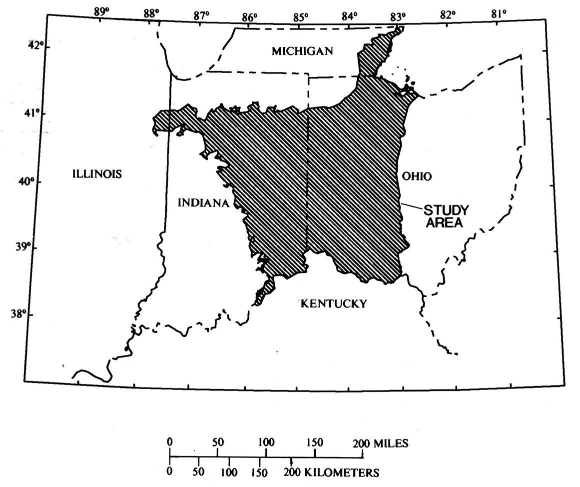

Figure 1.--Location of the Midwestern Basins and Arches Regional Aquifer System Analysis study area in parts of Indiana, Ohio, Michigan, and Illinois.

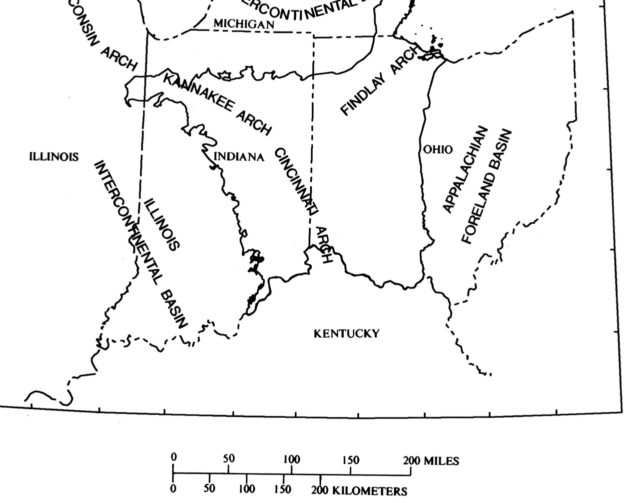

Figure 2.--Structural elements of the Midwestern Basins and Arches Region of Indiana, Ohio, Michigan, and Illinois.

