HYDROLOGIC INVESTIGATIONS
ATLAS HA–677
SHEET 1 OF 2

INTRODUCTION

FIGURE 1.—LOCATION OF HOLLANDALE EMBAYMENT, SOUTHEASTERN, MINNESOTA

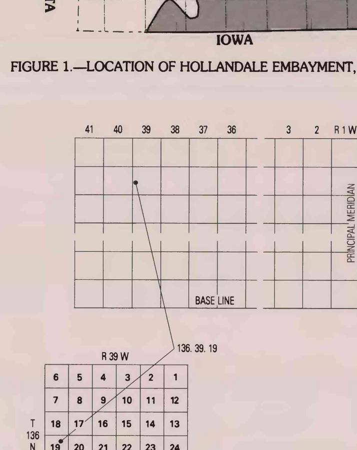

FIGURE 2A.—SYSTEM OF NUMBERING WELLS

The system of numbering wells that were gamma-logged is based on the U.S. Bureau of Land Management's system of subdivision of public lands. The well number, in addition to designating the well, locates its position in the land network. The first segment of a well number indicates the township north of the base line; the second, the range west of the principal meridian; and the third, the section in which the well is located. Figure 2A illustrates the method of numbering a test hole. Thus, the number 136N39W19 identifies a well in sec. 19, T. 136 N., R. 39 W.

CONVERSION FACTORS

For use of readers who prefer to use International System of Units (SI), conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric) unit
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)

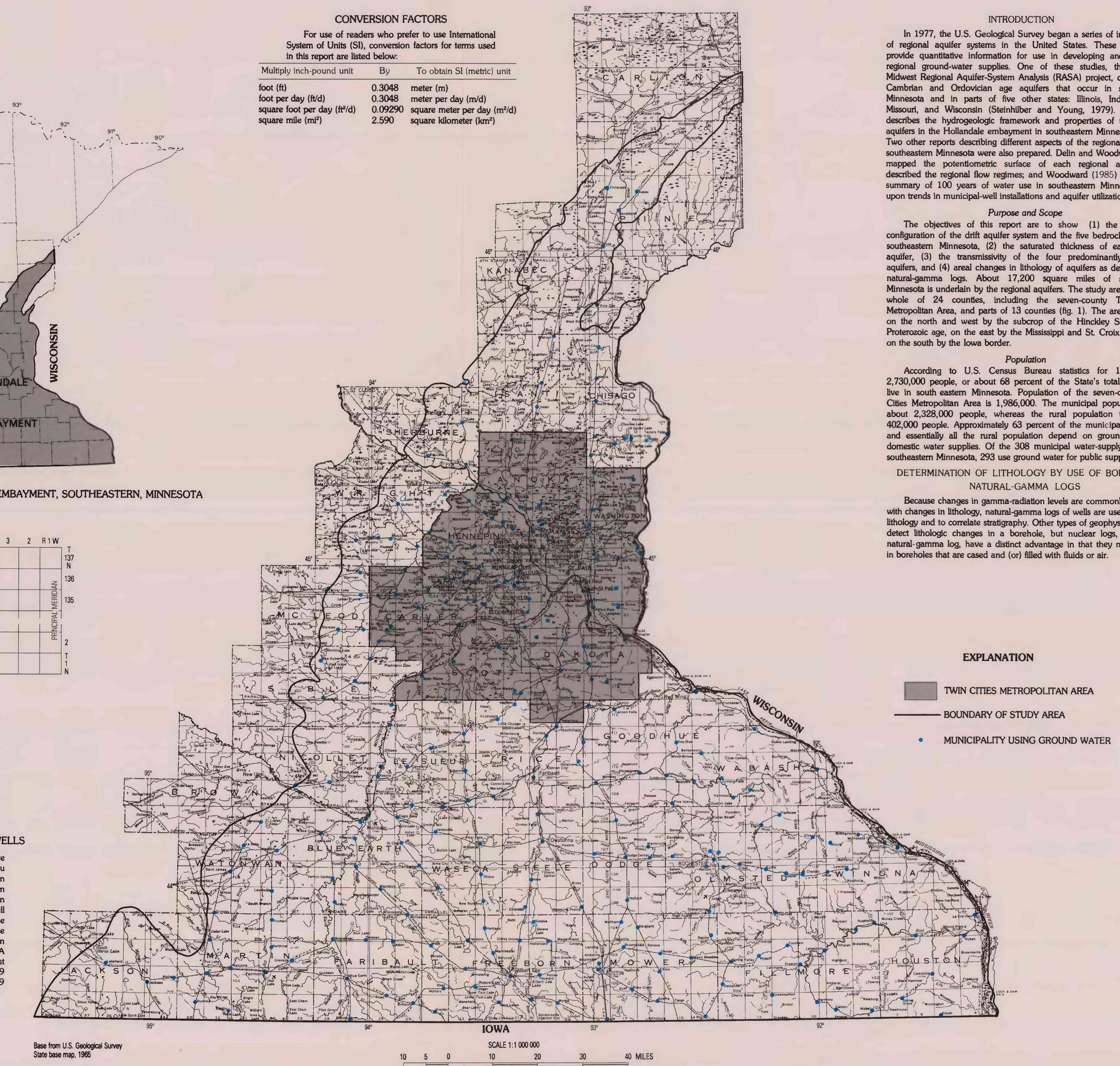

FIGURE 2.—MUNICIPALITIES THAT USE GROUND WATER FOR PUBLIC SUPPLY

INTRODUCTION

In 1977, the U.S. Geological Survey began a series of investigations of regional aquifer systems in the United States. These studies will provide quantitative information for use in developing and managing regional ground-water supplies. One of these studies, the Northern Midwest Regional Aquifer-System Analysis (RASA) project, concerns the Cambrian and Ordovician age aquifers that occur in southeastern Minnesota and in parts of five other states: Illinois, Indiana, Iowa, Missouri, and Wisconsin (Steinhilber and Young, 1979). This report describes the hydrogeologic framework and properties of the regional aquifers in the Hollandale embayment in southeastern Minnesota (fig. 1). Two other reports describing different aspects of the regional aquifers in southeastern Minnesota were also prepared. Delin and Woodward (1984) mapped the potentiometric surface of each regional aquifer, and described the regional flow regimes; and Woodward (1985) presented a summary of 100 years of water use in southeastern Minnesota based upon trends in municipal-well installations and aquifer utilization.

