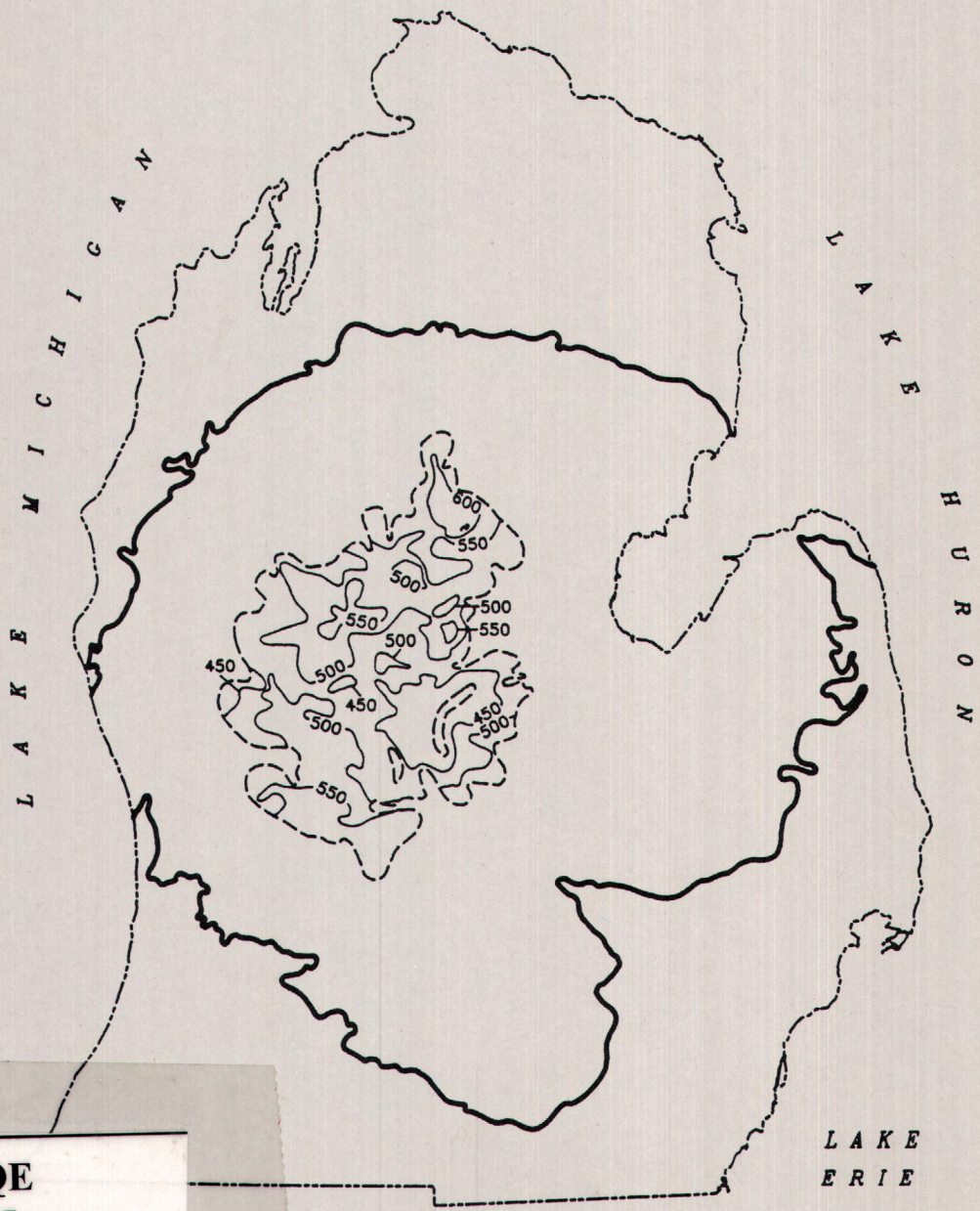
Hydrogeology of Pleistocene Glacial Deposits and Jurassic "Red Beds" in the Central Lower Peninsula of Michigan



United States
Geological Survey

Water-Resources
Investigations
Report 93-4152

Michigan Basin Regional
Aquifer-System Analysis

Cover illustration. From figure 7.

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By D.B. WESTJOHN, T.L. WEAVER, and K.F. ZACHARIAS

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1994

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BRUCE BABBITT, Secretary

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square miles (mi^2)	2.590	square kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expression the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Hydrogeology of Pleistocene Glacial Deposits and Jurassic "Red Beds" in the Central Lower Peninsula of Michigan

By D.B. Westjohn, T.L. Weaver, *and* K.F. Zacharias

ABSTRACT

Geologic-log data were used to construct thickness and surface-configuration maps of Jurassic deposits, and a map of general composition of Pleistocene glacial deposits, in the central Lower Peninsula of Michigan. These geologic units form the upper part of a regional system of aquifers and confining units in the Michigan Basin. In the peninsula, most bedrock is covered by glacial deposits that are primarily intercalated glaciofluvial sediments and till; in some areas, lacustrine clay and silt are surficial deposits. Areas of primarily glaciofluvial sediments (aquifer material) or till and lacustrine deposits (confining-unit material) were delineated.

Jurassic "red beds" underlie glacial deposits in the west-central part of the Michigan Basin. These confining deposits (primarily clay, shale, and gypsum) cover 4,000 square miles of saline-water-bearing Pennsylvanian rocks. Contour maps were generated to show general thickness and surface configuration of Jurassic "red beds." Contour maps of "red beds" and the map of general composition of glacial deposits were prepared to aid in assessing hydrogeologic and geochemical characteristics of the regional aquifer system.

INTRODUCTION

Aquifers and confining units within a 22,000-mi^2 area delineated by the contact of the Mississippian Coldwater Shale and Marshall Sandstone (fig. 1) are the subject of the Michigan Basin Regional Aquifer-System Analysis (RASA) project (Mandle, 1986). This project is one of many U.S. Geological Survey investigations of regional aquifer systems of the United States (Weeks and Sun, 1987). One goal of the Michigan Basin RASA is to delineate thickness and surface configuration of aquifers and confining units.

The uppermost aquifer in the Michigan Basin consists of Pleistocene glaciofluvial deposits (fig. 2). In many areas of Michigan, glaciofluvial deposits are complexly intercalated with till or fine-grained lacustrine sediments. Glacial deposits cover Jurassic and older bedrock units over most of Michigan. Jurassic "red beds"[1] form a subregional (4,000 mi^2) confining unit in the west-central part of the basin.

