GEOLOGY AND GROUND WATER

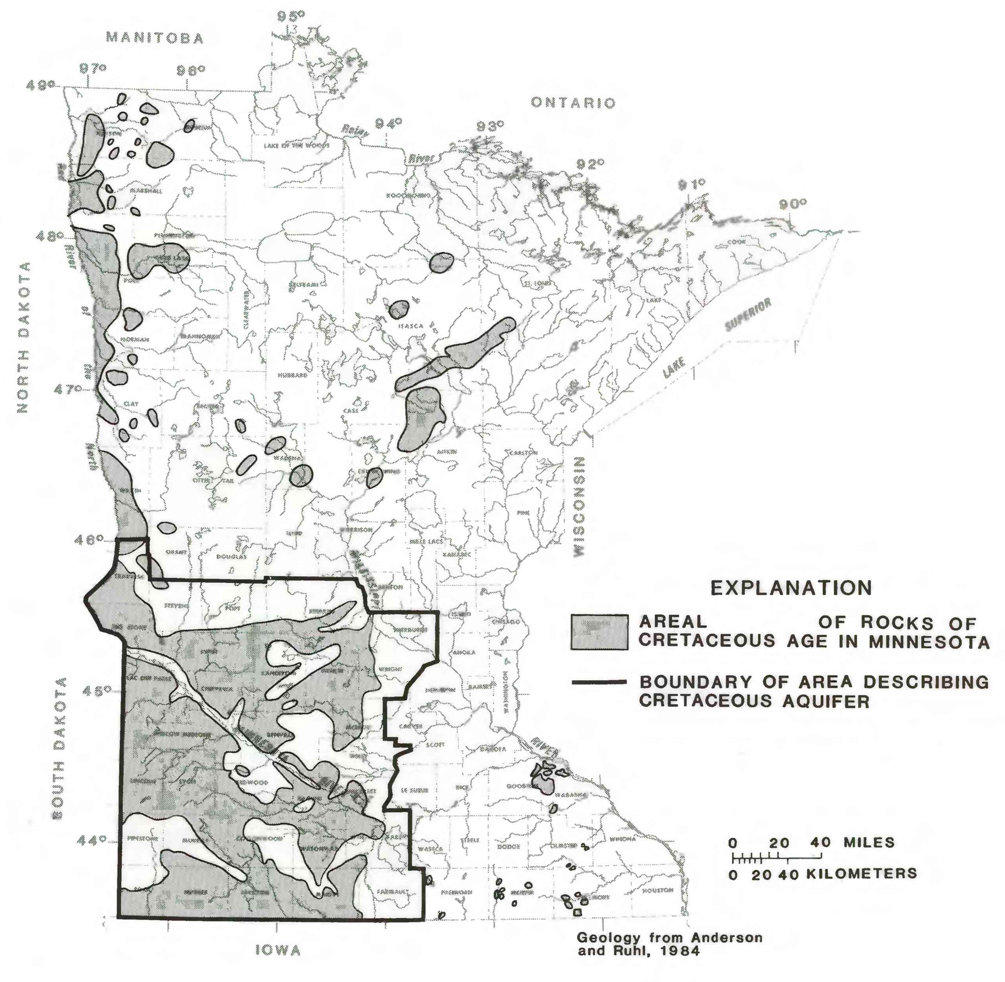

Figure 1.--Extent of rocks of Cretaceous age in Minnesota

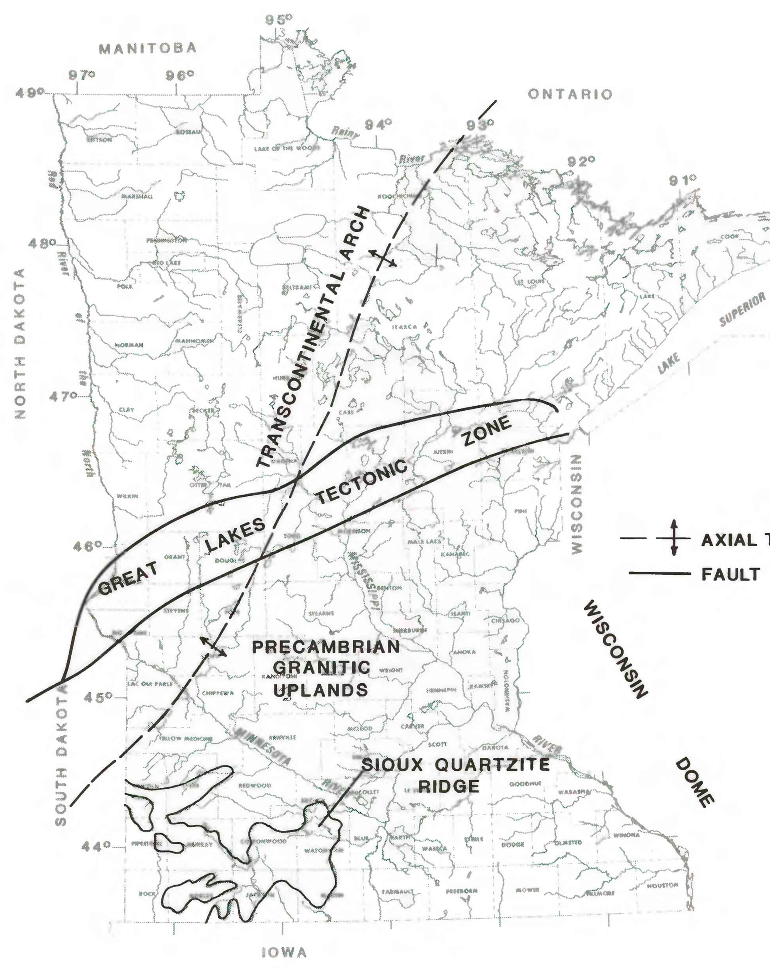

Figure 2.--Structure and topographic features affecting Cretaceous sedimentation in southwestern Minnesota

TIME UNITS	STRATIGRAPHIC UNITS				
EPOCH	Southwestern and west-central Minnesota			Northern Minnesota	Southeastern Minnesota
LATE CRETACEOUS	COLORADO GROUP	NIOBRARA FORMATION			?
		CARLILE SHALE	Unnamed Member		
			Codell Sandstone Member		
			Blue Hill Member		
			Fairport Member	?	
		GREENHORN FORMATION			OSTRANDER MEMBER OF WINDROW FORMATION
		GRANEROS SHALE		COLERAINE FORMATION	
	DAKOTA FORMATION				
EARLY CRETACEOUS	REGOLITH			REGOLITH	IRON HILL MEMBER OF WINDROW FORMATION

Modified from Austin, 1972; and from Shurr, 1980

Figure 3.--Stratigraphic correlation chart for rocks of Cretaceous age in Minnesota

