Attachment B-13

R Traub GWPS

Hydrogeology for Underground Injection Control in Michigan:

Part 1

Department of Geology
Western Michigan University
Kalamazoo, Michigan

U.S. Environmental Protection Agency
Underground Injection Control Program

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Acknowledgements

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I. INTRODUCTION

FOREWORD

The Hydrogeology for Underground Injection Control in Michigan and its companion volume, the Hydrogeologic Atlas of Michigan, are a unique compendium of text, maps, cross sections and tables synthesizing current and classical information on the hydrology and geology of the State of Michigan. Heretofore, no single reference has offered access to the wealth of hydrogeologic data evolved by researchers and authors throughout the years. The report represents two years of extensive investigation to identify, evaluate, organize and compile relevant and reputable contributions to the hydrogeologic data base of Michigan. Although the primary focus is on the hydrogeology of the State, the report also summarizes the past underground injection operations in Michigan. The Atlas contains many geologic structure, isopachous, lithofacies and other maps which lend a foundation for interpreting and understanding the hydrogeology of Michigan. As such, the report will be eminently useful, if not essential, to a broad spectrum of professionals in a variety of fields ranging from engineering firms and oil companies to planning councils and governmental agencies.

PLANNING AND FUNDING

In 1974, P.L. 93-523 (the Safe Drinking Water Act) was signed into law. Section 1421, Part C of the Act, dealt with the protection of the underground sources of drinking water and the underground injection of wastes. Primary responsibility for the Underground Injection Control Program was given to the United States Environmental Protection Agency (E.P.A.). In 1978, E.P.A. began the administration of the program in Michigan and in 1979, the Department of Geology of Western Michigan University was awarded the first of two grants totaling $650,000 to provide geologic data prerequisite to issuing permits for underground injection wells. After organizational meetings with personnel from Region V (E.P.A.) and the University, a team of administrators, consultants and research assistants was assembled and exploratory searches were initiated. What was to become a very fluid, but persistent, effort was begun.

SCOPE

The effort was essentially a review and compilation of existing data, mostly published information, but also unpublished information such as that stored in the files of County, State and Federal agencies. University libraries were visited by graduate and undergraduate assistants and requested to provide theses and dissertations related to Michigan geology. Project coordinators and assistants visited county, city and federal agencies to obtain information on ground-water resources and water quality. Maps and studies were requested from geologists most knowledgeable about the hydrology and geology of the State including those engaged in federally-funded and industry-sponsored research. WATSTØRE was made operational and its content validated. This report and a companion volume, the Hydrogeologic Atlas of Michigan, are the culmination of these efforts.

STAFFING

The project was accomplished by a team of staff and students from the Department of Geology of Western Michigan University, under the direction of Mr. Dennis L. Curran, and Mr. Donald N. Leske (project coordinators), Dr. Richard N. Passero, Dr. W. Thomas Straw (project co-directors), and Dr. Lloyd J. Schmaltz (chairman, Department of Geology). The Atlas was prepared under the cartographic direction of Ms. Linda J. Miller and in consultation with Dr. Thomas Hodler, Department of Geography. Most of the detailed work was done by 75 graduate and undergraduate students from the Departments of Geology and Geography.

LIMITATIONS OF DATA

At times data were difficult to acquire as result of inadequate records or inaccessible, out-of-print publications. An explanation precedes each map describing the data limitations, sources of information and mapping technique. The amount of information available for a particular area of the State was usually proportional to the population density within the area and there was commonly little data available for sparcely populated areas.

Hydrogeologic Limitations for Subsurface Wastewater Injection

The criteria for evaluating the regional and site-specific hydrogeologic limitations for wastewater injection wells has been described by Warner and Lehr (December, 1979). Figure 1.1 represents an adaptation of the evaluation process outlined by the authors and is keyed to chapters, figures and tables in this report and plates and tables in the Hydrogeologic Atlas of Michigan.

Regional Evaluation

Characteristics of regions suitable for subsurface wastewater injection were described as follows:

a. An extensive, thick sedimentary sequence should be present, to provide opportunity for an adequate injection interval and confining strata.

b. Geologic structure should be relatively simple; that is, the region should be reasonably free of complex and extensive faulting and folding. Complex geologic structure complicates prediction and monitoring of waste travel and faults are possible avenues of wastewater escape.

c. Possible injection intervals should contain saline water and should not be abundantly endowed with mineral resources (oil, gas, coal, etc.), so that the potential for degradation of natural resources in minimized.

d. Fluid flow in possible injection intervals should be negligible or at low rates, and the region should not be an area of ground water discharge for the injection intervals being considered.

e. The region should preferably not be one of high seismic risk, nor should it be a seismically active one. Earthquakes may damage injection facilities and, in seismically active area, injection may stimulate earthquakes.

Site Evaluation

Characteristics of suitable disposal sites and injection intervals were described as follows:

a. Injection interval sufficiently thick, with adequate porosity and permeability to accept waste at the proposed injection rate without necessitating excessive injection pressures.

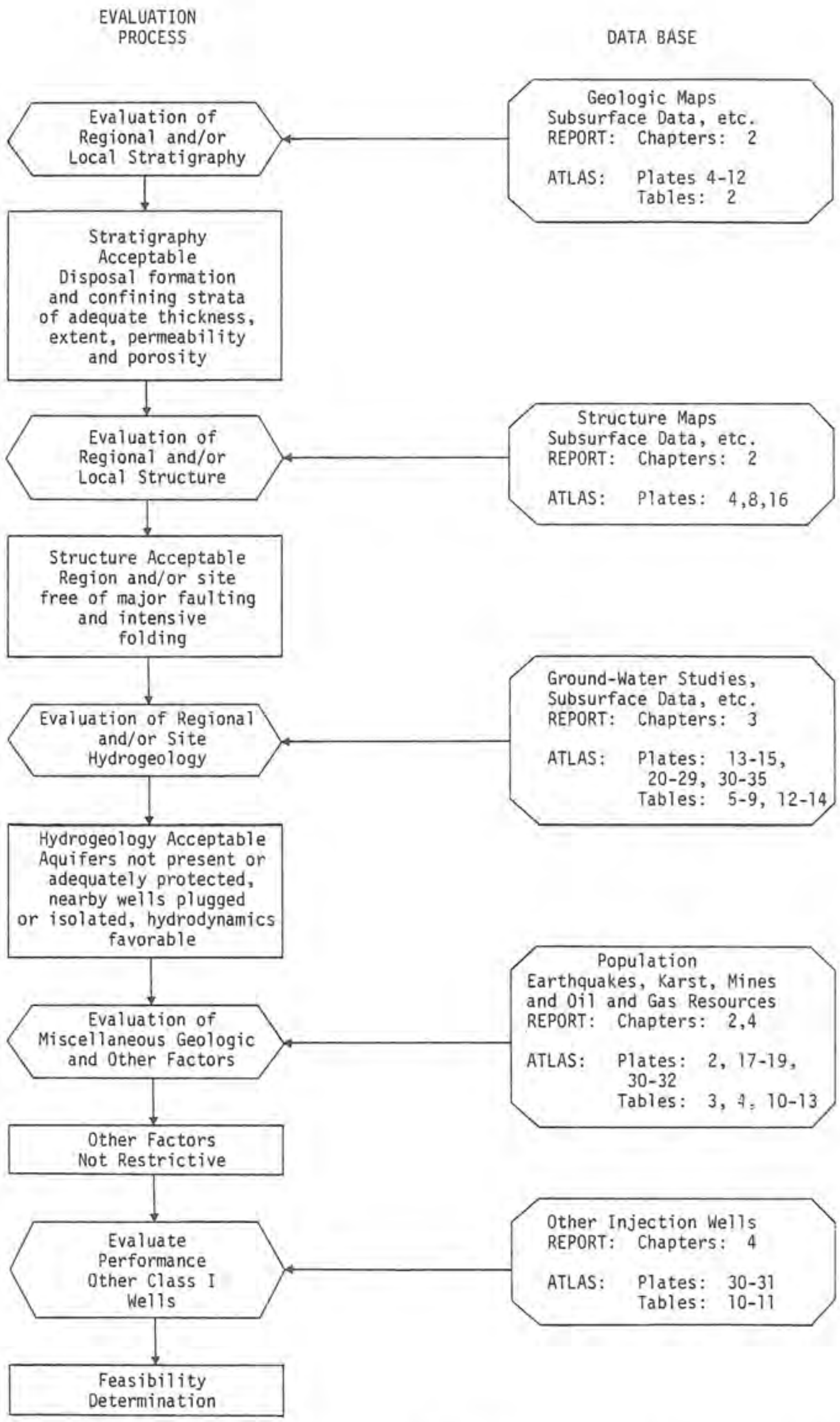

Figure 1.1. Evaluation Process for Subsurface Wastewater Disposal Through Class I Injection Wells (modified from Van Everdingen and Freeze, 1971).

b. Injection interval of large enough areal extent so that injection pressure is minimized and so that injected waste will not reach discharge areas.

c. Injection interval preferably "homogeneous" (without high-permeability lenses or streaks), to prevent extensive fingering of the waste-vs-formation water contact, which would make adequate modeling and monitoring of waste movement extremely difficult or impossible.

d. Overlying and underlying strata (confining beds) sufficiently thick and impermeable, to confine waste to the injection interval.

e. Structural geologic conditions generally simple, that is a site reasonably free of complex faulting and folding.

f. Site is an area of minor to moderate earthquake damage and low seismic activity so that the hazard of earthquake damage or triggering of seismic events is minimized.

g. Slow lateral movement of fluid in the injection interval, under natural conditions, to prevent rapid movement of waste away from the injection site, possibly to a discharge area.

h. Formation-fluid pressure normal or low so that excessive fluid pressure is not needed for injection.

i. Formation temperature normal or low so that the rates of undesirable reactions are minimized, including corrosion.

j. Wastewater compatible with formation fluids and minerals or can be made compatible by treatment, emplacement of a buffer zone, or other means.

k. Formation water in the disposal formation of no apparent economic value, i.e. not potable, unfit for industrial or agricultural use, and not containing minerals in economically recoverable quantities.

l. Injection interval adequately separated from potable water zones, both horizontally and vertically.

m. Waste injection not to endanger present or future use of mineral resources (coal, oil, gas, brine, others).

n. Waste injection not to affect existing or planned gas-storage or freshwater-storage projects.

o. No unplugged or improperly abandoned wells penetrating the disposal formation in the vicinity of the disposal site, which could lead to contamination of other resources.

Michigan Guidelines for Feasibility Studies

Preliminary studies related to the feasibility for subsurface disposal should address the following items:

1. Notice of Intent: Evidence that notice has been given to mineral owners within a two mile radius of the proposed well(s). These owners may waive right of protest. If the expected zone of influence of the proposed project is larger than two miles, then the area should be expanded accordingly.

2. Description of local topography, cultural features and human population in the area of the proposed disposal program and probable effects of the program on these factors.

3. Maps and cross sections illustrating detailed geologic structure and stratigraphic sections (formation, lithologic, and physical characteristics) for the local area and generalized maps and cross sections illustrating the regional geologic setting of the project.

4. A map indicating location of water wells and all other wells, mines, artificial penetrations (oil and gas wells, exploratory tests, etc.) showing depths and deepest formation penetrated, and their present condition within the expected area of influence of the proposed project. Exhaustive search shall be made to locate such penetrations. Well and abandonment records of the wells should accompany the map.

5. A map indicating vertical and areal extent of potable water supplies which would include surface water supplies and subsurface aquifers containing water with less than 10,000 ppm total solids, as well as available amounts and present and potential use of these waters.

6. The effect of this project on present or potential mineral resources in the area.

7. Description of the chemical, physical and biological properties and characteristics of the waste to be injected or disposed of. Relative alteration or stability characteristics of the wastes when exposed to time, pressures, temperature or other media.

8. Potentiometric surface maps of the injection aquifers and those aquifers immediately above and below the injection aquifer and copies of all drill stem tests, extrapolations and data used in making the maps.

9 Anticipated volume, rate, and injection pressure.

10. The following geological and physical characteristics of the injection interval and the confining units should be determined as accurately as possible and submitted by the owner along with the method of determination.

a. Effective thickness and areal extent (isopach map)

b. Lithology: Grain mineralogy, type and mineralogy of matrix, amount and type of cementing material, clay content and clay mineralogy.

c. Effective porosity (how determined).

d. Permeability, vertical and horizontal (how determined, or assumed, mechanical, radiation, electronic or other logs, core analysis, formation tests, etc.). Differentiation should be made between the relatively high permeability zones and the relatively low permeability zones and their comparative thicknesses.

e. Amount and extent of natural fracturing.

f. Location, extent and effects of known or suspected faulting.

g. Extent and effects of natural solution channels.

h. Fluid saturation.

i. Formation fluid chemistry (local and regional variations).

j. Temperature of formation (how determined).

k. Formation and fluid pressures (original and modifications resulting from previous fluid withdrawals).

l. Fracturing and fracture propogation gradients.

m. Osmotic characteristics of rock and fluids both comprising and contiguous to the reservoir.

n. Diffusion and dispersion characteristics of the waste and the formation fluid including effect of gravity segregation.

o. Compatibility of injected waste with the physical, chemical and biological characteristics of the reservoir.

p. Injectivity profiles.

q. Expected changes in pressure, rate and direction of fluid displacement, by injected wastes relative to time, in area affected by the project.

11. The following engineering recommendations should be supplied if available at this time.

    a. Size of hole and estimated depth of well.

    b. Type, size, weight, strength, etc. of all surface, intermediate, and production casing and accessory equipment.

    c. Specifications and proposed installation of tubing and packers.

    d. Proposed cementing procedures and type of cement.

    e. Proposed coring program.

    f. Proposed formation testing program.

    g. Proposed logging program.

    h. Proposed artificial fracturing or stimulation program.

    i. Proposed completion procedure (open hole, perforated casing).

    j. Plans of the surface and subsurface construction details of the system including a diagrammatic sketch of the system (pump, well head construction, casing depth, etc.).

    k. Plans for monitoring injection, annular and formation pressures (injection well(s), observation well(s)).

