DEPARTMENT OF INTERIOR

U.S. GEOLOGICAL SURVEY

A summary of petroleum plays and characteristics of the Michigan basin

by

Ronald R. Charpentier[1]

Open-File Report 87-450R

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1] Denver, Colorado 80225

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Michigan basin is a relatively simple, circular basin, up to 17,000 feet deep, centered in the Lower Peninsula of Michigan. The stratigraphic section consists primarily of clastic and carbonate rocks of Cambrian to Pennsylvanian age. Petroleum production from the Michigan basin dates back to 1885, and, as of 1984, cumulative production totaled over 958 million barrels of oil and almost 2.3 trillion cubic feet of natural gas. The discovered fields and remaining prospects can be divided into eight plays for purposes of description and assessment: (1) the Mississippian-Pennsylvanian gas play, (2) the Antrim Shale play, (3) the Devonian anticlinal play, (4) the Niagaran reef play, (5) the Trenton-Black River play, (6) the Prairie du Chien play, (7) the Cambrian play, and (8) the Precambrian rift play.

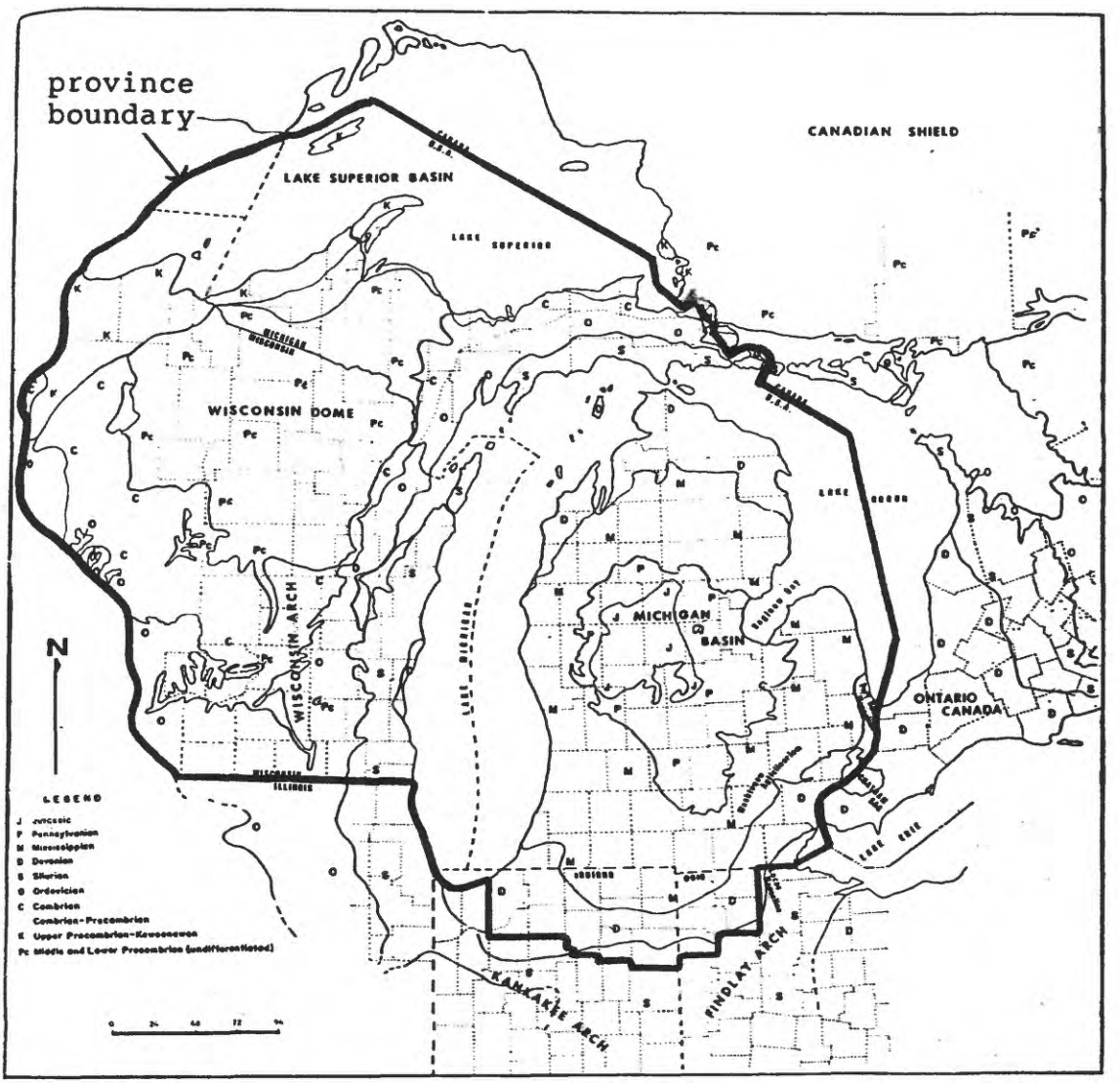
INTRODUCTION

In support of the recent U.S. Geological Survey assessment of the oil and gas potential of the onshore United States, data on each of the petroleum provinces were accumulated and synthesized. Both presently-producing and hypothetical petroleum plays were identified, characterized, and assessed. This report briefly summarizes the petroleum plays and characteristics of one of the provinces, the Michigan basin.

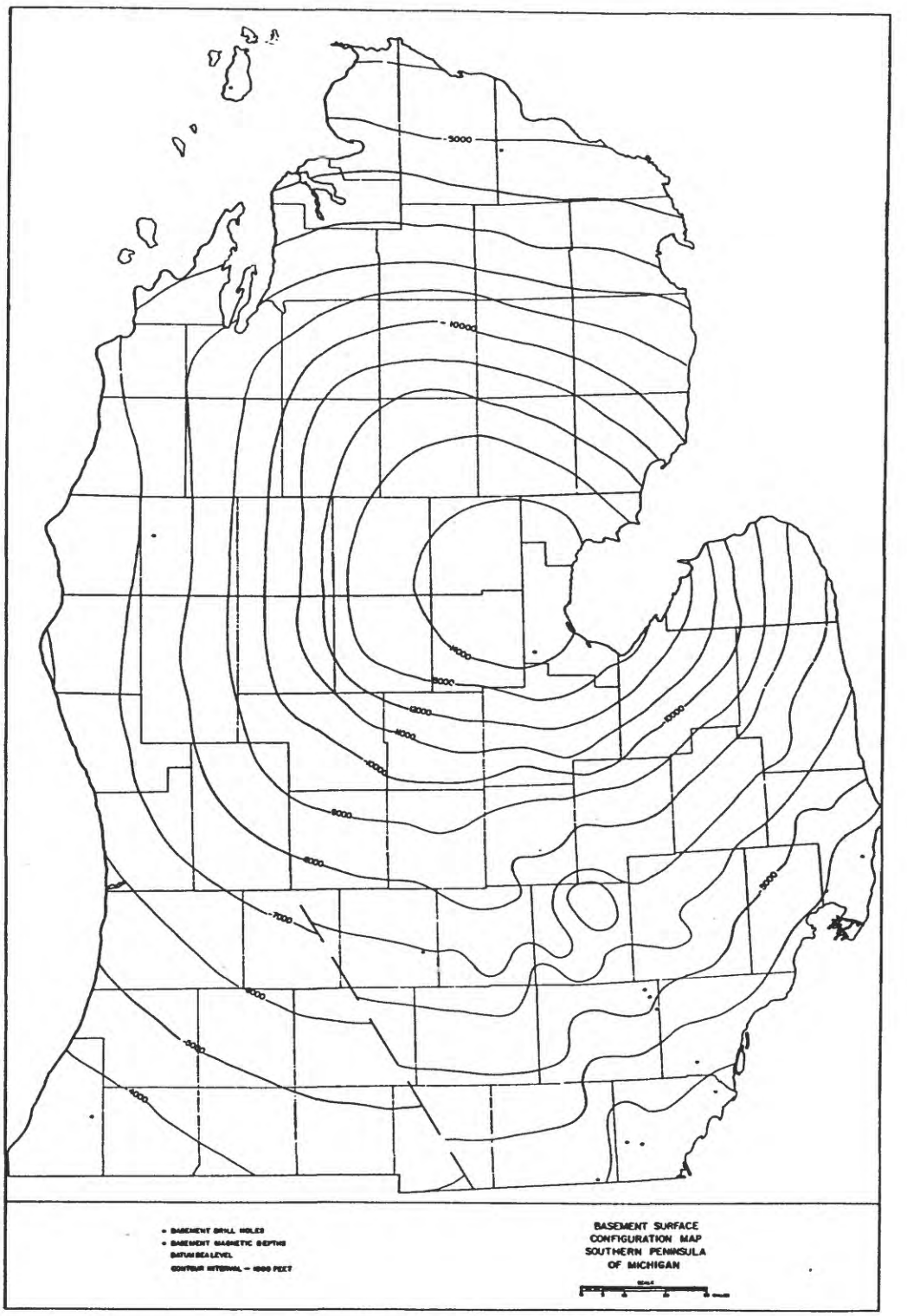
REGIONAL GEOLOGY

For the purpose of oil and gas resource assessment within the U.S. Geological Survey, Varnes and others (1981) divided the United States into provinces which correspond, for the most part, with geologic basins. The Michigan basin province is defined as including the entire states of Michigan and Wisconsin, twelve counties in northeast Indiana, five counties in northwest Ohio, and the U.S. portions of the adjoining Great Lakes (figure 1). The total area of the province is 164,000 square miles; of this, only 122,000 square miles are underlain by sedimentary rock (Varnes and Dolton, 1982). The rest, mostly in northern Wisconsin, the Upper Peninsula of Michigan, and under Lake Superior, are parts of the exposed area of the Canadian Shield.

The Michigan basin is a classic interior simple basin (Klemme, 1980) whose circular shape is well illustrated by the contours on top of Precambrian basement (figure 2). The edges of the basin are defined by a series of highs. Counterclockwise from the west these are the Wisconsin Dome, the Wisconsin Arch, the Kankakee Arch of Indiana, the Findlay Arch of Ohio, the Algonquin Arch in Ontario, and the Canadian Shield (figure 1).



1. Index map of Michigan basin province (modified from Ells, 1971, reprinted by permission of American Association of Petroleum Geologists).



2. Structure contour map on top of Precambrian basement, Lower Peninsula of Michigan (from Hinze and Merritt, 1969).

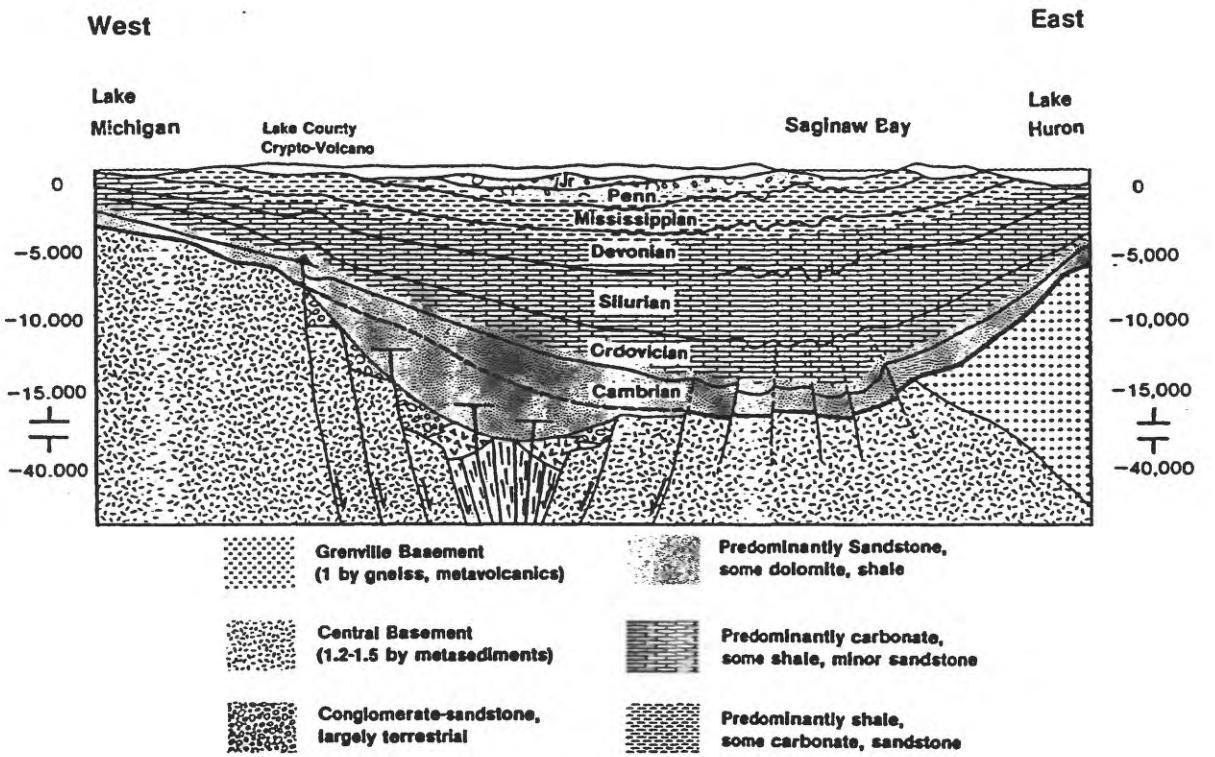
The province includes about 109,000 cubic miles of sedimentary rock, most of which is in Michigan where the sedimentary section reaches a thickness of about 17,000 feet (figure 3). Wisconsin has only a relatively thin sedimentary cover, the maximum thickness being only slightly more than 2000 feet near Milwaukee.