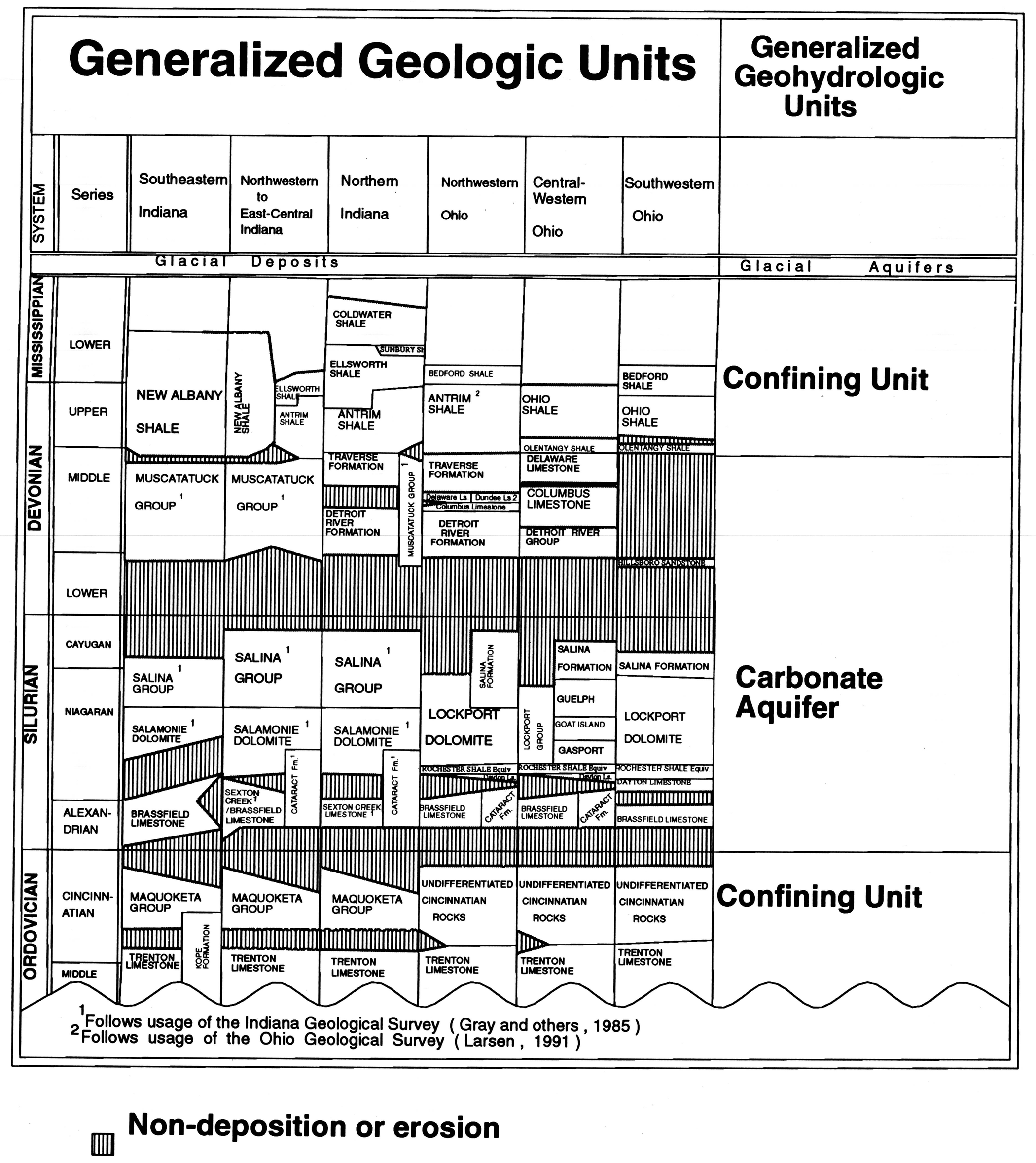

Figure 3.--Time- and rock-stratigraphic framework and nomenclature. (modified from, Bugliosi, 1990).

INTRODUCTION

The basal confining unit of the carbonate freshwater aquifer in Silurian and Devonian rocks of the Midwestern Basins and Arches region consists of the Maquoketa Group (Indiana usage) and its correlative units in Ohio, the undifferentiated Cincinnatian rocks (Ohio usage). The purpose of this report is to summarize the information about the geologic structure of these units and to explain the designation of the Maquoketa Group and the undifferentiated Cincinnatian rocks as the base of the regional freshwater aquifer system. Data used to construct the surface and thickness maps were collected during the course of the Midwestern Basins and Arches Regional Aquifer System Analysis (RASA) project or were derived from available records in the U.S. Geological Survey's National Water Information System (NWIS) data base, (specifically the Ground Water Site Inventory GWSI) data base, and from the Petroleum Information Corporation[1].

The Midwestern Basins and Arches Glacial and Carbonate Regional Aquifer System study area covers approximately 44,000 square miles of Indiana, Ohio, Michigan, and Illinois (fig. 1). This study area, which is approximately 250 miles wide and 180 miles long, lies above an arch complex and extends into three structural basins: the Appalachian Foreland, the Michigan Intercontinental, and the Illinois Intercontinental Basin.

The author gratefully acknowledges John Rupp, John Droste, and Robert Shaver of the Indiana Geological Survey and E. Mac Swinford, Gregory Schumocker, Lawrence Wickstrom Glen Larson, and Douglas Schrake of the Ohio Geological Survey for assistance in collecting and analyzing much of the data presented in this report.

