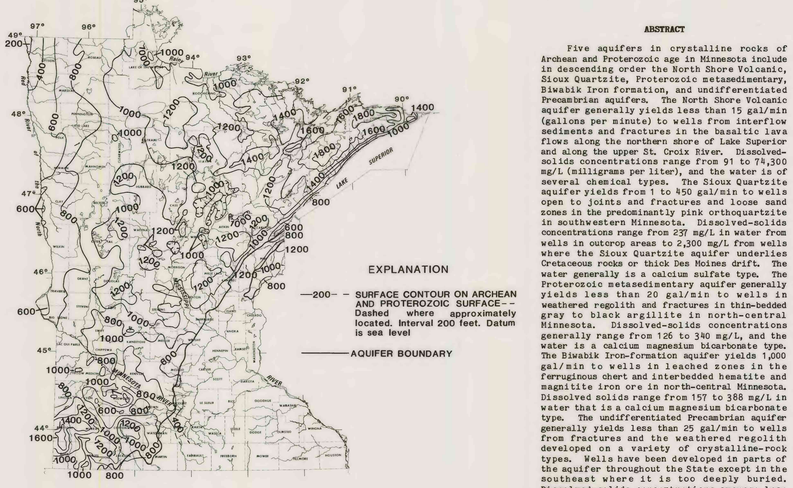


Figure 2.--Altitude of the surface of crystalline rocks of Archean and Proterozoic age in Minnesota

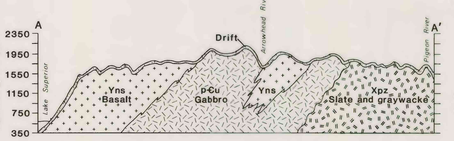


Figure 3.--Diagramatic geologic section A—A' shows igneous and metamorphic rocks of Proterozoic age in northeastern Minnesota

INTRODUCTION

In 1980, the U.S. Geological Survey began a study of the quality of water in the principal aquifers of Minnesota for the U.S. Environmental Protection Agency as part of the Underground Injection Control Program. The initial report of the study designated the 14 principal aquifers in the State and provided general information about their characteristics, lithology, hydrology, and water quality (Adolphson and others, 1981).

Purpose and Scope

This report, one in a series that describes individual aquifers in more detail, concerns hydrogeology and water quality of the five crystalline-rock aquifers of Archean and Proterozoic age--the North Shore Volcanic, Sioux Quartzite, Proterozoic Metasedimentary, Biwabik Iron-formation, and undifferentiated Precambrian aquifers; these were designated Precambrian aquifers by the Minnesota Geological Survey (Kanivetsky and Walton, 1979) and by the initial report in this series (Adolphson and others, 1981). Aquifers in the Hinckley Sandstone and Fond du Lac Formation of Middle Proterozoic age in southeastern Minnesota are not discussed here but are described in a report by Wolf and others (1983).

The geochronologic position of Precambrian rocks, those older than 570 million years, is shown in table 1.

The five aquifers are the North Shore Volcanic and Sioux Quartzite of Middle Proterozoic age, and Proterozoic metasedimentary and Biwabik Iron-formation of Early Proterozoic age, and Undifferentiated Precambrian of Archean and Proterozoic age (table 2). Aquifers in rocks of Archean and Proterozoic age, undifferentiated by stratigraphic unit, are referred to as the undifferentiated Precambrian aquifer in this report. The crystalline rocks that form the aquifer occur throughout much of the State, whereas rocks of the other four aquifers occur only in parts of the State (fig. 1). Rocks of all five aquifers are ancient; they make up the basement complex of the State. Although some of the rock units overlie one another, only the upper unit is apt to yield water in most areas. However, just south of the suborop of the Biwabik Iron-formation, several wells penetrate the Proterozoic metasedimentary aquifer and tap additional supplies from the underlying Biwabik. The Hinckley Sandstone of Middle Proterozic age overlies older Proterozoic rocks (including the Middle Proterozoic Fond du Lac Formation) and Archean and Proterozoic crystalline rocks in southeastern Minnesota. The Hinckley and Fond du Lac are not discussed here but are included in a separate report with the Mount Simon Sandstone of Cambrian age (Wolf and others, 1983).