The purposes of this report are to (1) summarize geologic features of Pleistocene and Jurassic deposits in the Michigan Basin, (2) illustrate thickness and surface configuration of Jurassic "red beds" and general composition of glacial deposits, (3) and summarize the quality of ground water in these deposits. Surface-configuration and thickness maps were prepared by use of geologic records of hydrocarbon-exploration drill holes on file at the Michigan Department of Natural Resources, Geological Survey Division. Descriptions of the geologic units are based primarily on published information.

[1]The term "red beds" refers to deposits in Michigan that are Jurassic in age. Jurassic deposits in Michigan have not been assigned formal stratigraphic nomenclature, and "red beds" is used informally by geologists statewide to refer to this stratigraphic unit (Cross, 1964).

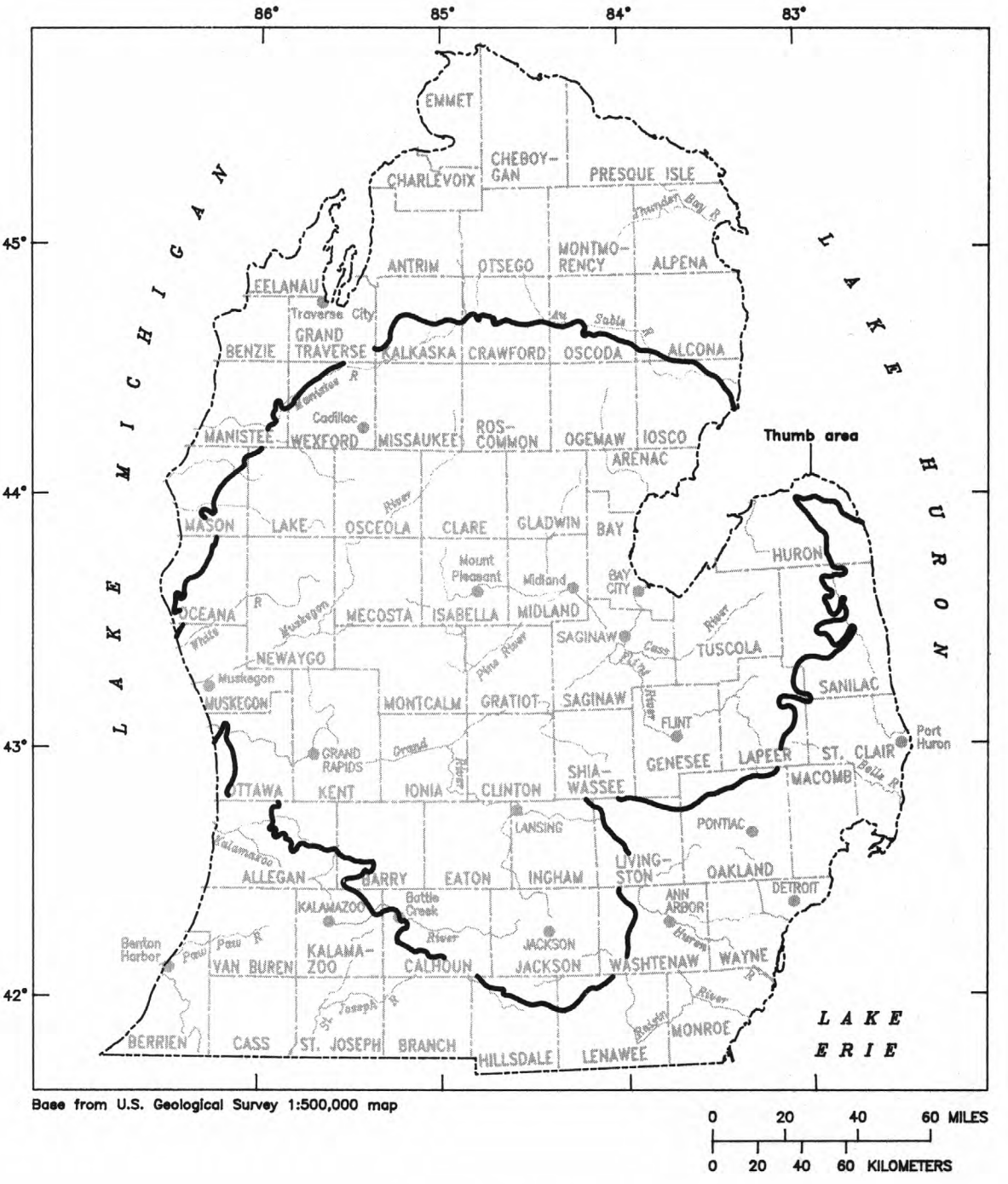
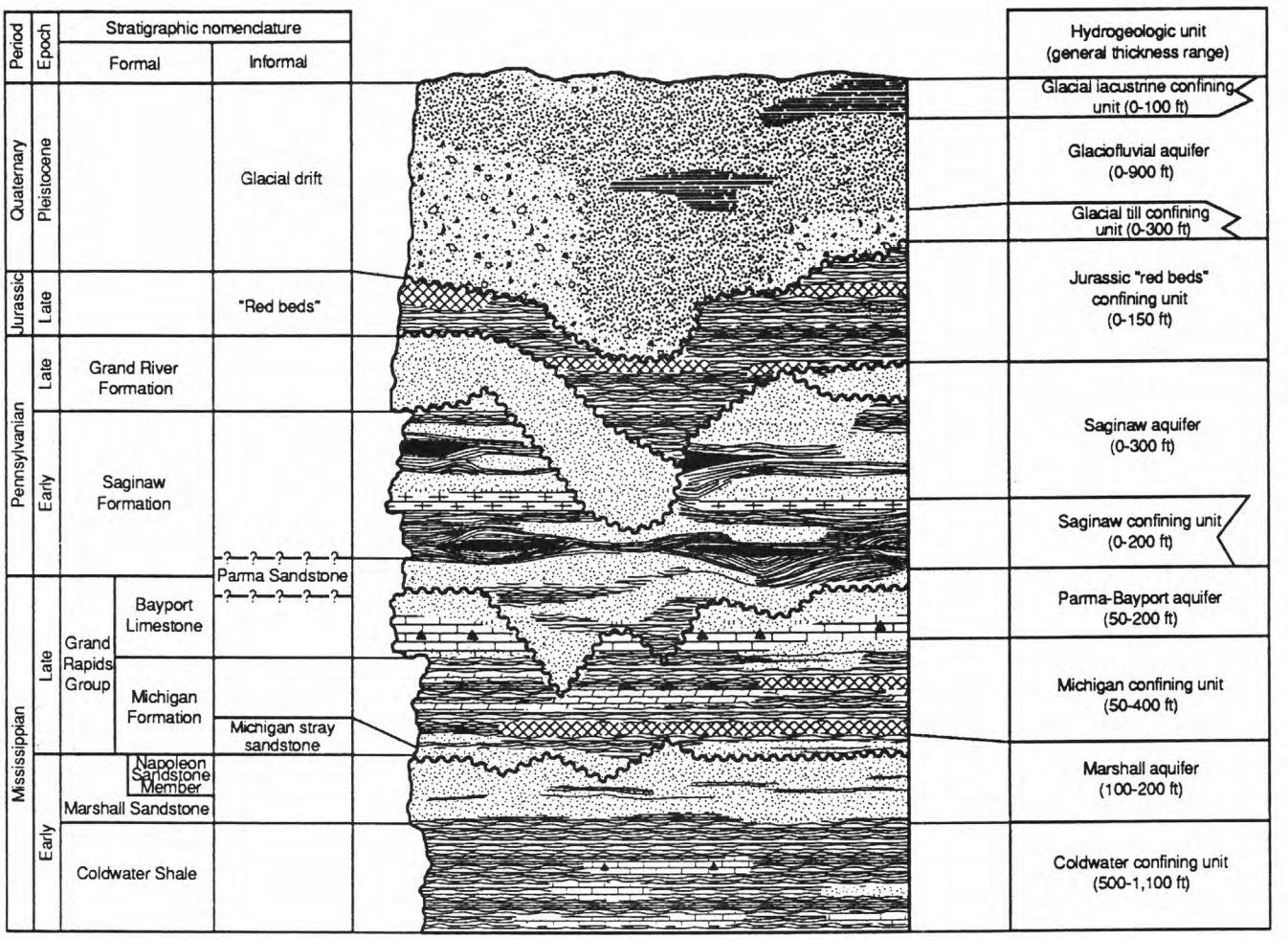


