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GEOLOGY AND SALT DEPOSITS OF THE MICHIGAN BASIN

Kenneth S. Johnson
Serge Gonzales

July 1976

NOTICE

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This report was prepared by K. S. Johnson and Serge Gonzales under Consultant Subcontracts 4494 and 4310 with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory and the Office of Waste Isolation.

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Lomenick

Geology and Salt Deposits of the Michigan Basin

Submitted by:

Earth Resource Associates, Inc.
Athens, Georgia 30601

July, 1976

Submitted to:

Office of Waste Isolation
Union Carbide Corporation
Oak Ridge, Tennessee 37830

Prepared by:

Kenneth S. Johnson (Subcontract No. 4494)
and
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ENVIRONMENT·ECONOMY·ENGINEERING
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LEGIBILITY NOTICE

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INTRODUCTION

The Silurian-age Salina salt, one of the greatest deposits of bedded rock salt in the world, underlies most of the Michigan basin and parts of the Appalachian basin in Ohio, Pennsylvania, New York, and West Virginia. Interest in this salt deposit has increased in recent years because there may be one or more areas where it could be used safely as a repository for the underground storage of high-level radioactive wastes.

The purpose of this report is to summarize the general geology of the Michigan basin and to describe the major salt deposits, in the hope that these data will be useful in determining whether there are any areas in the basin that are sufficiently promising to warrant further detailed study. Distribution of the important salt deposits in the basin is limited to the Southern Peninsula of Michigan (fig. 1).

As recently summarized in a document by the U.S. Energy Research and Development Administration (1976), permanent geologic storage is the leading method for the safe, long-term management of solidified, high-level radioactive wastes derived from the domestic nuclear fuel cycle. And it has been well established, in the long-standing opinion of many investigators (National Academy of Sciences-National Research Council, 1957; deLaguna, 1966; McClain and Bradshaw, 1969), that salt constitutes the most promising rock type in which to permanently store high-level radioactive waste. The properties of salt (halite) that make it

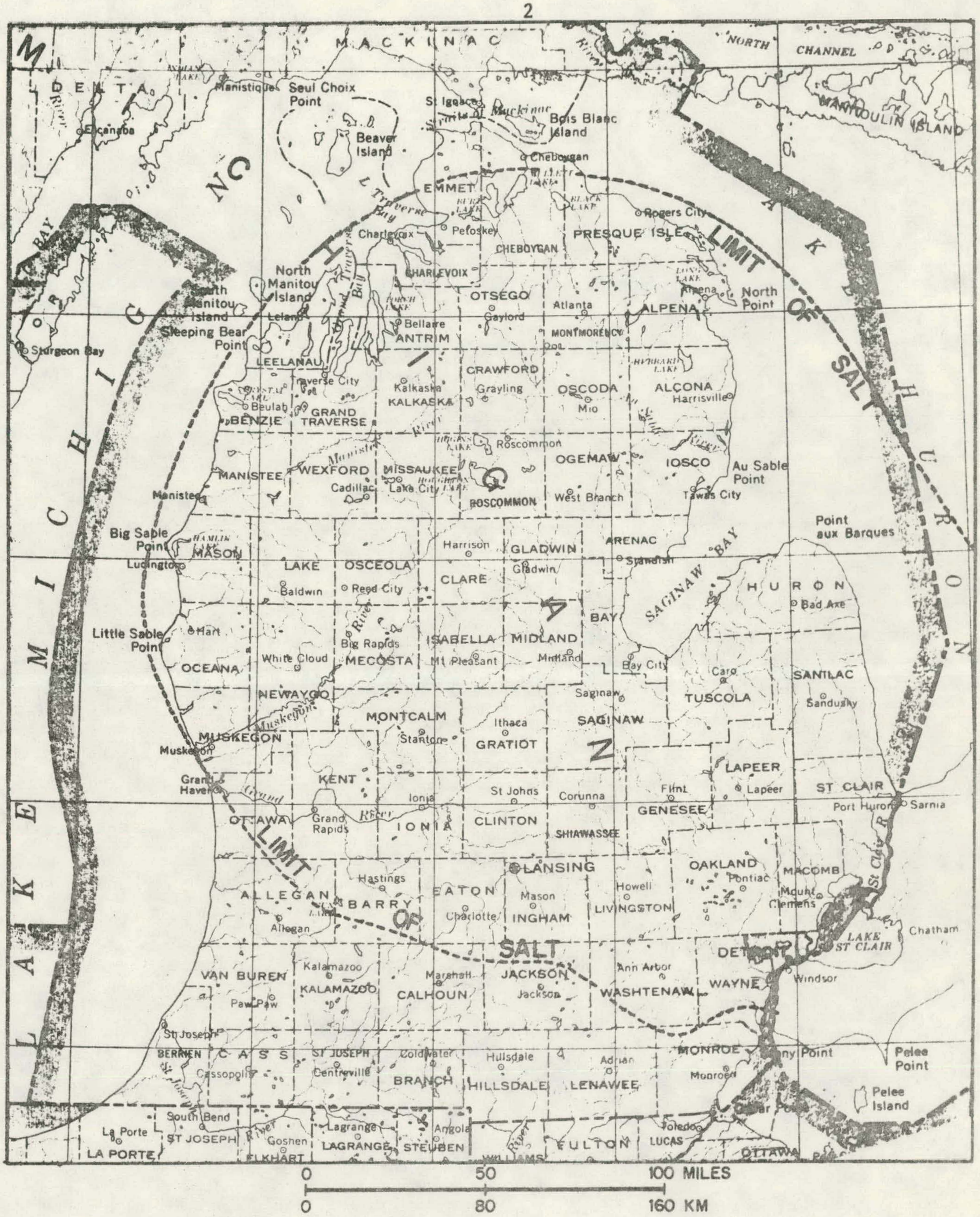


Figure 1. Base map of Michigan's Southern Peninsula showing surface drainage, counties, county seats, and area underlain by deposits of bedded rock salt (halite).

promising include its low permeability, low moisture content, high thermal conductivity, high plasticity, and high gamma-ray shielding. An aggregate thickness of 200 feet for a given salt-bearing sequence contained 1,000 to 3,000 feet below the surface is considered well within acceptable limits for insuring isolation of the buried waste material.

Sites for geologic isolation of radioactive waste must be selected to assure that there will be no release to the biosphere, and thus no radiation exposure to the general public. Because geologic environments vary appreciably, this assurance of isolation can be met in different ways at different sites, provided that all prospective sites are carefully evaluated and tested prior to selection. Inasmuch as circulating ground water is the most likely means by which radionuclides might escape a permanent geologic-storage site, each must be studied in detail to establish its own unique geologic and hydrologic features, as well as its geologic history. Major factors to be considered are the following:

1. Depth to disposal horizon - Disposal intervals should be located at depths sufficient to isolate waste from surface phenomena such as erosion and biological processes.
2. Thickness and extent of host rock - Vertical and lateral dimensions of the host rock used for storage should be sufficient to allow for adequate heat dissipation. They should also permit effective closure of any fractures that may develop near any repository.
3. Homogeneity of host rock - Homogeneous rock units are preferred over nonhomogeneous ones. They commonly are more easily mined,

can better dissipate heat, and generally lack features that can lead to ground-water problems.

4. Host-rock porosity and permeability - The more-favored host rocks exhibit both low porosity and low permeability to preclude movement of ground water. Rocks immediately adjacent to a soluble host rock should exhibit a similar low porosity and permeability.

5. Nature and occurrence of ground water - The nature of water-bearing intervals near potential host rocks is of utmost importance. The direction and rate of ground-water movement and resource utilization are some specific considerations.

6. Glacial drift - In glaciated regions, it is preferred to avoid siting repositories where thick glacial drift contains important water or other mineral resources.

7. Tectonic stability - A repository site should be located in a tectonically stable area that is distant from recorded earthquakes of moderate intensity, or greater.

8. Dip or inclination of host rock - The preferred dip of sedimentary rocks is less than a few degrees, because mining is easier and the rock is less likely to be faulted or fractured.

9. Geologic structures - Joints, fractures, and faults in a host rock are deleterious because they can serve as potential conduits for ground-water movement.

10. Mineral resources - It is preferable to avoid sites that would conflict with present or future production of oil and gas and significant deposits of important, nonpetroleum mineral resources.

11. <u>Boreholes and mines</u> - Sites are preferred in areas where boreholes or mines do not penetrate a potential host rock, because these man-made openings may allow water to enter and/or leave a repository.
12. <u>Remoteness</u> - Repositories should not be located in or near urban and resort areas, because this might conflict with specialized and high-priority use of nearby lands.
13. <u>Transportation</u> - Sites must be accessible to transportation such as highways and railways.

Appreciation is expressed to the Michigan Geological Survey and the Water Resources Division of the U.S. Geological Survey for assistance in obtaining data used in preparing parts of this report, and to the staff members of the Office of Waste Isolation in the Union Carbide Corporation for unpublished data and for discussing the project and making suggestions during the course of this study.

MAJOR SALT DEPOSITS OF THE UNITED STATES

Thick sequences of bedded rock salt have formed in a number of sedimentary basins by the precipitation of halite (NaCl) from evaporating sea water. The major salt deposits in the United States are in the Michigan and Appalachian basins in the northeast, the Gulf Coast basin in the south, and the Permian basin in the southwest (fig. 2). Other large salt deposits include those of the Paradox, Williston, and Supai basins in the West. For the purpose of this report, however, only the Michigan and Appalachian basins are discussed in additional detail.