Purpose and Scope

The objectives of this report are to show (1) the extent and configuration of the drift aquifer system and the five bedrock aquifers in southeastern Minnesota, (2) the saturated thickness of each bedrock aquifer, (3) the transmissivity of the four predominantly sandstone aquifers, and (4) areal changes in lithology of aquifers as determined by natural-gamma logs. About 17,200 square miles of southeastern Minnesota is underlain by the regional aquifers. The study area covers the whole of 24 counties, including the seven-county Twin Citites Metropolitan Area, and parts of 13 counties (fig. 1). The area is defined on the north and west by the subcrop of the Hinckley Sandstone of Proterozoic age, on the east by the Mississippi and St. Croix Rivers, and on the south by the Iowa border.

Population

According to U.S. Census Bureau statistics for 1980, about 2,730,000 people, or about 68 percent of the State's total population, live in south eastern Minnesota. Population of the seven-county Twin Cities Metropolitan Area is 1,986,000. The municipal population totals about 2,328,000 people, whereas the rural population totals about 402,000 people. Approximately 63 percent of the municipal population and essentially all the rural population depend on ground water for domestic water supplies. Of the 308 municipal water-supply systems in southeastern Minnesota, 293 use ground water for public supply (fig. 2).

DETERMINATION OF LITHOLOGY BY USE OF BOREHOLE NATURAL-GAMMA LOGS

Because changes in gamma-radiation levels are commonly associated with changes in lithology, natural-gamma logs of wells are used to identify lithology and to correlate stratigraphy. Other types of geophysical logs can detect lithologic changes in a borehole, but nuclear logs, such as the natural-gamma log, have a distinct advantage in that they may be used in boreholes that are cased and (or) filled with fluids or air.

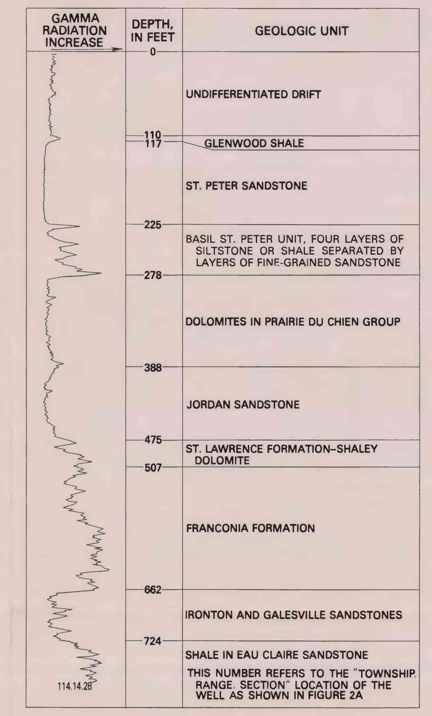

FIGURE 3.—INTERPRETED NATURAL–GAMMA LOG

The spontaneous disintegration of atomic nuclei of radioactive elements in rock materials causes the emission of gamma radiation. The disintegration of uranium and thorium (and their daughter products) and of potassium-40 is the source for virtually all gamma radiation measured in a borehole (Patten and Bennett, 1963). Natural-gamma logs record the intensity of the radiation, which is from sources within 6 to 12 inches of borehole wall. Deflections on natural-gamma logs may be affected by changes in borehole media (air, water, mud), casing, hole diameter, gravel pack, grout behind the casing, or well development, and are not necessarily related to changes in rock type (Keys and MacCary, 1971, p. 67). Deflections on the enclosed logs, however, are believed to result primarily from changes in lithology with the recorded level of radiation increasing from the left side of the log to the right.

Natural-gamma logs commonly indicate layers with high clay content and, therefore, a low effective porosity and permeability than coarser deposits (Keys and MacCary, 1971, p. 11). Feldspars and micas, which readily decompose into clay, contain abundant potassium and associated potassium-40. Clays also concentrate heavy radioelements through the processes of ion exchange and adsorption (Keys and MacCary, 1971). Thus, clay-bearing sediments generally have much higher natural-gamma activity than carbonate rocks and quartzose sediments such as sandstone. Consequently, the relatively low gamma radiation associated with quartzose sandstone aquifers (the Mount Simon-Hinckley, Ironton-Galesville, Jordan (basal part of the Prairie du Chien-Jordan), and St. Peter contrasts with the relatively high gamma radiation associated with intervening clayey, silty, and shaley confining beds (the Eau Claire, St. Lawrence-Franconia, basal St. Peter, and Decorah-Platteville-Glenwood), as shown in fugure 3.

Natural-gamma logs were collected throughout southeastern Minnesota during 1979-81. Selected natural-gamma logs are used in this report to assist in identifying lithologic changes in bedrock aquifers and confining beds in the Hollandale embayment; these logs were recorded in the field with the same instrument settings: logging speed was 25 feet per minute, time constant was 4 seconds, and the count rate was 100 counts per second. Depths to the top and bottom of the hydrogeologic units are noted on the logs.