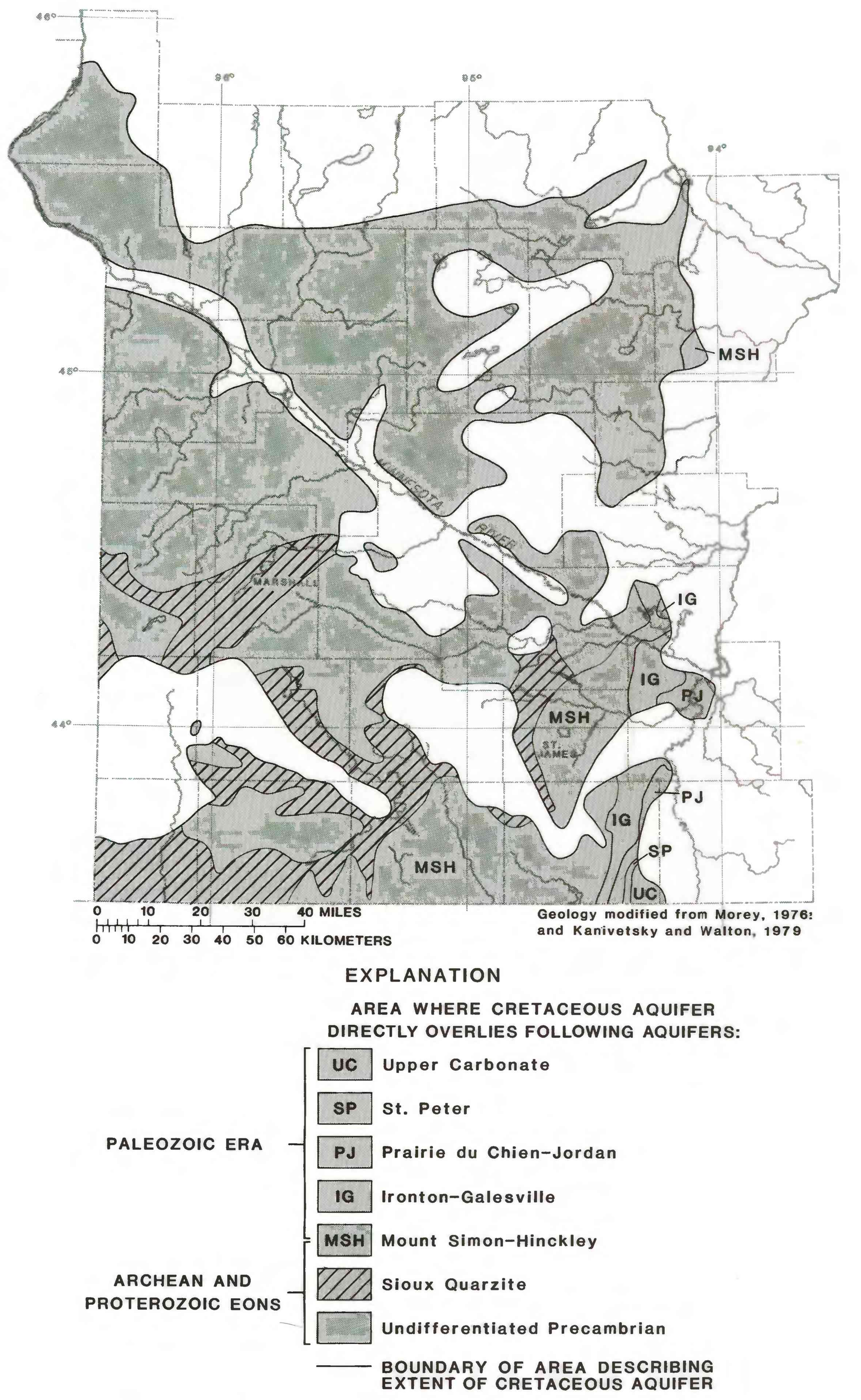

Figure 4.--Aquifers overlain by Cretaceous aquifer

ABSTRACT

The Cretaceous aquifer in southwestern Minnesota consists of discontinuous, basal sandstone beds in the Dakota Formation and the overlying Codell Sandstone Member of the Carlile Shale of the Colorado Group. These sandstone beds are not laterally or vertically persistent throughout the area and generally are separated by shale beds in the Dakota Formation and overlying Colorado Group of Cretaceous age. Water in the Cretaceous aquifer generally is confined by overlying shale and by overlying till as much as 700 feet thick. The Cretaceous aquifer overlies a sequence of crystalline and sedimentary rocks of Archean, Proterozoic, and Paleozoic age and is hydraulically connected to aquifers in the underlying rocks. Ground water moves away from the Sioux Quartzite ridge north toward the Minnesota River, south toward Iowa, and eastward. Recharge to the aquifer primarily is by infiltration of precipitation that percolates through the overlying drift and by underflow in the aquifer from South Dakota.

Water in the Cretaceous aquifer consists of five chemical types based on predominant ions, including calcium-magnesium bicarbonate, calcium-magnesium sulfate, sodium chloride, sodium bicarbonate, and sodium sulfate type waters. Dissolved-solids, chloride, and sulfate concentrations in the aquifer locally exceed standards recommended by the U.S. Environmental Protection Agency for public supplies, particularly in areas southwest of the Minnesota River.

This report is one of a series on the hydrogeology and quality of water in the 14 principal aquifers in Minnesota. The series of reports was prepared by the U.S. Geological Survey at the request of the U.S. Environmental Protection Agency to provide information for the Underground Injection Control Program.

INTRODUCTION