The altitude of the crystalline-rock surface in Minnesota (fig. 2) ranges from more than 1,800 feet above sea level in the northeast (Larson-Higden, 1976) to about 200 feet in the northwest. The surface is below sea level in the southeast where it is buried by a thick sequence of rocks of Paleozoic age. A regolith that formed on the crystalline-rock surface in much of Minnesota ranges from a few feet to as much as 200 feet in thickness in southwest Minnesota (Farham, 1970).

ABSTRACT

Five aquifers in crystalline rocks of Archean and Proterozoic age in Minnesota include in descending order the North Shore Volcanic, Sioux Quartzite, Proterozoic metasedimentary, Biwabik Iron formation, and undifferentiated Precambrian aquifers. The North Shore Volcanic aquifer generally yields less than 15 gal/min (gallons per minute) to wells from interflow sediments and fractures in the basaltic lava flows along the northern shore of Lake Superior and along the upper St. Croix River. Dissolved-solids concentrations range from 91 to 74,300 mg/L (milligrams per liter), and the water is of several chemical types. The Sioux Quartzite aquifer yields from 1 to 450 gal/min to wells open to joints and fractures and loose sand zones in the predominantly pink orthoquartzite in southwestern Minnesota. Dissolved-solids concentrations range from 237 mg/L in water from wells in outcrop areas to 2,300 mg/L from wells where the Sioux Quartzite aquifer underlies Cretaceous rocks or thick Des Moines drift. The water generally is a calcium sulfate type. The Proterozoic metasedimentary aquifer generally yields less than 20 gal/min to wells in weathered regolith and fractures in thin-bedded gray to black argillite in north-central Minnesota. Dissolved-solids concentrations generally range from 126 to 340 mg/L, and the water is a calcium magnesium bicarbonate type. The Biwabik Iron-formation aquifer yields 1,000 gal/min to wells in leached zones in the ferruginous chert and interbedded hematite and magnitite iron ore in north-central Minnesota. Dissolved solids range from 157 to 388 mg/L in water that is a calcium magnesium bicarbonate type. The undifferentiated Precambrian aquifer generally yields less than 25 gal/min to wells from fractures and the weathered regolith developed on a variety of crystalline-rock types. Wells have been developed in parts of the aquifer throughout the State except in the southeast where it is too deeply buried. Dissolved-solids concentrations average less than 400 mg/L in central and northeastern Minnesota, but average about 700 mg/L in the northwest and 900 mg/L in the southwest. The water is a calcium magnesium bicarbonate type in central and northeastern Minnesota and a variety of mixed water types in northwestern and

HYDROGEOLOGY

North Shore Volcanic Aquifer

The North Shore Volcanic aquifer in the North Shore Volcanic Group of Middle Proterozoic age crops out along the north shore of Lake Superior and along the upper St. Croix River in east- central Minnesota (fig. 1). The rocks consist of a thick series of basaltic lava flows ranging in composition from olivine basalt to latite and, locally, rhyolite. These lava flows contain interbeds of conglomerate and related clastic rocks. Figure 3 shows gabbro that intruded the Precambrian rocks, undifferentiated between the underlying slate and graywacke of Early Proterozoic age and the overlying North Shore Volcanic Group of Middle Proterozoic age. Thin drift less than 50 feet thick covers the Proterozoic rocks in much of the area.

Volcanic rocks along the upper St. Croix River in east-central Minnesota are separated from volcanic rocks of the north shore by the Douglas fault--a major structural discontinuity. The lava flows in the two areas are assumed to be more or less contemporaneous, but direct evidence for such a correlation is lacking (Morey and Mudrey, 1972, p. 426). Kanivetsky and Walton (1979) include these volcanic rocks of east-central Minnesota with the North Shore Volcanics Group along the north shore of Lake Superior and the same is done for this report.