HYDROGEOLOGIC SETTING

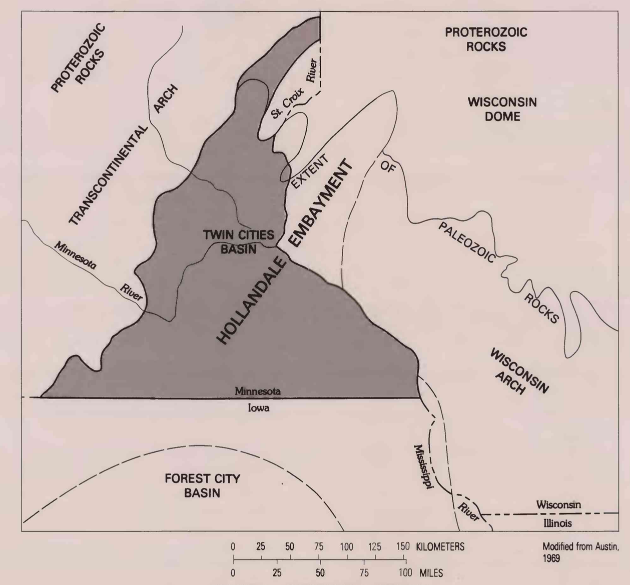

FIGURE 4.—STRUCTURAL SETTING

HYDROGEOLOGIC SETTING

Sedimentary rocks of Paleozoic age in southeastern Minnesota were deposited in seas that occupied a shallow depression bordered by the Transcontinental Arch to the west and the Wisconsin Arch and Wisconsin Dome to the east and north. Austin (1969) called this shallow depositional basin the Hollandale embayment of the Ancestral Forest City basin (fig. 4). Structurally, the Hollandale embayment developed as a southerly plunging synclinorium over the pre-existing Lake Superior syncline of Proterozoic age, which is dissected by numerous large- and small-scale faults (Sims and Zietz, 1967). Reactivation of some faults in Paleozoic time not only produced secondary structural features in the embayment (Craddock and others, 1963), but also affected sedimentation rates and the thickness of units.

Many of the Paleozoic formations show transitional facies changes from a marine depositional environment in the middle of the embayment to a nearshore environment along the periphery. The nearshore facies, according to Austin (1972), initially differed significantly from correlative units within the embayment, and deep weathering prior to the advance of seas in Late Cretaceous time increased the differences. The hydrogeologic significance of these differences will be discussed in following sections of this report.

The hydrogeologic column, shown in figure 5, illustrates how Delin and Woodward (1984) divided the sequence of sedimentary rocks in southeastern Minnesota into regional aquifers and regional confining beds for the RASA study. The occurrence of localized well-completion zones does not in itself constitute a regionally significant aquifer. For example, the consolidated Cretaceous aquifer in western Minnesota unconformably overlaps all the older bedrock aquifers in the southwestern part of the study area (fig. 6). Although the Cretaceous aquifer is utilized locally, it is not considered to be a regional aquifer for this study. The bedrock hydrogeologic map (fig. 6) shows the distribution of aquifers and confining beds beneath the drift deposits. The hydrogeologic sections in figure 7 illustrate the vertical layering of these sedimentary rocks, and show regional structural relationships in the Hollandale embayment.