A study of water quality in the principal aquifers in Minnesota was begun in 1980 by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency. The study was part of the Environmental Protection Agency's Underground Injection Control Program, which is intended to control disposal of liquid wastes beneath the land surface. This report is one of a series by the U.S. Geological Survey that describe the hydrogeology and quality of water in 14 principal aquifers in Minnesota. The initial report in the series designated the 14 aquifers and provided general information on their geologic, hydrologic, and water-quality characteristics (Adolphson and others, 1981). This report presents information on the hydrogeology and quality of water in the Cretaceous aquifer in southwestern Minnesota (fig. 1).

HYDROGEOLOGIC CHARACTERISTICS

Rocks of Cretaceous age underlie a large part of Minnesota (fig. 1); most are covered by glacial deposits. The distribution and character of the rocks indicate that they were deposited in and adjacent to a sea that invaded Minnesota from the west during Late Cretaceous time and advanced eastward over highly irregular terrain (Sloan, 1964). The rocks generally are continuous throughout the southwestern part of the State, less continuous along the northwestern border and north-central region, and very discontinuous in the southeast where there are numerous outliers (fig. 1). Erosion has completely removed Cretaceous rocks from much of the State.

Cretaceous rocks locally are water bearing. In southwestern Minnesota, south of the Minnesota River and south of Lac Qui Parle County, the most productive interval is in discontinuous, basal sandstone beds of the Dakota Formation. In southwestern Minnesota, north of the Minnesota River and north of Lac Qui Parle County, the most productive interval is in the Codell Sandstone member of the Carlile Shale. The Cretaceous aquifer, as described in this report, includes the discontinuous, basal sandstone beds in the Dakota Formation, and the overlying Codell Sandstone Member of the Carlile Shale of the Colorado Group. Sandstone beds comprising the Cretaceous aquifer are not laterally or vertically persistent throughout the area and locally are separated by shale or claystone beds in the Dakota Formation and in the Colorado Group.