REGIONAL GEOLOGIC SETTING

The Midwestern Basins and Arches Region is located in the Interior Lowlands of eastern North America (King, 1977) that cover the central part of the North American craton and extend from the Appalachian mountain system west to the Colorado Plateaus. The study area of the Midwestern Basins and Arches Glacial and Carbonate Regional Aquifer System addressed in this report lies in central and western Ohio; northern, south-central, and southeastern Indiana; southeastern Michigan; and a small part of northeastern Illinois. This area straddles the Cincinnati, the Kankakee, and the Findlay Arches; the crests of these arches form a southeast-northwest trend with an arm that splays southwest to north-northeast. This feature is known as the Ohio-Indiana Platform. The study area is bounded on the north by the Michigan Intercontinental Basin, on the east by the Appalachian Foreland Basin, and on the west by the Illinois Intercontinental Basin (fig. 2).

The study area is underlain by sedimentary rocks that range in age from Cambrian through Permian but only Late Ordovician through Permian rocks crop out. The sedimentary rocks of primary interest range in age from Late Ordovician through Early Mississippian. These units dip away from the crests of the arches and the Silurian through Late Devonian rocks thicken into the adjacent structural basins. The oldest sedimentary rocks are exposed along the crest of the Cincinnati Arch in southwestern Ohio and southeastern Indiana (fig. 1) and are overlain by younger strata toward the center of the basins. These units also crop out along the crest of the Wisconsin Arch in northern Illinois.

HYDROGEOLOGY OF THE BASAL CONFINING UNIT

The nomenclature of the regional basal confining unit of the Silurian and Devonian carbonate freshwater aquifer system depends largely on the geographic location. In Indiana, it is referred to as the "Maquoketa Group" both in the subsurface and in southeastern Indiana, near the Ordovician outcrop (Gray and others, 1985). In Ohio terminology, the names of outcrop units are used to describe the Upper Ordovician in southwestern Ohio; in the subsurface in northwestern Ohio, however, the Upper Ordovician is described as undifferentiated shale and limestone (Hull, 1990). To minimize confusion and to maintain uniformity with the usage of the various State Geological Surveys, this RASA study has adopted the names "Maquoketa Group" in Indiana and "undifferentiated Cincinnatian rocks" in Ohio (Shaver, 1985) (fig. 3). This naming convention follows the usage of the Ohio Geological Survey and the Indiana Geological Survey.

GEOLOGIC CHARACTERISTICS

The Upper Ordovician units are present throughout the study area and unconformably overlie the Trenton Limestone in Indiana and northwestern and central Ohio (Gray, 1972a; Janssens, 1977; Droste and Shaver, 1985). The Upper Ordovician units are overlain unconformably by the Sexton Creek Limestone or Brassfield Limestone and Cataract Formation of Silurian age (LaFerriere and others, 1986).

The Maquoketa Group or the undifferentiated Cincinnatian rocks are a clastic wedge that extends across the study area from the west. The shale that predominates in these units is generally gray and calcareous, but the unit also contains a brown carbonaceous shale (100-300 feet thick) in the lowermost part of the unit. Limestone comprises approximately 20 percent of the basal confining unit and is found predominantly in the uppermost part of the unit (Gray, 1972a).

The Maquoketa Group thickens eastward from the western border of Indiana toward Ohio, and ranges in thickness from 200 feet in northwestern Indiana to nearly 1,000 feet at the Ohio-Indiana border (fig. 4). The undifferentiated Cincinnatian rocks in Ohio gradually thicken as they dip into the Appalachian Foreland Basin. Where these units crop out in southeastern Indiana and southwestern Ohio, they thin because of pre-Silurian erosion of the group and post-Permian uplift and subsequent erosion along the crest of the Cincinnati Arch (fig. 4).

In Indiana, the Maquoketa Group is cut by three major faults: the Royal Center, the Fortville, and the Mount Carmel. These faults, which are located along the northeastern and eastern edge of the Illinois Intercontinental Basin, are thought to represent movement during Mississippian and Pennsylvanian time (Melhorn and Smith,1959; Shaver and Austin, 1972). Vertical displacement on these faults is generally thought to be less than 200 feet; therefore, the basal confining unit does not appear to be breached along any of the faults. The location of the faults and the altitude of the Maquoketa Group near the faults were determined by Bassett and Hasenmueller (1980).