This report will demonstrate that, on a regional basis and perhaps with the exception of item c, the Southern Peninsula of Michigan generally satisfies the above criteria; the Northern Peninsula does not. It follows that suitable sites exist in the Southern Peninsula, but are improbable in the Northern Peninsula.

The stratigraphy of Michigan is described in Part II of this report, Geology for Underground Injection: An Overview. Structure and thickness maps are included in the report, as well as the Hydrogeologic Atlas of Michigan, and lithologic units from the Precambrian through the Jurassic have been evaluated as aquifers, injection reservoirs and confining strata. Geologic structures of the Southern Peninsula are shown as interpreted by Prouty (1971) and faults and fault densities in the Northern Peninsula have been mapped from numerous Michigan and U.S. Geological Survey publications.

Part III of the report, Distribution and Occurrence of Potable Ground Waters in Michigan, assesses municipal, industrial and domestic water use, sources including glacial drift and bedrock aquifers, and quality of ground water in Michigan. The Atlas contains specially prepared maps of water well densities, bedrock wells, community supplies, water quality (total dissolved solids and specific conductance), and ground-water contamination sites. Of particular note are new maps of glacial drift thickness, vulnerability of the drift aquifer to contamination, and an interpretation of the glacial drift as an aquifer system.

Miscellaneous geologic factors including karst, earthquakes and mines are discussed in the report and mapped in the atlas. The history, geology and statistics of Class I, II and III wells are described and mapped in separate sections of the report and atlas. A system for estimating the potential for ground-water contamination from oil field brines was devised and the values displayed on maps in the atlas. Finally, maps of aggregate thickness of confining units (shales and evaporites) and isolation intervals were prepared to assist in determining the regional and site specific potential for underground injection.

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United States Geological Survey Library (Lansing, Michigan)
American Association of Petroleum Geologists
Cosuna Project
Great Lakes Basin Commission
Michigan Basin Geological Society
Western Michigan University, Physical Sciences Library, Waldo Library
Michigan State University, Geology Library
University of Michigan, Natural Sciences Library
Michigan Department of Public Health, Water Supply Division
County and District Health Departments
United States Department of Energy

United States Geological Survey (Lansing, Michigan)
Southeast Michigan Council of Governments
Region II Planning Commission
Southcentral Michigan Planning Council
Southwest Regional Planning Commission
GLS Region V Planning and Development Commission
Tri-County Regional Planning Commission
East Central Michigan Planning and Development Region Commission
West Michigan Regional Development Commission
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Northwest Michigan Regional Planning and Development Commission
Eastern Upper Peninsula Regional Planning and Development Commission
Central Upper Peninsula Planning and Development Regional Commission
Western Upper Peninsula Regional Planning Commission
Western Michigan Shoreline Regional Development Commission

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Bank Facies

The Niagaran section is thickest in the bank facies of the Upper Peninsula where it is as much as 900 feet thick. Across the southern Lower Peninsula the facies is between 300 feet and 400 feet thick. The Bank facies is a dolomitized carbonate bank-reef complex that developed along and on the stable arch areas (Findly Arch, Algonquin Arch, Wisconsin Arch, and Indiana Platform). Here, the Michigan Basin subsided less and widespread organic activity resulted in a broad accumulation of reefal material. Dolomitization of this unit has produced a very porous and permeable lithology that is generally filled with brine throughout the subsurface. In the outcrop area of the Upper Peninsula, the bank facies (Burnt Bluff Group, Cordell Group and the Manistique Dolomite) has been flushed of brine and contains fresh water.

Characteristics as an Aquifer. The bank facies is an aquifer in the Upper Peninsula. In the subsurface, although the unit is very porous and permeable, it contains brines rendering it unsuitable as an aquifer.

Characteristics as a Confining Layer. The bank facies is far too permeable to be a confining layer.

Characteristics as an Injection Formation. Although the very high porosity and very rapid permeability of the bank facies of the Niagaran would seem to make it an ideal injection formation, the fact that it has been, and no doubt will be, penetrated by numerous tests for oil and gas greatly diminishes its availability for waste disposal other than brine.

Porosity. Locally very porous. On outcrop this facies contains cavernous porosity; in the subsurface of the southern Lower Peninsula it displays vuggy and moldic (leached) porosity.

Permeability. On outcrop permeability is associated with cavernous zones. In the subsurface of the southern Lower Peninsula the unit is generally permeable throughout.

Oil and Gas Potential. The bank facies of the Niagaran does not produce oil or gas and hydrocarbon shows in this unit are uncommon. Thus its potential for oil and gas production is considered low.

Salina Group

In the Michigan Basin subsurface the Upper Silurian is represented by the Salina and Bass Islands Groups. The Salina Group is a thick sequence of carbonate, anhydrite, salt and shale. A number of these lithologies are restricted to an area roughly equivalent to the combined extent of the basin and shelf facies of the Niagaran Group.

The basal portion of the Salina was designated the "A" member by Landes (1945). The "A" was further subdivided by Evans (1950) into a basal unit he termed the A-1 and an upper unit he named the A-2. Each of these units consists of a lower evaporite unit and upper carbonate. Each of the four "A" elements are extensive enough to warrant formational status, and at least the A-1 Carbonate has been elevated to this rank (Budros, 1974).

Characteristics as an Aquifer. The Salina serves as an aquifer only in its outcrop area in southeastern Michigan and the eastern part of the Northern Peninsula, especially on the St. Ignace Peninsula, where it produces from joints and bedding planes in dolomite.

Characteristics as a Confining Layer. Throughout the central portion of the Michigan Basin where the group contains thick salts and basinward of the reef trend, the unit is essentially an aquiclude.

Characteristics as an Injection Formation. Solution and fracture permeability, variable lithology, and aquifer and hydrocarbon reservoir potential render the Salina Group generally unfavorable as an injection unit. However the Salina is utilized for brine injection in St. Clair County.

Porosity. Porosity associated with joints, brecciation fractures and solution along bedding planes is common in the Northern Peninsula.

Permeability. Highly variable fracture and bedding plane permeability in Northern Peninsula.

Oil and Gas Potential. Near the margins of the evaporite containing Salina, the A-1 and A-2 Carbonates produce hydrocarbons.

A-1 Evaporite

The A-1 Evaporite consists of a basal and upper anhydrite that enclose a thick salt in the basinal area (fig. 2.19, pl. 10). The salt consists mainly of halite (NaCl), but it contains up to 40 feet of sylvite (KCL) in the center of the basin (Matthews, 1970). The unit is anhydrite over most of the Niagaran shelf facies. It is generally not present south of the shelf facies and extends only a short distance onto the bank facies in the northern Lower Peninsula (fig. 2.17 and 2.19). Locally, as long a line from Holland, Michigan southeast to Wayland and beyond, the A-1 salt has been removed by dissolution and the overlying rock has been draped over the abrupt escarpment formed by the salt.

Characteristics as an Aquifer. The A-1 Evaporite is not an aquifer.

Characteristics as a Confining Layer. The anhydrite beds and salt of the A-1 Evaporite are essentially impermeable and are excellent confining layers. Furthermore, they contain only a very small amount of formation water, and fractures in either lithology should "heal" either by flowage or secondary mineral growth.

Characteristics as an Injection Formation. None.

Porosity. Extremely low.

Permeability. Essentially impermeable.

Oil and Gas Potential. The A-1 Salt contains gas over some major structures. Gas was tested from this zone over the Mio anticline in Ogemaw County and over the Kawkawlin anticline in Bay County.

A-1 Carbonate

The A-1 Carbonate overlies that portion of the Michigan Basin underlain by the basin and shelf facies of the Niagaran Group and extends northward some distance onto the northern portion of the bank facies (fig. 2.20). South of the shelf facies in the southern part of the Southern Peninsula, the A-1 Carbonate extends only a short distance onto the bank facies. The carbonates in the A-1 are generally limestone except in areas adjacent to reefal buildups, over the abrupt margin of the A-1 salt in southwestern Michigan, and in local areas along its distal margins.

The A-1 Evaporite is gradational upward into the basal A-1 Carbonate and the A-1 Carbonate is apparently gradational into the overlying A-2 Evaporite. In areas where the A-1 Carbonate is overlain by the A-2 salt and underlain by the A-1 salt, all porosity in it is plugged by salt (halite). The A-1 Carbonate is less than 60' thick in the central part of the Michigan Basin and is more than 150 feet thick where it overlies the carbonate bank facies in the northern Lower Peninsula.

Characteristics as an Aquifer. The A-1 Carbonate is not an aquifer.

Characteristics as a Confining Layer. In areas where the A-1 Carbonate is limestone and salt plugged, it is an excellent confining layer.

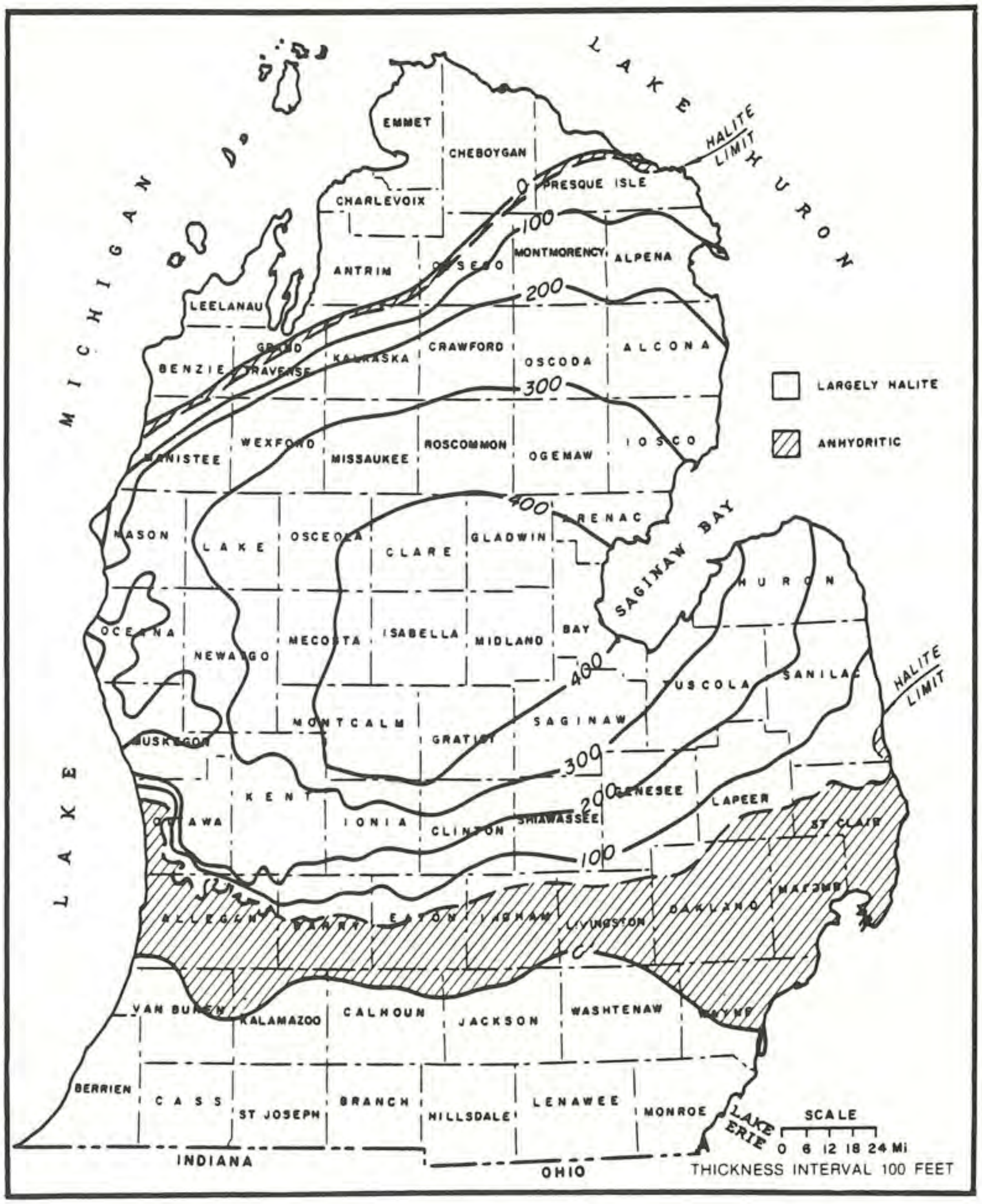

Figure 2.19. Thickness of the A-1 evaporite. Contour interval is 100 feet. (From Mesolella, 1974.)