Geologic Framework

Sediments were deposited in Minnesota during the Cretaceous Period along the eastern margin of the Western Interior Seaway (Witzke and Ludvigson, 1982) which inundated Minnesota, Iowa, and western Wisconsin from the west. Five major transgressive-regressive cycles of the seaway affected the regional deposition of sediments. In general, marine sandstones and shales were deposited in the western and northern parts of Minnesota and estuarine, paludal, deltaic, and lacustrine sediments were deposited to the east (Sloan, 1964). According to Witzke and others (1983), the localized distribution and lithology of Cretaceous sediments in southern Minnesota were greatly influenced by the topographic features that existed at the time of deposition--primarily the Transcontinental arch, Sioux Quartzite ridge, Precambrian granitic uplands, and, to a lesser degree, the Great Lakes tectonic zone and the Wisconsin dome (fig. 2).

In southwestern Minnesota and along the western border of the State, Cretaceous rocks mainly include the Dakota Formation and the overlying formations of the Colorado Group (Anderson and Ruhl, 1983). The Dakota Formation consists of interbedded sandstone, claystone, and shale primarily of fluvial-deltaic depositional origin (Witzke and others, 1983). The Colorado Group includes, in ascending order, the Graneros Shale, the Greenhorn Formation, the Carlile Shale including the Codell Sandstone Member, and the Niobrara Formation or equivalent. Recent studies by J. R. Poppe (Minnesota Geological Survey, personal commun., 1982) show that the Dakota Formation is absent in Lac Qui Parle County and may be absent from northwestern Minnesota. Formations of the Colorado Group extend northward in discontinuous patches along the western border of Minnesota. Two formations of Cretaceous age that form outliers in northern and southeastern Minnesota include (1) the predominantly marine Coleraine Formation in the Mesabi iron-mining district and adjacent areas in northern Minnesota, and (2) the Windrow Formation of southeastern Minnesota (Sloan, 1964). Both names follow the usage of the Minnesota Geological Survey. Age and stratigraphic relationships between the formations are shown in the correlation chart (fig. 3).

The Cretaceous aquifer in Minnesota rests unconformably on a highly irregular erosional surface comprised of bedrock aquifers ranging in age from Archean to Paleozoic (fig. 4). Maximum relief on the erosional surface is 1,400 feet (Sloan, 1964). A regolith developed on the Archean, Proterozoic, and Paleozoic rocks, which were exposed in the area prior to Cretaceous deposition. The regolith overlying Archean and Proterozoic rocks in southwestern Minnesota generally ranges in thickness from 0 to 200 feet (Parham, 1970) and consists of weathered rock fragments and sand in a predominantly kaolinitic matrix (Witzke and others, 1983). In contrast, regoliths overlying Paleozoic rocks in southeastern Minnesota have maximum thicknesses of about 50 feet and are composed of residual Paleozoic carbonate rocks, chert, and sand clasts commonly in a kaolinitic matrix (Witzke and others, 1983).

Cretaceous rocks are thin or missing from topographically high areas of the buried pre-Cretaceous erosional surface. Rocks of the Dakota Formation and Colorado Group onlapped the emergent landmass formed by the Sioux Quartzite ridge and thinly covered the Precambrian granitic uplands in southwestern Minnesota (fig. 2). Thicknesses of Cretaceous rocks are as much as 500 feet where the rocks were deposited in basins or erosional valleys in the crystalline rocks (Sloan, 1964).

The altitude of the upper surface of the Cretaceous rocks in southwestern Minnesota (fig. 5) reflects both the onlap relationship with the Sioux Quartzite ridge (the surface altitude is more than 1,300 feet above sea level adjacent to the ridge) and the postdepositional erosion caused by four episodes of continental glaciations during the Pleistocene. Channels of many glacial melt-water streams incised the bedrock surface and form the dendritic pattern shown in figure 5.

Drift, composed of till, outwash, lake sediments, and loess, underlies most of the land surface of southwestern Minnesota (Matsch, 1972); Cretaceous outcrops are primarily restricted to road and quarry cuts and stream channels. Most drift at the land surface of southwestern Minnesota was deposited by the most recent glaciation, the Wisconsin Glaciation. In extreme southwestern Minnesota, however, pre-Wisconsin drift occurs at or near the land surface. An upland with a steep easterly facing escarpment is located in the southwestern corner of the State, and is called the Coteau des Prairies, or "Highland of the Prairies" (fig. 7). The Coteau, postulated to result from a bedrock upland of Cretaceous rocks (Wright, Jr., 1972), deflected the advance of the Des Moines Lobe of the Wisconsin Glaciation. The terminal moraine on the western part of the Des Moines Lobe--the Bemis moraine--was deposited near the crest of the Coteau, and a recessional moraine--the Altamont--was deposited along the flank (fig. 6). Thickness of the drift overlying the Cretaceous rocks in southwestern Minnesota ranges from 0 to about 700 feet (fig. 6). Moraines and filled bedrock valleys contain the thickest deposits.