In Ohio, the undifferentiated Cincinnatian rocks are displaced by faults within the Bowling Green Fault Zone. A large number of multiple faults have been mapped within this fault zone (VanWagner, 1988), which is a feature that extends from northwestern Ohio into southeastern Michigan along the western edge of the Appalachian Foreland Basin. Movement along this feature may have occurred during early Paleozoic time but could have occurred as recently as Mesozoic or even Cenozoic time (Onasch and Kahle, 1991). Vertical displacement along the Bowling Green Fault Zone ranges from 90 to 300 feet (VanWagner, 1988) and, therefore, the basal confining unit is not completely breached.

Data used to compute the altitude of the top of the basal confining unit were obtained primarily from the oil and gas sections of the Indiana and the Ohio Geological Surveys; supplemental information was obtained from the Petroleum Information Corporation's data base and deep-test-well data from GWSI. The locations of the production and test wells are shown in figure 5.

The altitude and configuration of the top of the basal confining unit are shown in figure 6. Along the eastern flank of the Cincinnati and Findlay Arches the slope (the change in altitude over distance) of the top of the basal confining unit is fairly low near the arches crests. But increases as the distance from the arches crests increase, because of the effects of downwarping of the crust in the Appalachian Foreland Basin. A similar configuration is found along the Michigan and Illinois Intercontinental Basins, again because of the relative position of the crests of the arches and downwarping of the crust in the basins.

HYDROLOGIC CHARACTERISTICS

Hydrologic data for the Upper Ordovician rocks are sparse, but some vertical and horizontal hydraulic conductivities have been determined from analysis of core collected from the upper sections of the undifferentiated Cincinnatian rocks in southwestern Ohio. These values range from 10^{-5} to 10^{-7} feet per day (Lawrence Wickstrom, Ohio Geological Survey, written commun., 1991). Transmissivities (T) for the Silurian and Devonian carbonate bedrock aquifer determined from aquifer tests, range from 70 feet squared per day to 28,000 feet squared per day (Robert L. Joseph, U.S. Geological Survey, written commun. 1992). Assuming the length of the saturated open hole or screened interval in the carbonate aquifer system is the total saturated thickness (b), horizontal hydraulic conductivities (K) can be calculated by dividing T by b. Results of such calculations indicate that the hydraulic conductivities of the Upper Ordovician rocks range from 10^{-5} to 10^{-7} feet per day and the calculated hydraulic conductivities of the carbonate aquifer range from 10^{-2} to 5×10^{2} feet per day. Hydraulic conductivities in the basal confining unit are three to five orders of magnitude lower than the calculated hydraulic conductivities for the carbonate bedrock aquifer. In southwestern Ohio and southeastern Indiana, data from an inventory of drillers' logs indicate a relatively small number of wells completed in the Ordovician bedrock compared with those completed in the overlying Silurian carbonate bedrock. Wells that are completed in the Ordovician bedrock typically have low yields (less than 2 gallons per minute) or are dry.

The low hydraulic conductivity of the Ordovician shale units make them favorable repositories for underground storage of liquefied natural gas. During the initial excavation of the Texas Eastern Transmission Company's room-and-pillar storage facility in south-central Indiana, the entire Maquoketa Group was found to be highly impermeable. No problems related to water infiltration or flooding were encountered during construction (Droste and Vitaliano, 1976). After construction, the vault was pressurized with nitrogen gas to 125 pounds per square inch. Water levels measured in nearby observation wells completed in the same stratigraphic unit as the vault did not change; the absence of water-level changes indicates little or no leakage from the vault through the Ordovician units (Droste and Vitaliano 1976).

Additional evidence of the low hydraulic conductivity of the Ordovician shale units is provided by the fact that the shale units have functioned as a barrier to the migration of oil and gas reserves, and the associated highly concentrated brines located within the Trenton limestone. This stratigraphic trap is created by the low permeability values of the Ordovician shale units and the post-Ordovician uplift that formed the Cincinnati Arch (Keller and Abdulkareem, 1980).