Water enters the interflow sediments and weathered top of individual lava flows in the highlands and moves downdip under confined conditions toward Lake Superior (Olcott and others, 1978, sheet 1). Dissolved-solids concentrations in excess of 1,000 mg/L indicate slow water movement and a correspondingly long period of rock contact and solution. This slow movement in the flow system probably is caused by low hydraulic conductivity and poor hydraulic connection to Lake Superior (Olcott and others, 1978, sheet 1).

Depths of 276 wells completed in the North Shore Volcanic aquifer range from 23 to 927 feet, with a median depth of 143 feet (Olcott and others, 1978, sheet 1). Most wells are for domestic and stock use. Depth to water is about 40 feet in 80 percent of the wells. All wells are completed as open hole, and many flow. Water from the aquifer also discharges through springs.

Most of the wells in the North Shore Volcanic aquifer are along Lake Superior. Yields are highly variable, but most wells yield less than 15 gal/min (Olcott and others, 1978, sheet 1). In the St. Croix River area, small supplies (5 gal/min or less) are available from wells in the upper part of the aquifer. The average depth of wells in this area is about 150 feet.

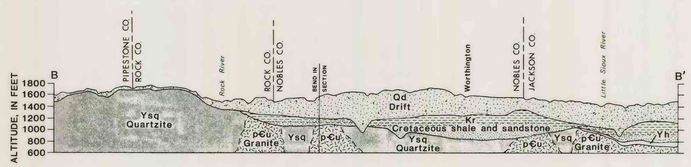


Figure 4.--Diagramatic geologic section B—B' shows igneous and metamorphic rocks of Archean and Proterozoic age in southwestern Minnesota

Sioux Quartzite Aquifer

The Sioux Quartzite aquifer of Middle Proterozoic age, underlies about 60 percent of southwestern Minnesota (fig. 1). Approximately equal areas of the aquifer underlie drift and Cretaceous rocks. The quartzite crops out in Rock, Pipestone, and Cottonwood Counties. Maximum thickness is greater than 5,000 feet (Kanivetsky and Walton, 1979, p. 6). The Sioux Quartzite extends south into Iowa and west into South Dakota; it crops out in extreme northwestern Iowa and southeastern South Dakota (Austin, 1972, p. 450).

The Sioux Quartzite is an orthoquartzite composed of greater than 94 percent silica (Miller, 1961) including interbedded, hard, red mudstone and porous, poorly cemented sandstone. The sandstone layers range in thickness from a few inches to as much as 25 feet (Anderson and others, 1976b, sheet 2). The upper 200 to 300 feet also may contain joints and fractures. Color is predominantly pink, but it ranges from white to dark red depending on the concentration of limonite and hematite (Miller, 1961).

The hydrogeologic section B-B' (fig. 4) indicates that the topographic high in southern Pipestone and northern Rock Counties controlled deposition of the Cretaceous rocks and Pleistocene drift. The high in Cottonwood County trends south- eastward and also dominates the geologic structure of the Cretaceous rocks in that area. The high is expressed as erosion-resistant surfaces exposed to chemical weathering during part or all of the Cretaceous and later periods (Austin, 1970). The highs are areas of great secondary permeability, which decreases with depth.

The Sioux Quartzite provides fairly reliable sources of water from joints, fractures, and loose sand beds within the quartzite. The weathered zone at the surface of the Sioux Quartzite is widespread, permeable, and generally yields water to wells.