Silurian-age salt deposits of the northeastern United States are one of the greatest accumulations of salt in the world (Lefond, 1969; Pierce and Rich, 1962). These thick, high-purity deposits occur in the Salina Group and they underlie a total area of about 100,000 square miles that embraces both the Michigan and Appalachian basins (fig. 3).

The Michigan basin contains the major portion of the Salina Group salt. For example, the salt attains an aggregate thickness of more than 2,000 feet in the central part of the basin. The thickness of individual salt beds and of the entire salt-bearing sequence decreases toward the edge of the basin. The depth to the top of the salt ranges from about 6,000 feet in the center of the basin to between 500 and 1,000 feet along the margins.

The northern half of the Michigan basin also contains salt in the Detroit River Group of Devonian age. This salt section is more than

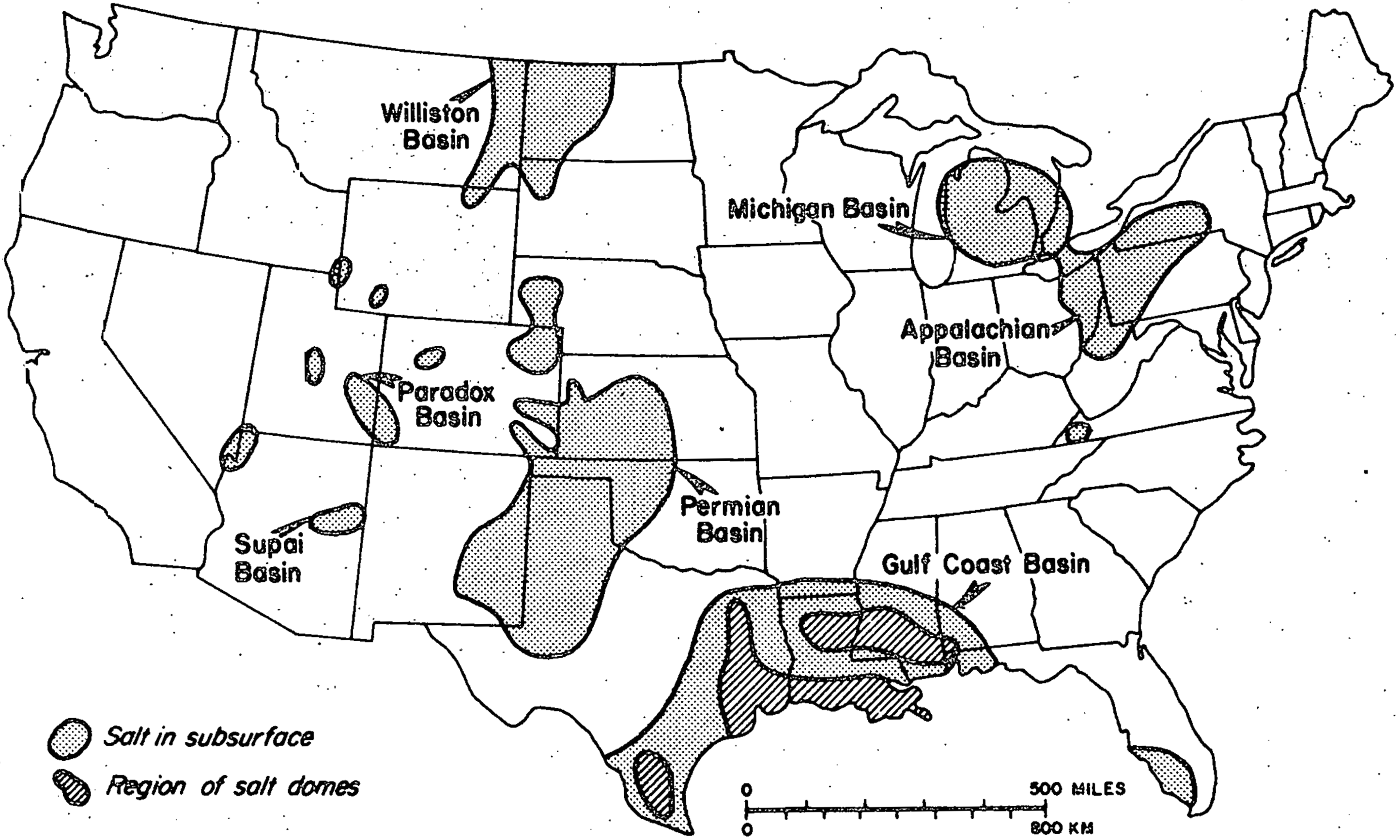


Figure 2. Map showing distribution of major salt deposits in the United States (modified from Lefond, 1969).

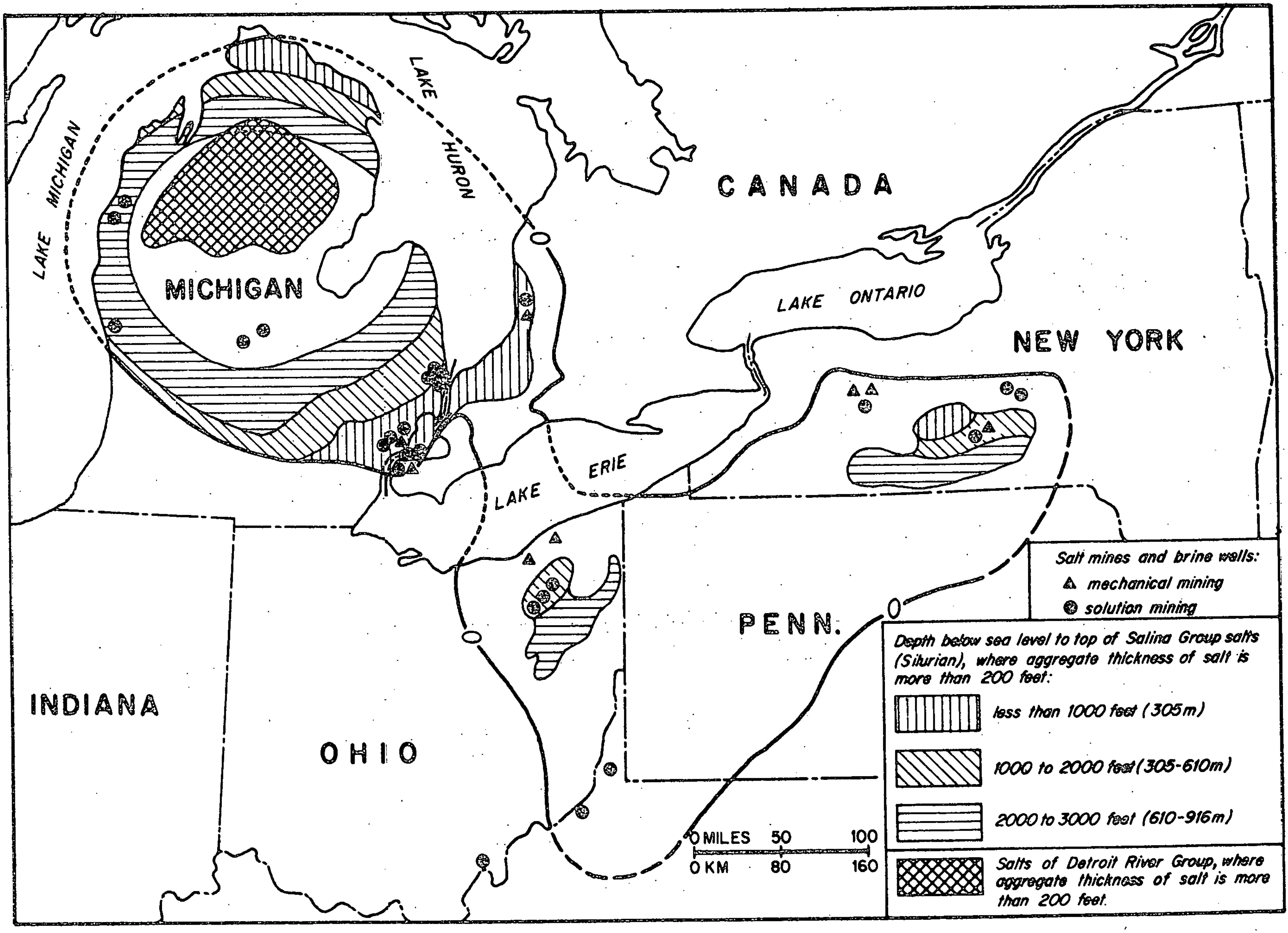


Figure 3. Map showing distribution and depth of Silurian and Devonian salt deposits in Michigan, Ohio, and New York (modified from U.S. Energy Research and Development Administration, 1976, vol. 5).

500 feet thick and contains as many as 8 different salt beds, the thickest of which is more than 100 feet thick. Although the top of the salt is more than 4,000 feet deep in the central part of the State, it is less than 1,300 feet deep locally along the northeastern margin of the basin.

The Appalachian basin contains a southeastward extension of the Salina Group salt sequence. Here, the salt reaches an aggregate thickness of about 300 feet in parts of eastern Ohio and more than 900 feet in south-central New York (Pierce and Rich, 1962). Salina Group salts also underlie west-central and northwestern Pennsylvania, but are less than 200 feet thick. Dipping southeastward into the Appalachian basin, the salt sequence lies from 1,000 to more than 5,000 feet below the surface in these states.