Figure 1. Lower Peninsula of Michigan showing the Michigan Basin Regional Aquifer-System Analysis study area.



EXPLANATION

- Glacial lacustrine sediments
- Glaciofluvial sand and gravel
- Glacial till
- Shale
- Sandy or silty shale
- Sandstone
- Argillaceous or shaly sandstone
- Limestone
- Argillaceous or shaly limestone
- Cherty limestone
- Dolomite (Same variations as limestone)
- Coal beds
- Anhydrite or gypsum
- Erosional surface

Figure 2. Stratigraphic nomenclature, hydrogeologic units, and rock units, Mississippian through recent.

PLEISTOCENE GLACIAL DEPOSITS

Geologic Setting

Most previous studies of glacial deposits in Michigan focused almost entirely on surficial deposits. The principal goal was to interpret glacial processes on the basis of morphology and composition of landforms. Early studies of the surficial geology of the Great Lakes area resulted in voluminous literature. For example, one of the most commonly cited reports by Leverett and Taylor (1915) lists more than 400 references in an extensive bibliography that accompanies the monograph. Leverett and Taylor (1915) described many lithologies in the subsurface that constitute glacial deposits in some areas of the basin; but their emphasis was on landforms, glacial-lake stages, and reconstruction of glacial events of the Pleistocene Epoch.

A map of the surficial geology of Pleistocene glacial deposits in Michigan was published by the Michigan Department of Conservation (Martin, 1955). This map shows distributions of glacial landforms and is a compilation of work by many individuals. (See Martin, 1955, for a complete list of references.) Farrand and Bell (1982) mapped and classified till, lacustrine, and glaciofluvial deposits on the basis of textures and facies distributions, and they produced a revised map of surficial deposits that shows the same general trends illustrated by Martin (1955).

Surficial deposits in the study area can be separated into three general provinces (fig. 3): (1) glacial deposits in the southern part are primarily morainal and outwash deposits formed at the front of advancing or retreating ice sheets; (2) surficial deposits in the Saginaw Lowlands are primarily basal-lodgement tills and lacustrine sediments deposited in former glacial lakes; and (3) glacial deposits of the northern half of the study area are primarily glaciofluvial deposits and some coarse-textured till (Farrand and Bell, 1982). Distinct terminal moraines are uncommon in province 3. Landforms in the northwestern part of the study area have the morphology of moraines, but, by definition, are not moraines. (See Bates and Jackson, 1987, p. 433.) These landforms are not composed of unsorted, unstratified till; they are composed primarily of glaciofluvial sediments. Most moraine-like landforms in the northern part of Michigan were deposited in the interlobate zone between Michigan and Saginaw ice lobes (Reick, 1993). These glaciofluvial deposits are similar in morphology and composition to deposits mapped and described by Currier (1941) as stagnation-deglaciation deposits, and they are probably the result of stagnation-zone retreat.

Hydrogeologic Setting

The most recent publication that focuses on some of the hydrogeologic aspects of glacial deposits is the "Hydrogeologic Atlas of Michigan" (Western Michigan University, 1981). This publication contains plates illustrating drift thickness, altitude of bedrock surface, and geology of surficial deposits. It also contains plates that show the density of water wells completed in glacial deposits (and in bedrock aquifers) and quality of water in surficial and bedrock aquifers of the basin. The map of thickness of Pleistocene deposits included in the "Hydrogeologic Atlas of Michigan" is a modification of work by Reick. (See Western Michigan University, 1981, pl. 15.) The thickness map is based on compilation and interpretation of approximately 80,000 logs of oil and gas wells (Richard Reick, Western Illinois University, oral commun., 1990). Geologic logs of water wells were used to construct the drift-thickness map for areas where logs of oil and gas wells are sparse or lacking (Richard Reick, Western Illinois University, oral commun., 1990). A map illustrating the altitude (topography) of the bedrock surface is also included in the "Hydrogeologic Atlas of Michigan" (Western Michigan University, 1981, pl. 13). The map of the thickness of glacial deposits and the map of the altitude of bedrock surface (Western Michigan University, 1981, pls. 13 and 15) are detailed enough to be used in establishing boundary conditions for groundwater-flow modeling (N.G. Grannemann, U.S. Geological Survey, oral commun., 1993).