The information presented in this report indicates that the Maquoketa Group and the undifferentiated Cincinnatian rocks are relatively impermeable and regionally extensive. It is concluded, therefore, that these units collectively form a barrier to ground-water flow that effectively limits the transfer of significant quantities of water to and from the overlying aquifer.

SELECTED REFERENCES

Bassett, J. L., and, Hasenmueller, N. R., 1980, Map of Indiana showing structure on top of the Maquoketa Group (Ordovician): Indiana Department of Natural Resources, Geological Survey, METC/EGSP Series 812, scale 1:500,000

Bownocker, J.A., comp.1920 [1981], Geologic map of Ohio: Ohio Geological Survey, scale 1:500,000.

Bugliosi, E.F., 1990, Plan of study for the Ohio-Indiana carbonate-bedrock and glacial-aquifer system: U.S. Geological Survey Open-File Report 90-151, 26p.

Burger, A.M., Forsyth, J.L., Nicoll, R.S., and Wayne, W.J., 1971, Geologic map of the 1° x 2° Muncie Quadrangle, Indiana, and Ohio showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey Regional Geologic Map 5, scale 1:250,000.

Droste, J. B., 1976, Paleozoic stratigraphy of two areas in southwestern Indiana: U.S. Energy Research and Development Administration Report, 28 p.

Droste, J. B., and Shaver, R. H., 1985, Comparative stratigraphic framework for Silurian reefs--Michigan Basin to surrounding platforms: Michigan Basin Geological Society Special Paper 4, p. 73-93.

Droste, J. B., and Vitaliano, C. J., 1976, Geologic report of the Maquoketa Shale, New Albany Shale, and Borden Group rocks in the Illinois Basin as potential solid waste repository sites: U.S. Energy Research and Development Administration Report, 25 p.

Gray, H. H., 1972a, Lithostratigraphy of the Maquoketa Group (Ordovician) in Indiana: Indiana Department of Natural Resources, Geological Survey Special Report 7,31 p.

________ 1972b, Geologic Map of the 1° x 2° Louisville Quadrangle, Indiana, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey Regional Geologic Map 6, scale 1:250,000.

Gray, H. H., Forsyth, J.L., Schneider, A.F., and Gooding, A.M., 1972, Geologic Map of the 1° x 2° Cincinnati Quadrangle, Indiana and Ohio, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey Regional Geologic Map 7, scale 1:250,000.

Gray, H. H., Bleuer, N.K., Hill, J.R., and Lineback, J.A., 1979, Geologic Map of the 1° x 2° Indianapolis Quadrangle, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey Regional Geologic Map 1, scale 1:250,000.

Gray, H. H., Droste, J.B., Patton, J.B., Rexroad, C.B., and Shaver, R.H.,1985, Correlation chart showing Paleozoic stratigraphic units of Indiana: Indiana Department of Natural Resources, Geological Survey Supplement to Miscellaneous Map 48, 1 sheet.

Gray, H. H., Ault, C.H., and Keller, S.J.,1987, Bedrock geologic map of Indiana: Indiana Department of Natural Resources, Geological Survey Miscellaneous Map 48, scale 1:500,000.

Hatfield, C. B., 1981, Stratigraphy and paleoecology of the Saluda Formation (Cincinnatian) in Indiana, Ohio, and Kentucky: Geological Society of America Special Paper No. 95, 26 p.

Hassenmueller, N. R., and Bassett, J. L., 1980, Map showing structure on top of the Trenton Limestone (Ordovician): Indiana Department of Natural Resources, Geological Survey METC/EGSP Series 813, scale 1:500,000.

Hull, D. N., 1990, Generalized column of bedrock units in Ohio: Ohio Department of Natural Resources, Geological Survey, 1 p.

Janssens, Adriaan, 1977, Silurian rocks in the subsurface of northwestern Ohio: Ohio Department of Natural Resources, Geological Survey Report of Investigations 100, 96 p.