STRUCTURE AND GEOLOGIC HISTORY OF THE MICHIGAN BASIN

The Michigan basin is a major sedimentary and structural basin that embraces all of Michigan, as well as parts of Wisconsin, Illinois, Indiana, Ohio, and Ontario. It is bounded on the north and northeast by the Canadian shield; on the east and southeast by the Algonquin arch in Ontario and the Findlay arch in northern Ohio; on the southwest by the Kankakee arch in northwestern Indiana and northeastern Illinois; and on the west and northwest by the Wisconsin arch and Wisconsin dome (Ells, 1967 and 1969). Although nearly circular in outline, the basin has a slight north-south elongation (fig. 4).

The basin is located in the tectonically stable interior of North America. It is characterized by essentially flat-lying sedimentary rocks that are folded or faulted at only a few places. Strata dip gently into the center of the basin from the adjacent arches and shield area at a rate of 25 to 50 feet per mile (¼ to ½ degree).

The deepest part of the basin apparently underlies Clare and Gladwin Counties, in the central part of the Southern Peninsula, where 14,000 to 15,000 feet of sedimentary rocks are believed to overlie the Precambrian (Ells, 1967). These sedimentary rocks include strata of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Jurassic age, that are chiefly carbonates, shales, evaporites (salt and anhydrite), and sandstones (figs. 5 and 6). They are overlain at

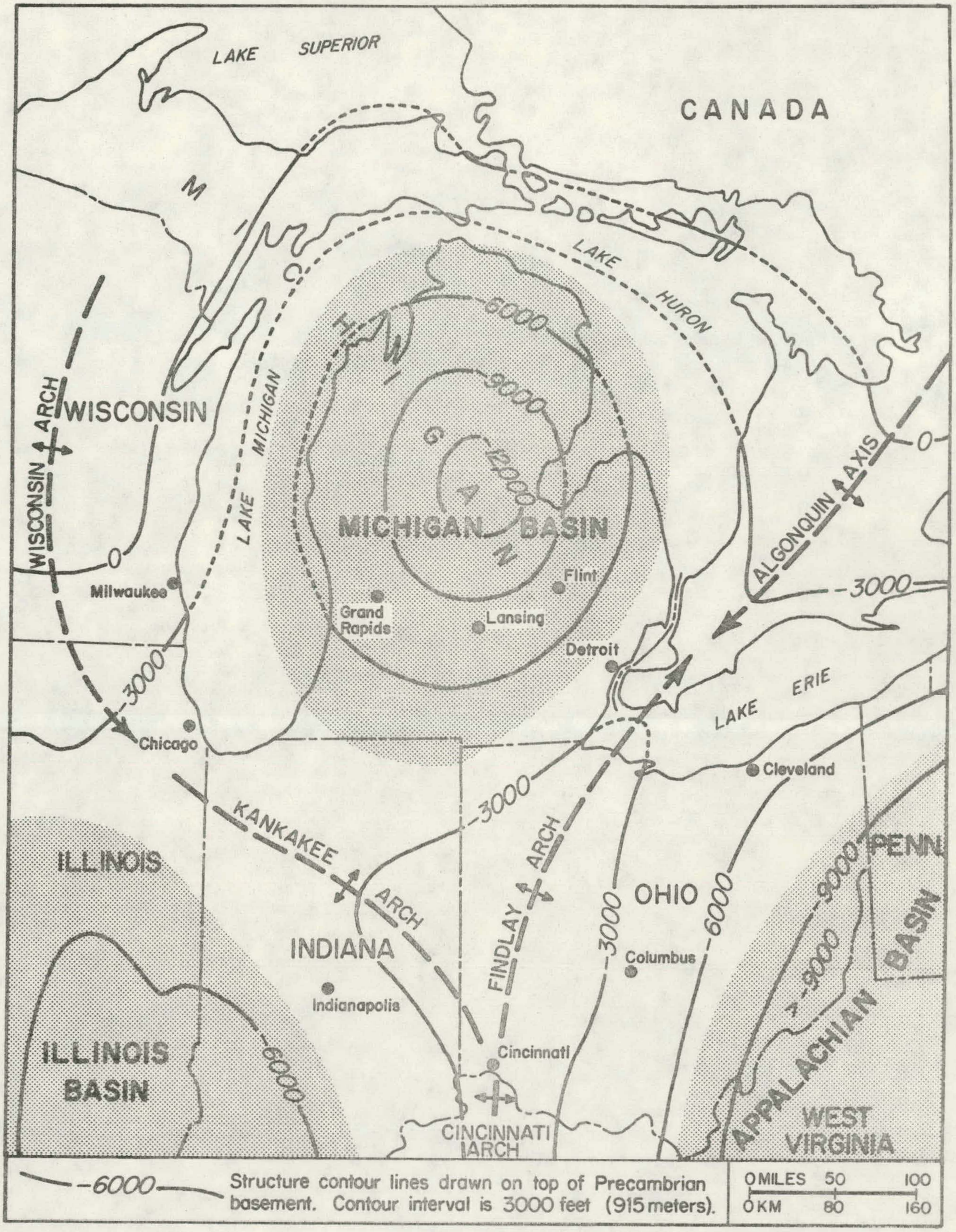


Figure 4. Map of Michigan basin and surrounding area showing principal tectonic provinces.

Figure 5.

STRATIGRAPHIC SUCCESSION IN MICHIGAN

PALEOZOIC THROUGH RECENT

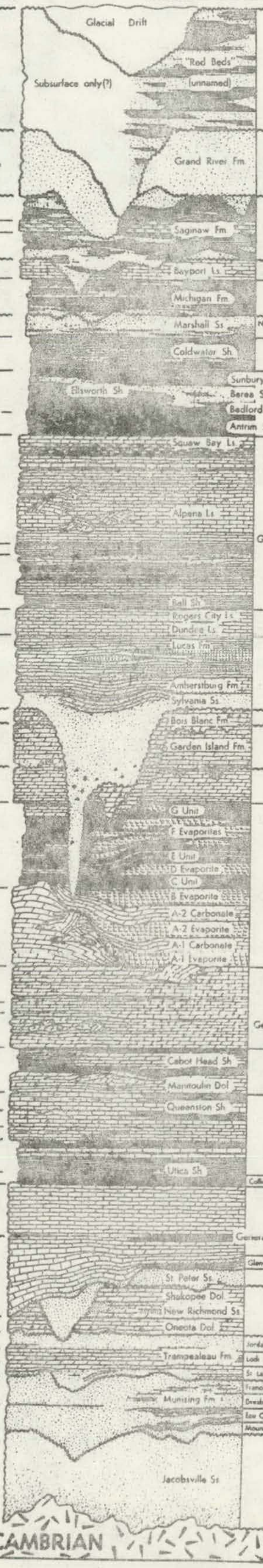
PLEISTOCENE NOMENCLATURE

ERA	SYSTEM	SERIES	STAGE	
CENOZOIC	QUATERNARY	RECENT		
		PLEISTOCENE	Wisconsin Glaciation	Valders Stade Two Creeks Interstade Mankato Stade (Pt Huron?) Cary Stade Tazewell Stade
			Sangamon Interglaciation	
			Illinoian Glaciation	

OUTCROP NOMENCLATURE

GEOLOGIC TIME: ERA	PERIOD	EPOCH	TIME-STRATIGRAPHIC: SYSTEM	SERIES	ROCK-STRATIGRAPHIC: GROUP		FORMATION	MEMBER
MESOZOIC	JURASSIC	LATE	JURASSIC	KIMERIDGIAN				
PALEOZOIC	PENNSYLVANIAN	LATE	PENNSYLVANIAN	CONEMAUGH			Grand River Fm	Ionia, Eaton, and Woodville Sandstones
		EARLY		POTTSVILLE			Saginaw Fm	Verne Ls
	MISSISSIPPIAN	LATE	MISSISSIPPIAN	MERAMECIAN	GRAND RAPIDS		Bayport Ls	
							Michigan Fm	
		EARLY		OSAGIAN			Marshall Ss	Napoleon Ss
				KINDERHOOKIAN			Coldwater Sh	
	MISSISSIPPIAN-DEVONIAN Unassigned							
	DEVONIAN	LATE	DEVONIAN				Ellsworth Sh (Western Michigan)	
				CHAUTAUQUAN			Antrim Sh	
				SENECAN	TRAVERSE		Squaw Bay Ls	
		MIDDLE		ERIAN			Thunder Bay Ls	
							Potter Farm Fm	
							Norway Point Fm	
							Four Mile Dam Fm	
							Alpena Ls	
							Newton Creek Ls	
							Genshaw Fm	Killians
							Ferron Point Fm	
							Rockport Quarry Ls	
							Bell Sh	
							Rogers City Ls	
							Dundee Ls	
				ULSTERIAN	DETROIT RIVER	MACKINAC BRECCIA	Anderdon Fm	
							Lucas Fm	
							Amherstburg Fm	
							Sylvania Ss	
							Bois Blanc Fm	
		EARLY					Garden Island Fm	
	SILURIAN	LATE	SILURIAN	CAYUGAN	BASS ISLANDS		Raisin River Dol	
							Put-in-Bay Dol	
					SALINA		St Ignace Dol (Northern Peninsula)	
							Pte. aux Chenes Sh	
		MIDDLE		NIAGARAN			Engadine Dol	
					MANISTIQUE		Cordell Dol	
							Schoolcraft Dol	
					BURNT BLUFF		Hendricks Dol	Fiborn Ls
							Byron Dol	
							Lime Island Dol	
		EARLY		ALEXANDRIAN	CATARACT		Cabot Head Sh	
							Manitoulin Dol	
	ORDOVICIAN	LATE	ORDOVICIAN	CINCINNATIAN	RICHMOND		Big Hill Fm	
							Stonington Fm	Ogontz Bay de Noc
							Bill's Creek Sh	Collingwood
		MIDDLE		MOHAWKIAN	TRENTON		Groos Quarry Fm	
							Chandler Falls Fm	
					BLACK RIVER		Bony Falls Fm	
		EARLY		CHAZYAN				
				CANADIAN	PRAIRIE DU CHIEN		Oneota Dol	
	CAMBRIAN	LATE	CAMBRIAN	ST CROIXAN	LAKE SUPERIOR		Trempealeau Fm	Jordan Ss Lodi St Lawrence
							Munising Fm	Miner's Castle Ss Chapel Rock Ss
		MIDDLE EARLY					Jacobsville Ss	