Glacial deposits are less than 200 ft thick and are locally absent in an area that extends southwest from the Thumb Area (fig. 2) to the southern fringes of the aquifer system. Northwest of this area, glacial deposits progressively thicken, and in some places are more than 900 ft thick (Western Michigan University, 1981, pl. 15). Farrand and Bell (1982) differentiate lithologies of surficial glacial deposits, but we know of no published large-scale map that differentiates drift lithologies in the subsurface. Data are insufficient to delineate the lateral continuity of lithologies in detail

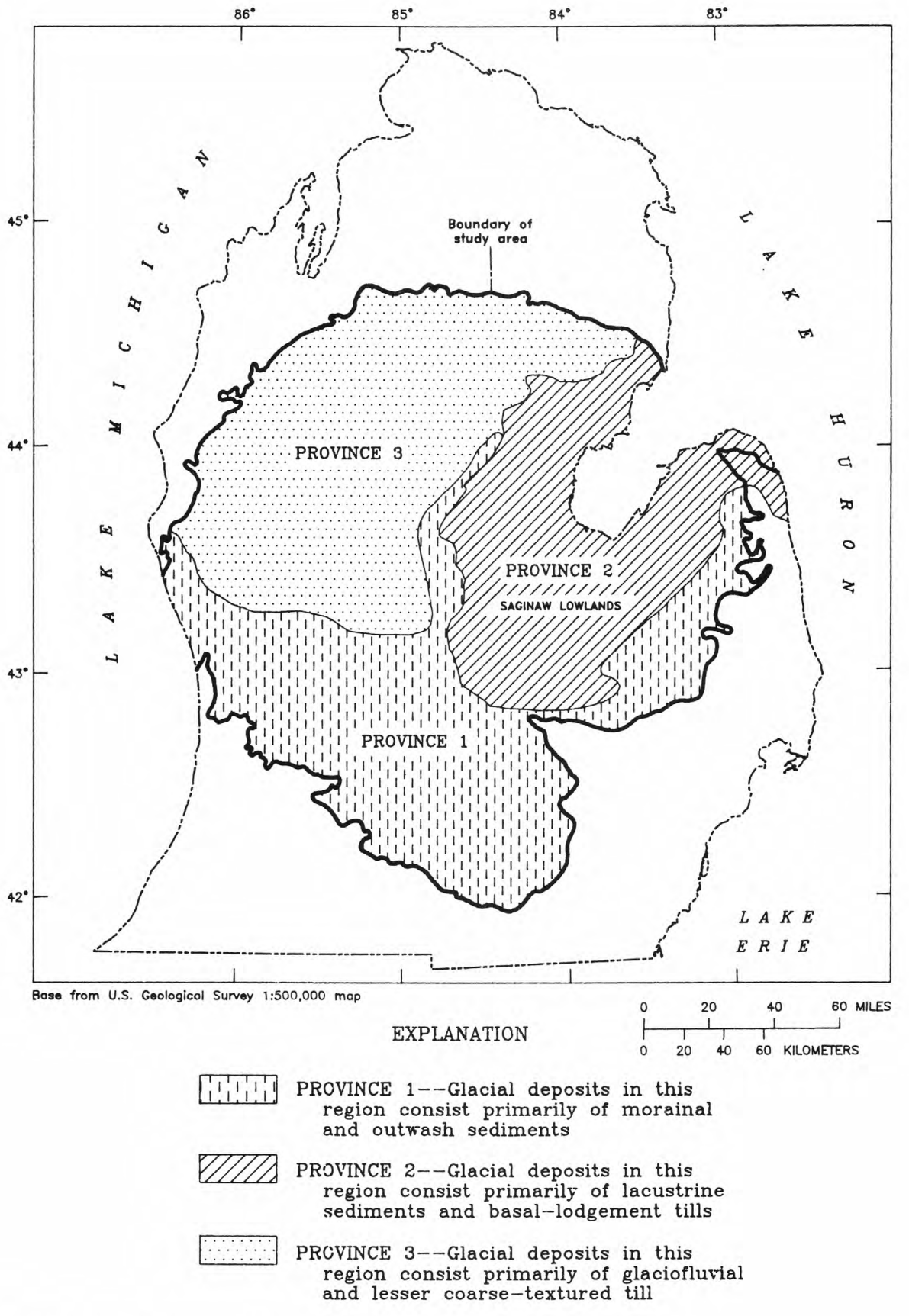


Figure 3. Lower Peninsula of Michigan showing glacial-deposit provinces.

because most geological logs note only general descriptions of glacial deposits. On many logs, glacial materials are listed under the single category "drift." Descriptions and thickness of different glacial lithologies from 534 geological logs were used to characterize the distribution of lithologies that comprise glacial deposits. The ratio of sand and gravel to till and lacustrine deposits was determined from these logs. The locations of boreholes with geologic logs used to construct the map showing the distribution of lithologies in glacial deposits are shown in figure 4.

Regional stratigraphic trends cannot be recognized from available data, probably because of the heterogeneity and the complex depositional history of glacial deposits. However, trends in dominance of sand and gravel or of till and lacustrine deposits can be recognized. For example, the percentage of sand and gravel increases in all directions (landward) with distance from the Saginaw Lowlands (fig. 5). Glaciofluvial deposits constitute more than 25 percent of glacial deposits in provinces 1 and 3 but not in the Saginaw Lowlands (fig. 3). Glaciofluvial deposits constitute more than 75 percent of glacial sediments in the northern part of the study area, where they are also thickest. Glaciofluvial deposits also dominate in most of the perimeter area of the aquifer system (fig. 5), where the Marshall Sandstone subcrops.

Ground-Water Quality

Most domestic water wells in Michigan are completed in glacial deposits. At least 77 municipalities in the study area withdraw ground water from glacial deposits (Baltusis and others, 1992). Dissolved-solids concentration of water from glacial deposits is generally less than 1,000 mg/L, except in the Saginaw Lowlands (fig. 3), where dissolved-solids concentration locally exceeds 7,000 mg/L (Dannemiller and Baltusis, 1990).

JURASSIC "RED BEDS"

Geologic Setting

"Red beds" were considered to be Permo-Carboniferous deposits by Newcombe (1933, p. 62), until Cross (Michigan State University, oral commun., 1964) suggested that these deposits are Jurassic in age. The absence of macroscopic fossils made age determination of these deposits problematic. Shaffer (1969) studied morphologies of plant microfossils extracted from "red beds" sampled from hydrocarbon-exploration boreholes in Michigan, and confirmed that these deposits are Jurassic in age.