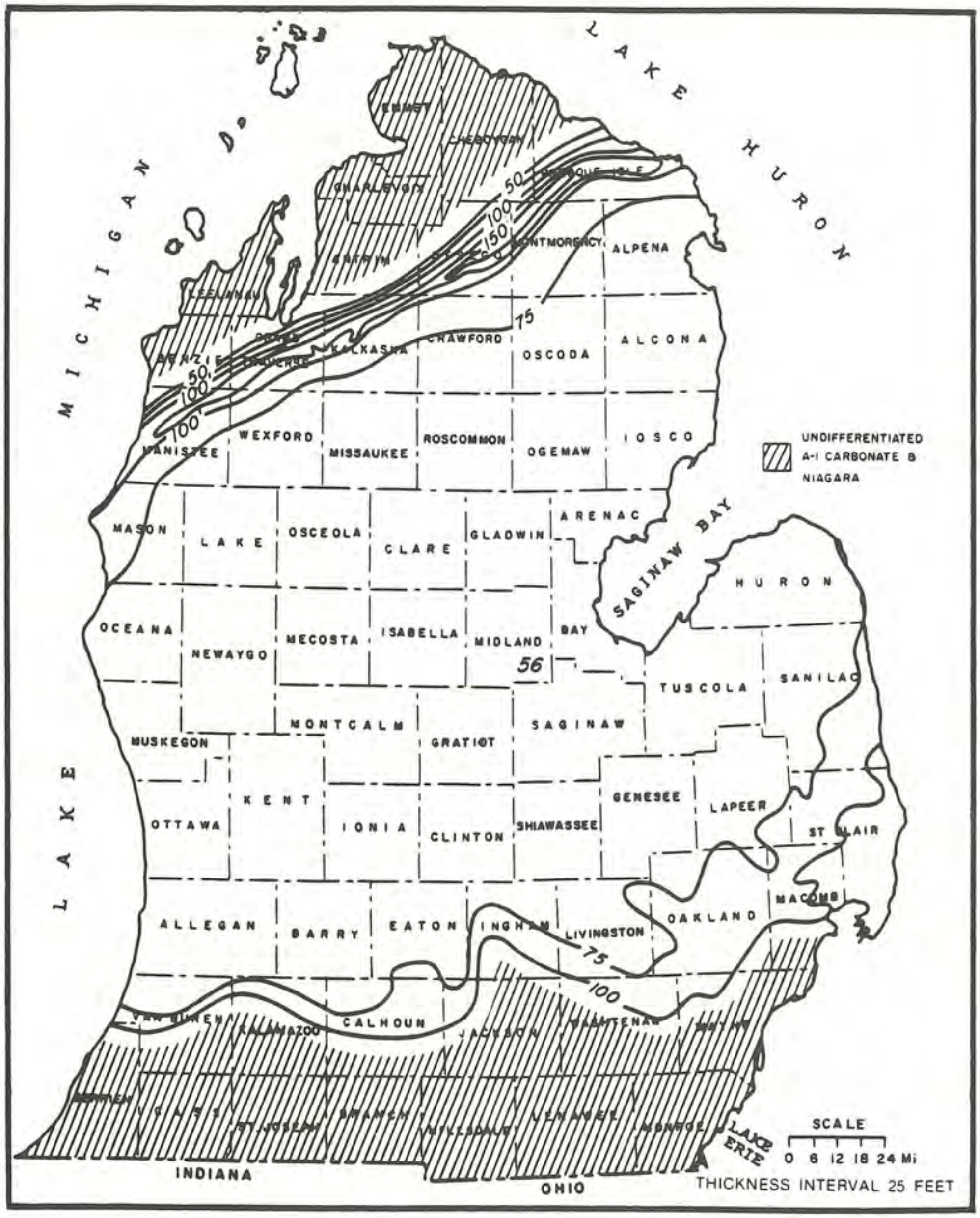

Figure 2.20. Thickness of the A-1 Carbonate. Contour interval is 25 feet. (From Mesolella, 1974.)

Characteristics as an Injection Formation. The A-1 Carbonate will accept fluids only where it is dolomite. In such areas, it is a target for oil and gas exploration, is productive of hydrocarbons, or it is in contact with very permeable reefal dolomites of the Niagaran.

Porosity. In areas where this unit is dolomite, it has low porosity. In areas where it is limestone and salt-plugged, it has extremely low porosity.

Permeability. Dolomites of the A-1 Carbonate are slowly permeable, and salt-plugged limestones are essentially impermeable.

Oil and Gas Potential. The A-1 Carbonate produces hydrocarbons and is an exploration target in those areas where reefs are developed in the Niagara Group.

A-2 Evaporite

The A-2 Evaporite conformably overlies the A-1 Carbonate except over "pinnacle" reefs where it lies directly on the Niagaran (fig. 2.21). It is dominantly halite and ranges from a zero edge at the basin margin to more than 475 feet thick in the central part of the basin (Tremper, 1973). Over the bank reef complex it is a dense anhydrite generally less than 40 feet thick. A-2 salt has been removed by dissolution southwestward of a line that extends from Muskegon southeastward to the Walker Oil Field in Kent County. The A-2 salt, may have been removed in the area just north of the Straits of Mackinac and south to the present salt margin.

Characteristics as an Aquifer. The A-2 Evaporite is not an aquifer.

Characteristics as a Confining Layer. The A-2 Evaporite is an excellent confining layer. It is the seal over the pinnacle reefs that developed in the shelf facies of the Niagaran and has the properites necessary to confine fluids under pressure.

Characteristics as an Injection Formation. Unsuitable.

Porosity. Extremely low.

Permeability. Extremely low.

Oil and Gas Potential. None.

A-2 Carbonate

The A-2 Carbonate is limestone in the central part of the basin and is dolomite over the bank facies and over pinnacle reefs in the southern part of the Lower Peninsula. This unit is more than 150 feet thick in the middle of the basin and thins to less than 50 feet in the northernmost part of the Lower Peninsula (fig. 2.22). It also thins across the southern extension of the bank facies and is difficult to distinguish, or absent, in the area just north of the Michigan-Indiana State line.

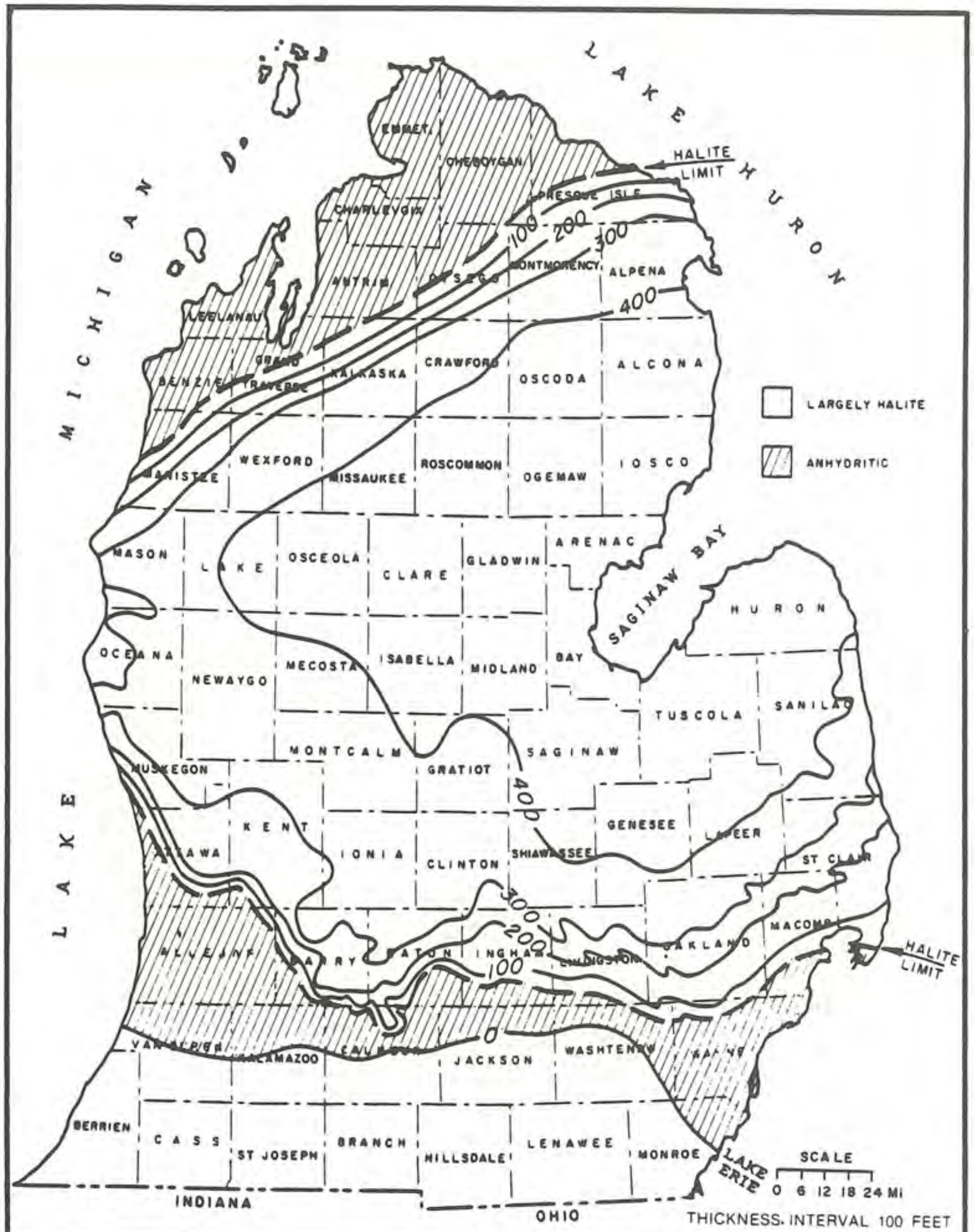

Figure 2.21. Thickness of the A-2 Evaporite. Contour interval is 100 feet. (From Mesolella, 1974.)

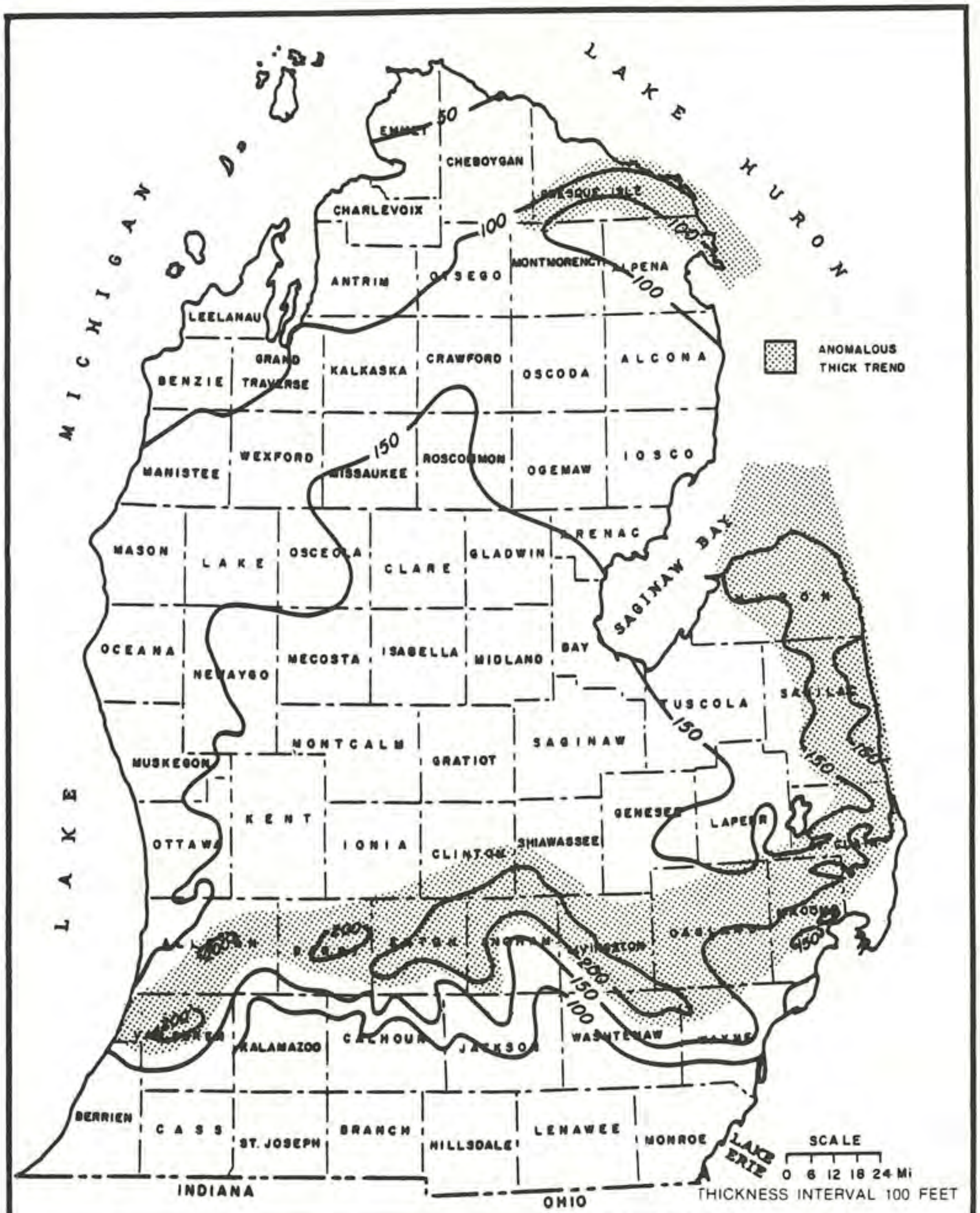

Figure 2.22. Thickness of the A-2 Carbonate. Contour interval is 50 feet. (From Mesolella, 1974.)

Characteristics as an Aquifer. The A-2 Carbonate is not an aquifer. Where the unit is a dolomite, it is slightly porous and slowly permeable, but contains oil and/or gas or brine.

Characteristics as a Confining Layer. In areas where this unit is limestone, all pore space is generally plugged with salt. In such areas it is an excellent aquiclude.

Characteristics as an Injection Formation. In areas where the A-1 Carbonate is dolomite it may serve as an injection formation, but its hydrocarbon potential should first be evaluated. It is currently used as a gas storage reservoir along the A-1 salt edge in southwestern Michigan.

Porosity. Where the A-1 Carbonate is limestone it has very little porosity. In the areas where it is dolomite, it has a porosity of a few percent.

Permeability. The A-2 Carbonate is virtually impermeable in areas where it is a limestone and is salt-plugged. Where it has undergone dolomitization, it is slowly permeable.

Oil and Gas Potential. The A-2 has produced gas in areas where it is dolomite.

B Member

The unit defined as the "B" Member by Landes (1945) includes, in the central part of the basin, up to 450 feet of basal salt and an upper unit comprised of 0 feet to about 80 feet of shale, dolomite and anhydrite (fig. 2.23). The B-salt is thickest in the basin and thins toward the northern carbonate bank where it thickens (Tremper, 1973). North of the thickest portion of the bank facies the unit thins toward the basin margin. On the southern flank of the basin, the B-salt does not extend south of the southern edge of the shelf facies of the Niagaran. The upper part of the B, termed the B-Unit by Ells (1978) thins from a maximum of more than 80 feet in the basin center to a zero edge near the Straits of Mackinac on the north and over the northern part of the bank facies and the southern flank of the basin.