Besides the basin and arches, a secondary structural trend exists consisting of northwest-southeast trending anticlines within the central basin (figure 4). These anticlines persist upwards into Mississippian rocks and are probably of Late Mississippian age but there is some evidence for persistence and rejuvenation of older structures. Some other anticlinal features in the Michigan basin were formed over buried reefs. Others may be related to salt flowage.

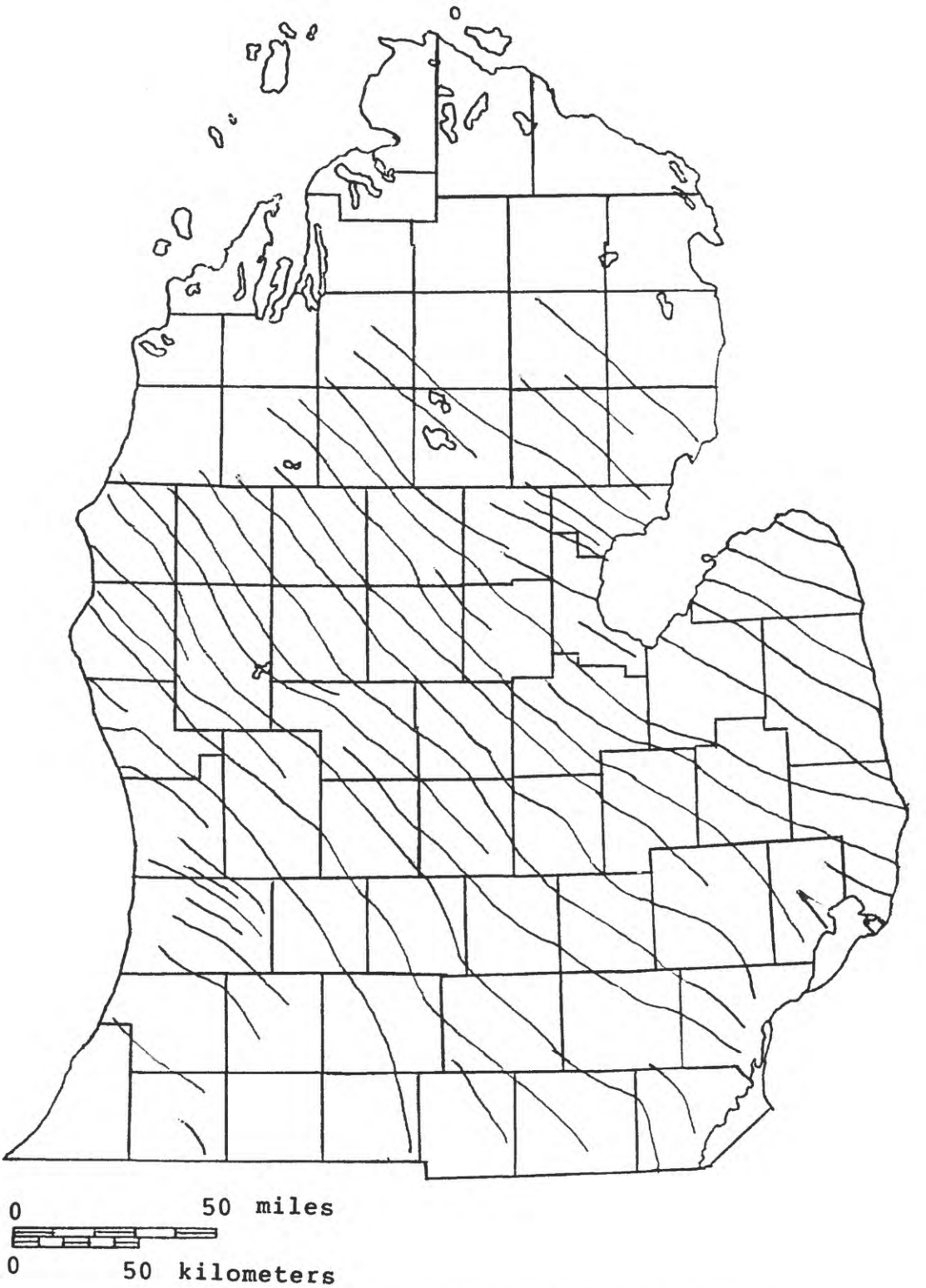
Lying above the Precambrian crystalline basement is a series of Keweenawan (late Precambrian) clastics associated with central rifts and flanking basins (figure 5). The Paleozoic rocks begin with transgressive marine clastics, mainly sandstones, of the Cambrian and Lower Ordovician (figure 6). These are overlain by marine carbonates representing much of the rest of the Ordovician through Devonian. Significant evaporite deposits, up to about 2000 feet thick, are present in the Middle to Upper Silurian. Lesser evaporite deposits, up to about 400 feet thick, are found in the Middle Devonian. The sequence became dominated by marine clastics again at the end of the Devonian and through the Mississippian but during the Pennsylvanian became terrestrial. Above the Pennsylvanian rocks is a small amount of Jurassic terrestrial rock. The entire area is blanketed with Pleistocene glacial drift which reaches a thickness of up to about 1000 feet.

SOURCE ROCKS

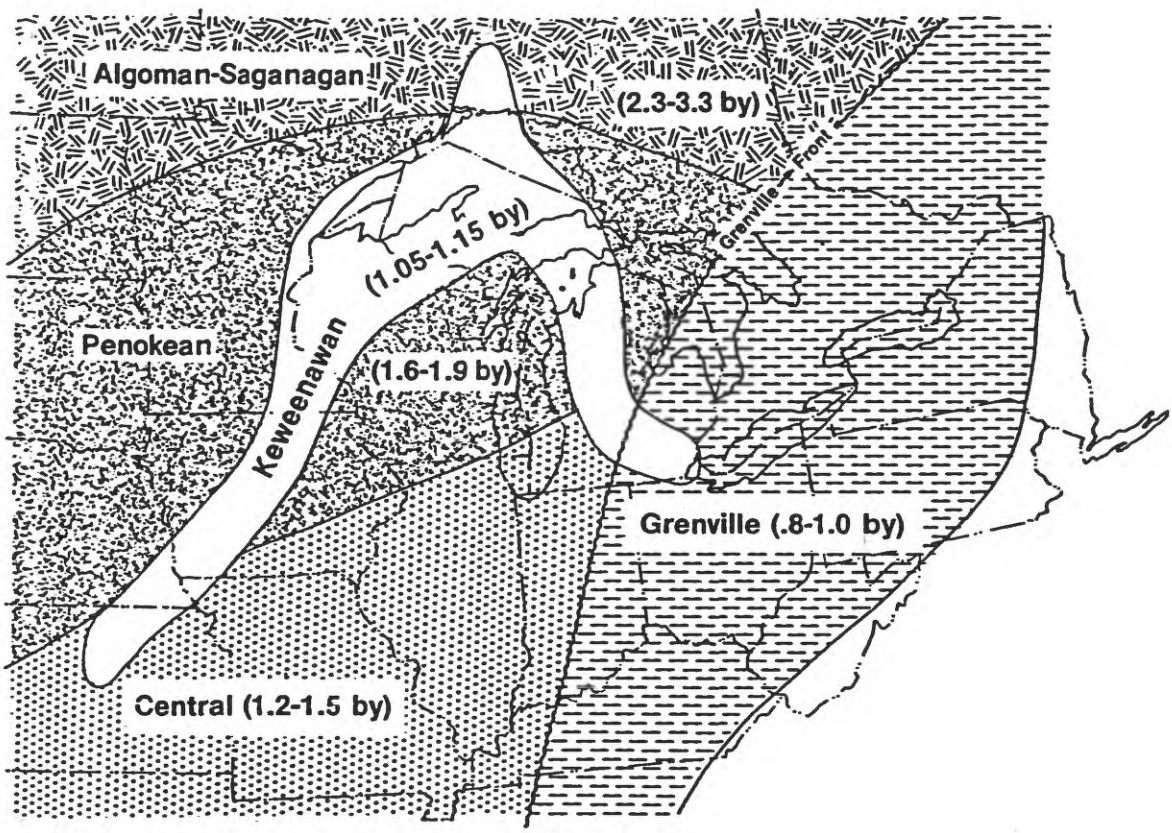
Geochemical studies of crude oils from the Michigan basin (Vogler and others, 1981; Illich and Grizzle, 1983; Pruitt, 1983; Meyers and Moore, 1983; Gardner and Bray, 1984; and Rullkotter and others, 1986) have suggested that the oils belong to three main families. Oils produced from the Ordovician Trenton Group have the distinctive chemical composition noted by Reed and others (1986) in Ordovician oils from various localities worldwide. In the Michigan basin, these oils are postulated to have an Ordovician source, possibly the Utica Shale. This hypothesis is strengthened by Powell and others' (1984) geochemical studies in Ontario, where they showed the Collingwood Member of the Lindsay Formation (the approximate equivalent of the Utica) to be the probable source of the Ordovician oils in that area. Devonian Dundee Limestone oils are chemically similar to the Trenton oils (Rullkotter and others, 1986), but their origin is controversial in that an Ordovician source of these oils would require migration through



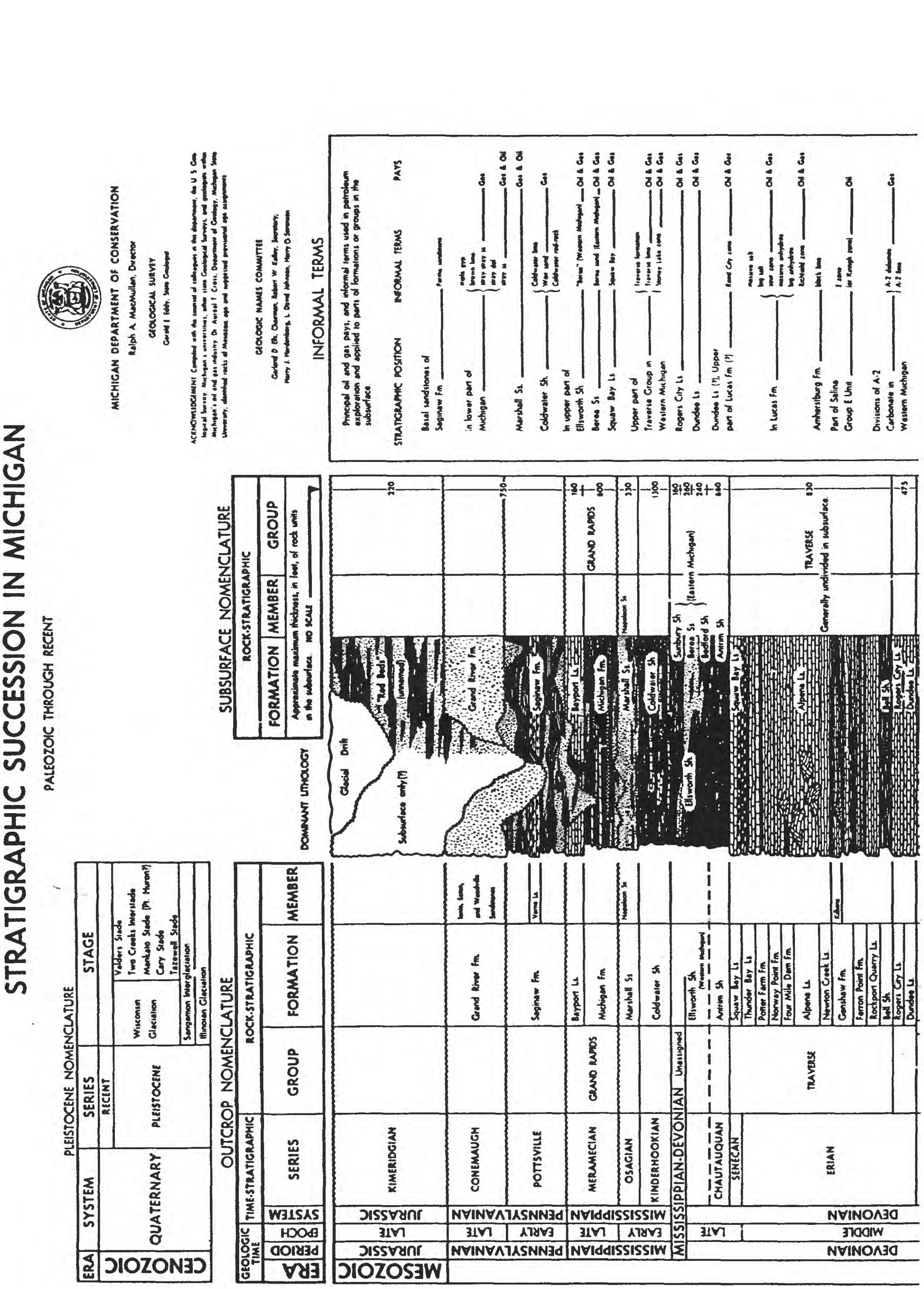
3. Generalized cross section through Michigan basin from offshore Manistee to Huron counties (from Petroleum Information Corporation, 1984). Total length of section is approximately 220 miles. See figure 10 for county locations.