DOMINANT LITHOLOGY



SUBSURFACE NOMENCLATURE

Approximate maximum thickness, in feet, of rock units in the subsurface. NO SCALE

ROCK-STRATIGRAPHIC: FORMATION	MEMBER	GROUP	Thickness
"Red Beds" (unnamed)			220
Grand River Fm Saginaw Fm			750
Bayport Ls		GRAND RAPIDS	160
Michigan Fm			600
Marshall Ss	Napoleon Ss		330
Coldwater Sh			1300
Sunbury Sh	(Eastern Michigan)		160
Berea Ss			260
Bedford Sh			240
Antrim Sh			660
Squaw Bay Ls Alpena Ls Bell Sh		TRAVERSE Generally undivided in subsurface	830
Rogers City Ls Dundee Ls			475
Lucas Fm Amherstburg Fm Sylvania Ss		DETROIT RIVER	1450
Bois Blanc Fm			800
Garden Island Fm			100
		BASS ISLANDS	700
G Unit F Evaporites E Unit D Evaporite C Unit B Evaporite A-2 Carbonate A-2 Evaporite A-1 Carbonate A-1 Evaporite		SALINA	3150
		NIAGARA Generally undivided in subsurface	980
Cabot Head Sh Manitoulin Dol		CATARACT	200?
Queenston Sh Utica Sh	Collingwood	RICHMOND	950
		TRENTON Generally undivided in subsurface	1100
	Glenwood	BLACK RIVER	
St Peter Ss			260
Shakopee Dol New Richmond Ss Oneota Dol		PRAIRIE DU CHIEN	425
Trempealeau Fm	Jordan Ss Lodi St Lawrence	LAKE SUPERIOR	750
Munising Fm	Franconia Ss Dresbach Ss Eau Claire Mount Simon Ss		1175?
Jacobsville Ss			1100+

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
Ralph A. MacMullan, Director

GEOLOGICAL SURVEY DIVISION
Arthur E. Slaughter, State Geologist and Chief

ACKNOWLEDGEMENT: Compiled with the counsel of colleagues in the department, the U. S. Geological Survey, Michigan's universities, other state Geological Surveys, and geologists within Michigan's oil and gas industry. Dr. Aureal T. Cross, Department of Geology, Michigan State University, identified rocks of Mesozoic age and suggested provisional age assignments.

GEOLOGIC NAMES COMMITTEE

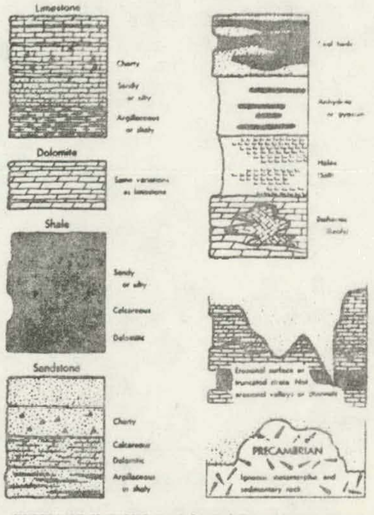
Garland D. Ells, Chairman; Robert W. Kelley, Secretary
Harry J. Hardenberg, L. David Johnson, Harry O. Sorensen

INFORMAL TERMS

Principal oil and gas pays, and informal terms used in petroleum exploration and applied to parts of formations or groups in the subsurface

STRATIGRAPHIC POSITION	INFORMAL TERMS	PAYS
Basal sandstones of Saginaw Fm	Parma sandstone	
In lower part of Michigan	triple gyp brown lime stray stray ss stray dol	Gas
	stray ss	Gas & Oil
Marshall Ss		Gas & Oil
Coldwater Sh	Coldwater lime Weir sand Coldwater red rock	Gas
In upper part of Ellsworth Sh	"Berea" (Western Michigan)	Oil & Gas
Berea Ss	Berea sand (Eastern Michigan)	Oil & Gas
Squaw Bay Ls	Squaw Bay	Oil & Gas
Upper part of Traverse Group in Western Michigan	Traverse formation Traverse lime	Oil & Gas
	Stoney Lake zone	Oil & Gas
Rogers City Ls		Oil & Gas
Dundee Ls		Oil & Gas
Dundee Ls (?), Upper part of Lucas Fm (?)	Reed City zone	Oil & Gas
In Lucas Fm	massive salt big salt sour zone	Oil & Gas
	massive anhydrite big anhydrite Richfield zone	Oil & Gas
Amherstburg Fm	black lime	
Part of Salina Group E Unit	E zone (or Kintigh zone)	Oil
Divisions of A-2 Carbonate in Western Michigan	A-2 dolomite A-2 lime	Gas
A-1 Carbonate	A-1 dolomite	Oil & Gas
Upper part of Niagaran Series	brown Niagaran gray Niagaran white Niagaran	Oil & Gas
Part of Niagaran Series	Clinton shale (Eastern Michigan)	
Trenton Group		Oil & Gas
Black River Group	Black River formation Black River shale Van Wert zone	Oil & Gas
Oneota Dol		Oil

EXPLANATION



GEOLOGIC NAMES COMPILATIONS: Harry O. Sorensen, Cambrian and Ordovician; Robert W. Kelley, Early and Middle Silurian; Garland D. Ells, Late Silurian through Detroit River Group of Devonian age; Harry J. Hardenberg, Dundee Limestone through Traverse Group of Devonian age; L. David Johnson, Antrim Shale through the Pennsylvanian System; F. Wells Terwilliger, glacial geology of the Cenozoic.

CHART 1

1964
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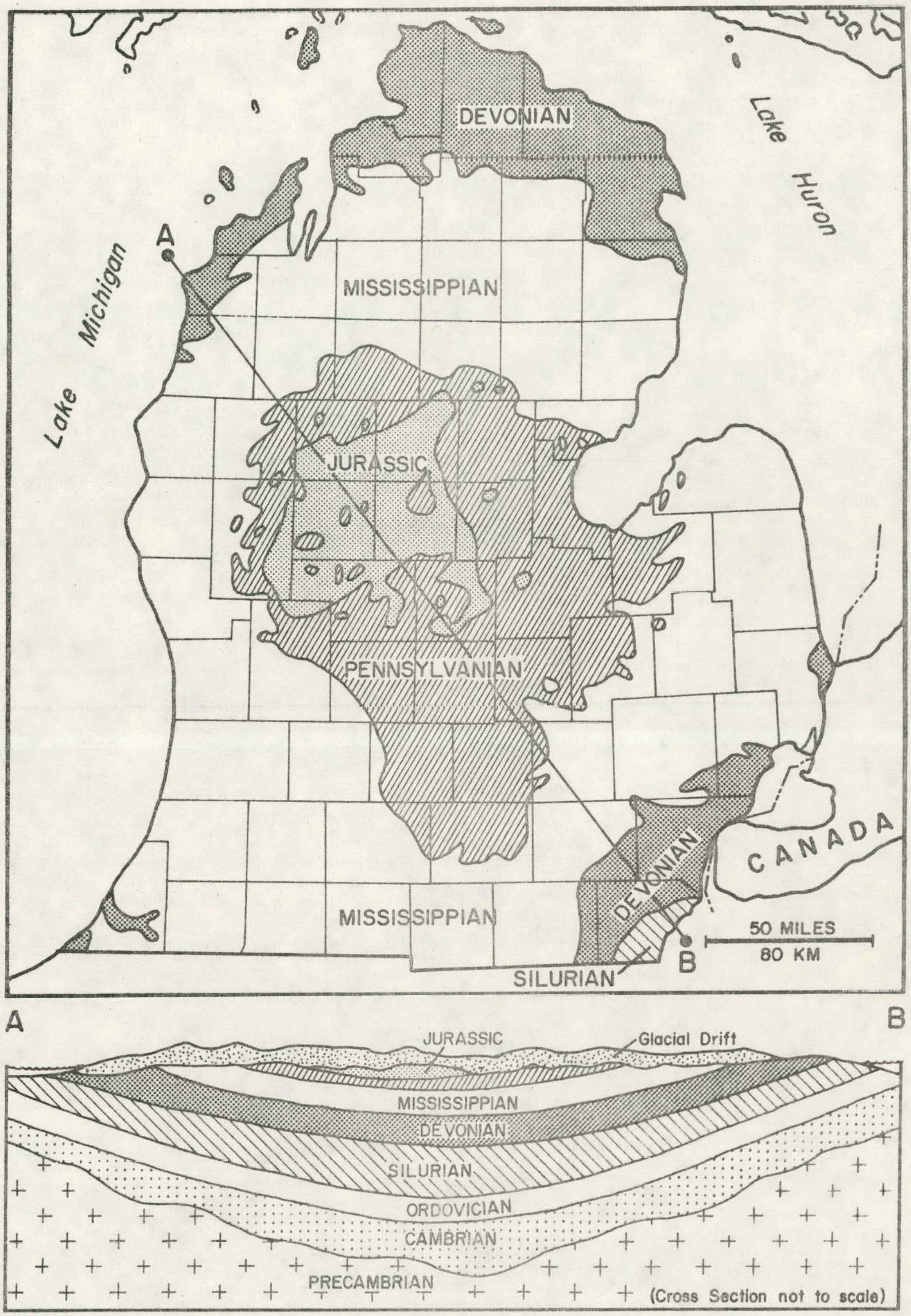