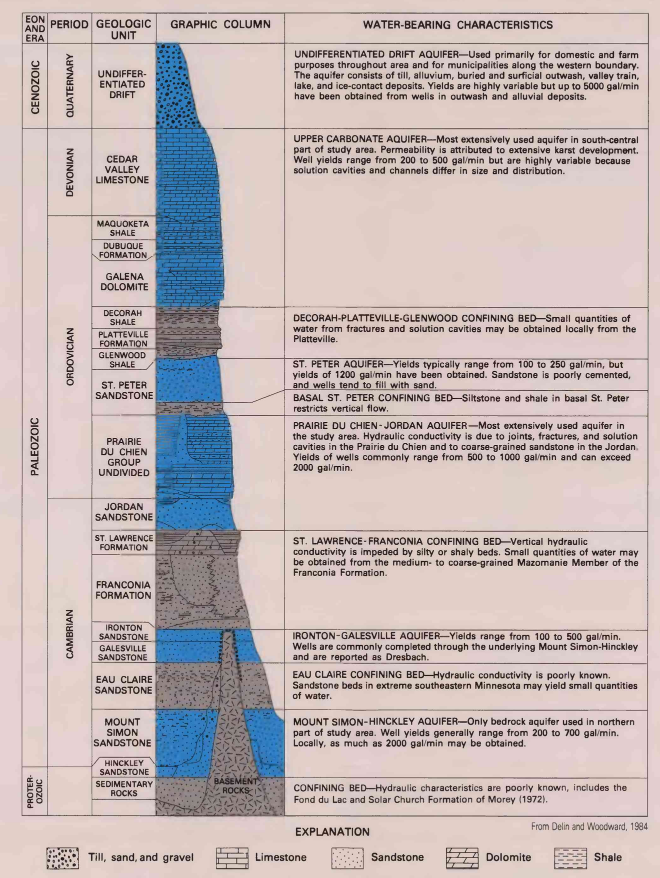

FIGURE 5.—HYDROGEOLOGIC COLUMN OF SOUTHEASTERN MINNESOTA

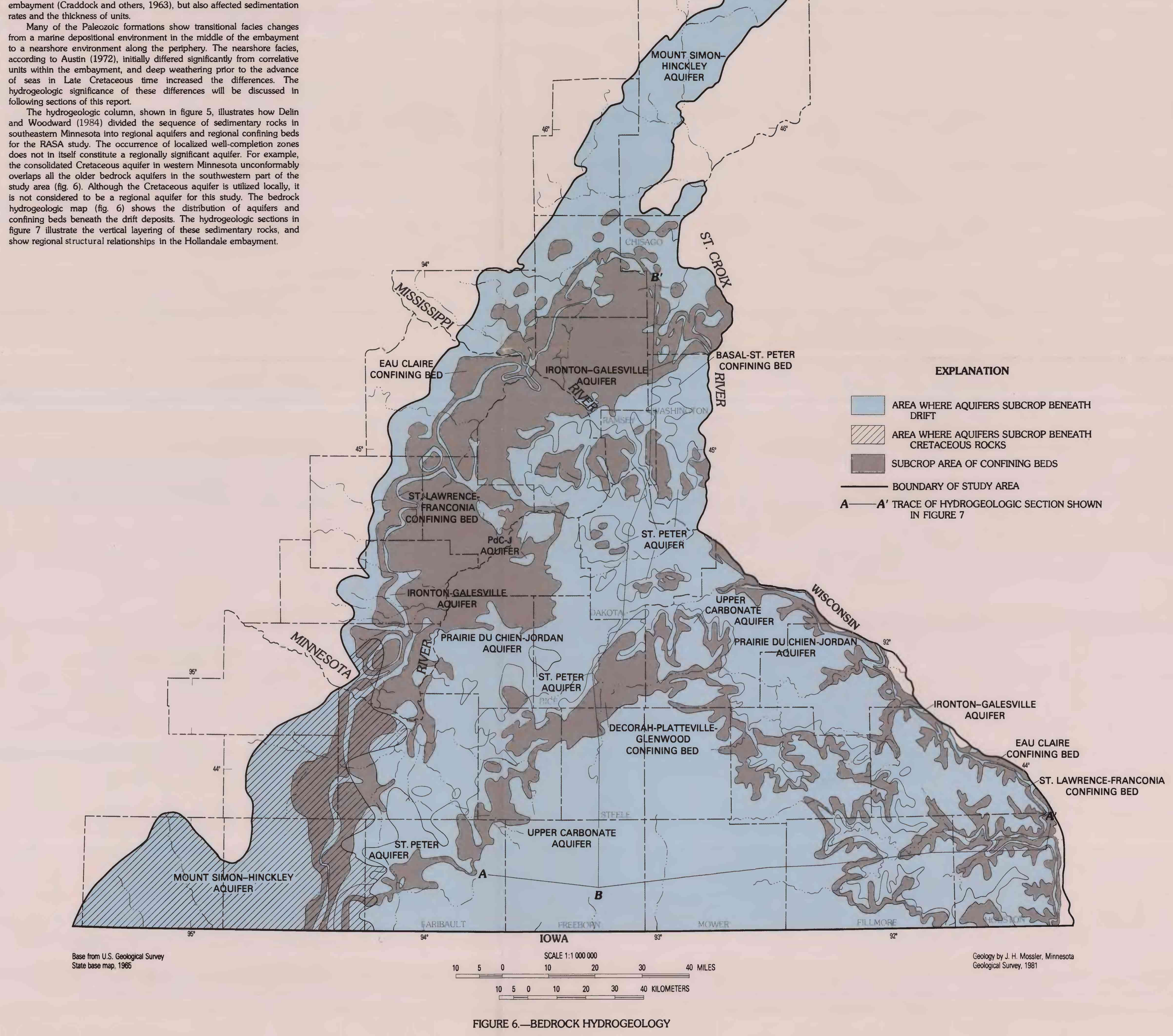

FIGURE 6.—BEDROCK HYDROGEOLOGY

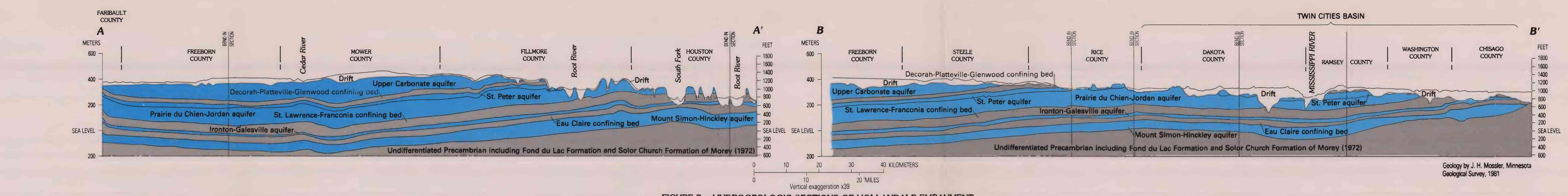

FIGURE 7.—HYDROGEOLOGIC SECTIONS OF HOLLANDALE EMBAYMENT

DRIFT AQUIFER

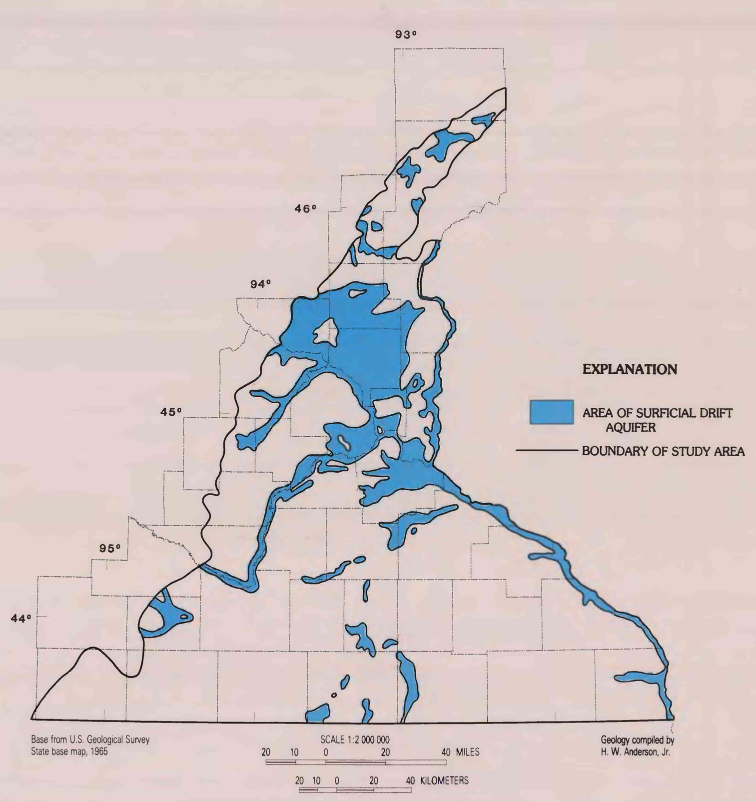

FIGURE 8.—LOCATION OF SURFICIAL DRIFT AQUIFERS

DRIFT AQUIFER

During the Pleistocene Epoch, four continental glaciations advanced and retreated across Minnesota, blanketing the bedrock surface with drift. The land surface of southeastern Minnesota is underlain primarily by drift deposited by the most recent glaciation, the Wisconsin Glaciation. In extreme southeastern Minnesota, however, pre-Wisconsin Drift is present at or near the land surface. The drift in southeastern Minnesota in heterogeneous, ranging in lithologic composition from till and clay to sand and gravel. Differentiation of drift types is beyond the scope of this study.

Undifferentiated drift in the area consists predominantly of till (an unsorted, unstratified mixture of clay, silt, sand, and gravel). Surficial and buried outwash, alluvium, ice-contact, valley-fill, loess, and lake clay deposits are also present. Thin outliers of unconsolidated Cretaceous deposits, the Windrow Formation, are present discontinuously throughout the southern part of the study area (Bleifuss, 1972). Because these scattered Cretaceous deposits have hydrologic and lithologic properties similar to that of drift, these Cretaceous deposits were therefore grouped with the undifferentiated drift aquifer for this study.