Hydrologic Regime

The Cretaceous aquifer in southwestern Minnesota, as defined in this report, comprises discontinuous, basal sandstone beds of the Dakota Formation, and the overlying Codell Sandstone Member of the Carlile Shale in the Colorado Group. Rodis (1963) found that sandstone beds in the Cretaceous rocks in parts of Lyon County, Minnesota, generally were found at three altitude intervals: a medium- to coarse-grained basal bed as much as 100 feet thick that occurs between the Archean or Proterozoic bedrock surface and an altitude of 825 feet; a fine-grained middle bed as much as 20 feet thick that occurs at an altitude between 890 and 1,020 feet; and a fine- to medium-grained upper bed as much as 50 feet thick which occurs at an altitude between 1,050 and 1,160 feet above sea level. However, Ludvigson and Bunker (1979, p. 12) report that individual sandstones in the Dakota Formation in northwestern Iowa are not laterally or vertically persistent; they rapidly interfinger with flood-basin siltstones and claystones. These more random stratigraphic relationships also are likely to occur in the Dakota Formation in most of southwestern Minnesota.

Water in most of the Cretaceous aquifer is confined either by Cretaceous shale in the Dakota Formation or the Colorado Group, or by till where the shales were eroded. Water in the aquifer is unconfined in certain areas where the aquifer is directly overlain by thin, permeable drift that is exposed at the land surface. Recharge to the aquifer is mainly from the infiltration of precipitation that percolates through the drift and shale overlying the aquifer (fig. 7). However, some water in the aquifer flows into Minnesota from South Dakota, and some water enters the aquifer by leakage through the Sioux Quartzite (Norvitch, 1964; Anderson and others, 1976a). Water from the Cretaceous aquifer is discharged primarily to underlying Paleozoic aquifers (fig. 4) and through overlying alluvium and drift deposits to the Minnesota River (fig. 7). Some water also is pumped from wells.

Regionally, water flows through the aquifer away from the Sioux Quartzite ridge northward toward the Minnesota River, southward toward Iowa, and eastward (fig. 8). Flow in the aquifer northeast of the Minnesota River is probably toward the river. Locally, flow is toward many of the drift-filled bedrock valleys shown in figure 5. Water levels used to produce the potentiometric map in figure 8 were measured in wells completed in various sandstone beds in the Cretaceous aquifer. It is probable, according to Burkart (1982), that in northwestern Iowa all the sandstone beds are hydraulically connected; however, the hydraulic head may differ among sandstones at any site. Therefore, the potentiometric map (fig. 8) represents an interpretation of the regional flow and not necessarily a depiction of local flow in the aquifer. The general direction of ground-water flow is at right angles to the potentiometric contours in the direction of the greatest slope. The gradient of the potentiometric surface ranges from about 300 to 500 ft/mi along the northeastern slope of the Coteau des Prairie (underlying the Altamont moraine) to about 50 to 150 ft/mi between the Coteau and the Minnesota River where the aquifer is underlain by the Mount Simon-Hinckley aquifer (fig. 4). Downgradient flexures or increased spacing of potentiometric contours with increasing distance from perennial streams indicate recharge by infiltration of water through the overlying deposits (Gutentag and Weeks, 1980). The flattening of the gradient shown by the widely spaced contours such as those between the Coteau and the Minnesota River, may be due to recharge through the thin overlying drift (fig. 6), increased thickness of the Cretaceous aquifer, or both.

Hydrologic characteristics of the Cretaceous aquifer are poorly known and highly variable. Ropes (1969) reported the results of an aquifer test for the Cretaceous aquifer conducted in St. James, Watonwan County, Minnesota; the transmissivity was calculated as 8,040 ft^2/d, and the storage coefficient as 0.00034. Furthermore, Ropes stated that wells yielding 1,000 gal/min could be completed in the aquifer near the St. James area. The hydraulic conductivity of the aquifer in northwestern Iowa ranges from 37 to 50 ft/d, and yields to wells average about 250 gal/min although they exceed 1,000 gal/min locally (Burkart, 1982). Smaller well yields have been reported for the aquifer elsewhere in Minnesota: 2 to 7 gal/min in Lyon County (Rodis, 1961); 2 to 45 gal/min near Marshall in Lyon County (Thompson, 1965); 3 to 10 gal/min in Nobles County and western Jackson County (Norvitch, 1964); and 5 to 250 gal/min for southwestern Minnesota (Anderson and others 1976a; 1976b). The smaller yields in Minnesota are attributed to thinning of the Dakota Formation (Anderson and Ruhl, 1983).

Water Use

Use of water from wells in the Cretaceous aquifer is limited by a variety of factors: (1) relatively high dissolved-solids, chloride, and sulfate concentrations--in some areas water in the aquifer has dissolved-solids concentrations of 1,500 mg/L, chloride concentrations of 1,500 mg/L, and(or) sulfate concentrations of 1,700 mg/L; (2) low well yields--in some areas well yields are 2 to 10 gal/min; and (3) depth of burial--where the aquifer underlies the Coteau des Prairies, it is covered by drift deposits as much as 700 feet thick.