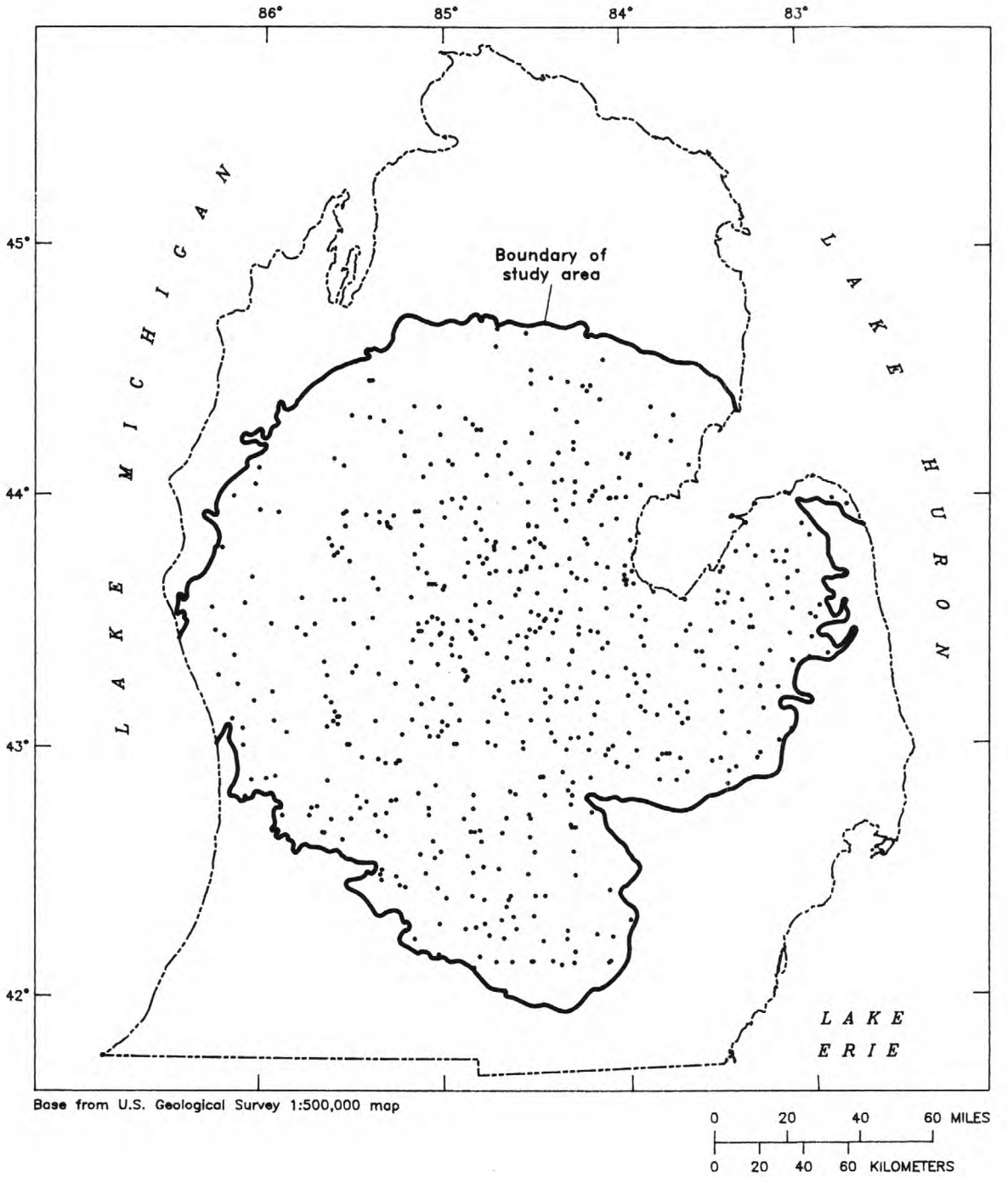
"Red beds" in Michigan have not been assigned formal stratigraphic nomenclature, although a stratigraphic column published by the Michigan Geological Survey (1964) shows "red beds" of Jurassic age overlying the Grand River Formation (Late Pennsylvanian). Shaffer (1969) reports that predominant lithologies of the "red beds" sequence are red clay, mudstone, siltstone and sandstone; as well as gray-green shale and mudstone; and gypsum.

Geologic maps on which the areal extent of Jurassic "red beds" is depicted have been published by several investigators (Milstein, 1987; Newcombe, 1933; Sander, 1959; Shaffer, 1969; Strutz, 1978; Swartz, 1951; Western Michigan University, 1981, pl. 6). Thickness maps of "red beds" were prepared as part of university research projects (Sander, 1959; Shaffer, 1969; Strutz, 1978). An extensive literature search failed to disclose any published surface-configuration map of Jurassic "red beds."

Hydrogeologic Setting

Previous investigations of Jurassic "red beds" focused on sedimentology and depositional environment (Sander, 1959; Swartz, 1951), palynology (Shaffer, 1969), or paleogeologic setting (Strutz, 1978). Data from these studies are useful for gaining a general understanding of geologic characteristics of "red beds," but are insufficient for relating these deposits hydrologically to the system of aquifers and confining units in the Michigan RASA study area (central Lower Peninsula). Geophysical and geologic logs were used to aid in interpreting the hydrogeologic setting and to delineate the thickness and the boundaries of the "red beds" confining unit for ground-water-flow models.

Analysis of geophysical logs shows that permeable sandstone is not volumetrically important and that most of the "red beds" sequence is impermeable. Electric logs (spontaneous potential and electrical resistivity) of boreholes open to "red beds" show that electrically-resistive gypsum beds are common. There is typically



EXPLANATION

· DATA POINT--Shows location of boreholes and geologic logs used to construct figure 5

Figure 4. Lower Peninsula of Michigan showing location of boreholes and geologic logs used to construct map of ratio of sand and gravel to till and lacustrine deposits.