Characteristics as an Aquifer. Neither the B-salt nor the B-Unit is an aquifer.

Characteristics as a Confining Layer. The B-salt and the B-Unit are excellent confining layers. The thick salt section in the central part of the basin would be most effective, but the presence of either salt or anhydrite should indicate that the member is an aquiclude.

Characteristics as an Injection Formation. Unsuitable.

Porosity. Essentially impermeable.

Permeability. Essentially zero.

Oil and Gas Potential. Very little to none.

Figure 2.23. Thickness of the B Evaporite. Contour interval is 100 feet. (From Mesolella, 1974.)

C Shale

The C-Unit is a dolomitic shale with beds of anhydrite and dolomite. It is more than 115 feet thick in the central basin area, thins to 70 feet across the thick portion of the northern bank facies and is more than 100 feet thick near the Straits of Mackinac (fig. 2.24). The unit thins across the southern bank facies, becomes more carbonate rich, and according to Shaver (personal communication, 1980) grades into the Mississenawa Shale in Indiana.

Characteristics as an Aquifer. None.

Characteristics as a Confining Layer. The C-Shale is a plastic shale and should not maintain open fractures at depth. Thus, it is considered to be an excellent confining layer.

Characteristics as an Injection Formation. Unsuitable.

Porosity. Effective porosity is essentially zero. Porosity associated with clay minerals is quite high.

Permeability. Essentially impermeable.

Oil and Gas Potential. None.

D-Unit

The Salina D-Unit is composed of two salt (halite) beds and an intervening argillaceous, anhydritic, fine-grained dolomite. Around the periphery of the basin the D-Unit is thin and consists mainly of shale and anhydrite. It is as much as 60 feet thick in the central basin area but thins to less than 15 at the margins of the basin (Tremper, 1973) (fig. 2.25).

Characteristics as an Aquifer. The D-Unit is not an aquifer.

Characteristics as a Confining Layer. In the basinal areas where the D-Unit salts are present the D-Unit is an aquiclude. Marginal to the area of salt development, the shaly anhydrite should be an aquitard, but would not form as formidable a barrier to the movement of fluids as a thick bed of salt (NaCl).

Characteristics as an Injection Formation. None.

Porosity. Extremely slow.

Permeability. Extremely slow.

Oil and Gas Potential. None.

E-Unit

The Salina E-Unit is a mixture of lithologies. Dominated by shales, it also contains dolomite beds that are locally oolitic and thin beds of anhydrite. It is more than 160 feet thick in the center of the Michigan Basin and thins to less than 90 feet in marginal areas (Tremper, 1973) (fig. 2.26).

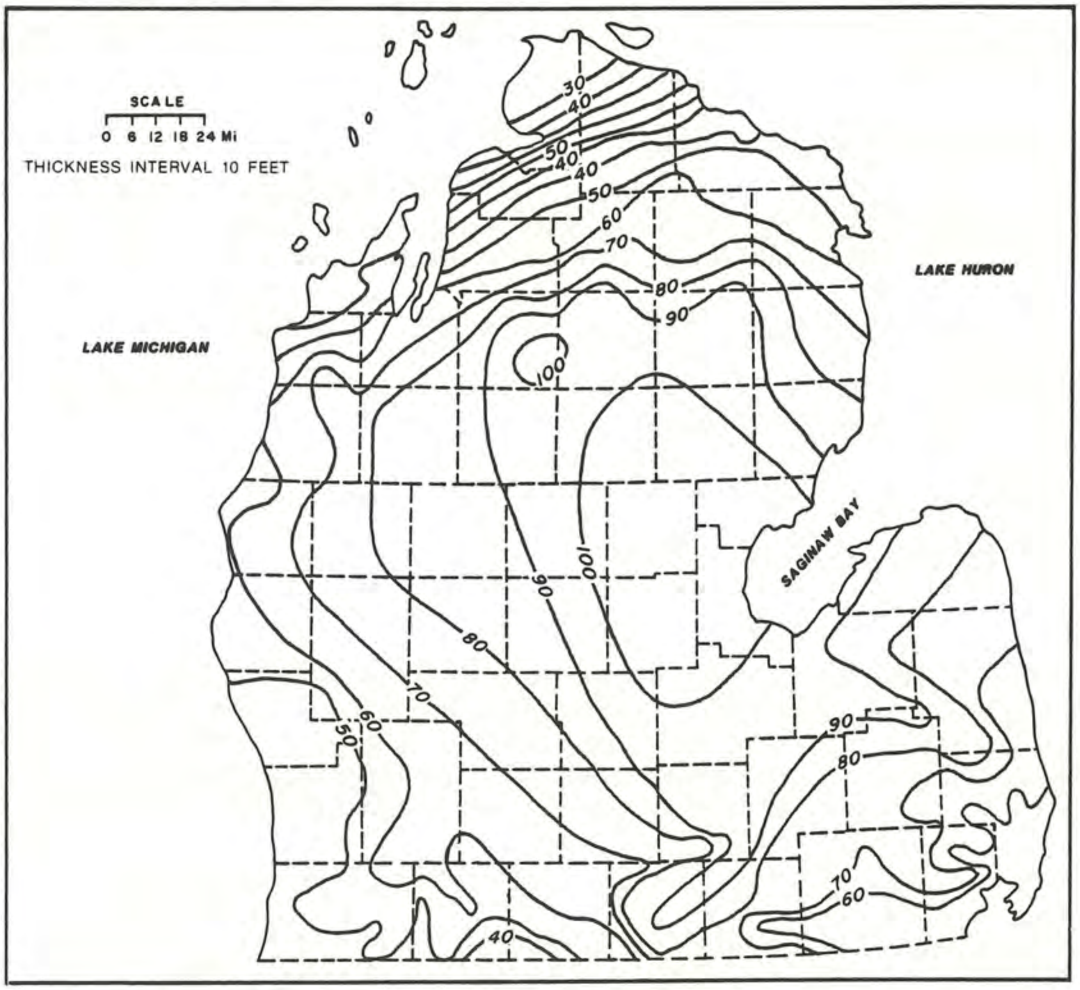

Figure 2.24. Thickness of Salina C Unit. (From Dali, 1975.)

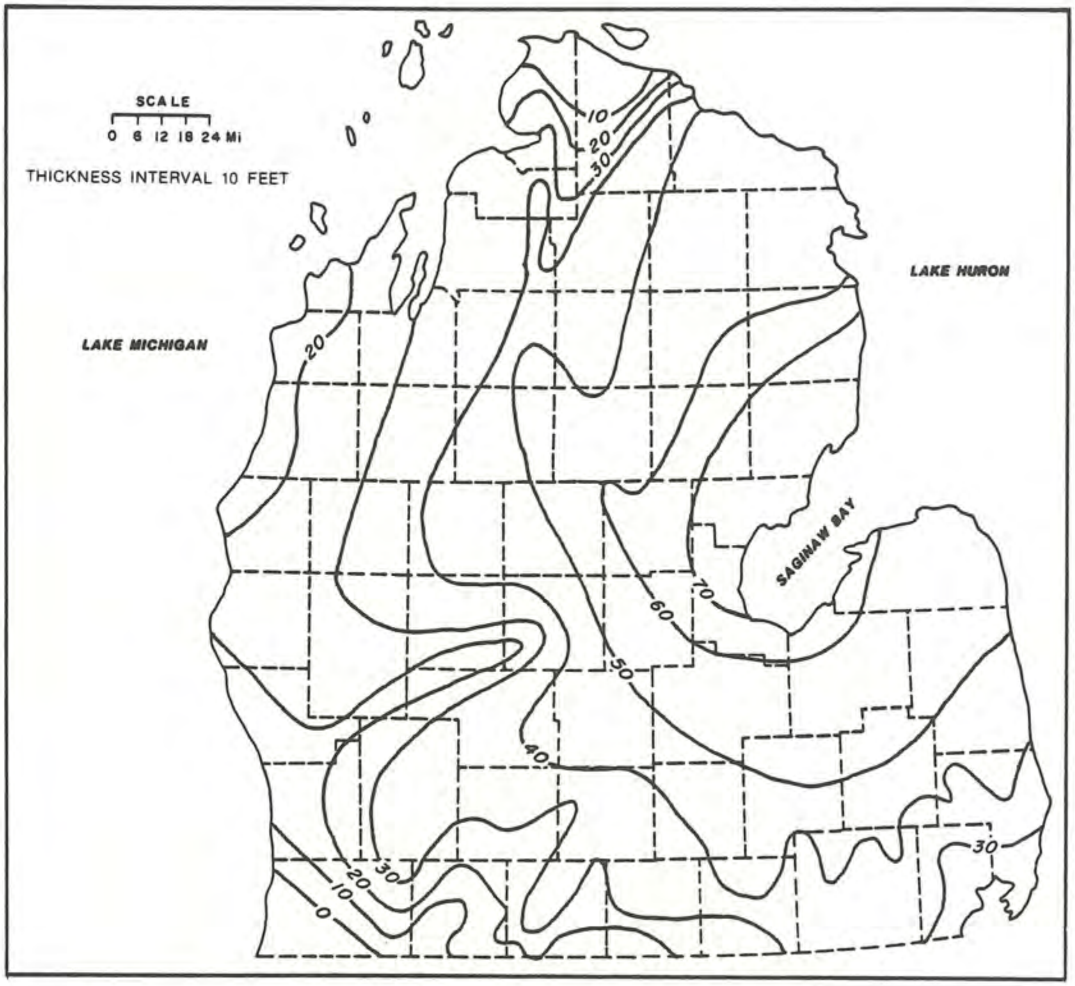

Figure 2.25. Thickness of Salina D Evaporite. (From Dali, 1975.)

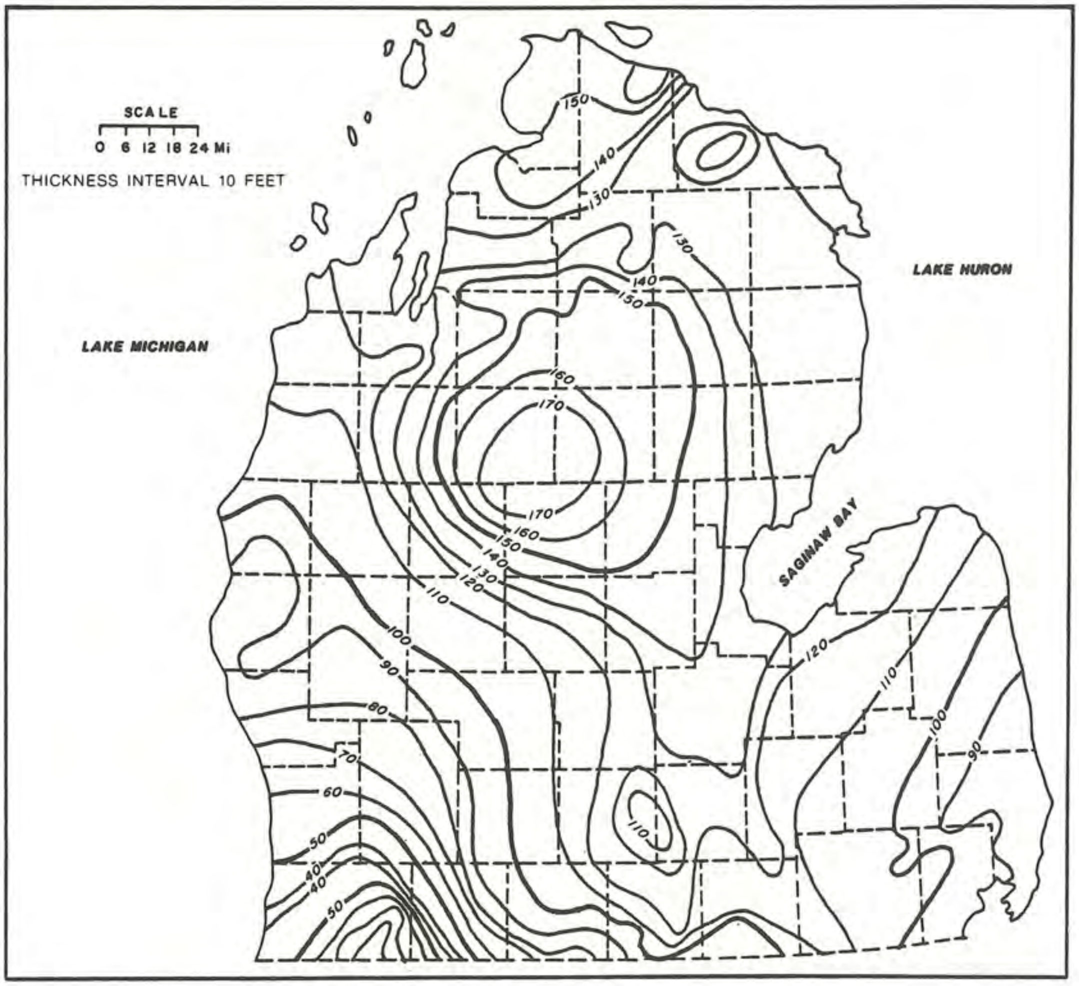

Figure 2.26. Thickness of Salina E Unit. (From Dali, 1975.)

Characteristics as an Aquifer. The E-Unit is not an aquifer.

Characteristics as a Confining Layer. Shales and anhydrite beds in the E-Unit should form a barrier to the migration of fluids. In the central portions of the basin the dolomite beds are most likely salt plugged and also form aquicludes. In areas marginal to salt development, the dolomite beds may permit vertical migration of fluids.

Characteristics as an Injection Formation. Generally unsuitable.

Porosity. Effective porosity of this unit is very low, especially in areas where salt plugging occurs. Marginal to the areas of salt development, the dolomite beds may contain some effective void space. Shales in this unit contain a high ineffective porosity associated with clay minerals.

Permeability. Where salts are developed in the Salina permeability is very low. Marginal to the area of salt development, the dolomite beds are probably permeable.