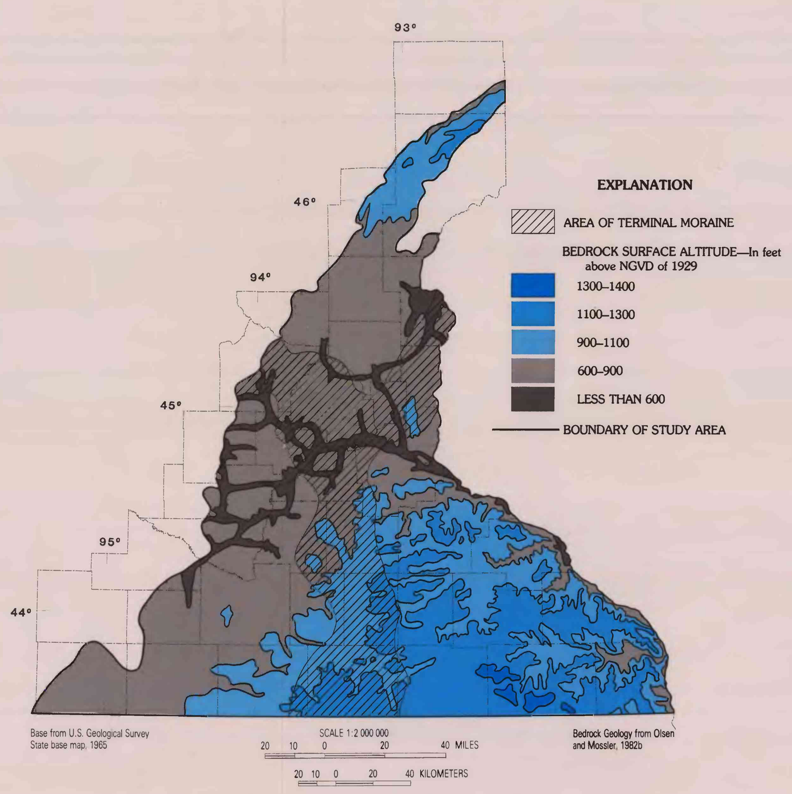

FIGURE 10.—CONFIGURATION OF TOP OF BEDROCK SURFACE

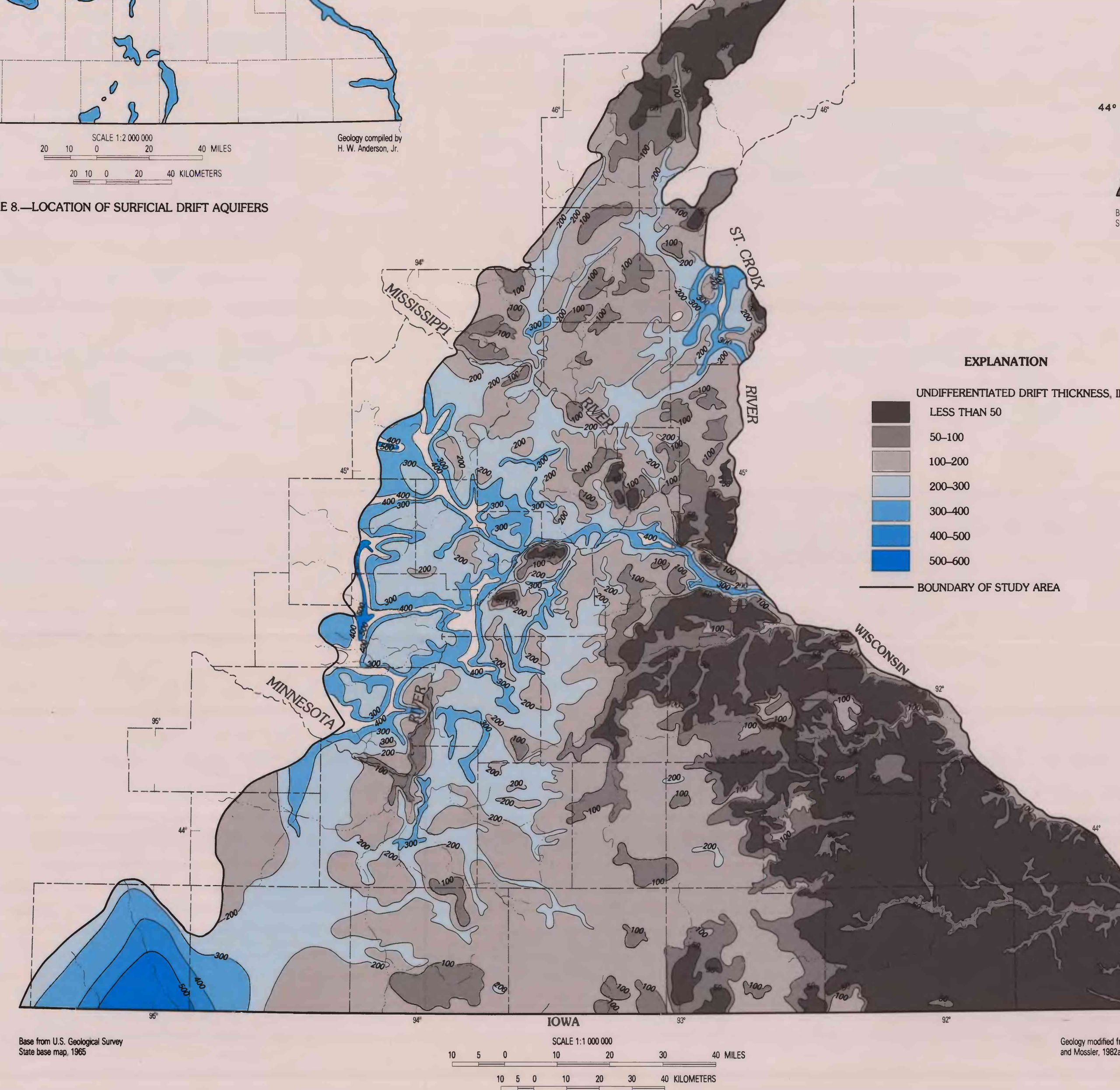

FIGURE 9.—THICKNESS OF UNDIFFERENTIATED DRIFT

Stratified sand and gravel, present in surficial and buried outwash, and alluvial, ice-contact, and valley-fill deposits form aquifers in the drift. Surficial-drift aquifers are composed primarily of outwash and alluvial deposits, and contain ground water under unconfined conditions. These aquifers have a characteristic surface expression and can be identified and delineated readily. Figure 8 shows the location of the major surficial aquifers in the study area. Buried-drift aquifers are difficult to locate because they cannot be seen at the land surface. These aquifers are commonly overlain by till or lake clay and contain ground water under confined conditions. Buried-drift aquifers are most common in areas of thick drift.

Regionally, the drift ranges in thickness from 0 to 600 feet. It is thickest along the western boundary of the area and progressively thins toward the northeast and southeast (fig. 9). The areal distribution and thickness of the undifferentiated drift depend, in part, on the configuration of the bedrock surface. Thick drift generally fills bedrock depressions such as buried valleys in the bedrock surface. Drift generally thins over bedrock highs.

The highest bedrock surfaces occur in extreme southeastern Minnesota where the bedrock ranges in altitude from 1,100 to 1,300 feet, as shown in figure 10. Bedrock altitudes decrease both northerly and westerly to about 700 to 800 feet. The high bedrock surface in extreme southeastern Minnesota deflected the advance of the Des Moines Lobe of the Wisconsin Glaciation and prevented the deposition of Wisconsin Drift in the area. Although this area has been mapped as "driftless," thin pre-Wisconsin Drift, commonly overlain by loess, blankets the bedrock.

Buried valleys in the bedrock surface, where partly filled with sand and gravel, commonly form buried-valley-fill aquifers. The major valleys are incised into the bedrock surface to an altitide of less than 600 feet (fig. 10). Buried valleys reflect both preglacial and glacial drainage patterns. The terminal moraine of the Des Moines Lobe marks the easternmost extent of the Wisconsin Glaciation in southeastern Minnesota. Some bedrock valleys, particularly in the south, head in the high bedrock area and incise the bedrock under the Des Moines Lobe moraine complex; these valleys probably predate the Wisconsin Glaciation. Other bedrock valleys head in the moraine complex; these valleys probably resulted from the Wisconsin Glaciation.