Figure 6. Generalized geologic map and cross section of Lower Peninsula of Michigan (modified from Kelley, 1968).

most places by Pleistocene glacial drift that averages between 200 and 300 feet in thickness, but locally is more than 850 feet thick.

The basin may have first developed as an embayment as early as Cambrian time (Fisher, 1969). Throughout the remainder of the Paleozoic Era, the basin continued to subside more than the adjacent regions, and thus it received a great thickness of sediments in its central part. The major period of subsidence took place in Late Silurian time and accounts in part for deposition of the thick Salina salts in the Michigan basin.

Basement rocks which underlie the Michigan basin include a complex of igneous, metamorphic, and metasedimentary rocks (Hinze and others, 1975). Four separate basement provinces have been recognized throughout the basin; the age of emplacement or metamorphism of rocks in these different provinces ranges from 0.8 to 1.8 billion years before the present.

Pre-Silurian rocks in the Michigan basin consist of Cambrian sandstones and Ordovician limestones, dolomites, and shales (fig. 5). Formations of Cambrian age range in thickness from several hundred feet in the southeast to 2,600 feet (estimated) in the north-central part of the basin (Fisher, 1969). The thickness of Ordovician strata ranges from 900 to 1,500 feet around the perimeter of the basin to more than 1,800 feet in the east-central part of the basin (Fisher, 1969).

Of principal interest for this report are the sedimentary rocks and geologic history of the Silurian and Devonian Periods, for these strata include the thick deposits of rock salt in the Michigan basin. Carbonates (limestone and dolomite) that formed during Early Silurian time represent deposition in shallow and warm marine waters. This carbonate deposition reached optimum conditions later during the Middle Silurian when the Niagaran reef platform developed along the borders of the Michigan basin (Briggs and Briggs, 1974). The reef bank ranges in width from 5 to 20 miles, and separates a back-reef lagoonal zone outside of the basin from a shelf area and the central-basin area enclosed by the reef. The shelf area, which is about 15 to 20 miles wide in the north and 20 to 40 miles wide in the south, was favorable for the growth of numerous pinnacle reefs, many of which are prolific oil and gas producers.

The Salina evaporites (Late Silurian) were not deposited until after major development of the Niagaran reefs had ceased in the Michigan basin (Briggs and Briggs, 1974; Mantek, 1973). Marine regression led to restricted circulation of the waters in the Michigan basin compared to those of the open ocean, and as a result, the waters in the basin were evaporated and bedded salts were deposited when the water became saturated with sodium chloride. Intermittent replenishment of marine water to the basin permitted deposition of thick sequences of rock salt that extended throughout most of the Southern Peninsula. During periods of marine transgression, the basin was flooded and carbonates and other normal-marine sediments were deposited. Salina deposition is therefore characterized by a series of marine transgressions and regressions, with evaporites being formed during the regressions.

Following deposition of the Salina Group, the Bass Islands dolomite was laid down during a minor transgression that preceded the final draining of marine waters from the Michigan basin and subsequent erosional period that produced the Silurian-Devonian unconformity. Total thickness of Silurian strata ranges from 600-1,500 feet in the south to 4,000 feet in the central part of the basin (Fisher, 1969).

Early Devonian dolomites comprise transgressive-marine shelf carbonates deposited unconformably upon the low-relief surface of eroded Bass Islands strata (Gardner, 1974). During subsequent deposition of the Middle Devonian Detroit River Group, the northern part of the basin became more restricted until a series of salts and anhydrites were laid down with the carbonates. Landes (1951) feels that these salt beds were the result of leaching and redeposition of salt from the older Salina Group. The Mackinac Breccia is a term used to describe zones of fragmented, angular rock which encompass strata ranging in age from the Salina through the Detroit River. The breccia represents collapse structures that resulted from dissolution of the Salina salts in Middle Devonian time (Landes, 1959).

Following this, a series of limestones designated the Dundee Limestone and the Traverse Group were deposited, and this in turn was followed by deposition of the Late Devonian-Early Mississippian Antrim and Ellsworth Shales. Total thickness of Devonian strata ranges from several hundred feet in the south to 3,400 feet in the north-central part of the basin (Fisher, 1969).

Mississippian, Pennsylvanian, and Jurassic rocks consist chiefly of shales and sandstones, and they are restricted to the central part of the basin (fig. 6). Their aggregate thickness is about 3,000 feet in this region (fig. 5).

Thick glaciers covered all of Michigan and surrounding areas during the Pleistocene Epoch. A series of four major ice sheets advanced southward across the region and then retreated, leaving behind thick deposits of glacial drift that mantle the bedrock. Thickness of the drift is more than 200 feet in much of the State (fig. 7), but locally exceeds 850 feet in the north-central part of the Southern Peninsula (Akers, 1938). The drift is thin or absent locally, particularly in the northeast, northwest, south-central, and east-central portions of the basin (fig. 7).

The most significant structural feature affecting Paleozoic and younger rocks in the Michigan basin is the Howell anticline, a northwest-trending fold located in the southeast part of the basin. Ells (1969) regards this fold as the largest of several northwest-plunging, subparallel structures on a broad, uplifted block designated as the Washtenaw anticlinorium.

Northwest-trending anticlines with salt-filled cores are developed within Salina and younger rocks in the central part of the Michigan basin (Ells, 1967). These structures result from draping of strata over elongated lenticular masses of Salina salt that remained after salt underlying adjacent areas was dissolved by circulating ground water.

Major faults within the Michigan basin appear to be minimal. Probably the most significant fault is one on the west flank of the Howell anticline where a basement-rock fault presumably grades upward into a sharp flexure in Ordovician and younger strata (Ells, 1969).