Oil and Gas Potential. Very low.

F-Unit

The Salina F-Unit comprises a sequence of salt (NaCl) beds with intervening shales and dolomite beds. The top of the unit is generally picked at the top of a buff, fine-grained, anhydritic dolomite. The unit thickens from less than 100 feet on the southwest margin of the basin to over 900 feet at the center of the basin (fig. 2.27). Around the northern margin of the Southern Peninsula the salts are absent and the F-Unit is composed mostly of shale. Southward across the state shale is of diminishing importance in this unit. Shales in the F and G Units probably correlate with the Point aux Chenes Shale in the Salina outcrop belt of the eastern Northern Peninsula.

Characteristics as an Aquifer. The F-Unit is not an aquifer.

Characteristics as a Confining Layer. In the basinal area where salts are present in this unit, and along the northern margin of the Northern Peninsula where the F-Unit is mostly salt, it is an aquiclude. South of the area of salt development the Salina does not contain thick shales and its value as a confining layer is probably minimal.

Characteristics as an Injection Formation. Generally unsuitable.

Porosity. The effective porosity of this unit is very low. Where shales are present, they contain porosity associated with clay minerals.

Permeability. Extremely slow.

Oil and Gas Potential. Extremely low.

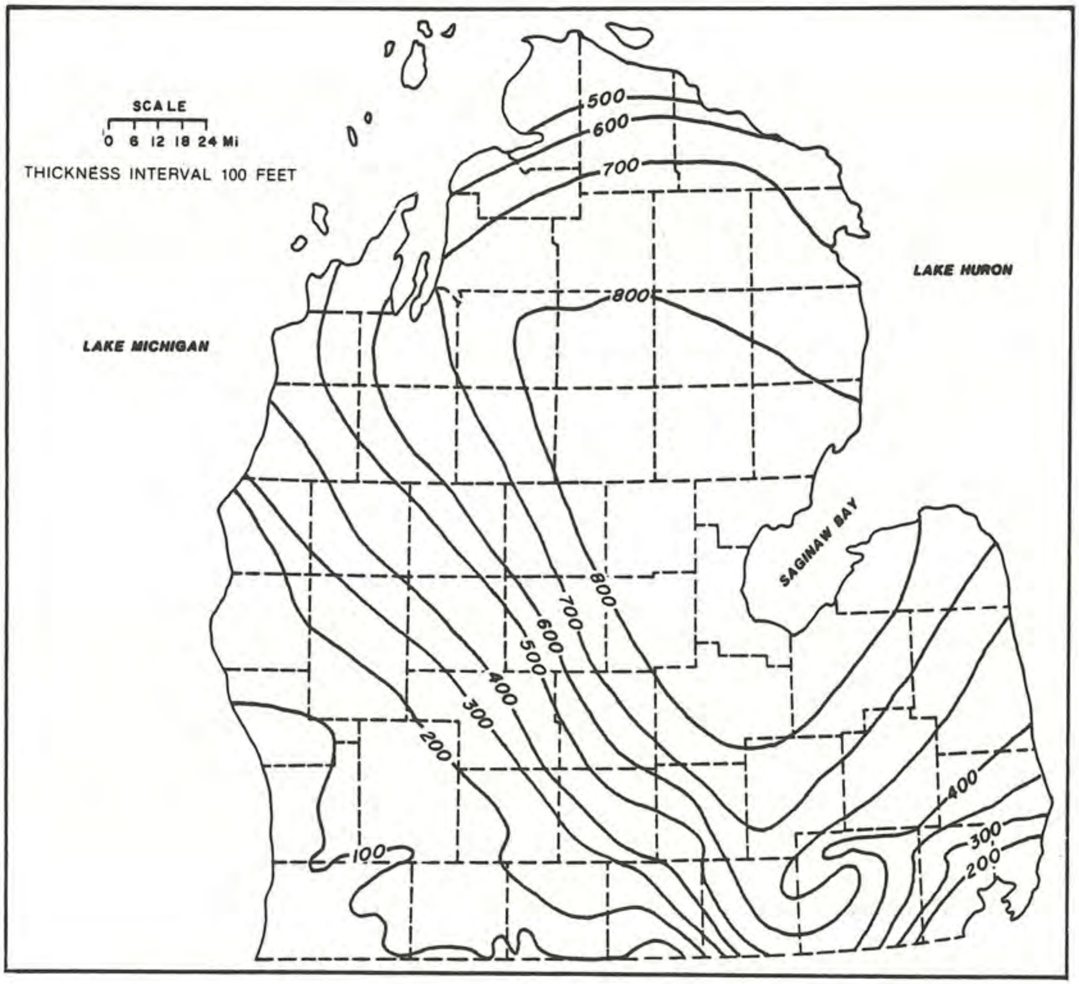

Figure 2.27. Thickness of Salina F Evaporite. (From Dali, 1975.)

G-Unit

The Salina G-Unit is a sequence of dolomitic and anhydritic shales that range in thickness from a zero edge in southern Michigan to more than 100 feet in the northeastern quadrant of the Southern Peninsula (fig. 2.28). This unit is probably correlative with the upper part of the Point aux Chense Shale in the Salina outcrop belt of the eastern Northern Peninsula.

Characteristics as an Aquifer. The G-Unit is not an aquifer.

Characteristics as a Confining Layer. In those portions of the Southern Peninsula where the shales of the G-Unit are more than 40 feet thick it is probably an aquiclude. Marginal to this area (fig. 2.28) its value as a confining layer is probably minimal.

Characterisitcs as an Injection Formation. Generally unsuitable.

Porosity. The effective porosity of the G-Unit is very low.

Permeability. Extremely slow.

Oil and Gas Potential. Extremely low.

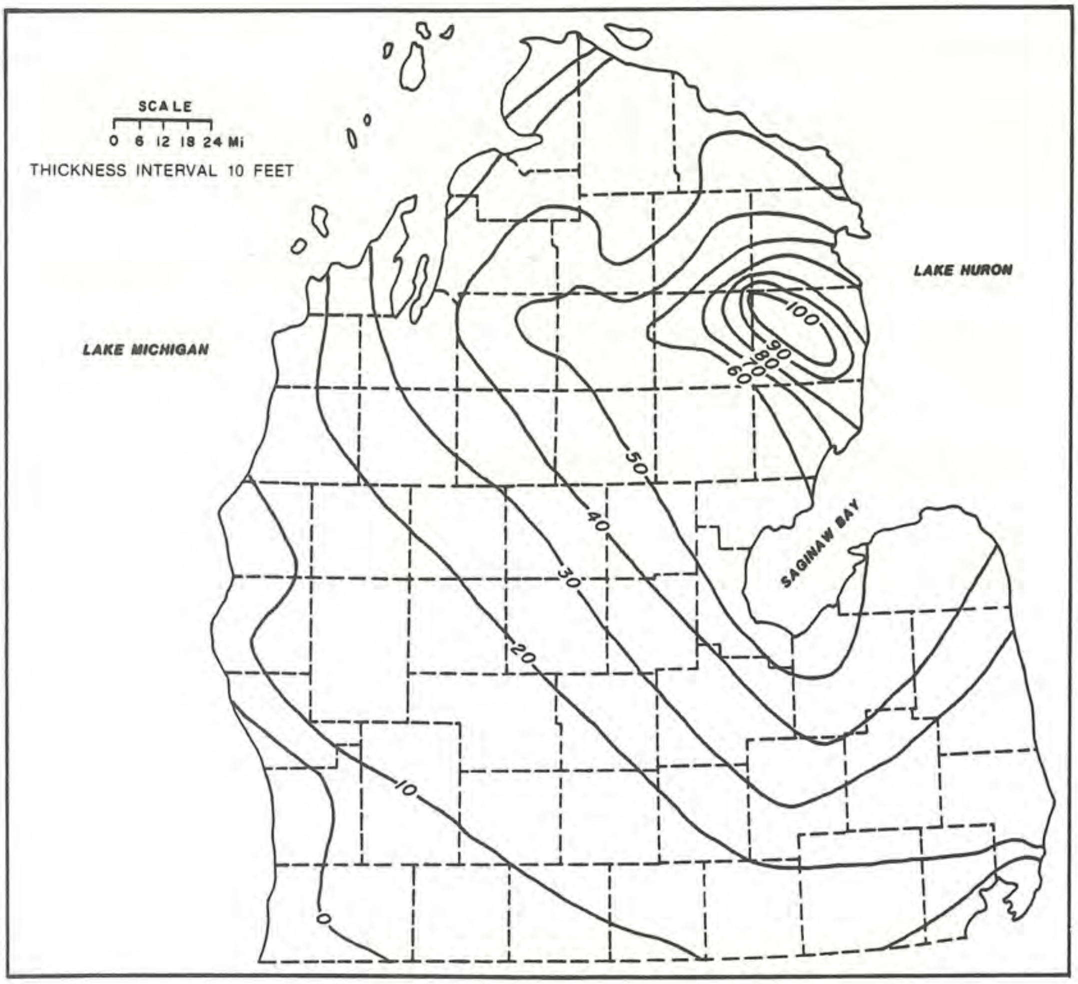

Figure 2.28. Thickness of Salina G Unit. (From Dali, 1975.)

Characteristics as a Confining Layer. In the eastern third of the Lower Peninsula, the Dundee is dominantly limestone and very slowly permeable. In this area the only limitations to its use as a confining layer is the presence of fractures.

Characteristics as an Injection Formation. In areas where the Dundee has been dolomitized, it could be and is used as an injection formation for chemicals and brine.

Porosity. In areas where the Dundee is limestone, it has very low effective porosity; however, in areas where the Dundee has been dolomitized it is very porous.

Permeability. Where the Dundee is limestone it is very slowly permeable but dolomitized zones are highly permeable.

Oil and Gas Potential. The Dundee has been a prolific oil and gas producer and is a prime target for oil and gas in the central Michigan Basin.

Traverse Group

The Traverse is a thick (100'-800') sequence of alternating shales and limestones in the northeastern two-thirds of the Southern Peninsula (figs. 2.38 to 2.40). In the "Thumb" area shales comprise more than 80 percent of the Traverse Group. In contrast, shale makes up less than 20 percent of the unit in southwestern Michigan. The Traverse has been subdivided in the Alpena and Traverse City areas and, in general, each of the alternating shales and limestone units has been assigned a formation name. To the southwest, the shales thin and the distinctive character of each limestone unit becomes progressively more obscure until it is impossible to distinguish units within the Traverse Group. Even the Traverse-Dundee contact is difficult to discern.

The Traverse crops out and subcrops beneath the glacial drift around the northern margin of the Southern Peninsula and in southeastern Michigan. In the northern outcrop band, the presence of shale or limestone at the surface is an important controlling factor in the potential of the Traverse as an aquifer. Where shales are at the surface, as in the area of Bell Shale (basal Traverse Group), bedrock is not generally used as an aquifer. In contrast, outcrop bands of the limestone units form bedrock aquifers.

Characteristics as an Aquifer. The shales in the Traverse Group are not aquifers. The limestone units are "karst" aquifers, and may supply large volumes of water locally. The cavernous nature of these units makes them extremely vulnerable to contamination.

Characteristics as a Confining Layer. The shales in the Traverse Group, especially the Bell Shale, are excellent confining layers. To the southwest, the shales thin and are less adequate barriers to the movement of fluids. The numerous oil and gas fields in the underlying Dundee attest to the impermeable nature of the Bell Shale. The limestone units should not be regarded as aquicludes, especially in and near the outcrop areas.

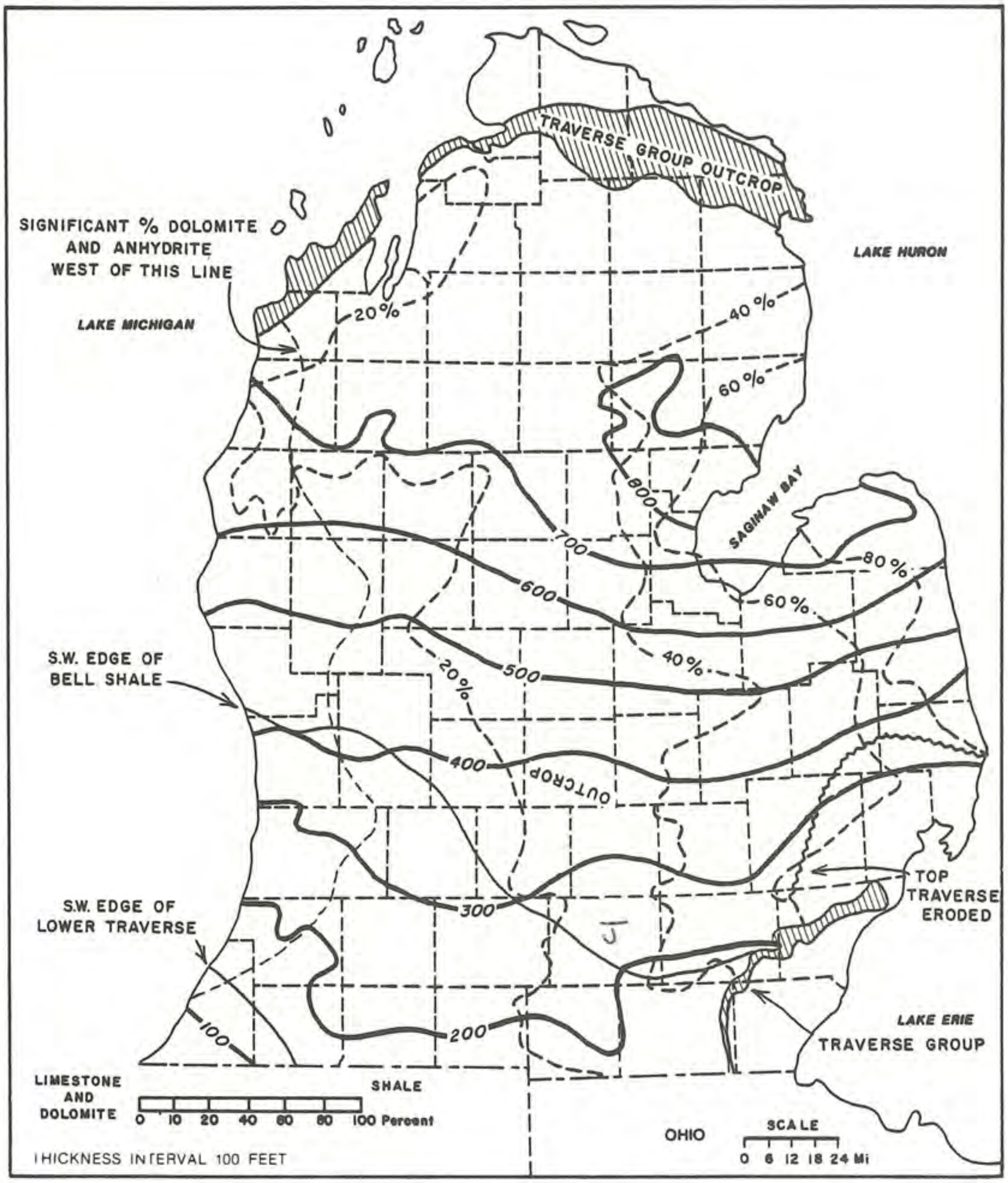

Figure 2.38. Thickness-percent shale map of Traverse Group. (From Gardner, 1974.)