The Sioux Quartzite provides most of the water supplies in the area of the topographic high in Pipestone and Rock Counties (figs. 2 and 4) where it crops out or is covered by thin glacial deposits. However, few wells tap the aquifer elsewhere. In the areas of topographic lows, the quartzite is deeply buried and the aquifer generally is used only if the overlying drift is less than 200 feet thick and unproductive. In seven municipalities with wells in the quartzite aquifer, yields average 100 gal/min. In topographically high areas, well yields range from 1 to 450 gal/min; in low areas, yields range from 1 to 250 gal/min (Anderson and others, 1976, sheet 2). Transmissivity ranges from 20 to 940 ft^2/d and horizontal hydraulic conductivity ranges from 0.2 to 3.3 ft/d (Kanivetsky and Walton, 1979, p. 9). Away from the topographic high, the hydrologic characteristics are poorly known. The range of well depths is 125 to 1,300 feet (median depth is 417 feet) based on a tabulation of 25 wells which produce from the Sioux Quartzite aquifer.

PROTEROZOIC METASEDIMENTARY AQUIFER

The Proterozoic metasedimentary aquifer of Early Proterozoic age consists of thinly bedded gray to black argillite, slate, and metagraywacke. The rocks, which may be as thick as 2,000 feet (Oakes and Bidwell, 1968), underlie drift of Pleistocene age and scattered rocks of Cretaceous age in north-central Minnesota (fig. 1). The aquifer is exposed in the Mille Lacs Lake northward to the Mesabi Iron Range. The Proterozoic metasedimentary aquifer is stratigraphically above the Biwabik and below the gabbro in the Precambrian rocks undifferentiated (fig. 5), which underlies the North Shore Volcanic Group (fig. 3).

The aquifer has low primary hydraulic conductivity and yields little water to wells unless secondary openings are present. Individual well yields generally are less than 20 gal/min, but yields of 30 gal/min are obtained locally from wells completed in the weathered zone near the bedrock surface. A yield of 270 gal/min is reported for a well in Aitkin County (Oakes and Bidwell, 1968, sheet 2). Specific capacities range from 0.5 to 5.2 gal/min per foot of drawdown (Oakes and Bidwell, 1968, sheet 2). Well depths range from 33 to 495 feet and the median depth is 175 feet, based on data from 30 wells.

The aquifer is a secondary source of water in most areas because of the relative ease of developing supplies from drift. Most wells are for domestic supplies. Near the northern edge of the aquifer it is used in conjunction with the underlying Biwabik Iron-formation when utilized for municipal and industrial supplies (Oakes and Bidwell, 1968, sheet 2).

Regionally, ground water in the Proterozoic metasedimentary aquifer moves slowly from areas of recharge through fractures toward the Mississippi and St. Louis Rivers, which are the principal drainages in the area. Near the surface, water in bedrock fractures and joints is hydraulically connected with water in overlying surficial aquifers in the drift, and water movement is coincident with local gradients on the water table. Significant recharge may be diverted by mine dewatering if the mines are hydraulically connected with fracture zones in the Proterozoic metasedimentary aquifer (Siegel and Ericson, 1980, p. 79). However, unless mining activities intersect thick sand and gravel deposits, the effect of mine dewatering on the water table should be minimal (Siegel and Ericson, 1980, p. 86).

Biwabik Iron-Formation Aquifer

The Biwabik Iron-formation of Early Proterozoic age is composed of iron-bearing chert 500 to 800 feet thick that underlies the Proterozoic metasedimentary aquifer or Pleistocene drift in north-central Minnesota (fig. 5). The rocks form a 1.5- to 3-mile wide subcrop belt that trends northeast from Cass County to St. Louis County (fig. 1). In the Mesabi Iron Range, the Biwabik Iron-formation yields more water than consonly is obtained elsewhere from Proterozoic metasedimentary rocks. Therefore, the Biwabik Iron-formation is shown as a separate aquifer (Kanivetsky and Walton, 1979, p. 7).