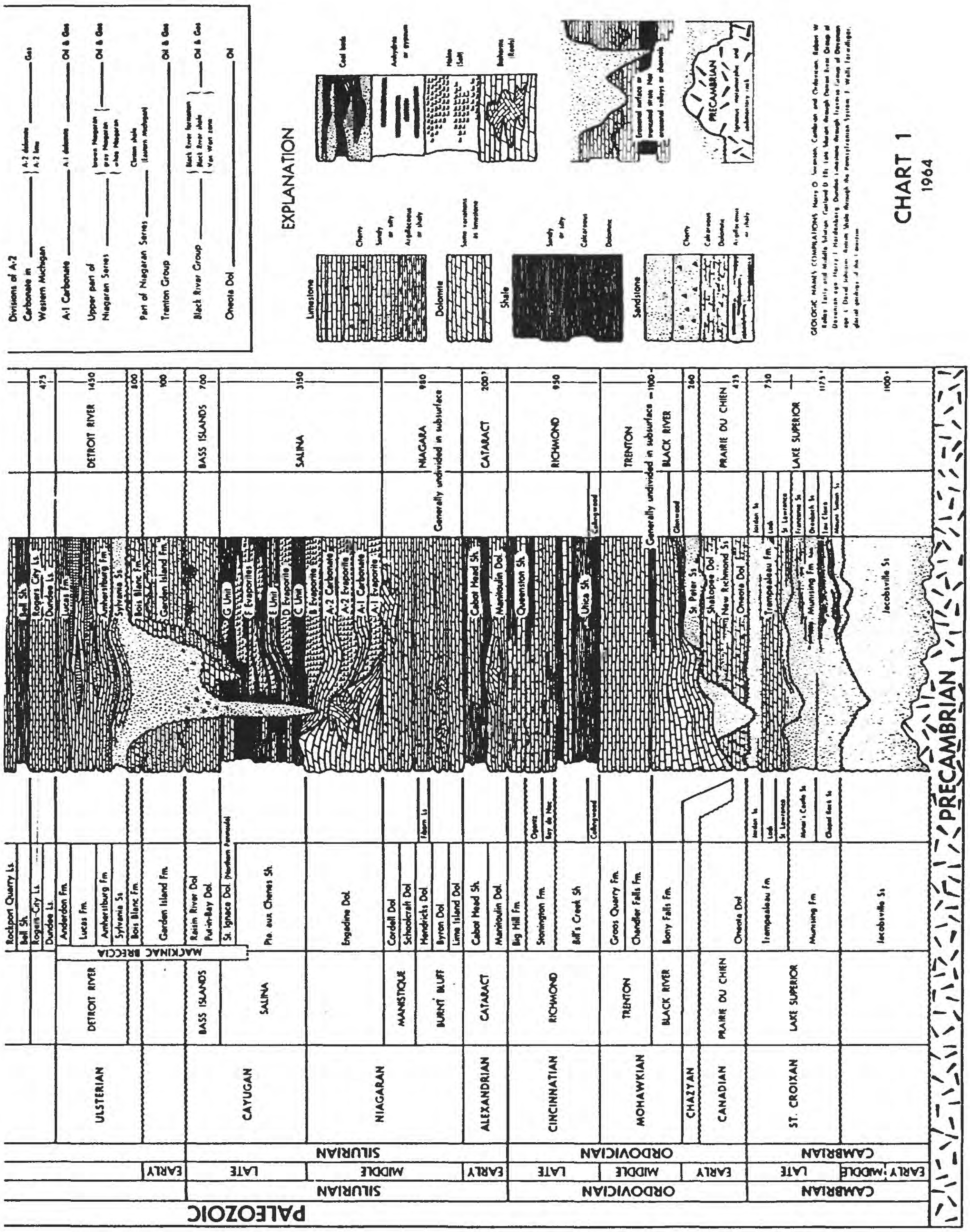
4. Map showing major anticlinal trends in the Lower Peninsula of Michigan (modified from Michigan Department of Natural Resources, Geological Survey Division, 1937).



5. Map showing large-scale basement provinces of central North America (from Petroleum Information Corporation, 1984). Keweenawan province consists of rifts and flanking basins.



6. Phanerozoic stratigraphic succession in Michigan (Michigan Department of Natural Resources, Geological Survey Division, 1964).


PALEOZOIC
CAMBRIAN
ORDOVICIAN
SILURIAN
ULSTERIAN
CAYUGAN
NIAGARAN
ALEXANDRIAN
CINCINNATIAN
MOHAWKIAN
CHAZYAN
CANADIAN
ST. CROIXAN
MACKINAC BRECCIA
DETROIT RIVER
BASS ISLANDS
SALINA
NIAGARA
CATARACT
RICHMOND
TRENTON
BLACK RIVER
PRAIRIE DU CHIEN
LAKE SUPERIOR
PRECAMBRIAN
EXPLANATION
Limestone
Dolomite
Shale
Sandstone
CHART 1
1964

6. (continued)

the thick Silurian evaporite section.

The second family of Michigan basin oils is found in the Silurian Niagara Group and Salina Group reservoirs. A strong phytane-over-pristane predominance and the lack of diasteranes indicates a carbonate source (Rullkotter and others, 1986), which was identified by Gardner and Bray (1984) as the Salina A-1 carbonates with some contribution from the "Brown Niagaran."

The third family is represented by oils of the Devonian Traverse Group reservoirs. These oils are probably from an as-yet unidentified Devonian source rock.

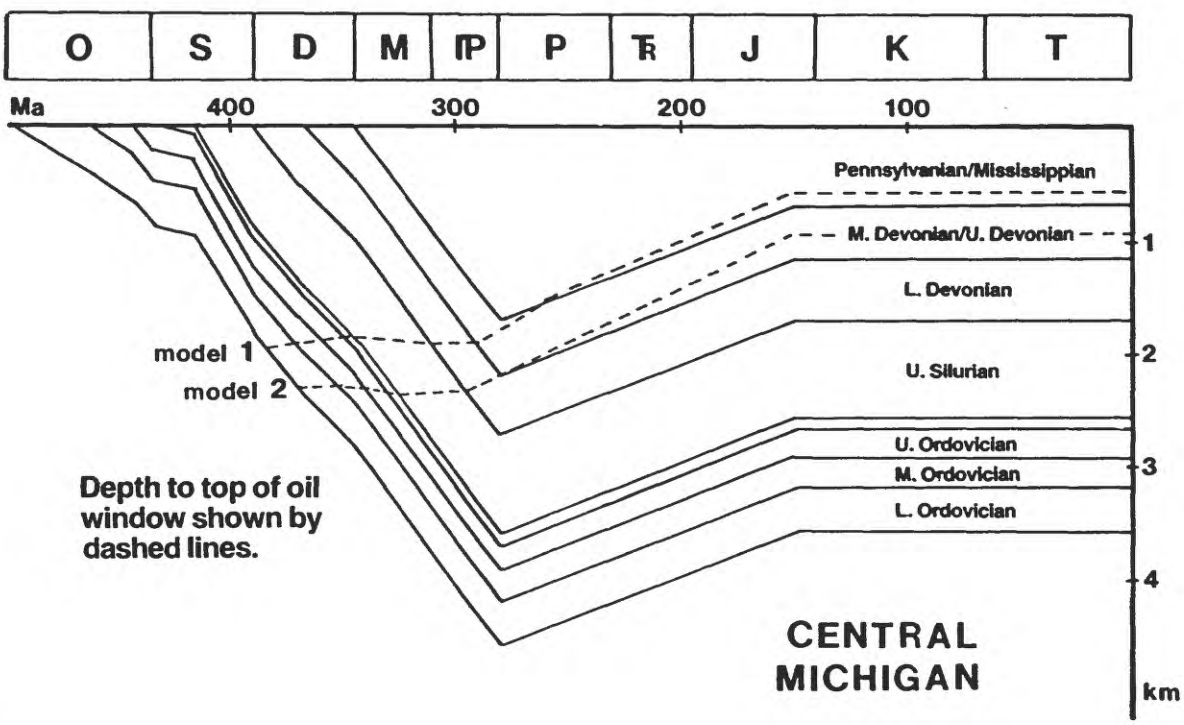
THERMAL MATURITY

Greatly conflicting thermal and burial history models of the Michigan basin have been reported in the literature. Nunn and others (1984), for example, computed a mechanical model of the basin as a flexure of the lithosphere caused by thermal contraction. By this model only Ordovician and older source rocks in the center of the basin would be mature for oil. This conflicts with the hypotheses of Silurian and Devonian source rocks suggested by geochemical analyses of the oils.

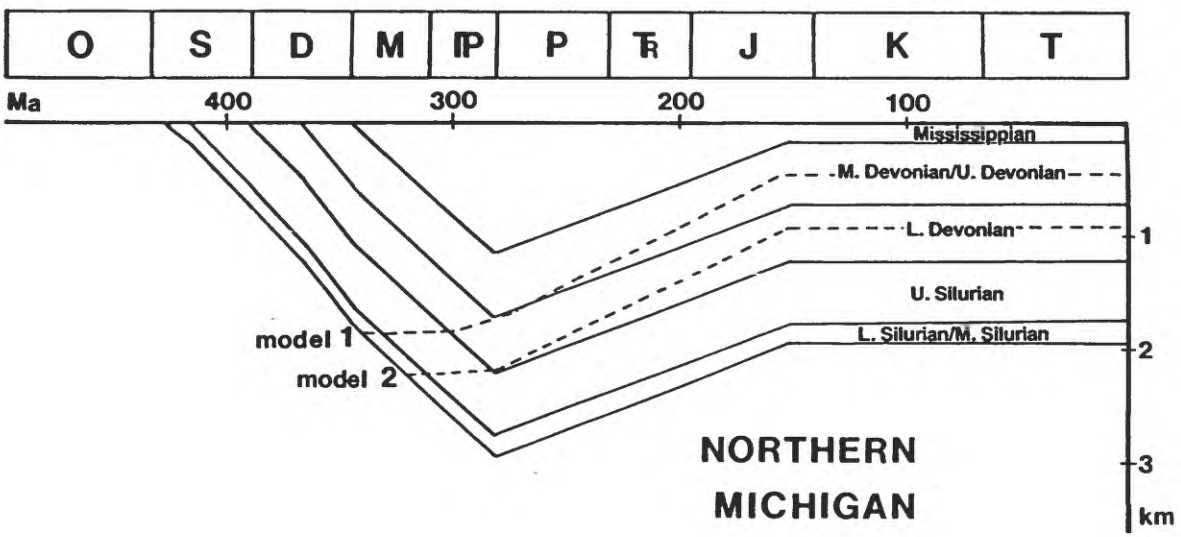
Cercone (1984) modeled the thermal and burial history of the basin based on Thermal Alteration Index (TAI) data and the Lopatin method. Her calculations (figures 7 to 9) show thermally mature rocks as young as Mississippian in the center of the basin and thus do not conflict with the results of organic geochemical studies (table 1). By her model, oil generation from the Utica Shale could have begun as early as during the Devonian. Outside of this speculation, little is known about actual timing or pathways of migration. Cercone's study also suggests not only that up to 1000 meters of sediment has been eroded from the surface of the basin but also that geothermal gradients were considerably higher during the Paleozoic.