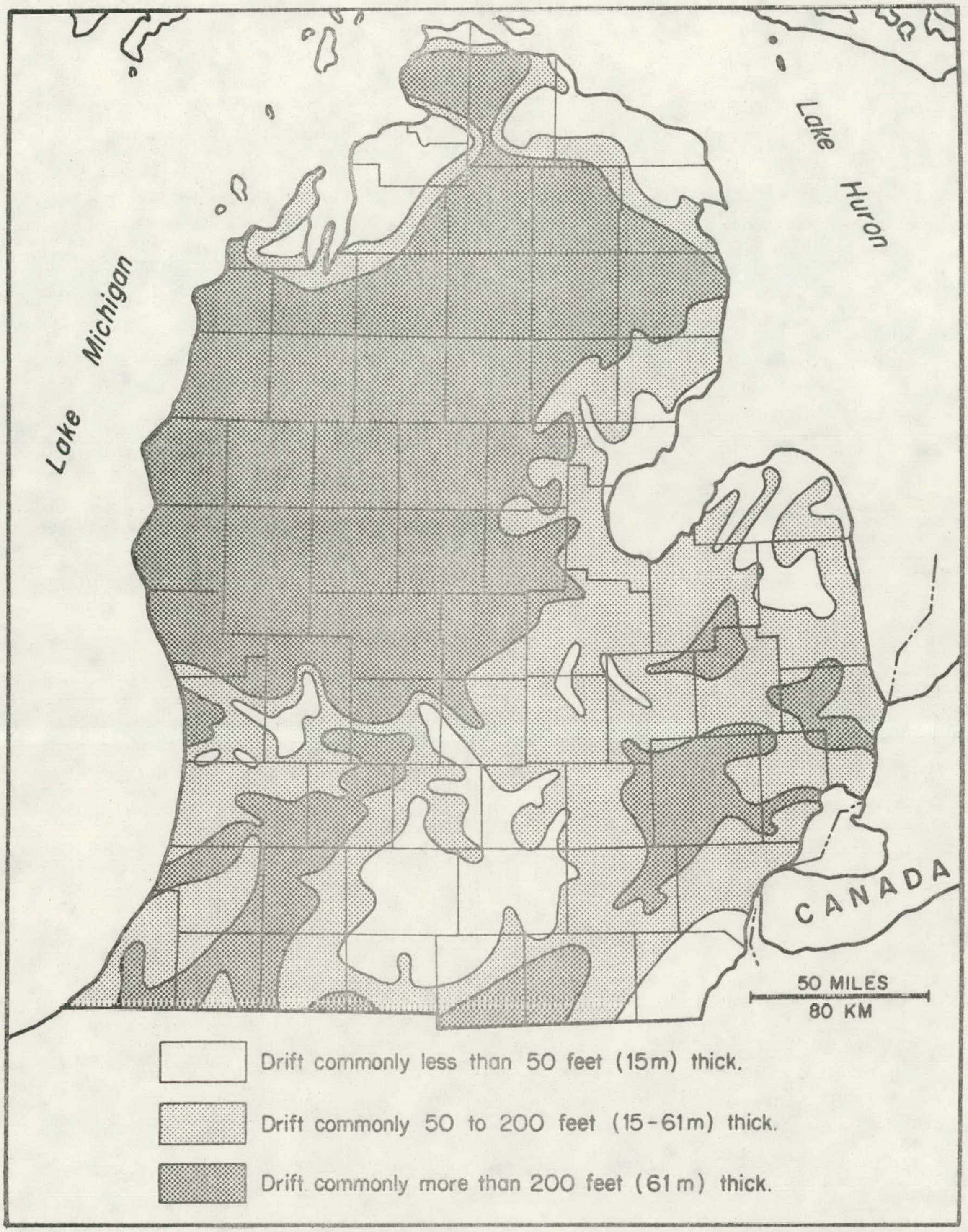


Figure 7. Map showing thickness of glacial drift in Michigan's Southern Peninsula (modified from Akers, 1938).

Locally, anomalous changes in dips and outcrop patterns suggest the presence of faults with small displacement, although in many cases the relationships are far from conclusive in proving the existence of faults. It has also been contended that certain surface lineaments detected on aerial photographs and satellite imagery may be the result of subsurface control due to faults (Prouty, 1976). More thorough regional and local studies are needed on possible faulting in the Michigan basin before any particular area can be considered free of such structures.

Thus, the history of the Michigan basin has been one of tectonic stability since the beginning of the Paleozoic Era. The region has not been affected by mountain-building processes, and the Salina salts and younger strata appear virtually free of significant deformation except near the Howell anticline and various salt-cored anticlines.

Since the final retreat of Pleistocene glaciers, land areas within the Michigan basin, relieved of a great weight of ice, have experienced some measure of glacial (elastic) rebound. Although the magnitude of rebound in certain parts of the World, such as the Scandanavian Peninsula and around Hudson's Bay, Canada, has been pronounced, the amount experienced in the Michigan basin is smaller by comparison. Glacial rebound in this area, moreover, does not pose a deformational hazard.

In some geologic settings, the natural processes of erosion and denudation have the potential, over long periods of geologic time, for stripping away a significant thickness of overburden and subjecting radioactive wastes buried at then-shallow depths to circulating ground and surface waters. Based upon the general knowledge of the landscape and on the sediment loads of streams draining this area (Great Lakes Basin Commission, 1975), however, it appears that the rates of denudation and stream incision in the Michigan basin would range up to only a few hundred feet over the next several hundred thousand years, and that the north half of the Southern Peninsula is being eroded at a much slower rate than the south half. The integrity of radioactive wastes buried between 1,000 and 3,000 feet below the present-day land surface would therefore be maintained over a sufficiently long period of time.

Soluble rocks, such as salt, gypsum, limestone, and dolomite, can be dissolved by surface waters and by ground waters. Sinkholes and other karst-like features are known in some areas of limestone and dolomite outcrop in the Michigan basin, and the dissolution of salt deposits is discussed in the next chapter.

SALT DEPOSITS IN MICHIGAN

Salina Group

The Salina Group contains the major deposits of rock salt (halite) in the Michigan basin. The Salina consists of a number of stratigraphic units that are equivalent to formations, with each unit composed predominantly of salt, carbonates, or shales. Individual units have a similar lithologic character over a wide geographic area, and the distinctive mechanical-log curves for each unit permit reliable correlations over large distances (Ells, 1967).

The greatest thickness of salts in the Salina Group is in the center of the basin, where salt has an aggregate thickness of more than 2,000 feet and exists at depths greater than 6,500 feet below land surface (fig. 8). Both the aggregate thickness of salts and the depth below land surface to the top of the salts in the Salina decrease outward from the center of the basin (fig. 9). The depth to the top of the Salina salts (and each of the salt units discussed in this chapter) is contoured based upon data interpreted from mechanical logs of 30 wells drilled throughout the basin.

An example of the lithology of the Salina Group, as interpreted from mechanical and sample logs, is presented in Figure 10 for an oil-well test drilled near the edge of the basin where the various salts are moderately thick and are at fairly shallow depths. The current terminology and rock divisions of the Salina Group are based largely on the

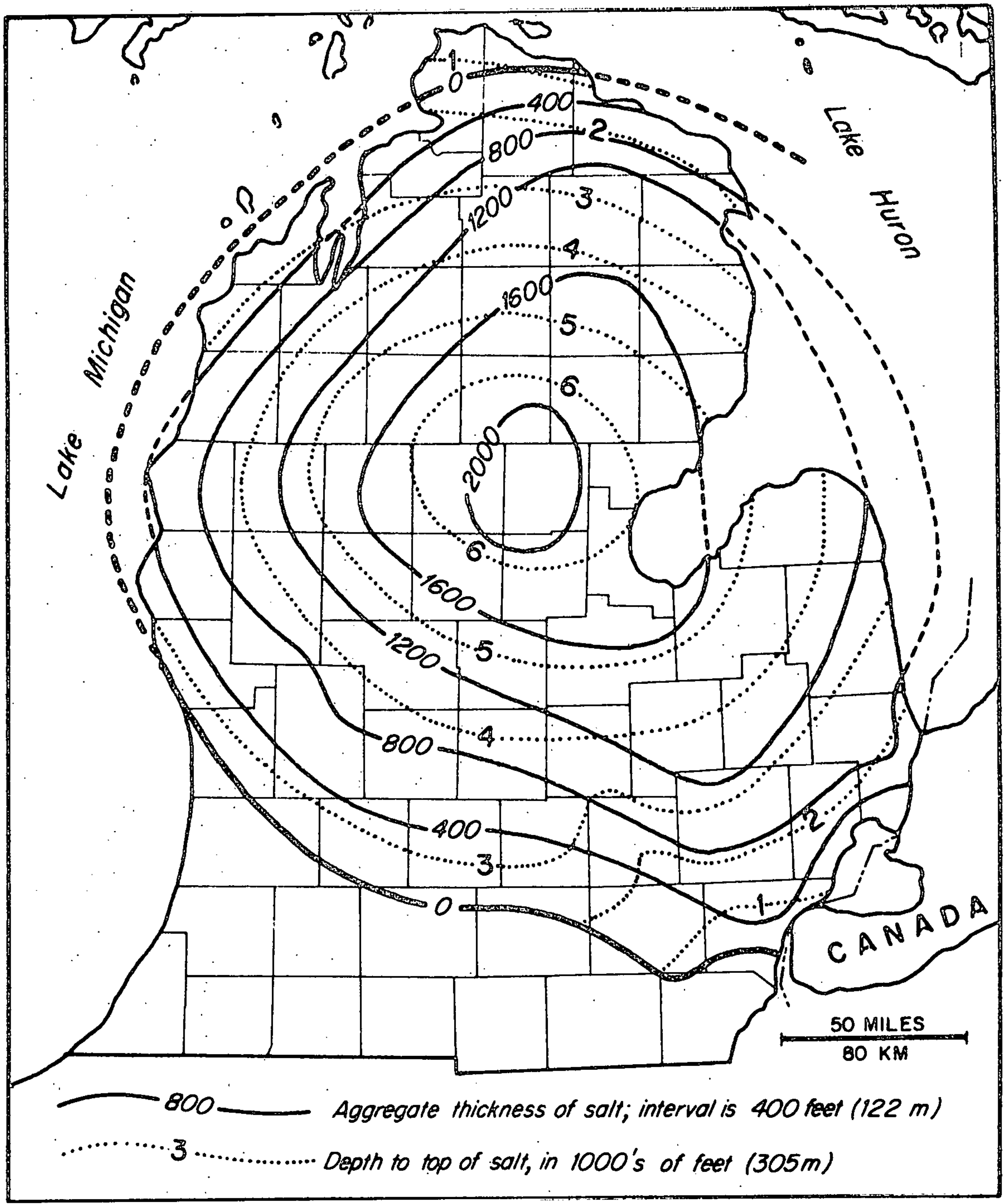
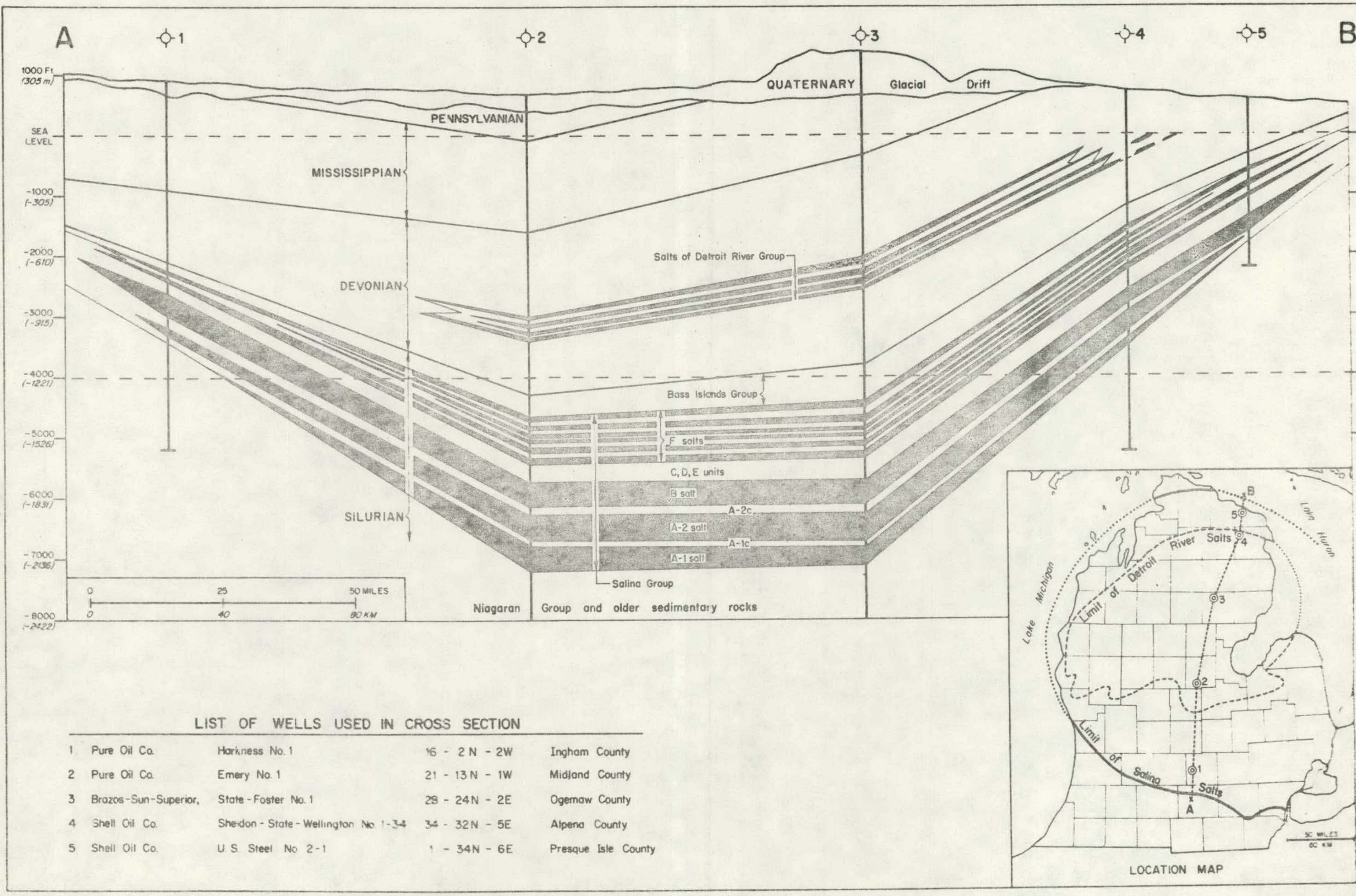