Wells are finished in the upper slaty, upper cherty, and lower slaty members of the Biwabik Iron-formation. The aquifer yields the most water from wells open to rocks altered by faulting and leaching. Yields generally range from 250 to 750 gal/min to wells completed in zones of joints, faults, and solution channels. Well yields are as much as 1,000 gal/min in highly fractured taconite iron ore in St. Louis County (Siegel and Ericson, 1980, p. 13). Specific capacities of wells range from 2 to 9 gal/min per foot of drawdown (Oakes and Bidwell, 1968, sheet 2). The water-bearing characteristics range widely because of their relationship to the degree of fracturing and alteration in the rock.

Water levels fluctuate in response to seasonal changes in recharge, which is related to precipitation, and also to long-term-climatic cycles. The hydrograph for well 057N20W05DAD01 (fig. 6) in west-central St. Louis County shows typical water-level fluctuations in the Biwabik Iron-formation.

The aquifer is utilized for municipal and industrial supplies and is an important source of water to wells in the Mesabi Iron Range. The aquifer will support additional large-yield wells, but additional supplies may be limited locally by mine dewatering (Oakes and Bidwell, 1968, sheet 2). Some mine pits are dewatered at 2,500 gal/min. Mining operations not only reduce the volume of the available supply but also degrade the water quality. Another disadvantage of using the aquifer is the high power cost, because the pumping lift generally is more than 200 feet. The range in depth of wells in the Biwabik Iron-formation is 170 to 600 feet with a median depth of 438 feet, based on data from 14 wells.

Ground-water movement is toward the major drainage systems, which are the Mississippi and St. Louis Rivers. The rate of movement is not known, but is believed to be slow.

Undifferentiated Precambrian Aquifers

Aquifers consisting of crystalline rocks of Archean and Proterozoic age, undifferentiated by stratigraphic unit, are referred to as undifferentiated Precambrian aquifers in this report. The aquifers are characterized by differences in lithology and water chemistry in different areas of Minnesota. The Undifferentiated Precambrian aquifers can be subdivided into four geographic areas in Minnesota: (1) central, (2) southwestern, (3) northeastern, and (4) northwestern.

Central Minnesota

The undifferentiated Precambrian aquifers in central Minnesota are located in the upper Mississippi River basin south and east of the Proterozoic metasedimentary aquifer (fig. 1) in central Minnesota the undifferentiated Precambrian aquifers are composed of various granitic intrusive rocks, including granite of Early Proterozoic age, which crops out in eastern Stearns County. West of the Proterozoic metasedimentary aquifer, the Undifferentiated Precambrian aquifers include older intrusives of Late Archean age, and metasedimentary and metavolcanic rocks of Archean age, largely inferred from gravity and aeromagnetic data.

Little is known about the hydrology or movement of water in the undifferentiated Precambrian aquifers in central Minnesota. Water from wells in these aquifers comes from fractures and the weathered zone at the bedrock surface. Yields to individual wells generally are less than 20 gal/min. Water is used mainly for domestic supplies. The median depth of wells is 160 feet; the range in depth is 33 to 453 feet, based on data from 69 wells.

Southwestern Minnesota

The undifferentiated Precambrian aquifers in southwestern Minnesota are located in the upper Minnesota River basin and in much of the Rock and Des Moines River basins. The aquifers here include gneiss and schist of Early Archean age along the Minnesota River in Redwood County, which are some of the oldest known rocks in North America (Goldich, 1972, p. 27). According to Sims (1970), these rocks were intruded by magma which formed granite of Late Archean age in Renville and Big Stone Counties. In part of the Rock and Des Moines River basins, the undifferentiated Precambrian rocks are overlain by Sioux Quartzite (figs. 1 and 4). The Precambrian crystalline rocks in much of southwestern Minnesota underlie shale and sandstone of Cretaceous age and drift of Pleistocene age, which may be as thick as 500 feet locally.

Recharge of the undifferentiated Precambrian aquifers in southwestern Minnesota is mainly by infiltration of precipitation through the overlying drift and Cretaceous sedimentary rocks. Some recharge is from water that moves eastward across the South Dakota border through the Dakota Sandstone of Cretaceous age (Swenson, 1968) and then into the undifferentiated Precambrian aquifers.