Johnson, G. H., and Keller, S. J., 1972, Geologic Map of the 1o x 2o Fort Wayne Quadrangle, Indiana, Michigan, and Ohio, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey Regional Geologic Map 8, scale 1:250,000.

Keller, S.J. and Abdulkareem, T.F., 1980, Post-Knox Unconformity-significance at Unionport gas-storage project and relationships to petroleum exploration in Indiana: Indiana Department of Natural Resources, Geological Survey Occasional Paper 31, 19 p.

King, P. B., 1977, The evolution of North America: Princeton, N.J., Princeton University Press, 197 p.

LaFerriere, A. P., Hattin, D.E., Foell, C.J., and Abdulkareem, T.F.,1986, The Ordovician-Silurian unconformity in south-eastern Indiana: Indiana Department of Natural Resources, Geological Survey Occasional Paper 53, 12 p.

Larsen, G.E., 1991, Development of Silurian and Devonian lithostratigraphic nomenclature, central-western and northwestern Ohio: Ohio Department of Natural Resources, Geological Survey Open-File Report 91-1, 1 pl.

Melhorn, W. N., and Smith, N. M., 1959, The Mt. Carmel Fault and related structural features in south-central Indiana: Indiana Geological Survey Report of Progress 16, 29 p. 1 pl.

Onasch, C. M., and Kahle, C. F., 1991, Recurrent tectonics in a cratonic setting -- An example from northwestern Ohio: Geological Society of America Bulletin, v. 103, p. 1259-1269.

Rodgers, G. D.,and Luckey, R. R.,1990, Ground-water retrieval/tabling program, in Mathey, S. B., ed., Chap. 4 of National Water Information System user's manual: Ground-Water Site Inventory System, U.S. Geological Survey Open-File Report 89-587, v. 2, p. 8-1-8-56.

Rupp, J. A., 1991, Structure and isopach maps of the paleozoic rocks of Indiana: Indiana Geological Survey Special Report 48, 106 p.

Shaver, R. H. (regional coordinator), 1985, Midwestern Basins and Arches Region--Correlation of stratigraphic units of North America (COSUNA) project: American Association of Petroleum Geologists, 1 sheet.

Shaver, R. H., and Austin, G. S., 1972, A field guide to the Mt. Carmel Fault of southern Indiana: Indiana Department of Natural Resources, Geological Survey Guidebook 13, 25 p.

VanWagner, Elmer, III,1988, An integrated investigation of the Bowling Green Fault using multispectral reflectance, potential field, seismic, and well log data sets: Bowling Green, Ohio, Bowling Green State University, unpublished Master's thesis, 171 p.

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
pounds per square inch	6.895	kilopascal
foot per day	0.3048	meter per day
foot squared per day [1]	0.0929	meter squared per day

[1] This unit is used to express transmissivity, the capacity of an aquifer to transmit water. Conceptually, transmissivity is cubic feet (of water) per day per square foot (of aquifer area) times feet (of aquifer thickness). In this report the unit is reduced to its simplest form.

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 (NGVD of 1929) the United States and Canada, formerly called Sea Level Datum of 1929.