PETROLEUM PRODUCTION

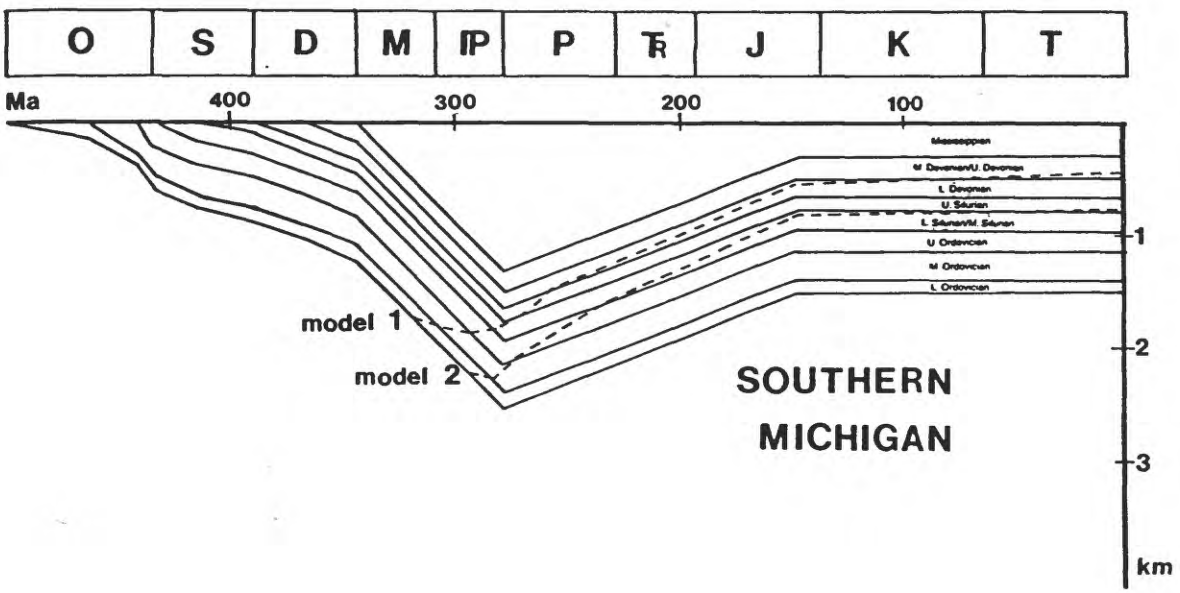
Except for a few small fields in northern Indiana and Ohio, all petroleum discoveries have been in the Lower Peninsula of Michigan (figure 10). Hydrocarbon accumulations have been discovered in rocks ranging in age from Early Ordovician through Pennsylvanian, as well as in Pleistocene glacial drift. Cumulative production, as of 1984, was over 958 million barrels of oil and almost 2.3 trillion cubic feet of natural gas (table 2). Cambrian rocks are prospective, but little explored, and even some late Precambrian sedimentary rocks in the rift zones have been considered prospective. Structural, structural-stratigraphic, and stratigraphic traps all exist in the basin.



7. Burial history of central Michigan basin (from Cercone, 1984, reprinted by permission of American Association of Petroleum Geologists). Model 1 and model 2 have different assumed geothermal gradients.



8. Burial history of northern Michigan basin (from Cercone, 1984, reprinted by permission of American Association of Petroleum Geologists). Model 1 and model 2 have different assumed geothermal gradients.



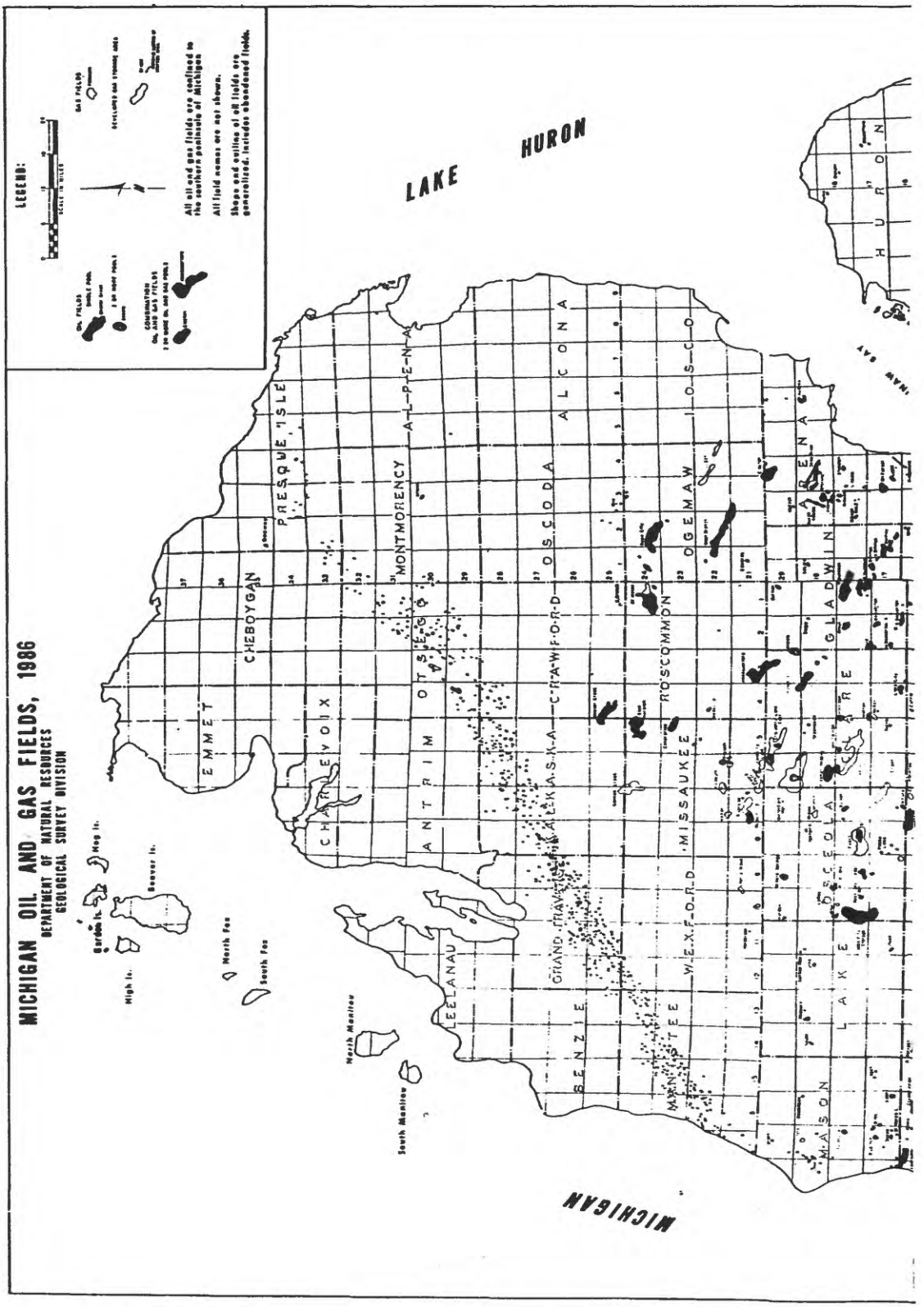
9. Burial history of southern Michigan basin (from Cercone, 1984, reprinted by permission of American Association of Petroleum Geologists). Model 1 and model 2 have different assumed geothermal gradients.

Table I

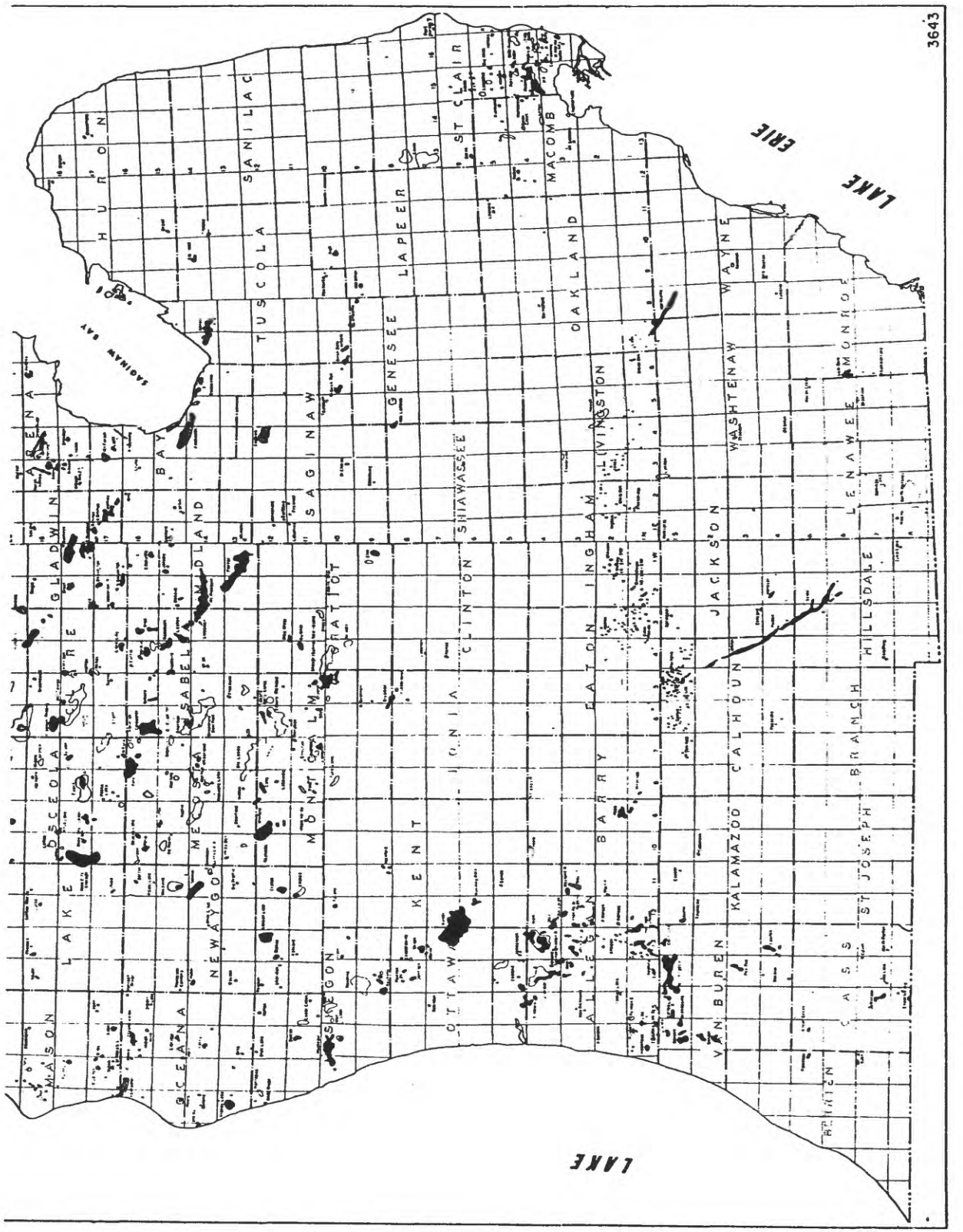
Observed organic maturities
in the Michigan basin

Formation	TAI	R_o
	Central Michigan Basin	
Saginaw	2.70	0.70
Michigan	2.75	0.77
Antrim	3.20	1.30
Bell	3.30	1.36
Salina C	3.50	1.50
Utica	3.90	3.00
	Northern Michigan Basin	
Salina G *	3.10	1.22
Salina C	3.20	1.30
Niagara *	3.40	1.42
Utica *	3.50	1.50
	Southern Michigan Basin	
Antrim	2.20	0.40
Salina C	3.60	1.75
Utica	3.70	2.00

As reported by Cercone (1984). Original data from Moyer (1982) except those with * which are from Gardner and Bray (1984). Moyer's SCI values were assumed to equal 2 x TAI.