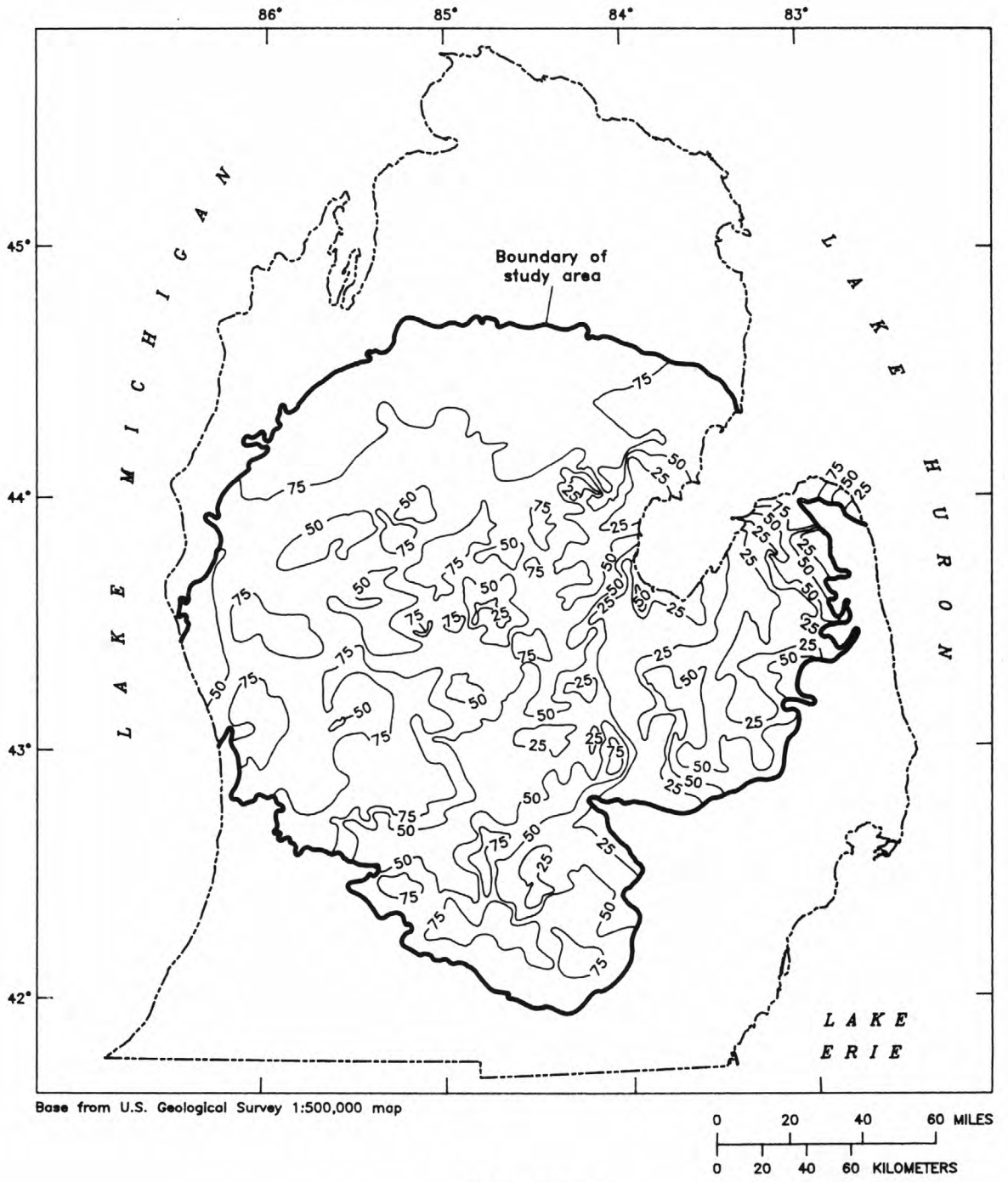


Figure 5. Lower Peninsula of Michigan showing ratio of sand and gravel to till and lacustrine deposits.

one but as many as three gypsum units, and the thickness of individual gypsum strata is usually less than 10 ft. Gypsum beds seem to be stratigraphically continuous and, in some cases, are at approximately the same altitude throughout areas that are more than 500 mi^2. The presence of stratigraphically continuous gypsum beds at approximately the same altitude supports the interpretation that basin subsidence was negligible during and after Jurassic time. Gypsum may have been more abundant in "red beds" than reported on driller's logs. Lost circulation during drilling of hydrocarbon-exploration or production wells is commonly recorded on driller's logs. Many lost-circulation zones have been recorded for depth intervals that can be traced by use of geophysical logs to areas where gypsum beds are at approximately the same altitude. These lost-circulation zones are probably related to areas of dissolution of gypsum or other soluble evaporites, although it is possible that circulation may have been lost in zones where the "red beds" sequence is poorly consolidated.

"Red beds" seem to restrict vertical movement of ground water between Pleistocene glacial deposits and bedrock aquifers underlying them. Electrical-resistivity logs have been interpreted to show that bedrock units underlying "red beds" contain saline water or brine (Westjohn, 1989, 1993), except in the eastern subcrop area of "red beds," where Pennsylvanian sandstones contain freshwater. This condition supports the interpretation that "red beds" form a subregional confining unit overlying saline-water-bearing Pennsylvanian rocks in the west-central part of the regional aquifer system.

Thickness and Surface Configuration

The thickness and surface-configuration maps of "red beds" published with this report (figs. 6 and 7) were prepared entirely from geologic records of hydrocarbon-exploration boreholes. A subset of geologic logs was selected from available collections (Michigan State University subsurface laboratory, Michigan Geological Survey, oil and gas records). Approximately 12,000 geologic logs were examined, but the bulk of these logs were rejected because they did not include the detailed information required for mapping. In many logs, glacial deposits, "red beds," and Pennsylvanian rocks were listed together, but formation contacts or unit thickness were not recorded. This type of detailed geologic information was generally not recorded because Pennsylvanian and Jurassic deposits were considered to be of little economic importance in Michigan.

The contact between glacial deposits and "red beds" is also difficult to delineate because Jurassic deposits are commonly unconsolidated or poorly consolidated. Delineation of the contact between "red beds" and underlying Pennsylvanian rocks was commonly neglected because many early investigators assumed that "red beds" mark the upper part of the Carboniferous Period, which negates the need to separate them from underlying Pennsylvanian rocks.

In most of the logs used to construct contour maps of Jurassic rocks, the top and thickness of "red beds" were clearly identified, or lithologies consistent with strata identified as Jurassic deposits (Shaffer, 1969) were described in detail. In nearly all the logs gypsum (usually selenite), known from geophysical logs to be a common constituent of "red beds" was reported. However, mention of gypsum was not used as a criterion for selection or rejection of logs for use in map construction. The areal extent of "red beds" was delineated by use of a subset of the logs examined (425 of 589). Neither "red beds" nor lithologies typical of Jurassic deposits were mentioned in these logs. The logs were judged to be reliable for delineating the areal extent of "red beds" because (1) drift thickness and top of bedrock surface were noted, and geologic units of different age were not combined, and (2) detailed descriptions and thicknesses of lithologies were listed, as well as depths to contacts of formations consistent with the stratigraphy established for the basin. The location of boreholes and their geologic logs used to construct contour maps of Jurassic "red beds" are shown in figure 8.

Although "red beds" are as much as 200 ft thick, thickness ranges from 50 to 150 ft throughout most of the mapped area (fig. 6). The contact of Jurassic and Pennsylvanian rocks is denoted by a coarse dashed line on the thickness and surface-configuration maps (figs. 6 and 7). Areas within the outer boundary of Jurassic rocks, where "red beds" are absent are noted in the same fashion. The relief on the surface of "red beds" is probably related to erosion before or during Pleistocene time (Lilienthal, 1978). Altitude of the top of Jurassic deposits generally ranges from 450 to 600 ft above sea level (fig. 7).