Well depths range from 33 to 900 feet (median depth is 200 feet), based on data from 64 wells. Most wells are for domestic and stock use, although five cities have municipal wells completed in the aquifer. Reported yields to wells range from less than 5 to as much as 1,200 gal/min.

Northeastern Minnesota

The undifferentiated Precambrian aquifers in northeastern Minnesota are located in the Rainy River basin north of the occurrence of the Biwabik Iron-formation and in the Lake Superior basin north of the occurrence of the North Shore Volcanic aquifer (fig. 1). In the Lake Superior basin, in the eastern part of this area, gabbro and other rocks of Middle Proterozoic age intruded along the unconformity between the overlying basalt of the North Shore Volcanic Group of Middle Proterozoic age and the underlying metamorphic rocks of Early Proterozoic age and older (Phinney, 1972, p. 333). Farther west and north of the occurrence of the Biwabik Iron-formation, the undifferentiated Precambrian includes Archean rocks (older Giants Range and Vermilion granites, and even older metasedimentary and metavolcanic rocks). The metavolcanic Ely Greenstone is the oldest known strata in northern Minnesota (Sims and Morey, 1972, p. 6). Precambrian rocks in northeastern Minnesota are overlain locally by rocks of Cretaceous age and by thin discontinuous drift of Pleistocene age that locally may be 100 feet thick.

The igneous and metamorphic rocks (granite, greenstone, slate, etc.) generally yield only small amounts of water to wells, commonly less than 5 gal/min; however, one well in St. Louis County produced 160 gal/min. Bedrock usually is not considered to be an aquifer in the Rainy Lake basin (Lindholm and Norvitch, 1976, p. 30). Well yields depend on fractures and weathering, and generally are greater where the bedrock underlies thick drift. Some wells are drilled several hundred feet into the bedrock, so that the drill hole serves as a reservoir. The median well depth is 143 feet; the range in depth is 12 to 1,000 feet, based on data from 29 wells.

Northwestern Minnesota

The undifferentiated Precambrian aquifers in northwestern Minnesota are located in the Red River basin. The Precambrian rocks are deeply buried and identification of rock types is inferred from gravity and aeromagnetic data. Sims' map (1970) shows intrusive rocks and metasedimentary and metavolcanic rocks of Archean age underlying the Red River basin. Granite and greenstone probably are the most common, but other rock types also occur (Maclay and others, 1972, p. 23). A small deposit of iron formation underlies about 600 feet of drift just east of the Red River basin in southeastern Becker and northeastern Otter Tail Counties (Anderson, 1957).

The undifferentiated Precambrian aquifers underlie rocks of Ordovician and Cretaceous age in four counties of northwestern Minnesota. Sandstone, limestone, and shale of Ordovician age are as much as 500 feet thick near the North Dakota border. Scattered patches of sandstone and shale of Cretaceous age overlie the undifferentiated Precambrian aquifers throughout the Red River basin. In much of the area, Cretaceous sedimentary rocks are less than 25 feet thick (Maclay and others, 1972, p. 27), but they are as much as 400 feet thick in Big Stone County (Hall and others, 1911, p. 134). Glacial deposits of Pleistocene age are nearly continuous in northwestern Minnesota and are from 200 to 400 feet thick in most of the area (Maclay and others, 1972, p. 29).

The undifferentiated Precambrian igneous and metamorphic rocks that underlie the entire Red River basin usually are not considered to be aquifers, although they may yield small amounts of water for domestic supplies where they are fractured or weathered (Lindholm and Norvitch, 1976, p. 18). A few municipal wells are completed in the undifferentiated Precambrian aquifer. The median depth for wells completed in this aquifer in northwest Minnesota is 300 feet; the range in depth is 88 to 456 feet, based on data from 35 wells. Most water supplies in northwestern Minnesota are from wells completed in drift.