The thickness and lithologic composition of the drift are factors that influence ground-water conditions in the underlying bedrock. Most recharge to the bedrock aquifers in the study area is from overlying sediments (Delin and Woodward, 1984). The greatest amount of recharge occurs in areas where the aquifers subcrop beneath thin, permeable drift. Delin and Woodward (1984) found that ground water in bedrock aquifers overlain by drift greater than 50 feet thick is usually confined, whereas ground water in bedrock aquifers overlain by drift less than 50 feet thick is usually unconfined (fig. 9).

UPPER CARBONATE AQUIFER

The Upper Carbonate aquifer consists of the four youngest formations deposited in the Paleozoic rock sequence in the Hollandale embayment. In ascending order, the formations are the Galena Dolomite, Dubuque Formation, and Maquoketa Shale of Ordovician age, and the Cedar Valley Limestone of Devonian age. Composed predominantly of limestone, dolomite, and dolomitic limestone, the aquifer also contains thin shale beds in the Ordovician rocks.

Undifferentiated drift directly overlies the Upper Carbonate aquifer everywhere except in the extreme southeastern part of Martin County where it is overlain by rocks of Cretaceous age (fig. 6). The Decorah-Platteville-Glenwood confining bed underlies the aquifer (Delin and Woodward, 1984).

Although the smallest of the regional aquifers in areal extent—about 3,800 square miles—the Upper Carbonate is the thickest; it reaches a maximum known thickness of 640 feet near the Iowa border. The configuration of the top of the Upper Carbonate aquifer is shown in figure 11. Maximum relief on the aquifer surface is about 300 feet. The aquifer yields water primarily from fractures, joints, and solution channels in the carbonate rocks.

The saturated thickness of the Upper Carbonate aquifers ranges from 0 at the periphery to about 640 feet towards the southeastern part of Mower County (fig. 12). The aquifer is fully saturated everywhere except along the eastern boundary where the overlying drift is thin and water-table conditions exist (Delin and Woodward, 1984).

Prominent karst features occur in an area along the eastern border of the Upper Carbonate aquifer (fig. 13). This area has numerous sinkholes, caves, stream sinks and sieves, and springs and seeps. About 6,250 sink holes have been located in Fillmore County alone (Alexander and Shaw, 1979). Karst features are most common where a thin mantle of drift, generally less than 50 feet thick, overlies the aquifer. The features have developed in each formation of the aquifer that subcrops beneath the thin mantle of drift, but the Galena Dolomite shows the greatest number and variety (Alexander and Shaw, 1979; Mohr and Pizzuto, 1979; Singer and others, 1980).

Ground-water quality in the Upper Carbonate aquifer in and near the karst area is extremely susceptible to degradation by the introduction of contaminants from the land surface (Kingston, 1943; Minnesota Department of Health, 1976; SIGMA Associates, Inc., 1979; Singer and others, 1980). Many karst features provide open conduits through which contaminants can be transported to the shallow ground-water system.