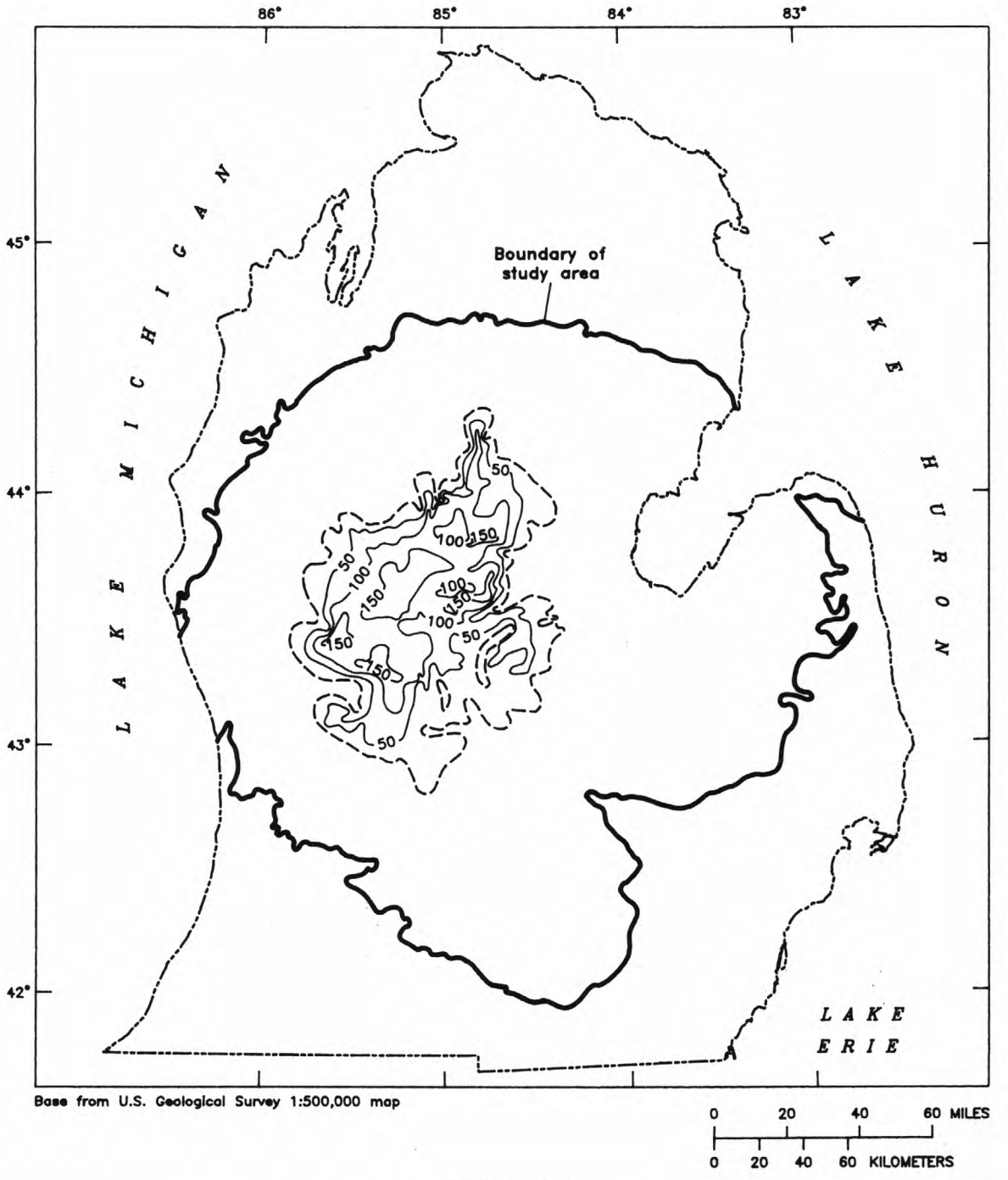
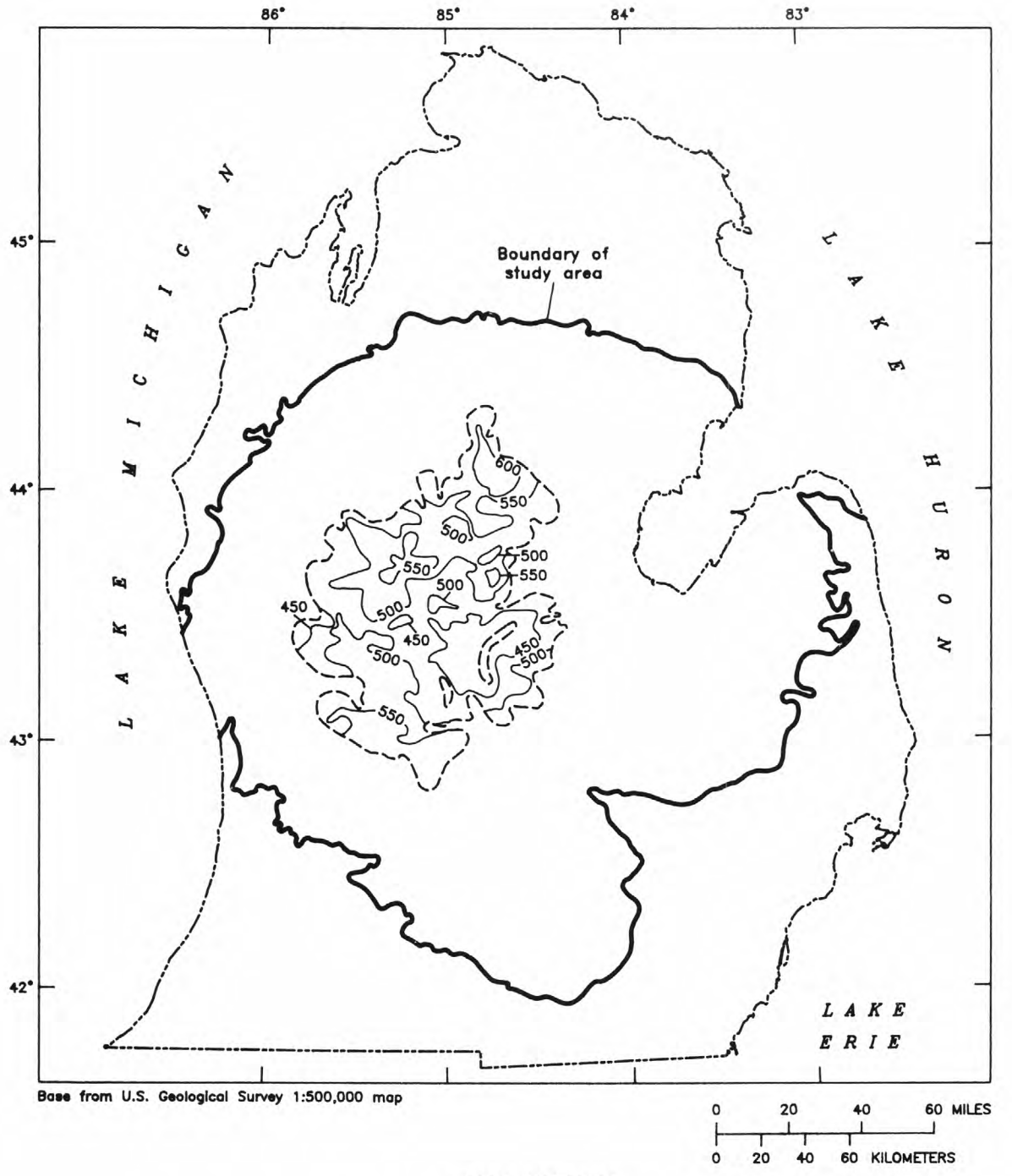


Figure 6. Lower Peninsula of Michigan showing thickness of Jurassic "red beds" confining unit.