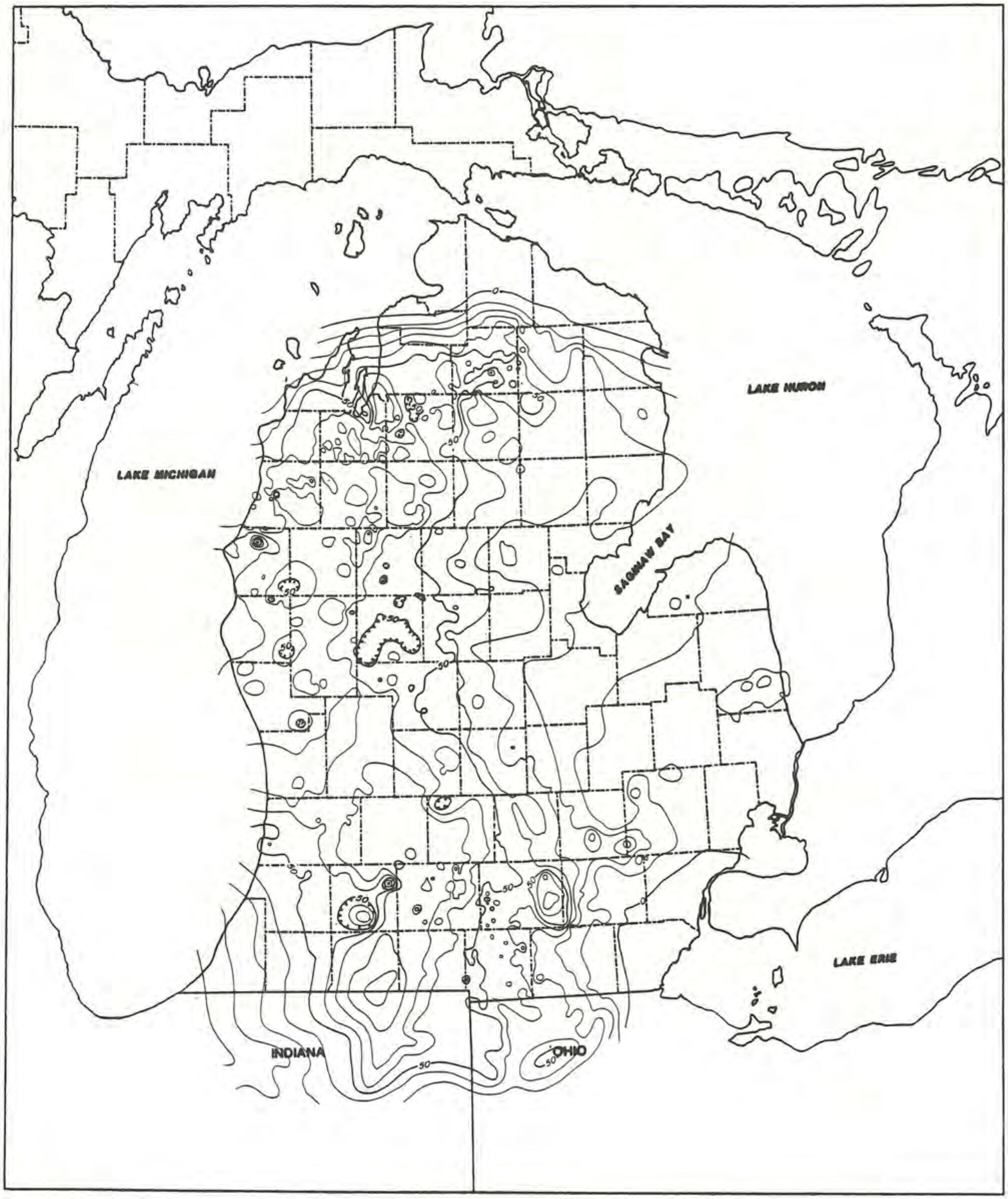

Figure 2.39. Thickness of Traverse Formation. (From Fisher, 1980.)

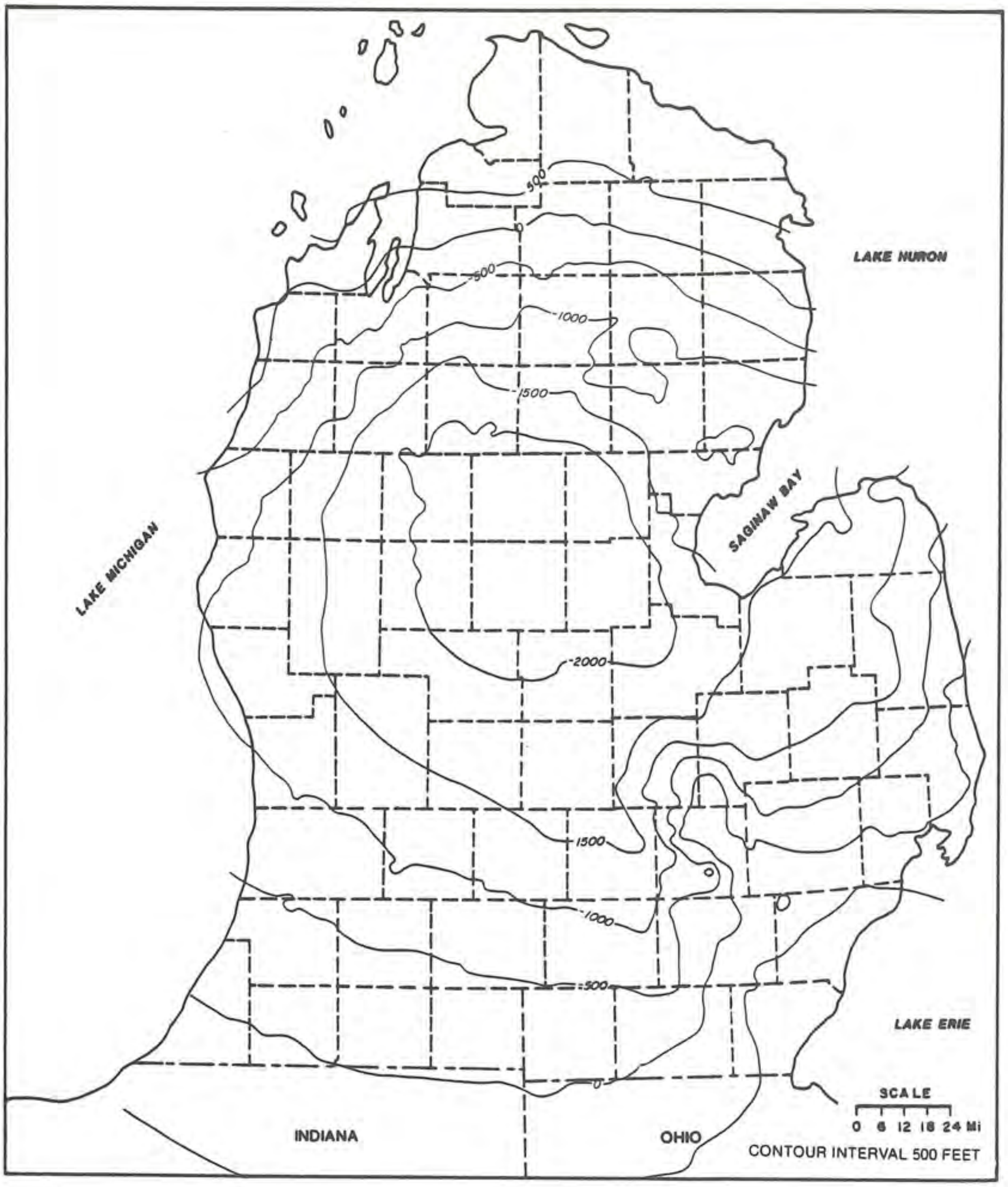

Figure 2.40. Structure map on Traverse Limestone. (From Fisher, 1980.)

Characteristics as an Injection Formation. The Traverse "Limestone" is productive of oil and gas in central and western parts of the Michigan Basin. The porous zones that produce hydrocarbons and brine can be, and are used for injection of fluids, but hydrocarbon potential should be considered when siting Traverse disposal wells.

Porosity. The shales in the Traverse Group generally have very low effective porosity. The limestone units are generally relatively impermeable, but have local porous zones. The uppermost limestone unit in the Traverse, generally referred to as the "Traverse Limestone," or in some reports as the "Squaw Bay," is porous over wide areas of the central and western Michigan Basin.

Permeability. The shales of the Traverse Group are generally impermeable, and the limestones are only locally so. The top few feet of the uppermost Traverse Limestone unit is generally permeable in the central and western parts of the basin.

Oil and Gas Potential. The Traverse Limestone unit produces oil, gas and brine throughout the central and western portions of the basin.

Antrim Shale

The Antrim Shale is a hard, dark gray to black or dark brown, pyritiferous shale that locally contains abundant silt. It ranges in thickness from 120 feet to more than 600 feet (figs. 2.41 and 2.42). In southern Michigan, the basal member of the Antrim is a dark gray dolomite that correlates with the Blocher Member of the New Albany Shale in Indiana. In Michigan this member is referred to as the Traverse Formation. The Antrim Shale is part of the greater "eastern black shale" that includes (1) the New Albany in Indiana; (2) the Ohio Shale in Ohio; and (3) the Chattanoga Shale in Kentucky.

Characteristics as an Aquifer. The Antrim Shale is generally too impermeable to be an aquifer. The low permeability coupled with the presence of abundant pyrite and marcasite generally restrict its use.

Characteristics as a Confining Layer. The Antrim is an excellent confining layer. It forms the seal over most of the Traverse oil fields in Michigan.

Characteristics as an Injection Formation. The Antrim is too impermeable to be used as an injection formation.

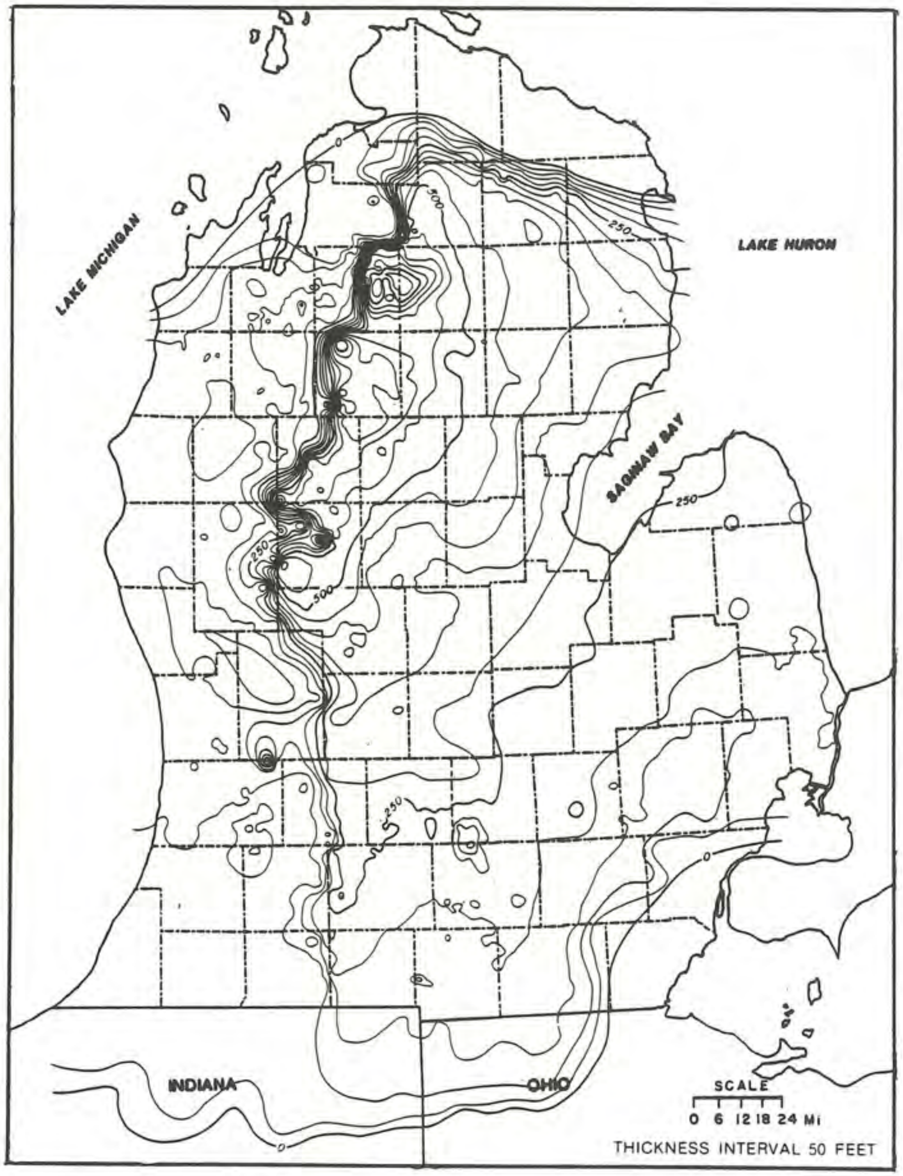

Figure 2.41. Thickness of Antrim Shale. (From Fisher, 1980.)