10. Michigan oil and gas fields (Michigan Department of Natural Resources, Geological Survey Division, 1987).



10. (continued)

Table II

Cumulative production by geologic system and formation as of 1984

	cumulative oil production (barrels)	cumulative gas production (10^3 cf)
Cenozoic		
Glacial Drift	--	8,180
Mississippian		
Stray-Marshall	89,883	213,861,570
Berea	3,512,889	12,750,992
Devonian		
Antrim	--	4,784,336
Traverse	109,108,343	11,647,370
Dundee-Reed City	348,969,107	41,577,604
Detroit River	86,488,742	90,853,384
Silurian		
Salina-Niagaran	283,695,233	1,662,804,472
Ordovician		
Trenton-Black River	126,977,203	233,452,983
Prairie du Chien	38,597	5,341,953
Total	958,879,997	2,277,082,844

Data from Michigan Geological Survey, 1987, Statistical Summary SS-OG 84.

PLAY DESCRIPTIONS

A combination of stratigraphy and trap type allows a division of the Michigan basin fields and prospects into eight main plays. Most of the plays are distinguished by the age of their producing interval. The Devonian anticlinal play is structurally defined, however, and includes Silurian and Mississippian pools in the same anticlines as the main Devonian pools. Thus Silurian pools in anticlines which mainly produce from the Devonian are in the Devonian anticlinal play rather than in the Silurian reef play.

Mississippian-Pennsylvanian gas play

The Mississippian-Pennsylvanian gas play has produced from many small, shallow sandstone reservoirs in the center of the basin (figure 11). Most of the production has been from the "Stray" sandstone in the Mississippian Michigan Formation and from the Berea Sandstone near the base of the Mississippian. Other minor gas-producing intervals in the Mississippian and Pennsylvanian are included in the play. The oil production from the Mississippian has been included in the Devonian anticlinal play.

The reservoirs are mostly blanket sandstones within a primarily clastic sequence. Many of these pools are shallow structural accumulations on the same anticlines which produce primarily from the Devonian. Seals are the interbedded shales and tight sandstones.

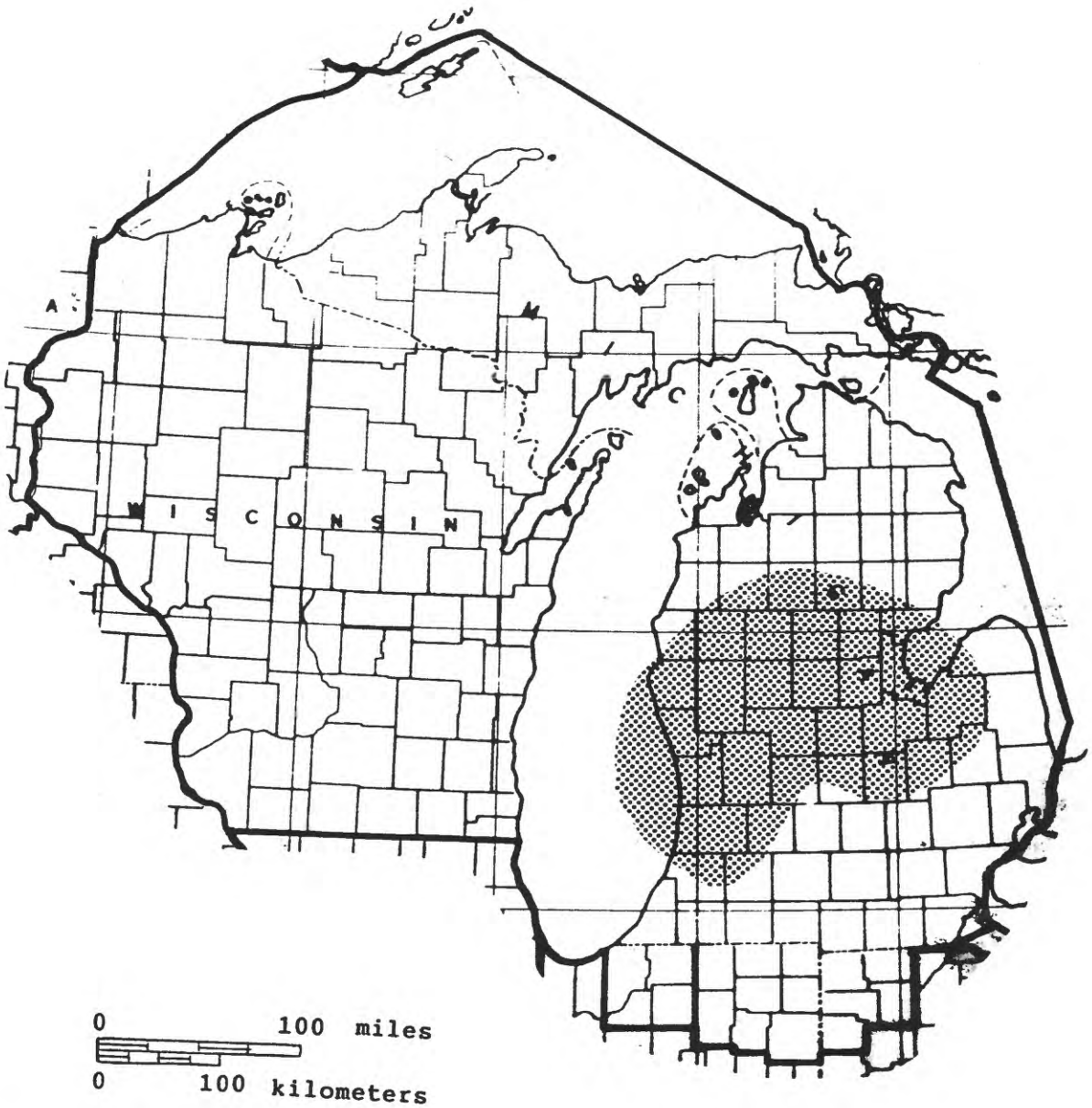
Source of the gas is unclear, but the Late Devonian Antrim Shale is a likely source of much of it. Thermogenic gas derived from Devonian oil is also likely.

The Mississippian-Pennsylvanian gas play has produced from almost 100 pools, mostly less than 6 billion cubic feet of natural gas in size. The pools are relatively shallow, less than 2600 feet deep. The play has been extensively explored since the first production in 1928, and little potential for significantly-sized pools is likely to be left.

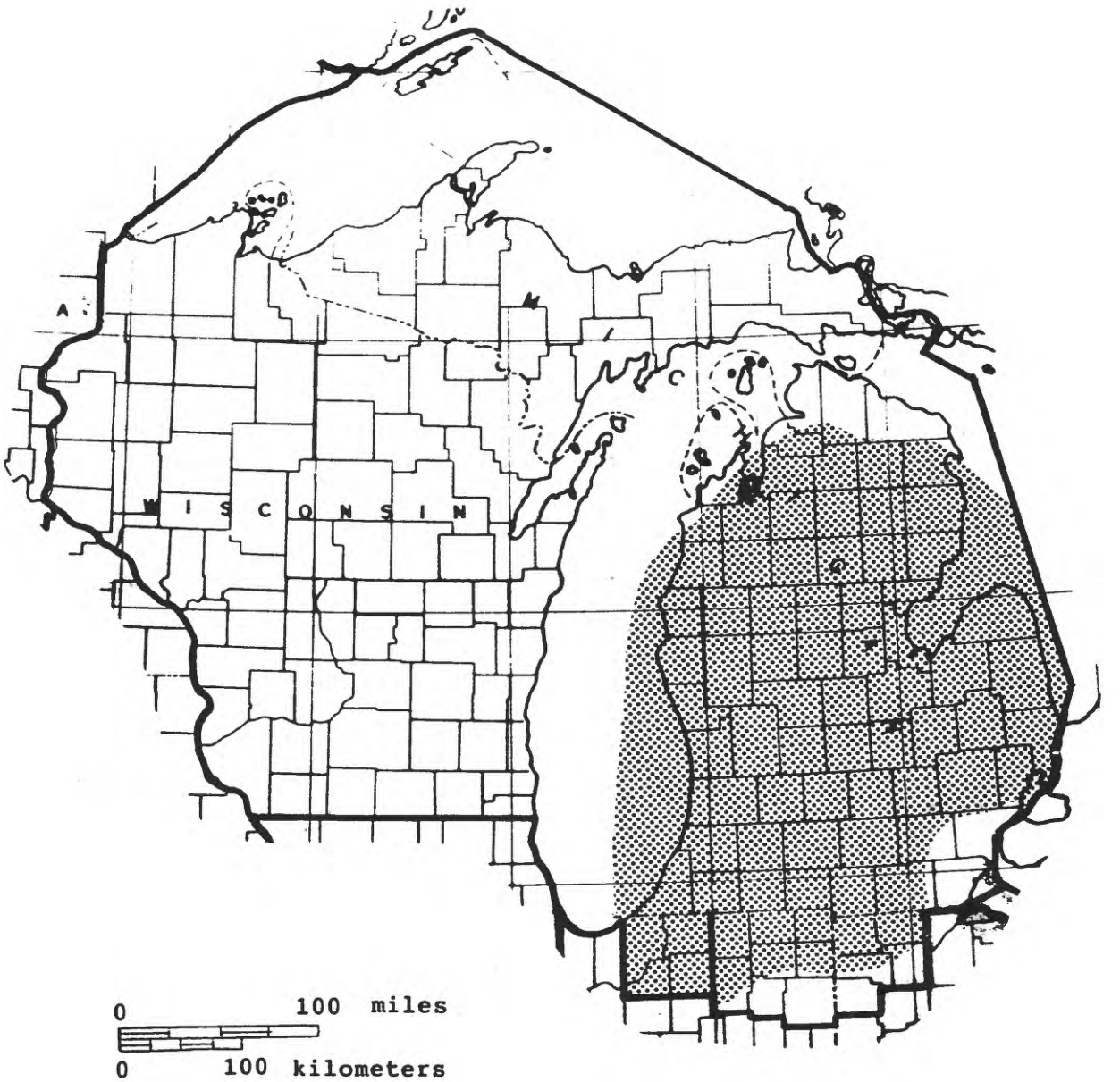
Antrim Shale play

The Antrim Shale play (figure 12) consists of fields and prospects within the fractured shales of Late Devonian and Early Mississippian age. Besides the Antrim itself, the play includes the Ellsworth Shale in western Michigan and the Bedford shale in eastern Michigan.

These shales are reservoirs for gas which presumably was generated by the shales themselves. Gas is probably distributed



11. Extent of Mississippian-Pennsylvanian gas play.



12. Extent of Antrim Shale play.

throughout the shale, but economic recovery is feasible only where the shales are fractured. The shales are shallow, up to 3300 feet deep, and as much as 800 feet thick.

Production dates back to 1947. About 15 pools, all very small, have been discovered, all from less than 2000 feet.

Devonian anticlinal play

The Devonian anticlinal play (figure 13) consists mainly of structural accumulations and prospects in the northwest-southeast-trending anticlines (figure 4). Production is mainly from the Devonian, but smaller amounts of production from other pools in the Silurian and Mississippian are also included. Not included are the gas reservoirs of the Mississippian and Prairie de Chien, even where they occupy the same anticline with Devonian production. Instead, these two are treated as separate plays. Production has mainly been from the center and southwest part of the basin.

Reservoir rocks are mostly porous limestones and, occasionally, dolomitized limestones. Traps are mostly anticlinal structural traps, but a small number of structural-stratigraphic and stratigraphic traps in Devonian reservoirs are also included. Seals are shales and anhydrites.