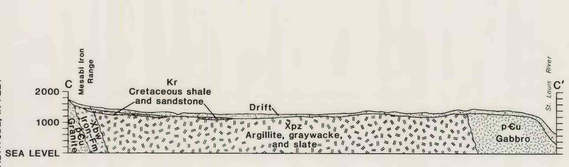


Figure 5.--Diagramatic geologic section C—C' shows igneous and metamorphic rocks of Archean and Proterozoic age in north—central Minnesota

Table 1.--Major geochronologic and chronostratigraphic units

Subdivisions in use by the U.S. Geological Survey (map symbols)					Age estimates of boundaries in million years[1,5]
Eon or Eonothem	Era or Erathem	Period or System		Epoch or Series	
Phanerozoic	Cenozoic (Cz)	Quaternary (Q)		Holocene	0.01
				Pleistocene	2 (1.7-2.2)
		Tertiary (T)	Neogene Subsystem or Subsystem (N)	Pliocene	5 (4.9-5.3)
				Miocene	24 (23-26)
			Paleogene Subperiod or Subsystem (Pg)	Oligocene	38 (34-38)
				Eocene	55 (54-56)
				Paleocene	63 (63-66)
	Mesozoic (Mz)	Cretaceous (K)		Late Upper	96 (95-97)
				Early Lower	138 (135-141)
		Jurassic (J)		Late Upper	
				Middle Middle	
				Early Lower	205 (200-215)
		Triassic (T)		Late Upper	
				Middle Middle	
				Early Lower	240
	Paleozoic (Pz)	Permian (P)		Late Upper	
				Early Lower	290 (290-305)
		Carboniferous Periods or Systems (C)	Pennsylvanian (P)	Late Upper	
				Middle Middle	
				Early Lower	330
			Mississippian (M)	Late Upper	
				Early Lower	360 (360-365)
		Devonian (D)		Late Upper	
				Middle Middle	
				Early Lower	410 (404-415)
		Silurian (S)		Late Upper	
				Middle Middle	
				Early Lower	435 (435-440)
		Ordovician (O)		Late Upper	
				Middle Middle	
				Early Lower	500 (495-510)
		Cambrian (€)		Late Upper	
				Middle Middle	
				Early Lower	570[2]
Proterozoic (P)	Late Proterozoic (Z)[3]				900
	Middle Proterozoic (Y)[3]				1600
	Early Proterozoic (X)[3]				2500
Archean (A)	Late Archean (W)[3]				3000
	Middle Archean(V)[3]				3400
	Early Archean(U)[3]				
pre-Archean (pA)[4]					~(3800?) 4550

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age of boundaries not closely bracketed by existing data shown by: Decay constants and isotopic ratios employed are cited in Steiger and Jager (1977).

[2] Rocks older than 570 million years also called Precambrian (pC), a time term without specific rank.

[3] Geochronometric units.

[4] Informal time term without specific rank.

[5] Age estimates for the Phanerozoic are by G. A. Izett, M. A. Lanphere, H. E. MacLachlan, C. W. Naeser, J. D. Obradovich, L. E. Peterman, R. Rubin, T. W. Stern, and R. E. Zartman at the request of the Geologic Names Committee. Age estimates for the Precambrian are by International Union of Geological Sciences Working Group on the Precambrian for the United States and Mexico, A. F. Hartson, Chairman. The chart is intended for use by members of the U.S. Geological Survey and does not constitute a formal proposal for a geologic time scale. Estimates of age of boundaries were made after reviewing published time scales and other data. Future modification of this chart will undoubtedly be required. The general references apply where references are not given for specific boundaries.