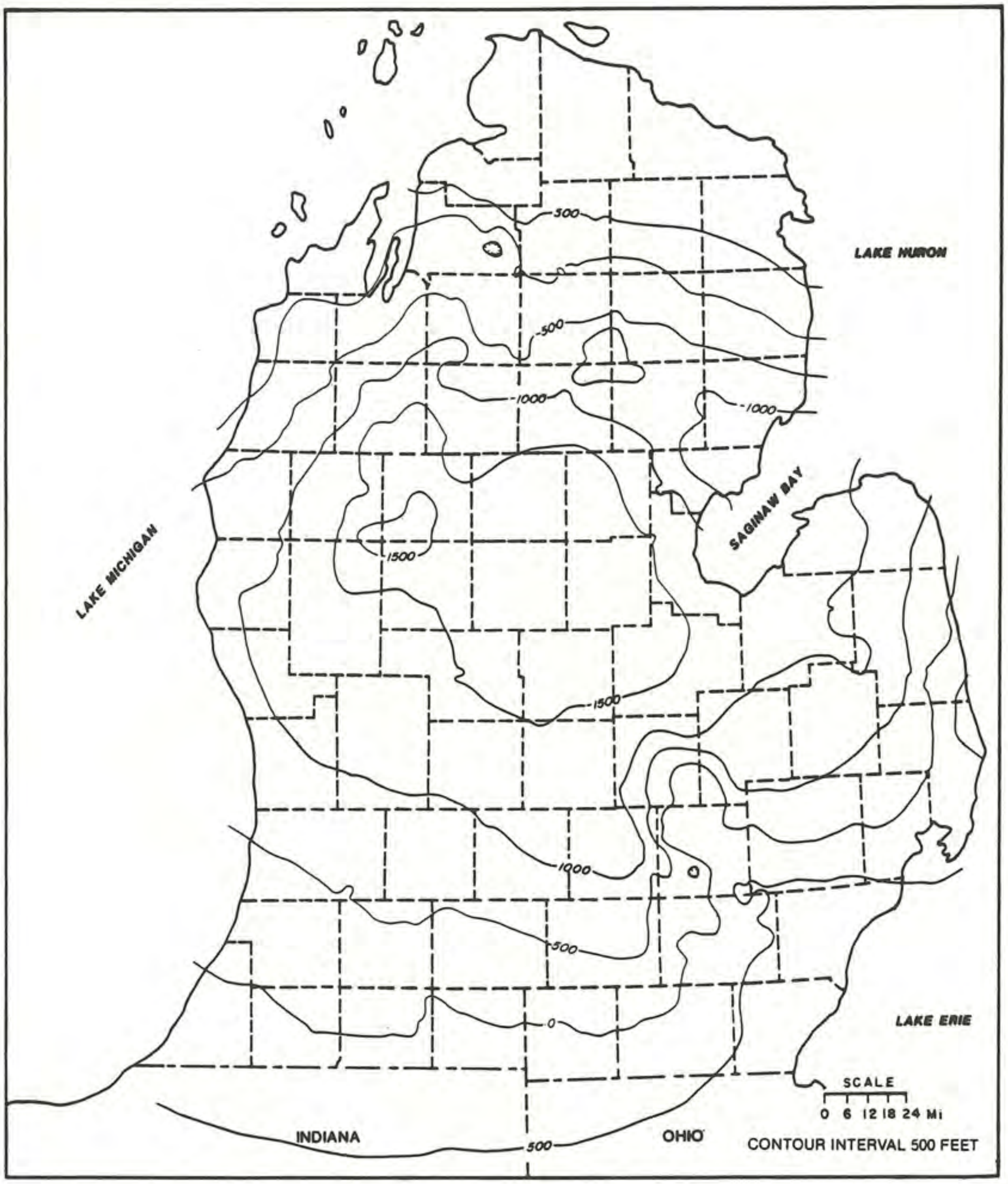

Figure 2.42. Structure map on Antrim Shale. (From Fisher, 1980.)

Porosity. The Antrim Shale has a very low effective porosity.

Permeability. The Antrim Shale generally has a very low permeability. In and near the area of outcrop it is commonly jointed and may have some fracture permeability.

Oil and Gas Potential. The Antrim Shale has produced some gas in Otsego County and it is now considered to be an exploration target for gas. It is also being investigated as a source of hydrocarbons generated by *in situ* combustion.

Ellsworth Shale

The Ellsworth shale is the lateral facies equivalent of the Antrim. It lacks the carbonaceous aspect of the Antrim, and is not regarded as a possible source of hydrocarbons. Otherwise, it has essentially the same characteristics. The Ellsworth ranges in thickness from 0 to 700 feet and is present only in the western part of the Southern Peninsula (fig. 2.43).

Characteristics as an Aquifer. None

Characteristics as an Aquiclude. The Ellsworth Shale is an aquiclude. It has very low permeability and a low effective porosity.

Characteristics as an Injection Formation. None.

Porosity. The effective permeability of the Ellsworth Shale is very low.

Permeability. The Ellsworth Shale has very low permeability.

Oil and Gas Potential. None.

Bedford Shale

The Bedford is a gray shale that overlies the Antrim Shale in the eastern two-thirds of the Southern Peninsula and intertongues with the Ellsworth Shale in the western part of this area. It ranges in thickness up to 200 feet and is overlain conformably by the Berea Sandstone (fig. 2.44).

Characteristics as an Aquifer. None.

Characteristics as an Aquiclude. The Bedford Shale is an aquiclude. It has very low permeability and a low effective porosity.

Characteristics as an Injection Formation. None.

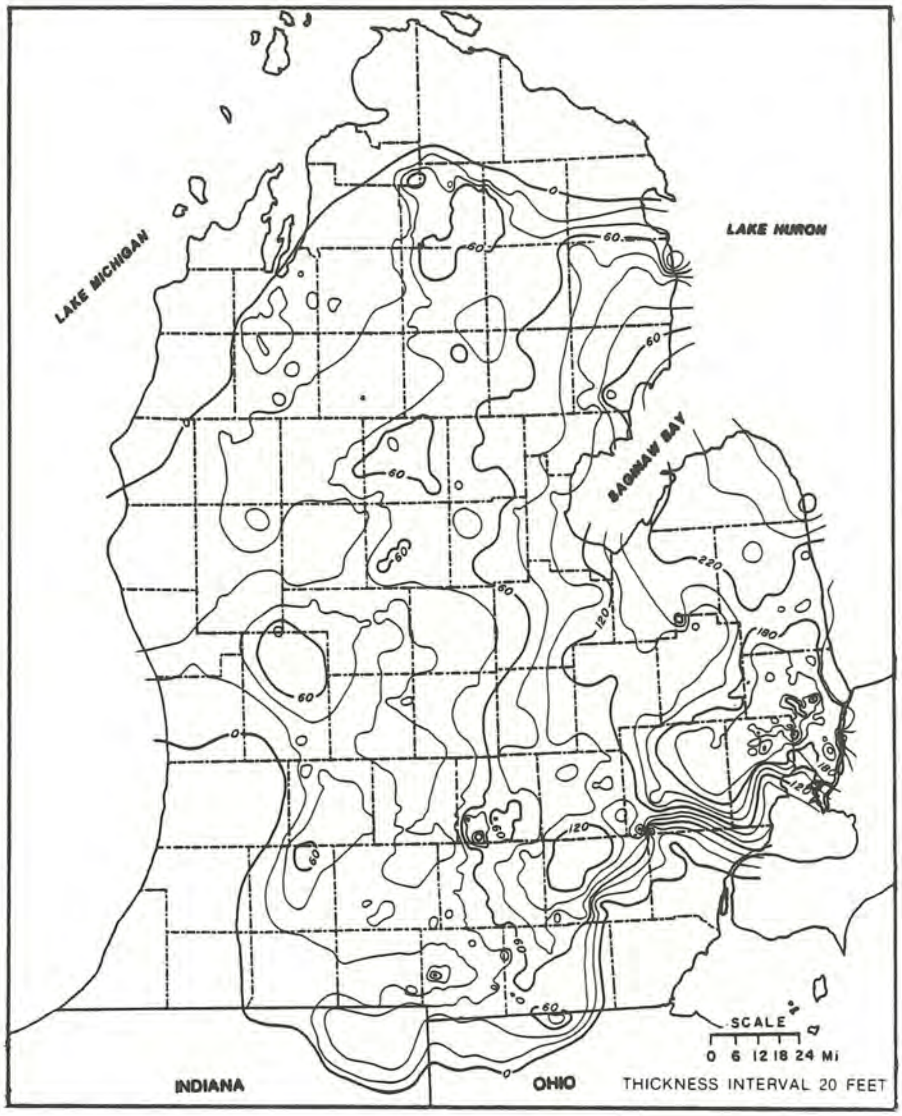

Figure 2.44. Thickness of Bedford Shale. (From Fisher, 1980.)

Porosity. The effective permeability of the Bedford Shale is very low.

Permeability. The Bedford Shale has very low permeability.

Oil and Gas Potential. None.

Berea Sandstone

The Berea Sandstone consists of a moderately fine-grained sandstone that grades upward and downward into shaly, dolomitic sandstone. The Berea is more than 100 feet thick on the east side of the Southern Peninsula and thins progressively to the west. In the central part of the basin, the Berea and Bedford are difficult to distinguish and farther west, the Berea grades into the upper Ellsworth Shale. In the central part of the Michigan Basin the Berea is as much as 1800 feet below sea level (figs. 2.45 and 2.46).

Characteristics as an Aquifer. In eastern Michigan, in and near its outcrop belt, the Berea has good aquifer characteristics.

Characteristics as a Confining Layer. The Berea is too permeable to serve as a confining layer.

Characteristics as an Injection Formation. In and near the outcrop, the Berea is an aquifer and should not be used as an injection formation. In the east-central part of the state it is capable of receiving fluids, but produces hydrocarbons and is relatively shallow.

Porosity. The middle portion of the Berea has good porosity, but the upper and lower parts of the unit are shaly and have a low effective porosity.

Permeability. The middle unit of the Berea is fairly permeable, but the upper and lower zones have a much diminished permeability because of an increased shale content.

Oil and Gas Potential. Several fields in eastern Michigan produce oil and gas from the Berea; however it is not considered to be a prime exploration target.

Sunbury Shale

The Sunbury is a dark gray to black or brown, bituminous, pyritic shale, similar in many respects to the Antrim Shale. It ranges in thickness from 0 feet in parts of the western Southern Peninsula to as much as 140 feet on the eastern side of the state (figs. 2.47 and 2.48). The formation thins from east to west and is the facies equivalent of the upper Ellsworth. The Sunbury reaches a maximum depth of about 1800 below sea level in the center of the Michigan Basin.

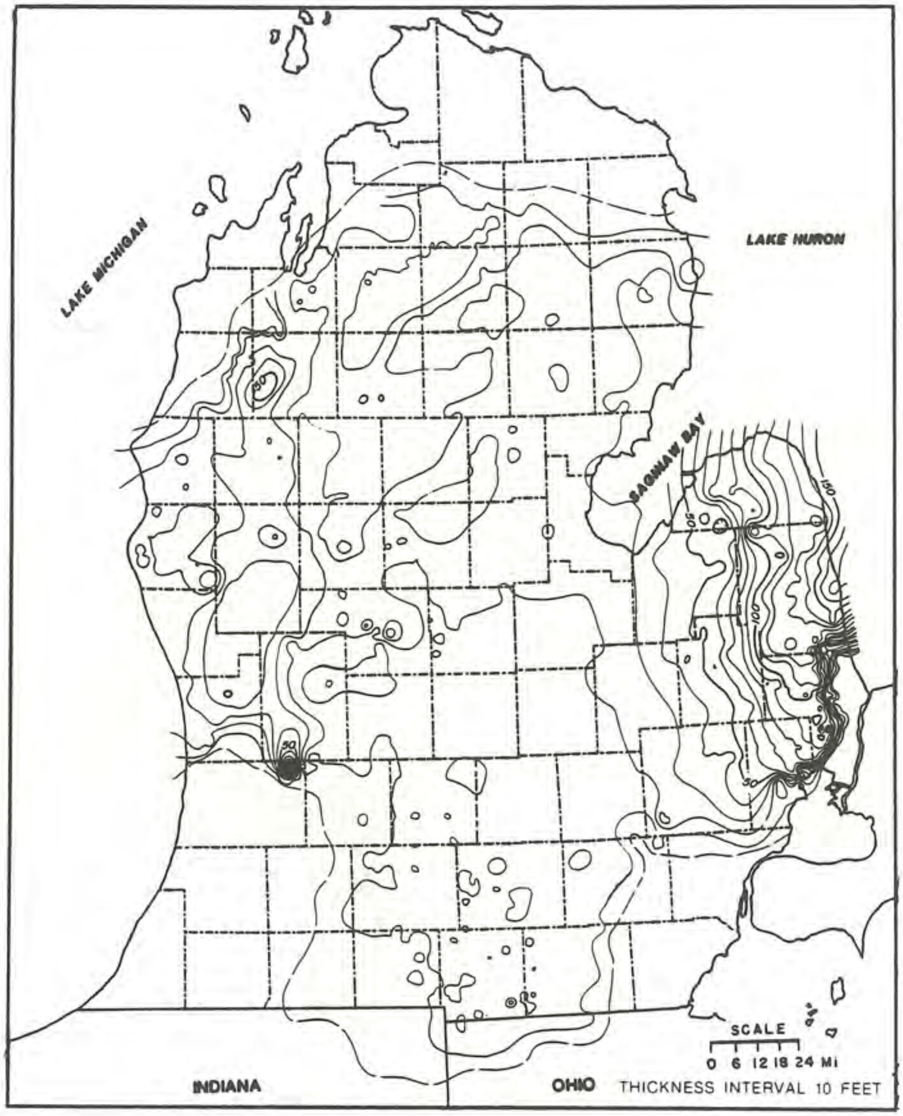

Figure 2.47. Thickness of Sunbury Shale. (From Fisher, 1980.)