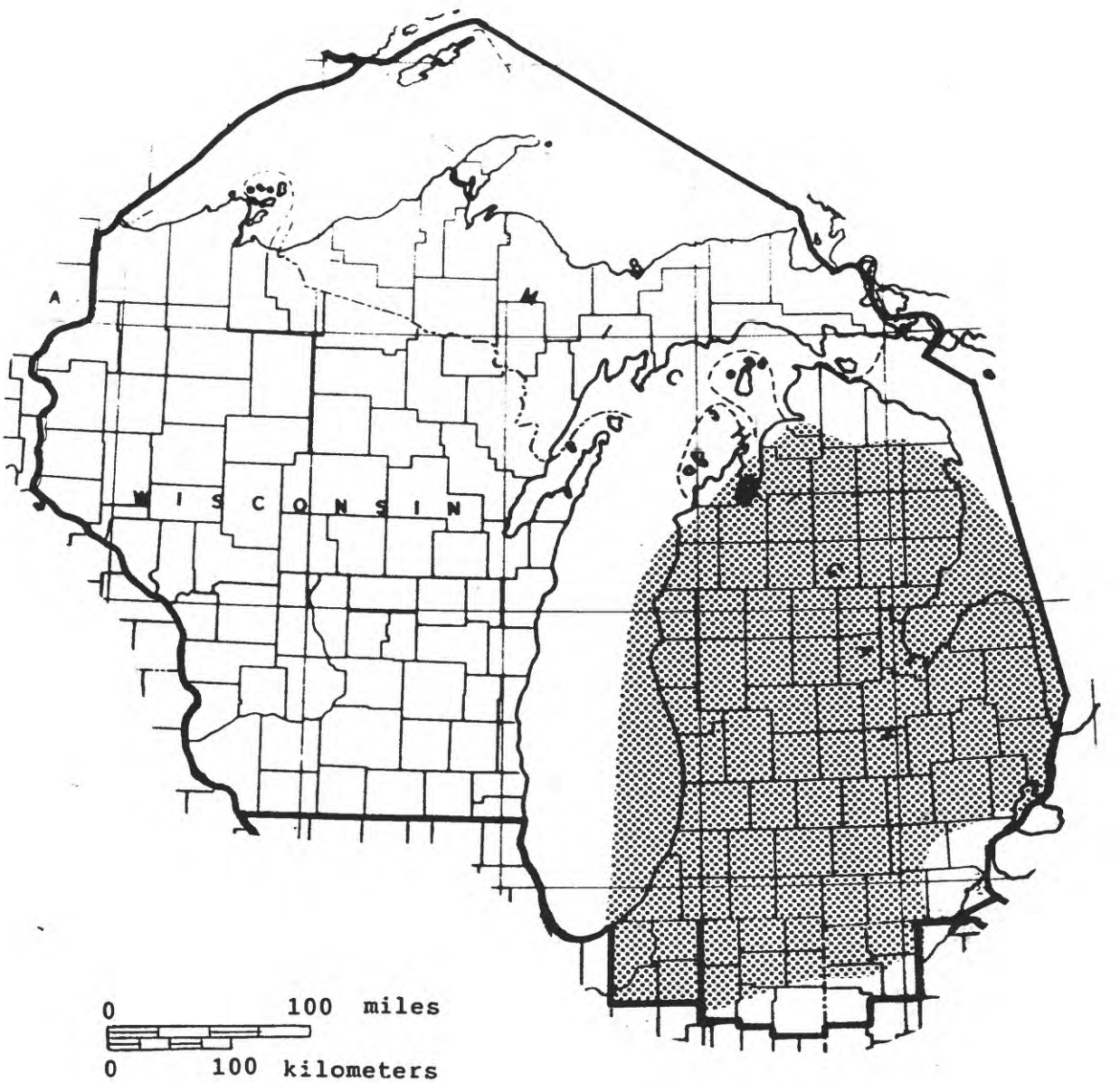
Studies of oil geochemistry in the Michigan basin suggest a relationship between oils found in the Ordovician Trenton Group and those found in the Devonian Dundee Limestone (Rullkotter and others, 1986; Vogler and others, 1981). The unusual chemistry suggests an Ordovician source (Reed and others, 1986) but this would require migration through the Silurian evaporite sequence. Oils from the younger Devonian Traverse Group seem to be primarily from a Devonian source with some contribution from Ordovician-sourced oil (Rullkotter and others, 1986).

Production from the Devonian in the Michigan basin dates from 1927. Since that time, about 350 fields have been discovered (about 75 of these greater than 1 million barrels in size) including the largest fields in the basin excepting the Albion-Pulaski-Scipio field. Depth to production of the Devonian reservoirs is generally 1500 to 5000 feet.

Drilling of major structures has been heavy and discovery rates are now low, so prospects for many further discoveries onshore are low to moderate. Offshore drilling is prohibited, but trends suggest some offshore prospects exist, especially beneath Saginaw Bay.

Niagaran reef play

The Niagaran reef play consists of oil and gas



13. Extent of Devonian anticlinal play.

accumulations traped in reefs of Niagaran (Middle Silurian) age which form a circular trend in the basin (figure 14). Discoveries have so far been only from the onshore part of Michigan's Lower Peninsula, but the trend seems to extend offshore into Lakes Michigan and Huron, where exploration is currently restricted.

Reservoir rocks within the reefs are dolomitized and have both intercrystalline and vugular porosity averaging about eight percent. Most of the producing reefs are pinnacle reefs about 50 to 200 acres in area and 300 to 600 feet high. Especially in the northern part of the trend, these pinnacles are very numerous. Sealing is partially by Salina Group evaporites encasing the reefs.

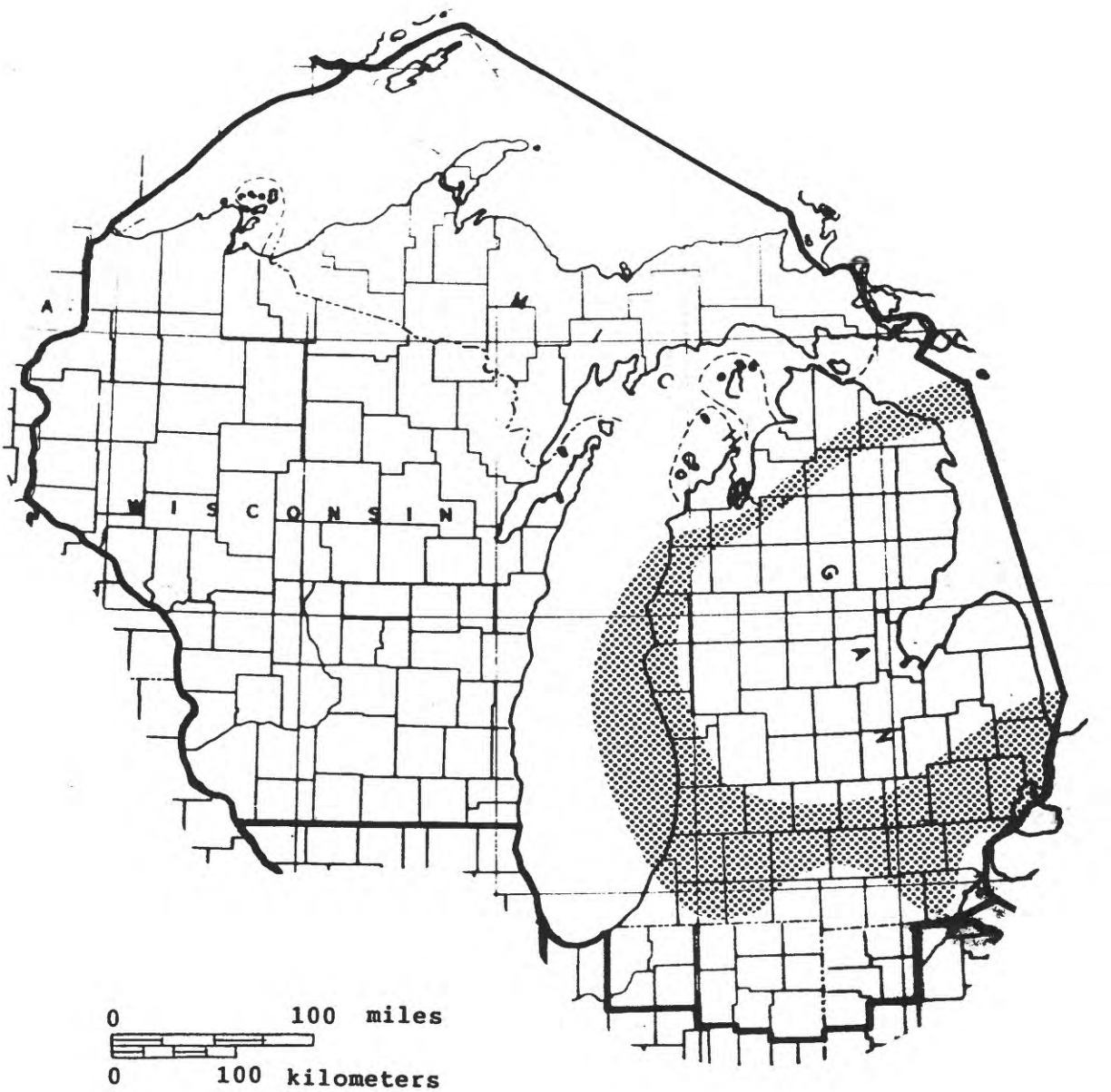
The Niagaran reef play produces an oil distinct from those in other Michigan basin accumulations. Correlation of these oils and potential source rocks using carbon-isotope data (Gardner and Bray, 1984) shows that the Salina A-1 carbonates are the principal source rocks, with lesser contributions from part of the Niagaran reef rocks themselves.

The exploration history of this play consists of two main phases. The first phase began in the 1950's and was related to an extension of drilling from the Silurian reef trend in Ontario into southeastern Michigan. The second phase began in the late 1960's and was due to improvements in seismic interpretation which allowed easier identification of reef prospects through the thick glacial drift. About 1100 reef fields had been discovered, about two-thirds of them in the northern part of the reef trend. Most of these are small, less than 1 million barrels of oil or 6 billion cubic feet of gas. Both oil and non-associated gas fields have been found. Discoveries continue in both the northern and southern parts of the trend at the rate of about 50 fields per year. Depths to production range from about 2500 to 7000 feet.

Prospects for further discoveries are very good. Onshore, large parts of the southern reef trend remain undrilled and even in the densely-drilled northern trend discovery rates remain high. Offshore drilling is prohibited in Lakes Michigan and Huron, but the reef trend undoubtedly also extends offshore.

Trenton-Black River play

The Trenton-Black River play consists of pools and prospects within the Middle Ordovician Trenton and Black River Groups. The play includes the largest field in the Michigan basin (the Albino-Pulaski-Scipio trend) as well as the oldest production (1885). Rocks of these groups extend over the entire Lower Peninsula and parts of the Upper Peninsula and Wisconsin but, to date, almost all discoveries have been from the southern



14. Extent of Niagaran reef play.

part of Michigan's Lower Peninsula as well as the Indiana and Ohio parts of the basin (figure 15).

The discovered oil and gas pools are stratigraphic traps caused by porosity and permeability variations in dolomitized limestone. The dolomitization is localized, however, by fault and fold trends which seem to be generally related to the same northwest-southeast structural trend seen in the Devonian anticlines.

Ordovician oils form a group with the Dundee oils (Vogler and others, 1981) and have compositional similarities to other Ordovician oils (Reed and others, 1986). Most likely source is the Utica Shale (Upper Ordovician) whose correlative in the Canadian part of the basin, the Collingwood Member of the Lindsay Formation, was suggested as the source of the Canadian Ordovician oils by Powell and others (1984).