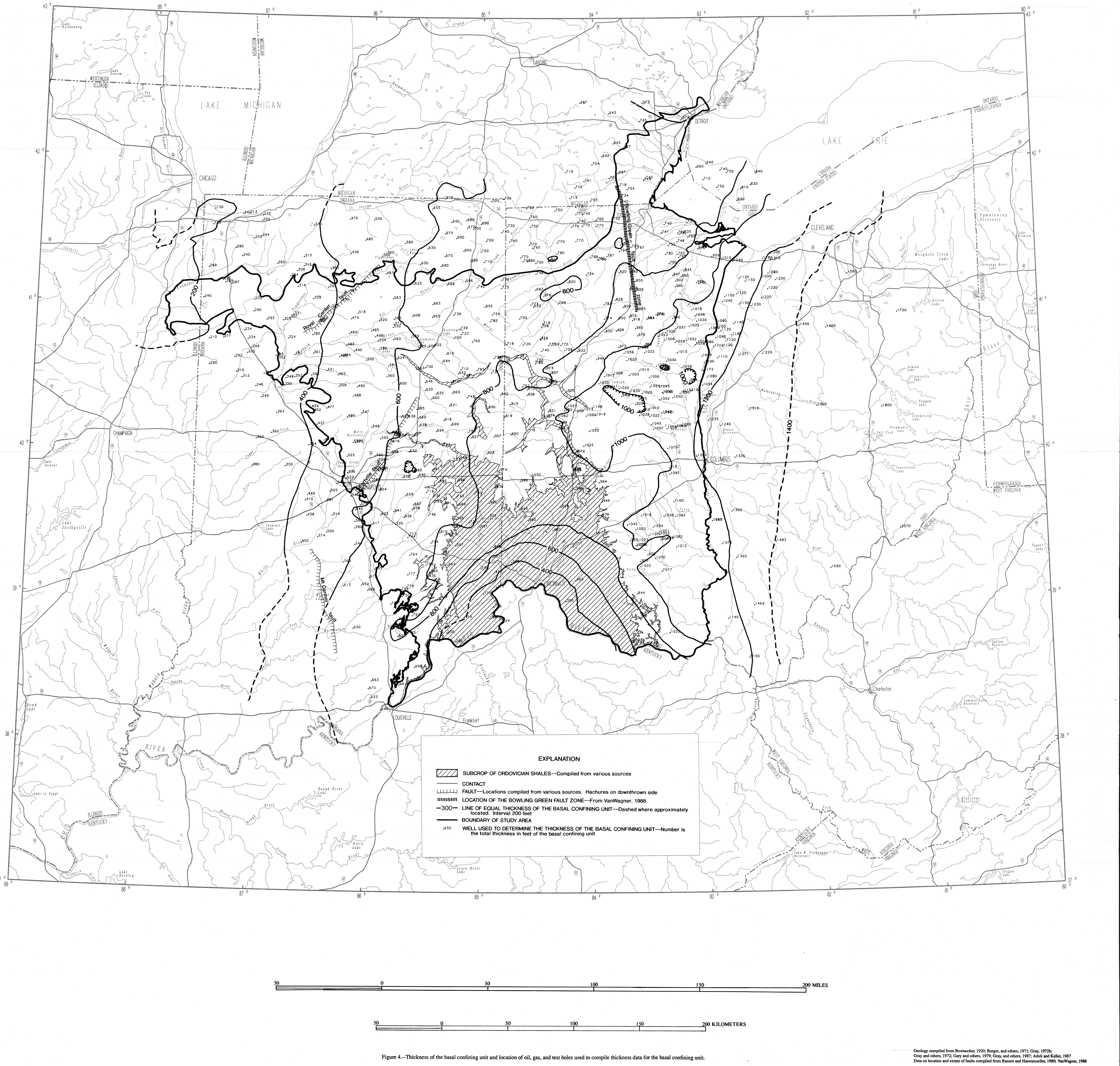

Figure 4.--Thickness of the basal confining unit and location of oil, gas, and test holes used to compile thickness data for the basal confining unit.

Geology compiled from Bownocker, 1920; Burger, and others, 1971; Gray, 1972b; Gray and others, 1972; Gray and others, 1979; Gray, and others, 1987; Ault and Keller, 1987
Data on location and extent of faults compiled from Bassett and Hasenmueller, 1980; VanWagner, 1988

Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Map scale 1:1,000,000
Map projection Albers Equal-Area Conic projection
First Standard Parallel 37° 50', Second Standard Parallel 41°10'
Central Meridan 84°

HYDROGEOLOGY OF THE BASAL CONFINING UNIT OF THE CARBONATE AQUIFER SYSTEM IN THE MIDWESTERN BASINS AND ARCHES REGION OF INDIANA, OHIO, MICHIGAN, AND ILLINOIS

By George D. Casey

1992

For sale by U.S. Geological Survey, Books and Open-File Reports Section
Box 25425, Federal Center, Denver, CO 80225