Table 2.--Hydrogeologic description and general quality of water from crystalline-rock aquifers of Archean and Proterozoic age

Aquifer and era (Map symbol)	Occurrence and lithology	Water-bearing characteristics	Water quality
North Shore Volcanic Middle Proterozoic (Yns)	A series of basaltic lava flows composed of fine-grained igneous rocks and interbedded sedimentary rocks along the north shore of Lake Superior and the upper St. Croix River.	Yields water from interflow sediment and from joints and fractures in the basalt. Most wells are completed in the upper 200 feet. Many flow. Well yields are highly variable, but generally less than 15 gal/min.	Ranges from drinking-water quality to highly mineralized. Dissolved solids range from 91 to 74,300 mg/L, and 25 percent of the samples exceed 1,000 mg/L. Several water types are present.
Sioux Quartzite Middle Proterozoic (Ysq)	Orthoquartzite interbedded with hard red mudstone and sandstone. Crops out or underlies drift or rocks of Cretaceous age in southwestern Minnesota	Yields water from weathered zones at the bedrock surface and from joints, fractures, and porous, poorly cemented sandstone at various depths. Most wells are completed in the upper 300 feet. Yields range from 1 to 450 gal/min. Major bedrock aquifer in southwest. Hydraulic characteristics poorly known.	Ranges from drinking-water quality to highly mineralized. Dissolved solids range from 237 mg/L in outcrop areas to 2,300 mg/L where Sioux Quartzite underlies Cretaceous rocks or thick drift. Most analyses indicate dissolved-solids concentrations less than 300 mg/L. Water is generally calcium sulfate type.
Proterozoic metasedimentary Early Proterozoic (Xps)	Thinly bedded gray to black argillite, slate, and metagraywacke that underlies drift and rocks of Cretaceous age in north-central Minnesota.	Yields water from fractures and weathered regolith. Individual well yields mostly are less than 20 gal/min, but some are as high as 275 gal/min. Hydraulic characteristics unknown. Aquifer is virtually undeveloped for water supplies.	Generally drinking-water quality. Dissolved solids range from 126 to 340 mg/L, except for one value of 2,420 mg/L. Predominantly calcium bicarbonate type water.
Biwabik Iron-formation Early Proterozoic (Xbw)	Hard ferruginous chert. Texture varies from dense to slaty. Interbedded with hematite and magnetite iron ore. Thickness ranges from 500 to 800 feet. Underlies drift or crops out in north-central Minnesota.	Leached zones of the ore deposits are major source of water. Yields as much as 1,000 gal/min. Major bedrock aquifer for municipal supplies in Mesabi Iron Range.	Generally drinking-water quality except for high concentrations of iron and sanganese. Dissolved solids range from 157 to 388 mg/L. Predominantly calcium bicarbonate type water.
Undifferentiated Precambrian Proterozoic and Archean (pCu)	Granite, gabbro, gneiss, schist, slate and other crystalline rocks that occur throughout much of the State and make up the basement complex. The rocks crop out locally.	Yields water from fractures and weathered regolith. Yields are generally from 1 to 25 gal/min, but locally are as high as 1,200 gal/min. Hydraulic characteristics poorly known. Too deeply buried to be tapped for water supplies in southeastern Minnesota.	Ranges from drinking-water quality to highly mineralized. Dissolved solids range from 96 to 2,450 mg/L. Generally more highly mineralized where the aquifer underlies Cretaceous deposits or thick drift. Water types differ between areas and include many mixed water types.

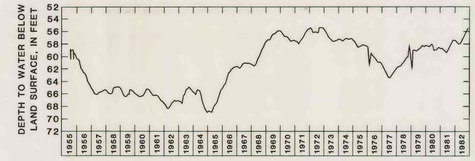


Figure 6.--Hydrograph showing water levels in well 057N20W05DAD01 completed in the Biwabik Iron—formation in St. Louis County

HYDROGEOLOGIC AND WATER—QUALITY CHARACTERISTICS OF CRYSTALLINE—ROCK AQUIFERS OF ARCHEAN AND PROTEROZOIC AGE, MINNESOTA

BY
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Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965