Despite these limitations, many wells have been completed in the Cretaceous aquifer for domestic and stock supplies. Additionally, 36 communities in southwestern Minnesota use or have used the aquifer for their municipal water supply (fig. 8). Use of water from the aquifer for irrigation is sporadic because of high concentrations of dissolved solids and boron (Broussard and others, 1973).

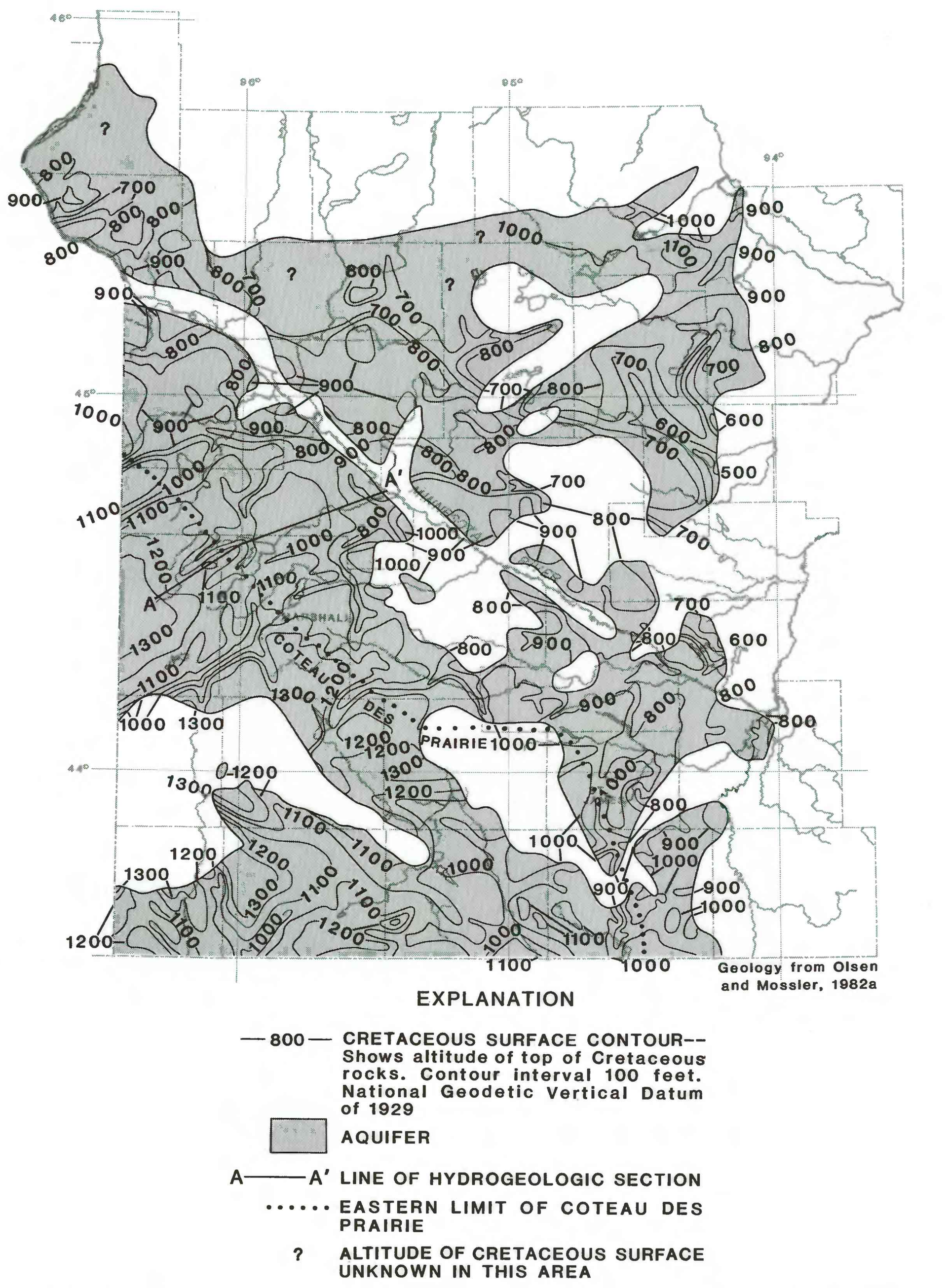

Figure 5.--Altitude of top of Cretaceous rocks in southwestern Minnesota

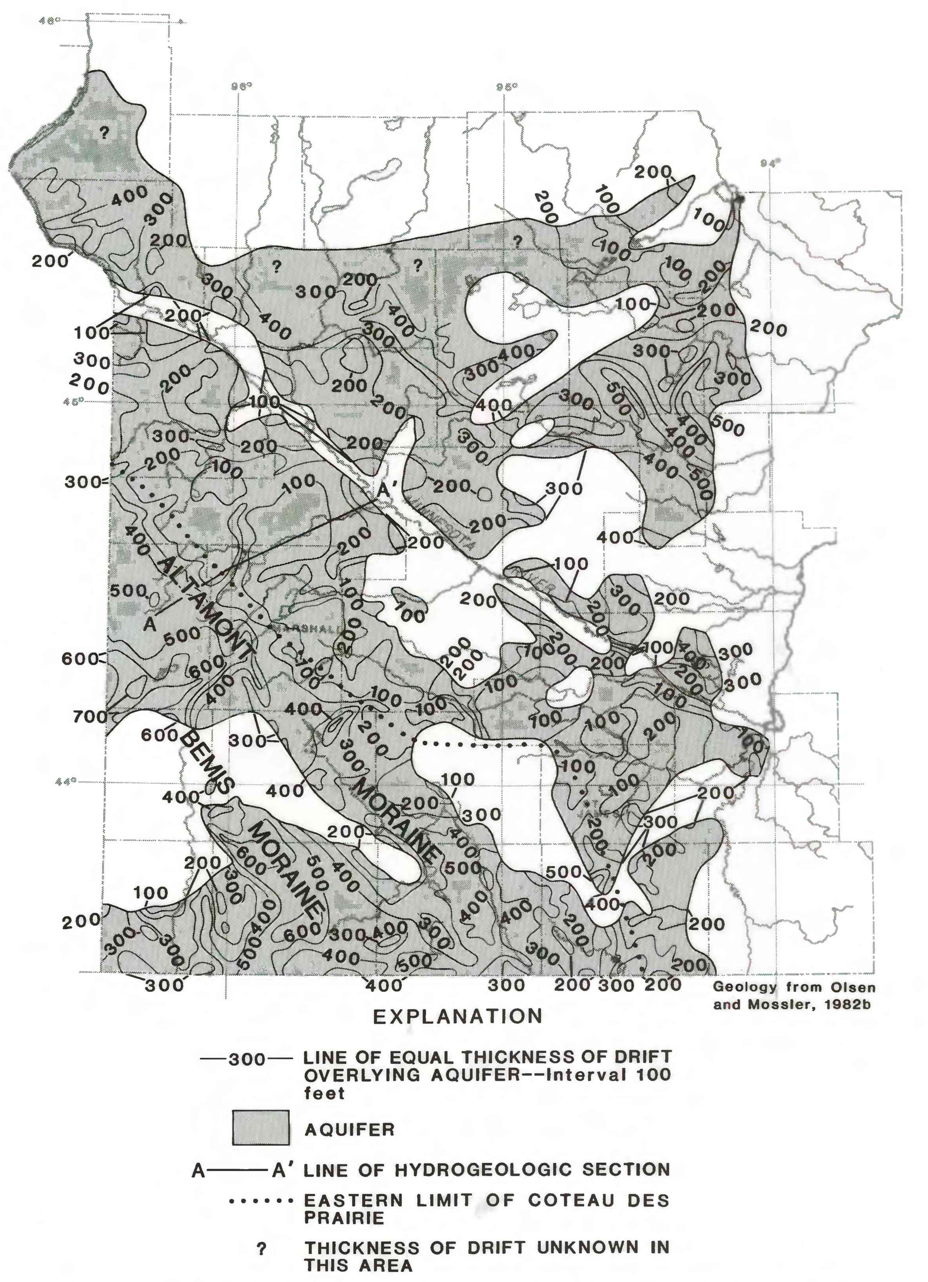

Figure 6.--Thickness of drift overlying the Cretaceous aquifer

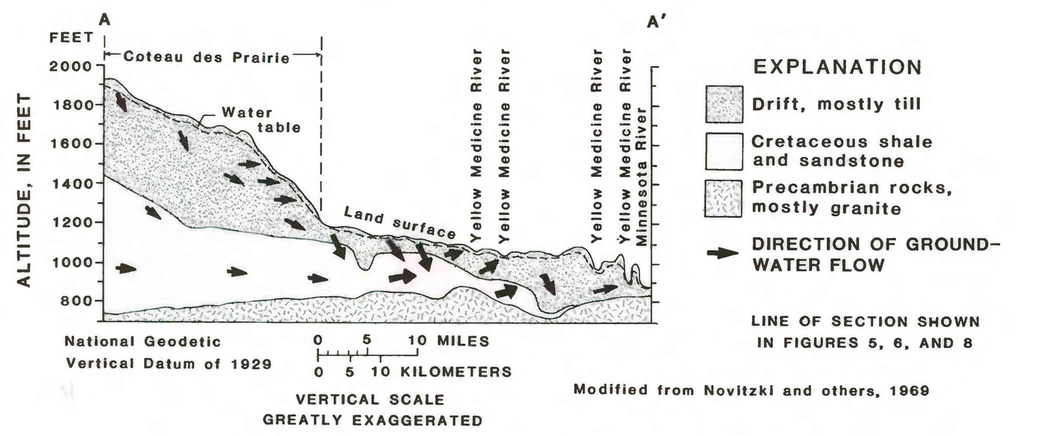

Figure 7.--Hydrogeologic section of part of study area

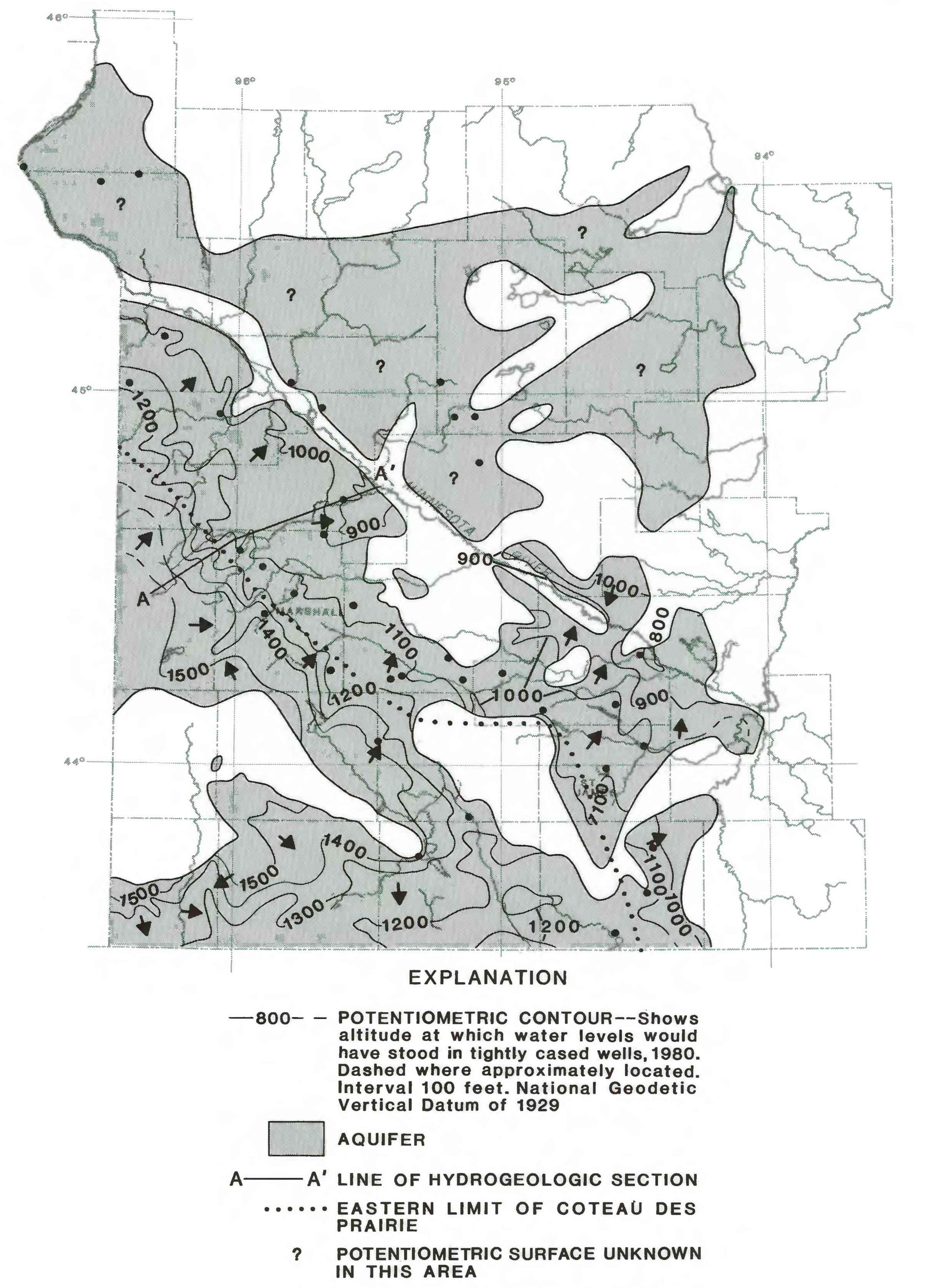

Figure 8.--Potentiometric surface of Cretaceous aquifer, 1970-80

CONVERSION FACTORS

For use by readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
foot per day (ft/d)	0.305	meter per day (m/d)

HYDROGEOLOGIC AND WATER-QUALITY CHARACTERISTICS OF THE CRETACEOUS AQUIFER, SOUTHWESTERN MINNESOTA

BY
D. G. WOODWARD AND H. W. ANDERSON JR., 1986

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