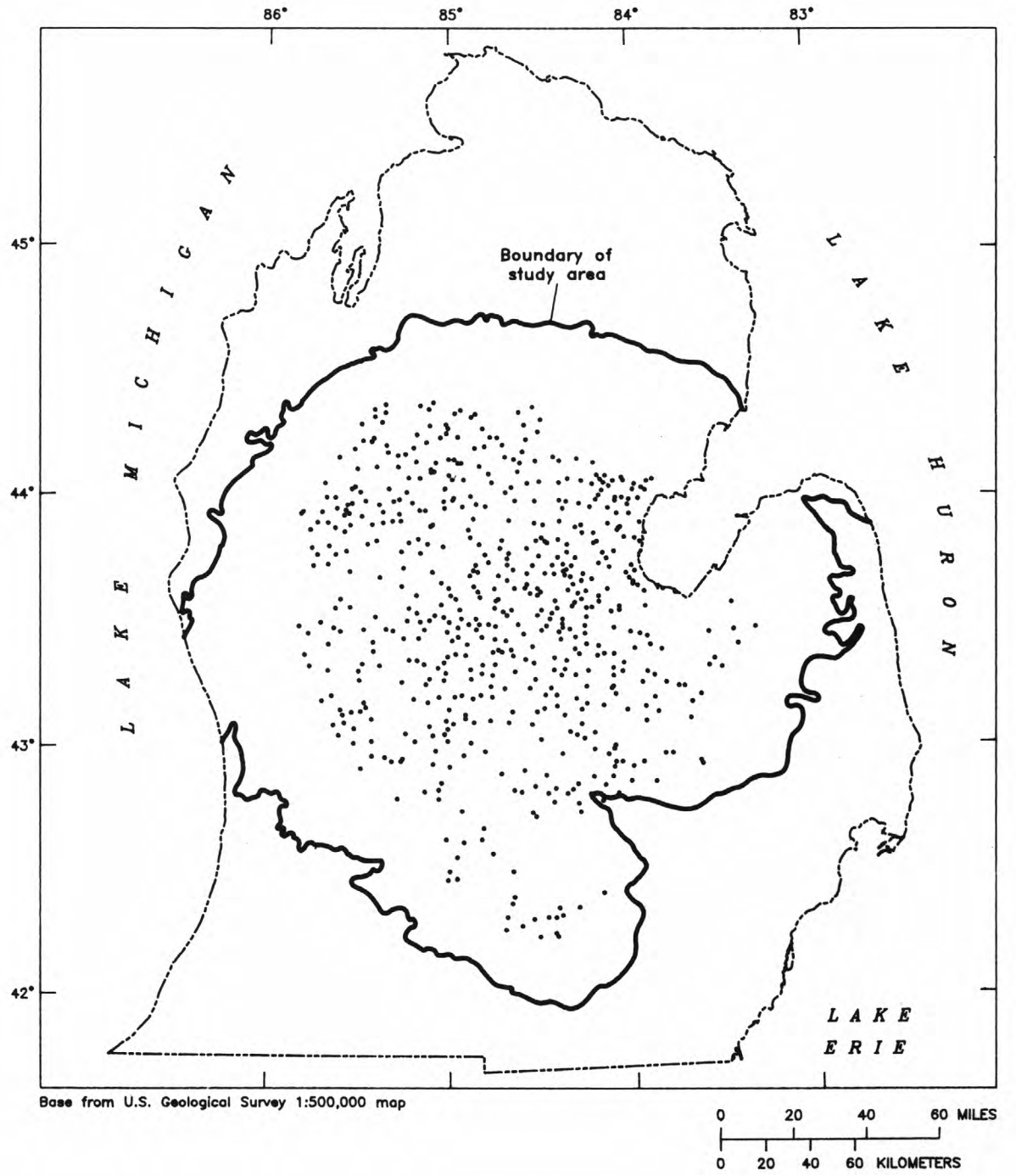


EXPLANATION

—550— BEDROCK CONTOUR--Shows altitude of top of Jurassic "red beds" confining unit. Contour interval 50 feet. Datum is sea level

------ BOUNDARY--Shows approximate limit of Jurassic "red beds" confining unit

Figure 7. Lower Peninsula of Michigan showing surface configuration of top of Jurassic "red beds" confining unit.



EXPLANATION

• DATA POINT--Shows location of boreholes and geologic logs used to construct figures 6 and 7

Figure 8. Lower Peninsula of Michigan showing location of boreholes and geologic logs used to construct thickness and surface-configuration maps of Jurassic "red beds."

Ground-Water Quality

Water wells are rarely completed in "red beds," because glacial deposits are a shallow source of ground water for municipal and domestic water supplies. However, where water-quality data are available for wells completed in "red beds," calcium and sulfate are the principal solutes, and dissolved-solids concentration exceeds 1,000 mg/L (Dannemiller and Baltusis, 1990).

SUMMARY

The general composition of Pleistocene glacial deposits was mapped by use of geologic records of water wells and of hydrocarbon-exploration/production drill holes. Glaciofluvial sediments constitute more than 75 percent of glacial deposits in the northern part of the area mapped, as well as in several other areas of the basin. Glacial till and lacustrine sediments compose more than 75 percent of glacial deposits in parts of the Saginaw Lowlands and Thumb Areas of the State.

Thickness of Jurassic "red beds" is as much as 200 ft in the basin, but generally ranges from 50 to 150 ft. Geophysical logs and water-quality data support the interpretation that "red beds" form a subregional confining unit overlying a 4,000-mi^2 area where Pennsylvanian rocks contain saline water or brine. These maps are part of a geological map set to be used in assessing the hydrogeological and geochemical characteristics of a regional aquifer system in the Michigan Basin.

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