Figure 8. Map showing aggregate thickness and depth to top of salt beds in Salina Group (Silurian). Modifed from Hardenberg (1949a, 1949b).



LIST OF WELLS USED IN CROSS SECTION

1	Pure Oil Co.	Harkness No. 1	16 - 2 N - 2W	Ingham County
2	Pure Oil Co.	Emery No. 1	21 - 13 N - 1W	Midland County
3	Brazos-Sun-Superior,	State - Foster No. 1	28 - 24 N - 2E	Ogemaw County
4	Shell Oil Co.	Sheldon - State - Wellington No. 1-34	34 - 32 N - 5E	Alpena County
5	Shell Oil Co.	U. S. Steel No. 2-1	1 - 34 N - 6E	Presque Isle County

Figure 9. Generalized north-south cross section through Michigan basin showing principal salt deposits of Silurian and Devonian age.

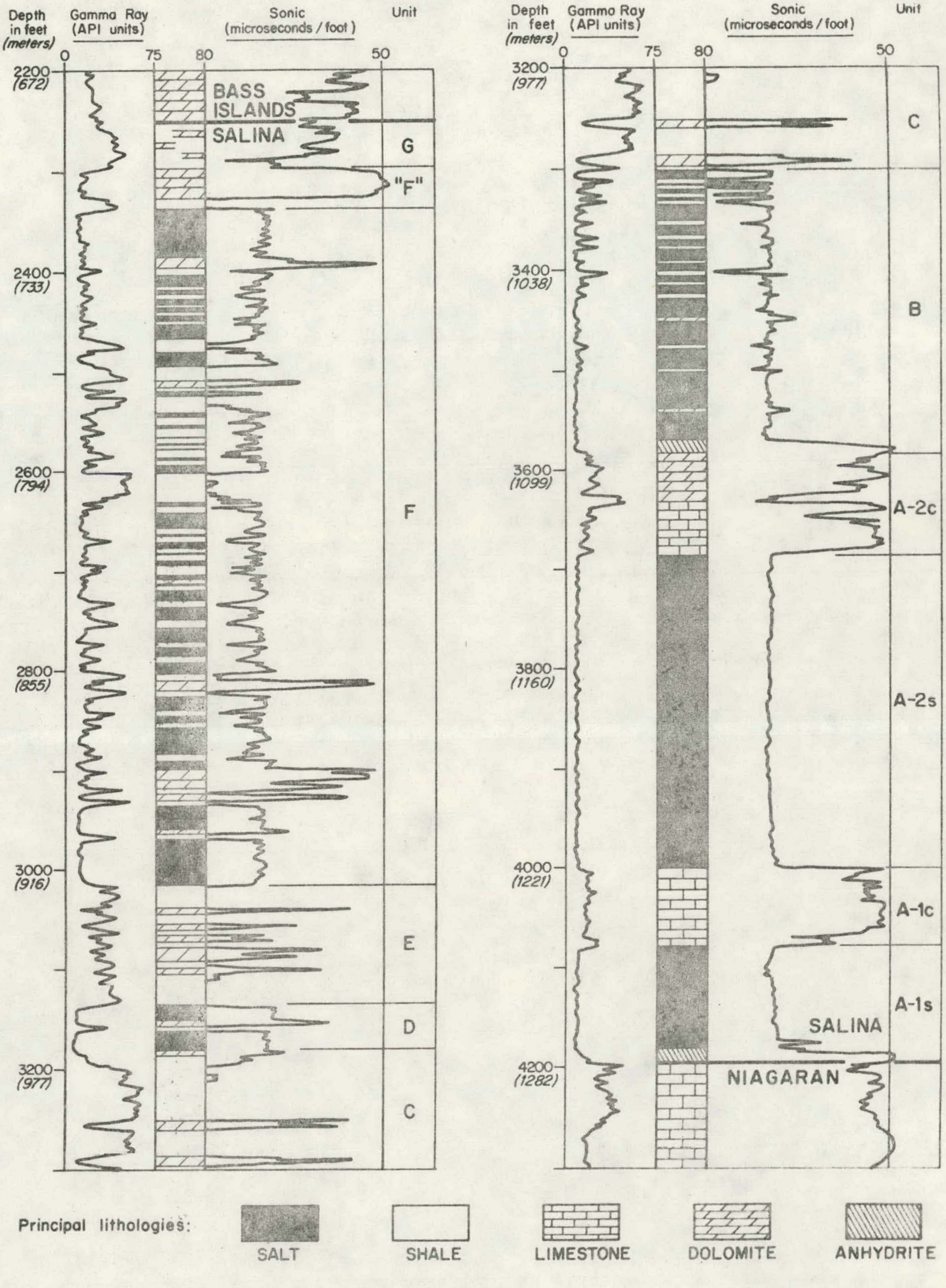


Figure 10. Lithology and mechanical logs of Salina Group near northeast margin of Michigan basin. Logs from Shell Oil Co., Sheldon-State-Wellington No. 1-34, sec. 34, T. 32 N., R. 5 E., Alpena County. Lithology interpreted from mechanical logs and sample log.

work of Landes (1945) and Evans (1950). Landes divided the Salina Group into units A through G, from oldest to youngest, and Evans further divided the A units. The following descriptions of individual units are largely from the reports by Ells (1967) and Mesolella and others (1974):

A-1 Salt

The A-1 salt is the deepest unit of the Salina Group, and rests conformably upon the limestones and dolomites of the underlying Niagaran Group. The A-1 contains clean salt in most parts of the basin interior, but also contains a few thin layers of potash (Anderson and Egleson, 1970; Mathews, 1970) in deeper parts of the basin.

Thickness of the A-1 salt is more than 200 feet in most parts of the basin interior, reaching some 475 feet in the center (fig. 11). Towards the margins of the basin the salt thins abruptly and grades laterally into anhydrite near the basinward edge of the Niagaran reef platform.

The depth to the top of the A-1 salt is as much as 8,000 feet in the central part of the basin, but in the northeast and southwest parts of the basin the salt is only a little more than 3,000 feet below the surface (fig. 11).

A-2 Salt

The A-2 salt is the thickest massive salt unit in most parts of the Michigan basin. It is separated from the deeper A-1 salt by the A-1 carbonate (fig. 10). The A-2 contains clean salt in the interior of the basin, but it grades laterally into anhydrite along the margins of the basin.