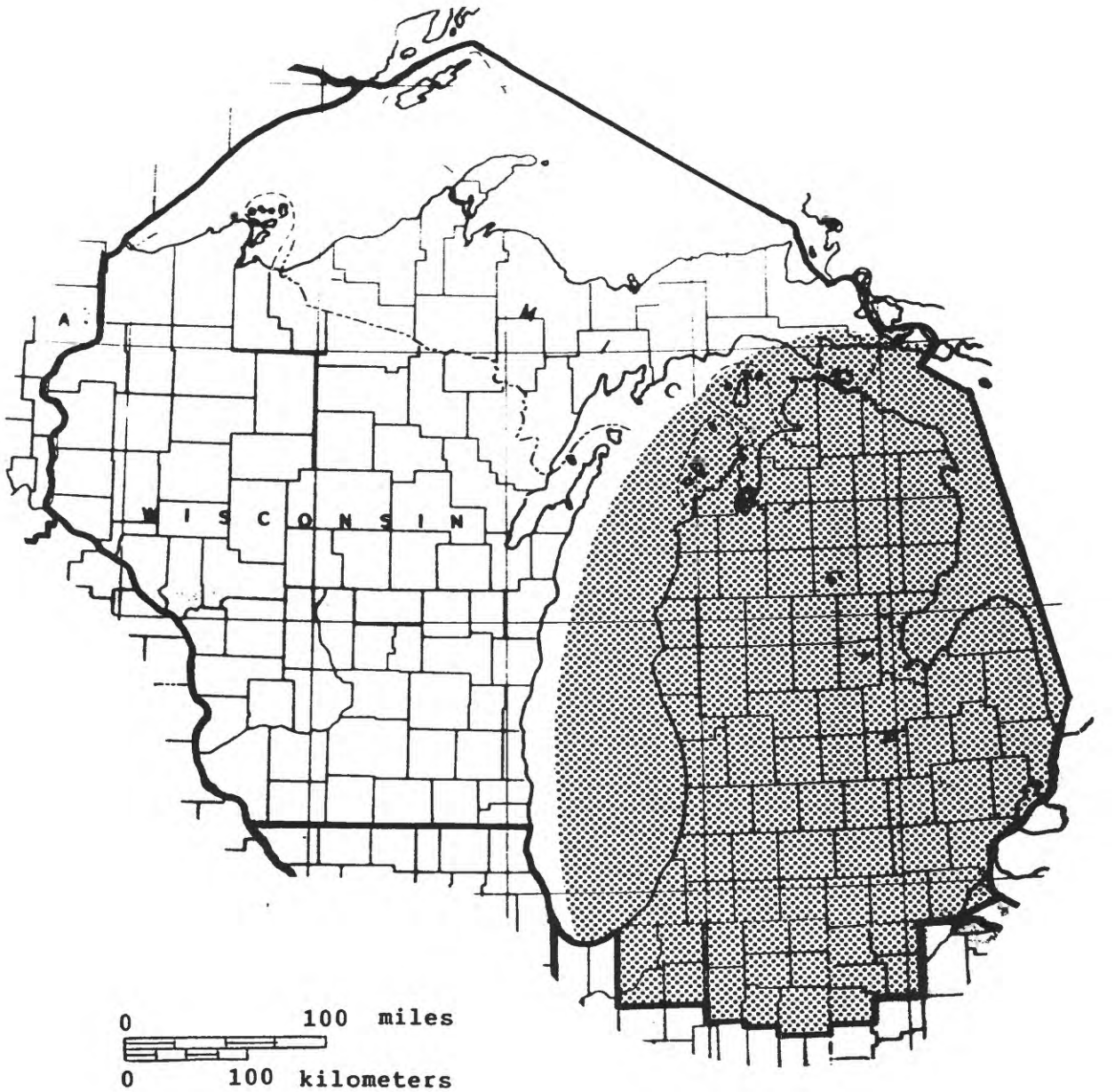
Earliest production was from a few small pools at the southern edge of the basin. In 1957, the Albion-Pulaski-Scipio trend was discovered. This field, the largest in the basin, is approximately 170 million BOE in size and dominates the production statistics for this play. It is located in south-central Michigan, in Calhoun, Jackson, and Hillsdale Counties (figure 10). To date, about 50 Trenton-Black River fields have been discovered. Of these only about four are greater than 1 million barrels in size. Both oil and gas are produced from the pools. Depths of discovered fields are fairly shallow--most produce from less than 5000 feet.

Prairie du Chien play

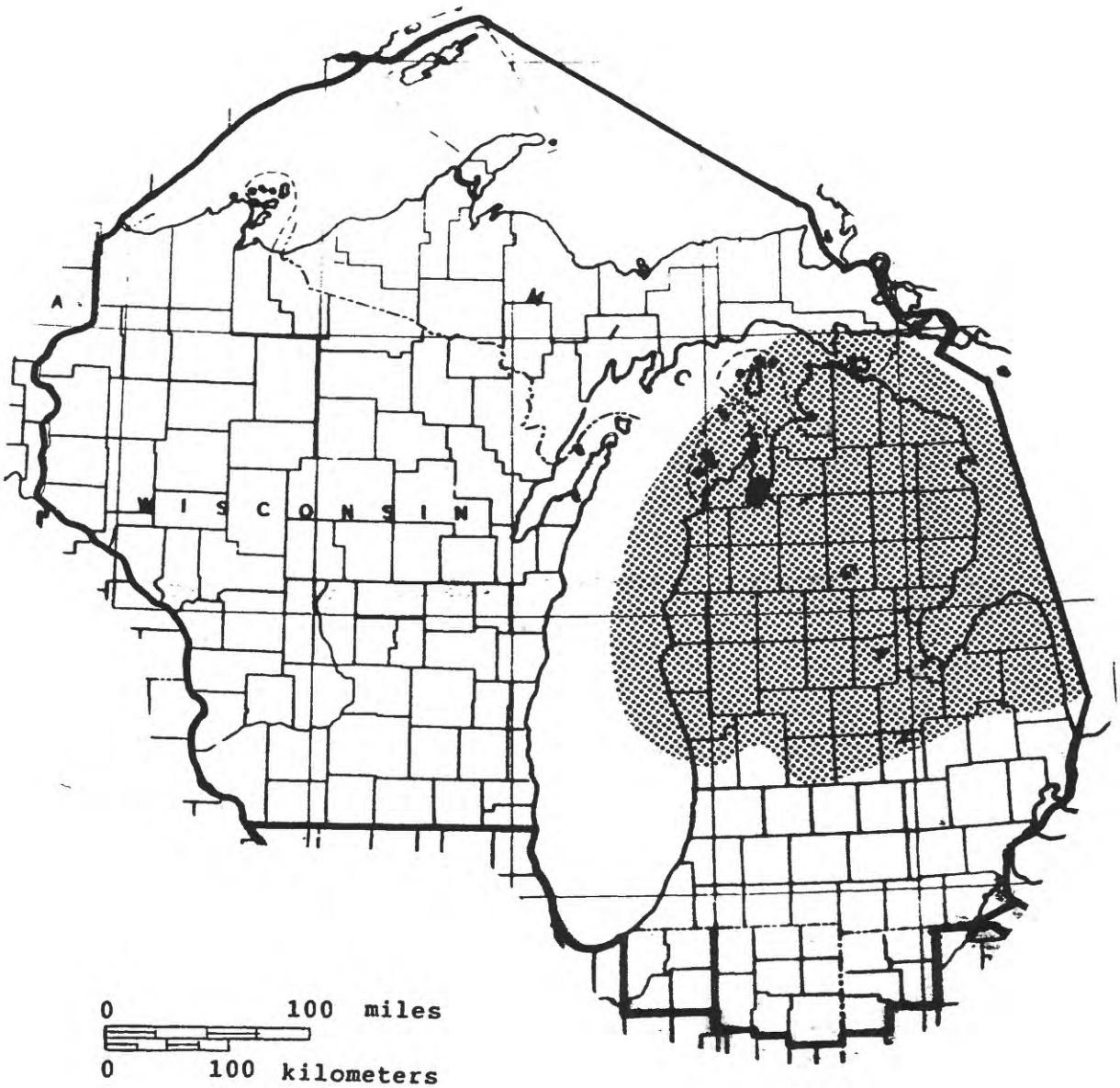
The Ordovician Prairie du Chien play includes discoveries and prospects in the Bruggers Formation (Fisher and Barratt, 1985)(figure 16). The pools are gas reservoirs and include the deepest production to date in the Michigan basin. The Bruggers Formation extends over much of the central part of the basin (figure 17) and is centered in Missaukee and Roscommon Counties (figure 10) where it reaches thicknesses of about 1200 feet.

The Bruggers is a silica-cemented clean quartz sandstone with porosity of about ten percent. Lithologically it is very similar to the St. Peter Sandstone which is also Middle Ordovician in age, but the precise correlation between the two is at present unresolved.

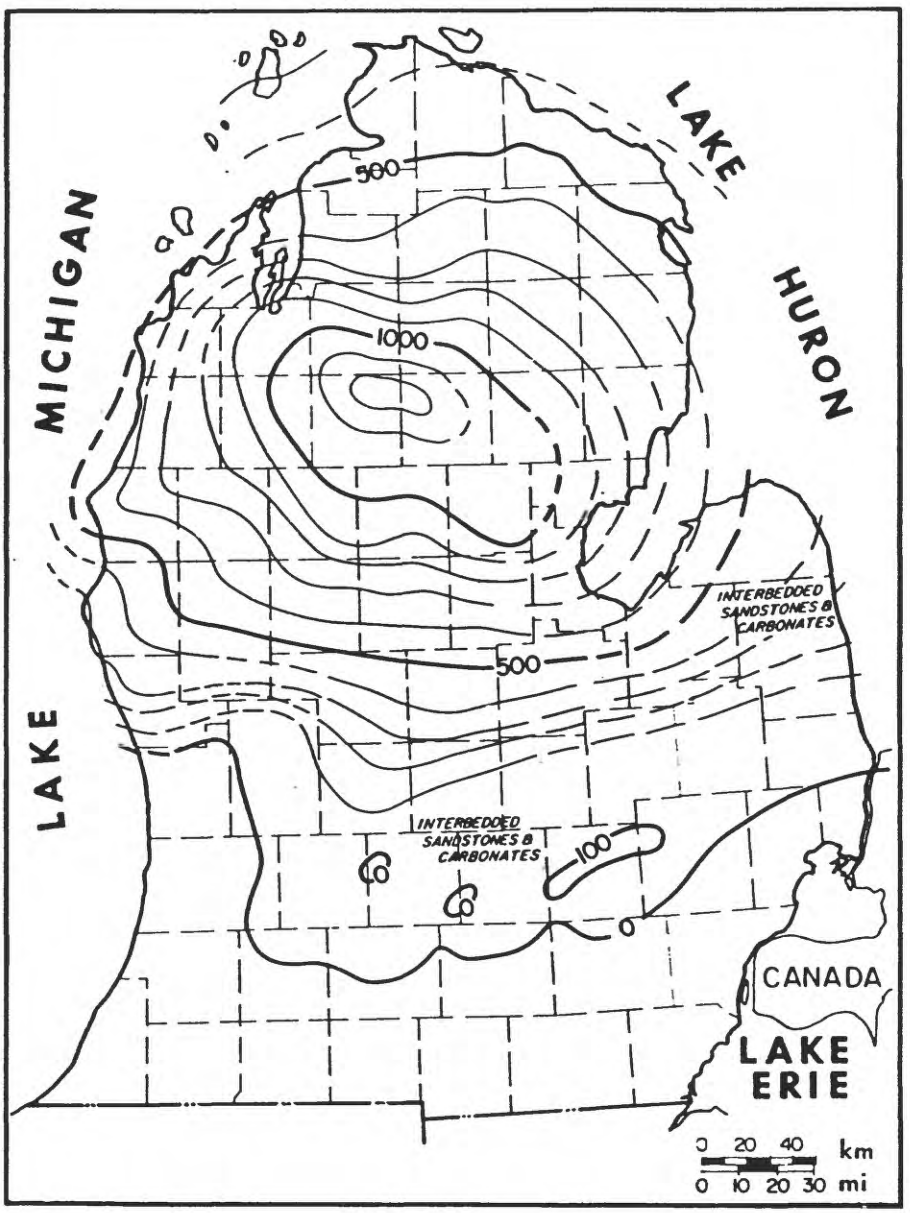
The trapping mechanism is not completely clarified, but seems to be a combination of factors. Although most discoveries have been deeper tests in producing Devonian anticlinal fields, porosity variation at least partially controls the trapping. According to Fisher and Barratt (1985), porosity may be controlled in part by diagenetic interactions between the quartz



15. Extent of Trenton-Black River play.



16. Extent of Prairie du Chien play.



17. Isopach map of Bruggers Formation (from Fisher and Barratt, 1985, reprinted by permission of American Association of Petroleum Geologists).

grains and the clay assemblage. The precise source rock is unknown, but a localized source (in the Ordovician) is suspected.

The Prairie du Chien play is the most recent of the major exploration plays in the Michigan basin, with the first discovery only dating back to 1980. Since then, almost 20 pools have been discovered in the Bruggers. Because of the recency of the discovery of these pools, little is known of their actual size. Producing depths range from about 7800 feet to over 11,000 feet--the deepest production in the basin.