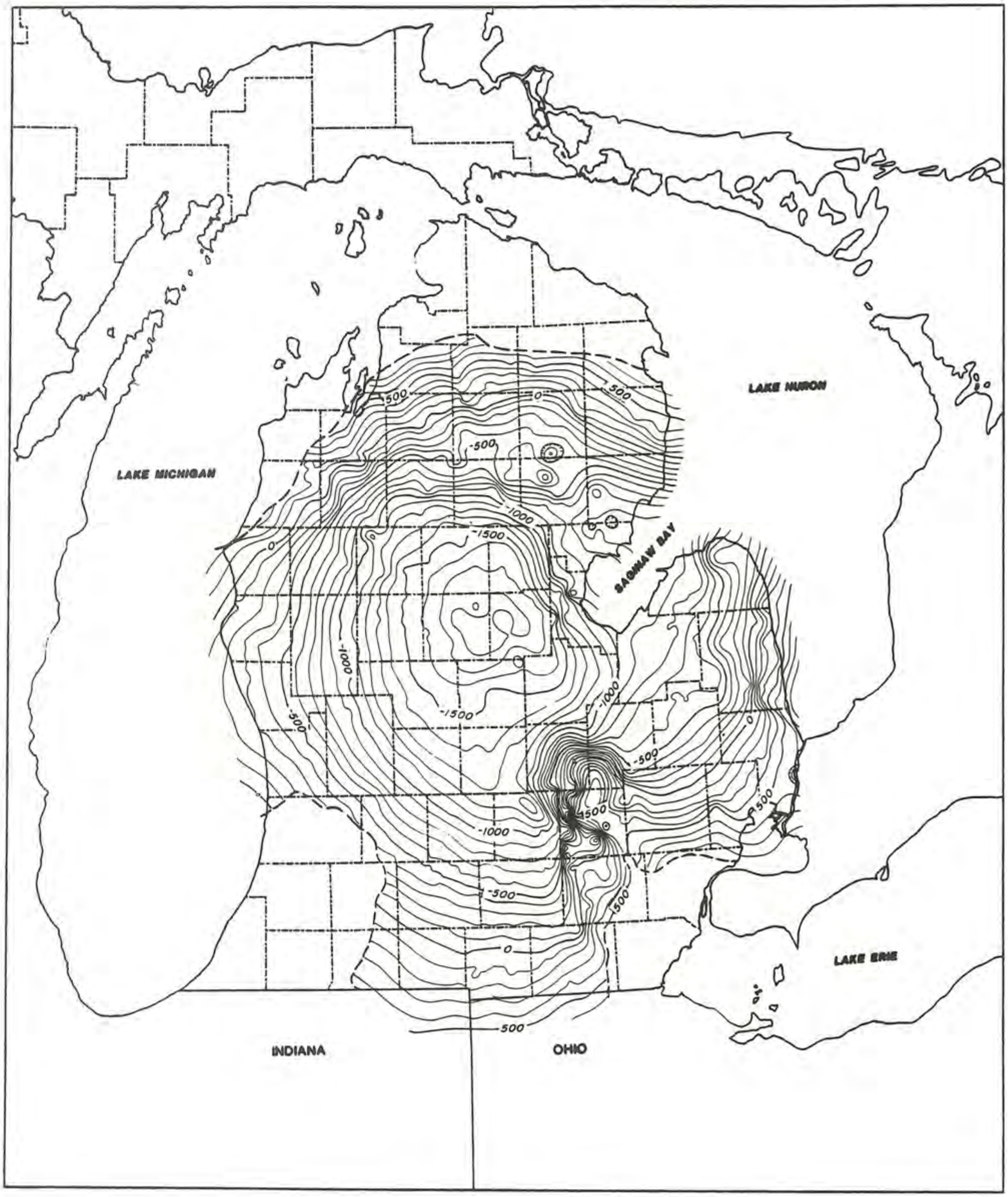

Figure 2.48. Structure map on Sunbury Shale. (From Fisher, 1980.)

Characteristics as an Aquifer. The Sunbury Shale is not an aquifer.

Characteristics as a Confining Layer. The Sunbury Shale and its western correlative, the Ellsworth, are confining layers.

Characteristics as an Injection Formation. It is far too impermeable to be used as an injection formation.

Porosity. The effective porosity of the Sunbury is very low.

Permeability. Very low.

Oil and Gas Potential. The Sunbury has limited potential as an oil shale.

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Coldwater Shale

The Coldwater Shale is a gray, micaceous shale that ranges in thickness from about 500 feet in southwestern Michigan to more than 1250 feet along the eastern margin of the Southern Peninsula (figs. 2.49 and 2.50, pls. 5,6 and 12). The Coldwater is apparently a deltaic sequence with sands developed in the thick, eastern portion and limestones in the thin, western part of the formation (Lilienthal, p. 7, 1978).

Characteristics as an Aquifer. The sandstones in the Coldwater have aquifer characteristics in the area around Saginaw Bay and the "Thumb" area. The Coldwater shales are not aquifers, nor is the thin Coldwater limestone in the western Southern Peninsula.

Characteristics as a Confining Layer. The Coldwater would be an excellent confining layer except in the eastern part of the state where sandstones are present.

Characteristics as an Injection Formation. The Coldwater shale and limestone are far too impermeable to serve as injection formations. Because sandstones in the Coldwater are close to the outcrop and are used as aquifers, they should not be considered for use as injection formations.

Porosity. The sandstones in the Coldwater are coarse, with good intergranular porosity. The shales and limestones lack effective porosity.

Permeability. The Coldwater shales and limestones are relatively impermeable. The sandstones are permeable except where they contain abundant clay.

Oil and Gas Potential. The Coldwater Formation has a very low potential for the production of hydrocarbons.

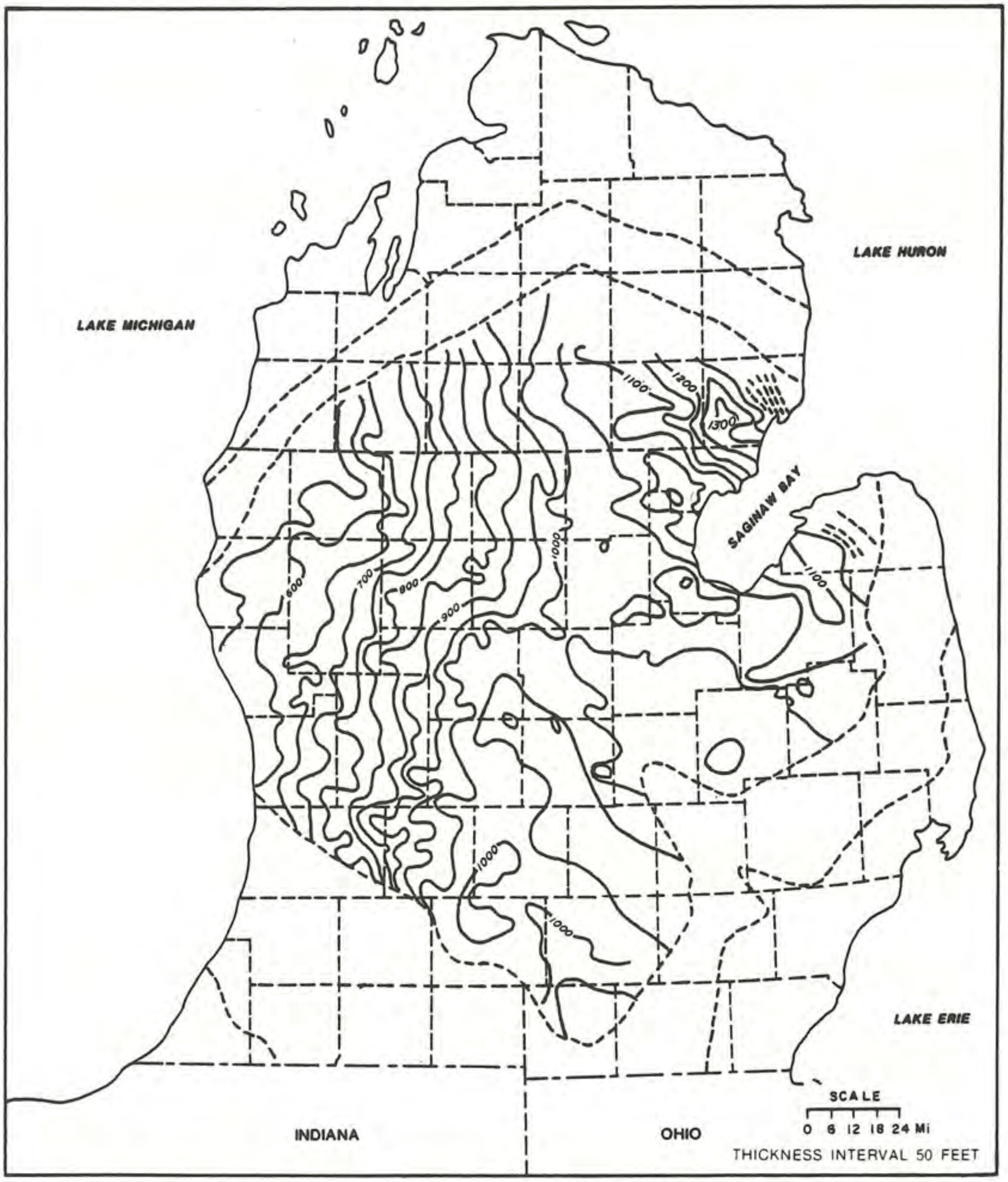

Figure 2.49. Thickness of Coldwater Formation. (From Chung, 1973.)

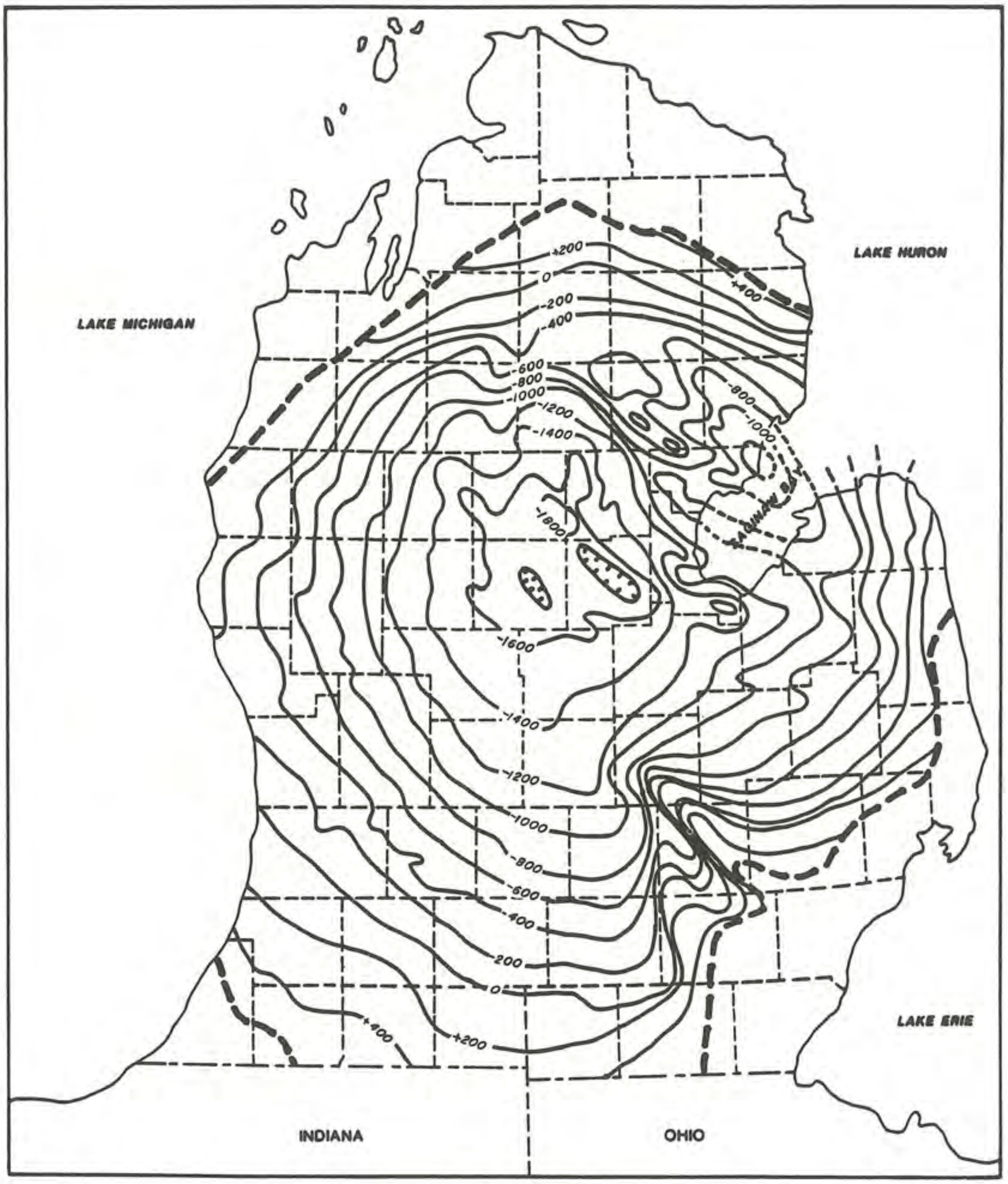

Figure 2.50. Structure contour map on the base of Coldwater Formation. (From Chung, 1973.)