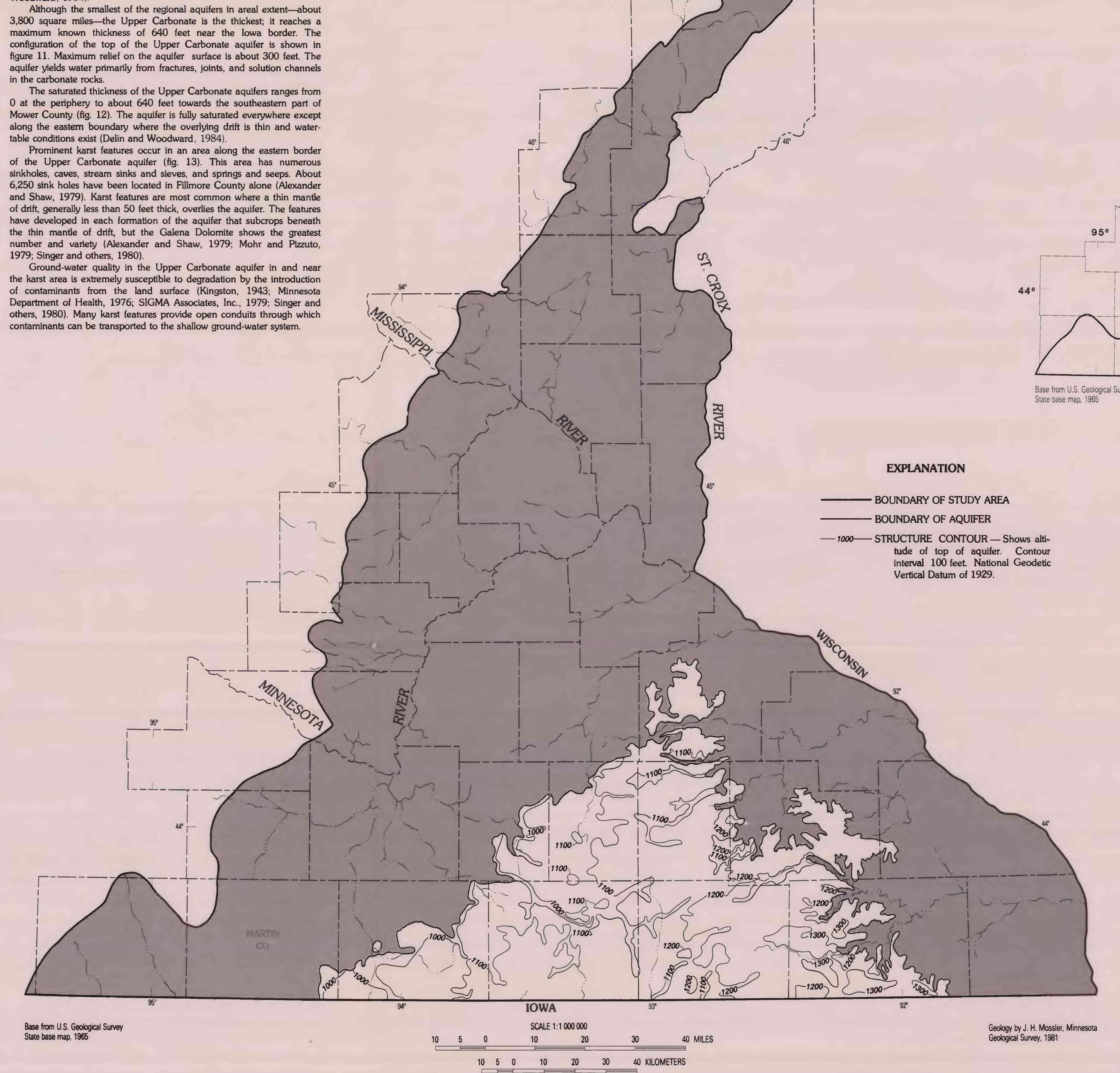

FIGURE 11.—CONFIGURATION OF TOP OF UPPER CARBONATE AQUIFER

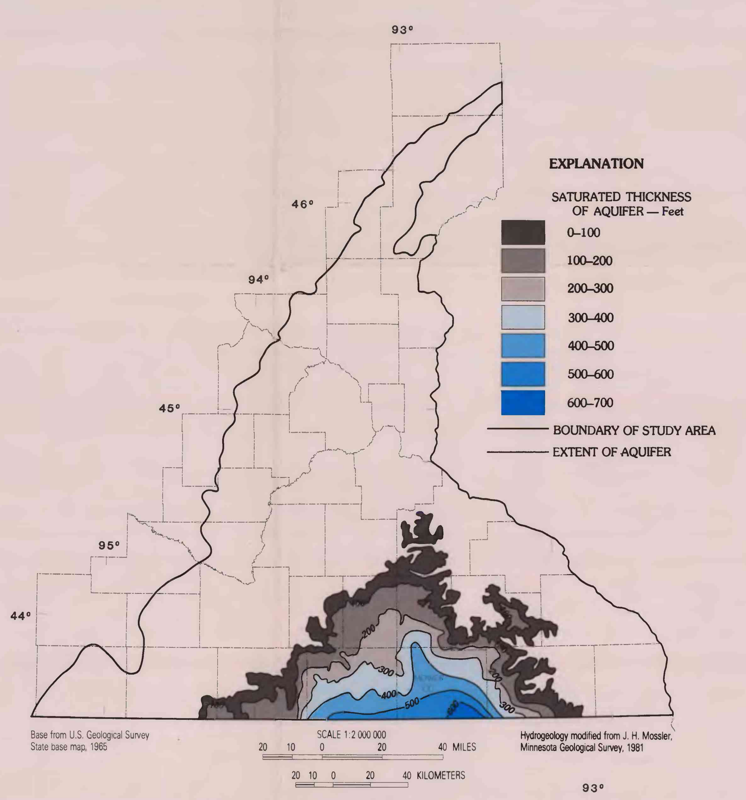

FIGURE 12.—SATURATED THICKNESS OF AQUIFER

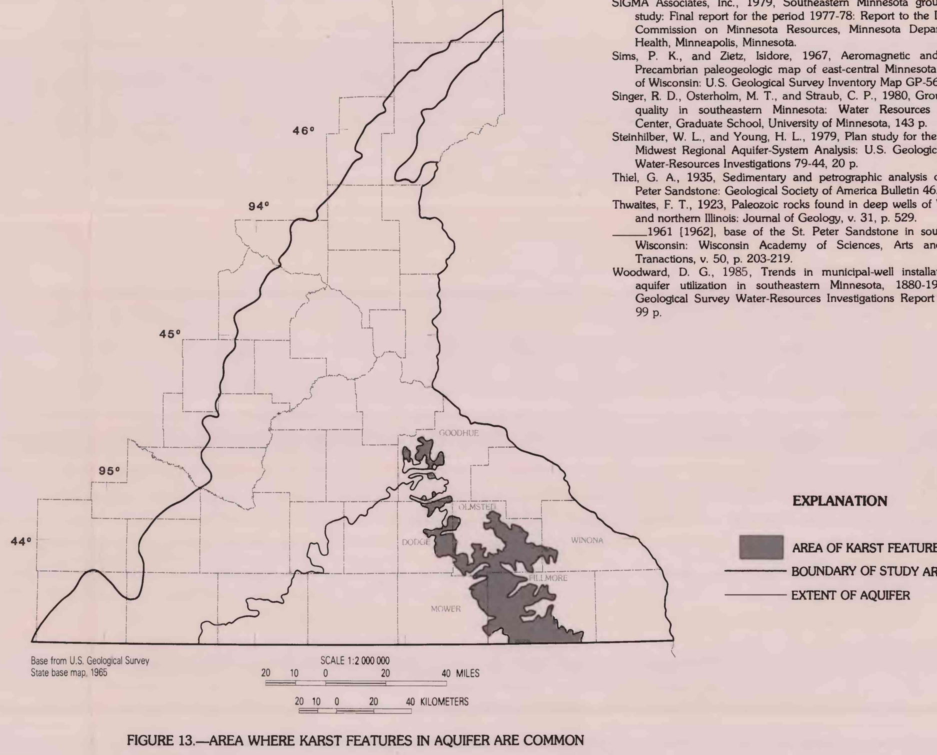

FIGURE 13.—AREA WHERE KARST FEATURES IN AQUIFER ARE COMMON

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By
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1986

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