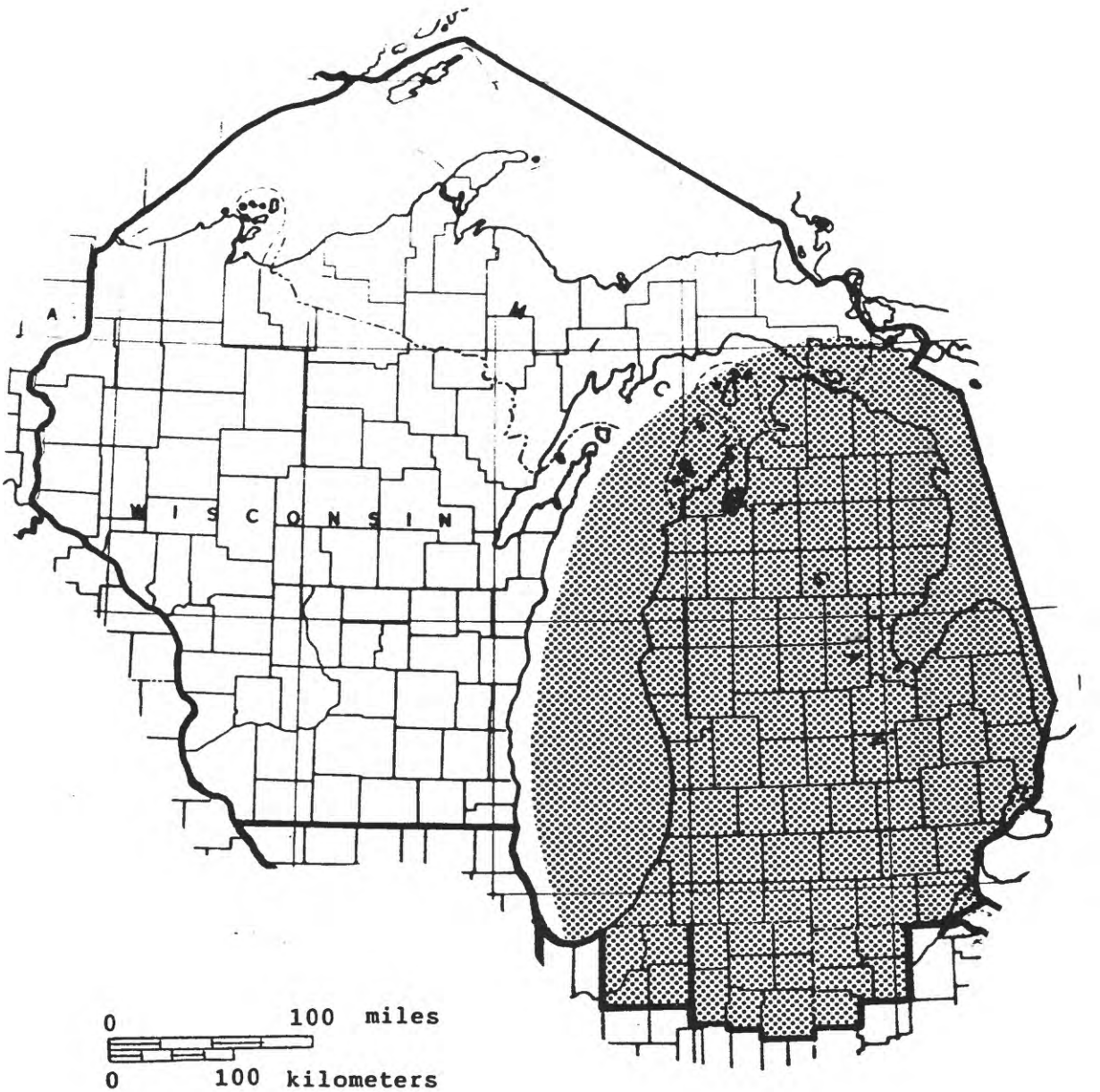
Because of the very sparse drilling below the Devonian in the central part of the basin, there are excellent prospects for further discoveries. Porosity control by diagenesis could further increase the number of prospects by adding the possibility of off-structure stratigraphic traps.

Cambrian play

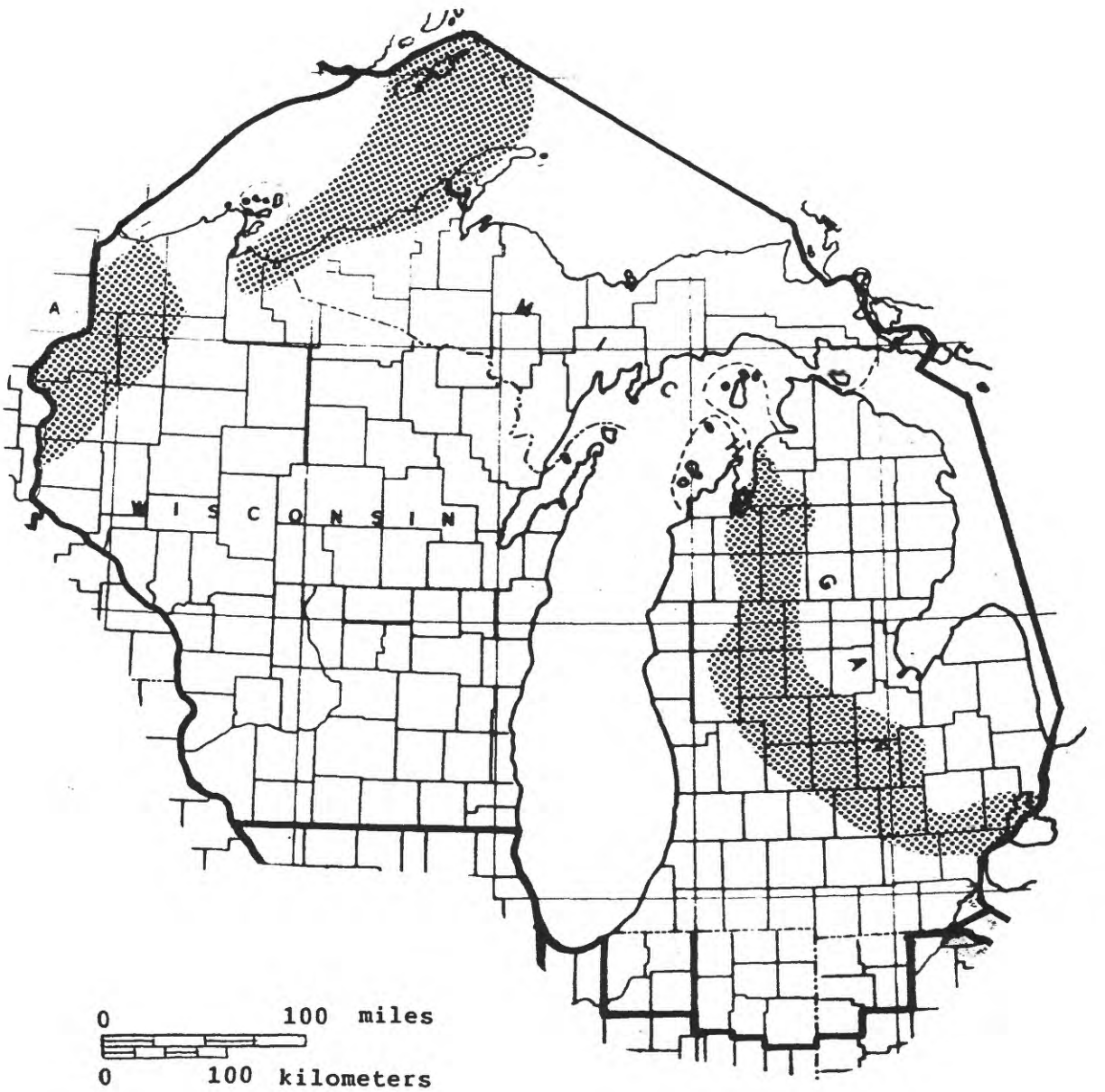
No discoveries have been made from the Cambrian of the Michigan basin, but future prospects have been assigned to a Cambrian play (figure 18). The Cambrian section in the Michigan basin attains a thickness of up to 2600 feet and mainly consists of sandstones, with minor amounts of dolomite. Relatively low density of the sandstones suggests adequate porosity. Possible trapping mechanisms include facies-related porosity variations as well as unconformities. Deeper pools in the anticlinal trends are also possible. Sources are unidentified, but an Ordovician source is conceivable. Gas would be more likely than oil. The Cambrian outcrops in the Upper Peninsula and in Wisconsin and is as deep as about 17,000 feet in the center of the basin, so production depths could range widely. Very few petroleum exploration wells have penetrated the Cambrian section. Potential could be significant but is difficult to assess with only the limited data currently available.

Precambrian rift play

The Precambrian rift play (figure 19) has had no discoveries, but oil seeping into the White Pine mine in the Upper Peninsula of Michigan (Hatch and Morey, 1985) has led to the suggestion that the Nonesuch Shale could be a source of Precambrian oil. Reservoirs would presumably be in the Precambrian Copper Harbor Conglomerate or the Freda Sandstone. Little exploration has taken place so far.



18. Extent of Cambrian play.



19. Extent of Precambrian rift play.

REFERENCES

Cercone, K.R., 1984, Thermal history of Michigan basin: American Association of Petroleum Geologists Bulletin, v. 68, no. 2, p. 130-136.

Ells, G.D., 1971, Future oil and gas possibilities in Michigan basin, in Cram, I.H., ed., Future petroleum provinces of the United States--their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 2, p. 1124-1162.

Fisher, J.H., and Barratt, M.W., 1985, Exploration in Ordovician of central Michigan basin: American Association of Petroleum Geologists Bulletin, v. 69, no. 12, p. 2065-2076.

Gardner, W.C., and Bray, E.E., 1984, Oils and source rocks of Niagaran reefs (Silurian) in the Michigan basin, in Palacas, J.G., ed., Petroleum geochemistry and source rock potential of carbonate rocks: American Association of Petroleum Geologists Studies in Geology 18, p. 33-44.

Hatch, J.R., and Morey, G.B., 1985, Hydrocarbon source rock evaluation of Middle Proterozoic Solor Church Formation, North American mid-continent rift system, Rice County, Minnesota: American Association of Petroleum Geologists Bulletin, v. 69, no. 8, p. 1208-1216.

Hinze, W.J., and Merritt, D.W., 1969, Basement rocks of the Southern Peninsula of Michigan, in Stonehouse, H.B., ed., Studies of the Precambrian of Michigan: Michigan Basin Geological Society Guidebook, p. 28-59.

Illich, H.A., and Grizzle, P.L., 1983, Comment on "Comparison of Michigan basin crude oils" by Vogler et al.: Geochimica et Cosmochimica Acta, v. 47, p. 1151-1155.

Klemme, H.D., 1980, Petroleum basins--classifications and characteristics: Journal of Petroleum Geology, v. 3, no. 2, p. 187-207.

Meyers, P.A., and Moore, W.E., 1983, Comparison of Michigan basin crude oils (reply to comments by Illich and Grizzle and by Pruitt): Geochimica et Cosmochimica Acta, v. 47, p. 1161-1162.

Michigan Department of Natural Resources, Geological Survey Division, 1937, Trend map of anticlinal folding, Southern Peninsula: 1 sheet.

_____, 1964, Stratigraphic succession in Michigan, Paleozoic through Recent: Chart 1, 1 sheet.

_____, 1987, Michigan's oil and gas fields, 1983 and 1984: Statistical Summary for Oil and Gas 84, SS-OG 84, 307 p.

Moyer, R.B., 1982, Thermal maturity and organic content of selected Paleozoic formations--Michigan basin: Michigan State University, Master's thesis, 62 p.

Nunn, J.A., Sleep, N.H., and Moore, W.E.,1984, Thermal subsidence and generation of hydrocarbons in Michigan basin: American Association of Petroleum Geologists Bulletin, v. 68, no. 3, p. 296-315.

Petroleum Information Corporation, 1984, Michigan basin: expanding the deep frontier: Petroleum Frontiers, v. 1, no. 3, 80 p.

Powell, T.G., Macqueen, R.W., Barker, J.F., and Bree, D.G., 1984, Geochemical character and origin of Ontario oils: Bulletin of Canadian Petroleum Geology, v. 32, no. 3, p. 289-312.

Pruitt, J.D., 1983, Comment on "Comparison of Michigan basin crude oils" by Vogler et al.: Geochimica et Cosmochimica Acta, v. 47, p. 1157-1159.

Reed, J.D., Illich, H.A., and Horsfield, B., 1986, Biochemical evolutionary significance of Ordovician oils and their sources, in Advances in Organic Geochemistry 1985: Organic Geochemistry, v. 10, no. 1-3, p. 347-358.

Rullkotter, Jurgen, Meyers, P.A., Schaefer, R.G., and Dunham, K.W., 1986, Oil generation in the Michigan basin: a biological marker and carbon isotope approach, in Advances in Organic Geochemistry 1985: Organic Geochemistry, v. 10, no. 1-3, p. 359-375.

Varnes, K.L., Coury, A.B., Dolton, G.L., Frezon, S.E., Khan, A.S., Pike, R.S., Powers, R.B., and Scott, E.W., compilers, 1981, Oil and gas resource assessment areas, U.S. Geological Survey, Geologic Division, 1980, lower 48 United States, Regions 2 through 11, 2A, 6A, and 11A: U.S. Geological Survey Open-File Report 81-84C, scale 1:5,000,000, 1 sheet.

Varnes, K.L., and Dolton, G.L., comps., 1982, Estimated areas and volumes of sedimentary rock in the United States by province--statistical background data for U.S. Geological Survey Circular 860: U.S. Geological Survey Open-File Report 82-666C, 11p.

Vogler, E.A., Meyers, P.A., and Moore, W.A., 1981, Comparison of Michigan basin crude oils: Geochimica et Cosmochimica Acta, b. 45, p. 2287-2293.