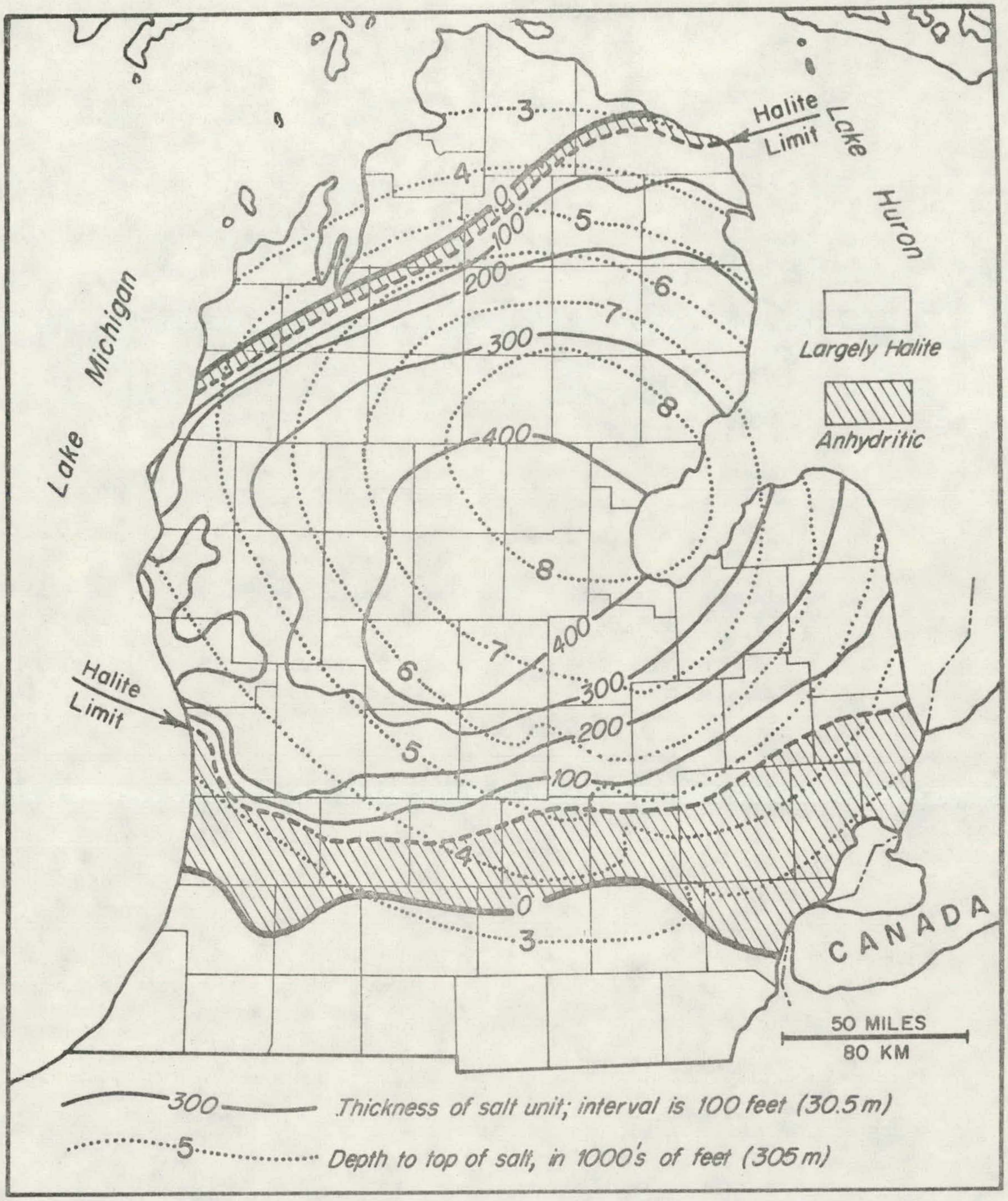


Figure 11. Map showing thickness and approximate depth to top of A-1 salt unit in Salina Group. Thickness data from Mesolella and others (1974).

The thickness of the A-2 salt is more than 300 feet in most areas, and exceeds 475 feet in the deeper parts of the basin (fig. 12). The depositional limits of salt are approximately the same as that of the A-1 salt.

In the central part of the basin the top of the A-2 salt is more than 7,000 feet below the land surface (fig. 12). The depth to the top of the salt decreases towards the edge of the basin and is only 3,000 to 4,000 feet in the southeast, southwest, and northeast parts of the basin.

B Salt

The B salt, the next youngest salt unit, consists of clean salt in the lower part and salt with thin interbeds of shale and dolomite in the upper part. It is underlain by the A-2 carbonate, by which it is separated from the deeper A-2 salt (fig. 10). As with the older salts, the B grades laterally into anhydrite towards the margin of the basin; but the salt extends farther to the north and southeast than the other salts (fig. 13).

Thickness of the B salt is more than 300 feet in most parts of the basin interior, and it reaches more than 475 feet in the center (fig. 13). The clean salt in the lower part commonly comprises about one-half the total thickness of the B unit.

The depth to the top of the B salt is just over 7,000 feet in the central part of the basin (fig. 13). The salt is only 2,000 to 3,000 feet below the surface in the southeast, southwest, northeast, and northwest parts of the basin.

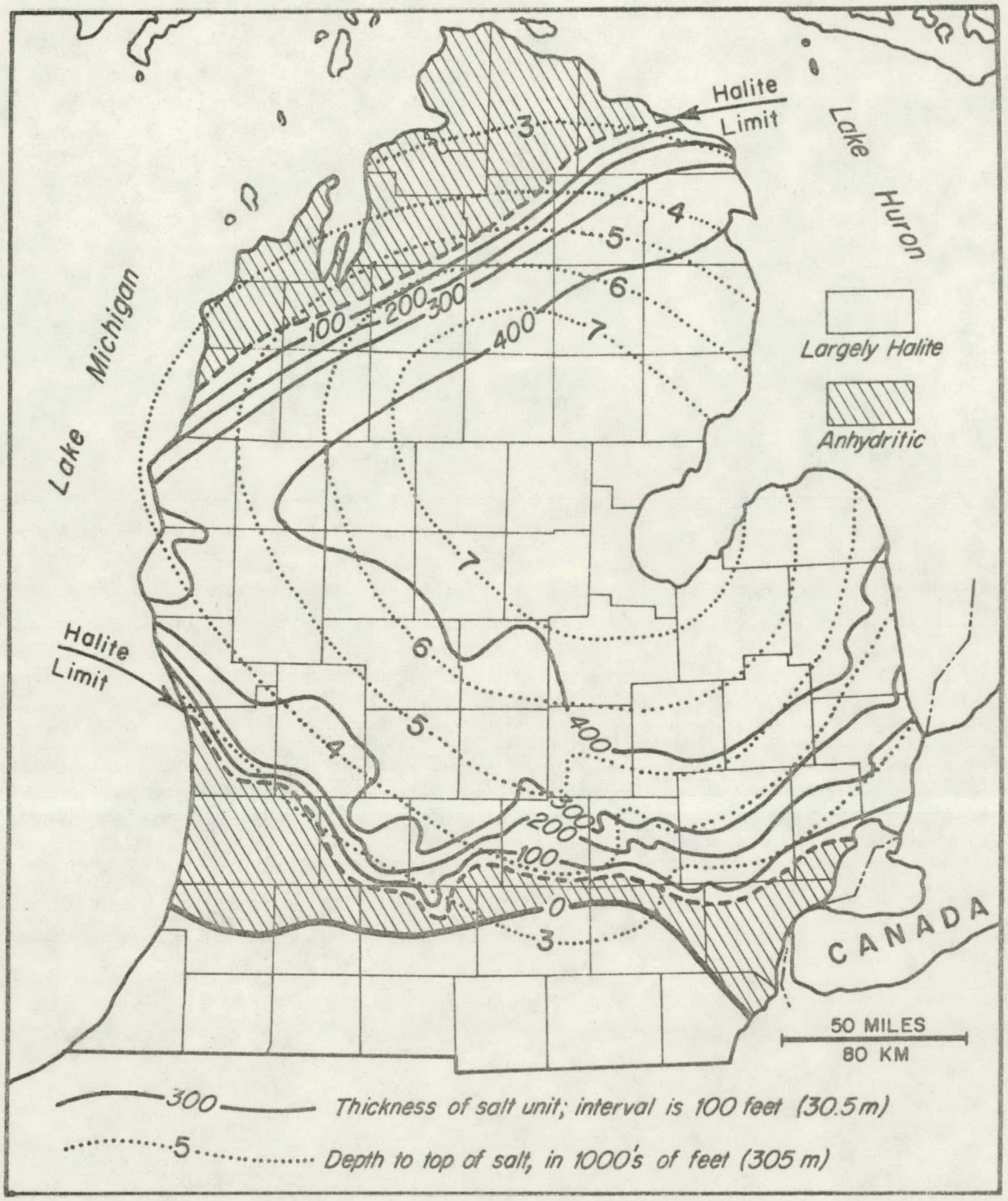


Figure 12. Map showing thickness and approximate depth to top of A-2 salt unit in Salina Group. Thickness data from Mesolella and others (1974).

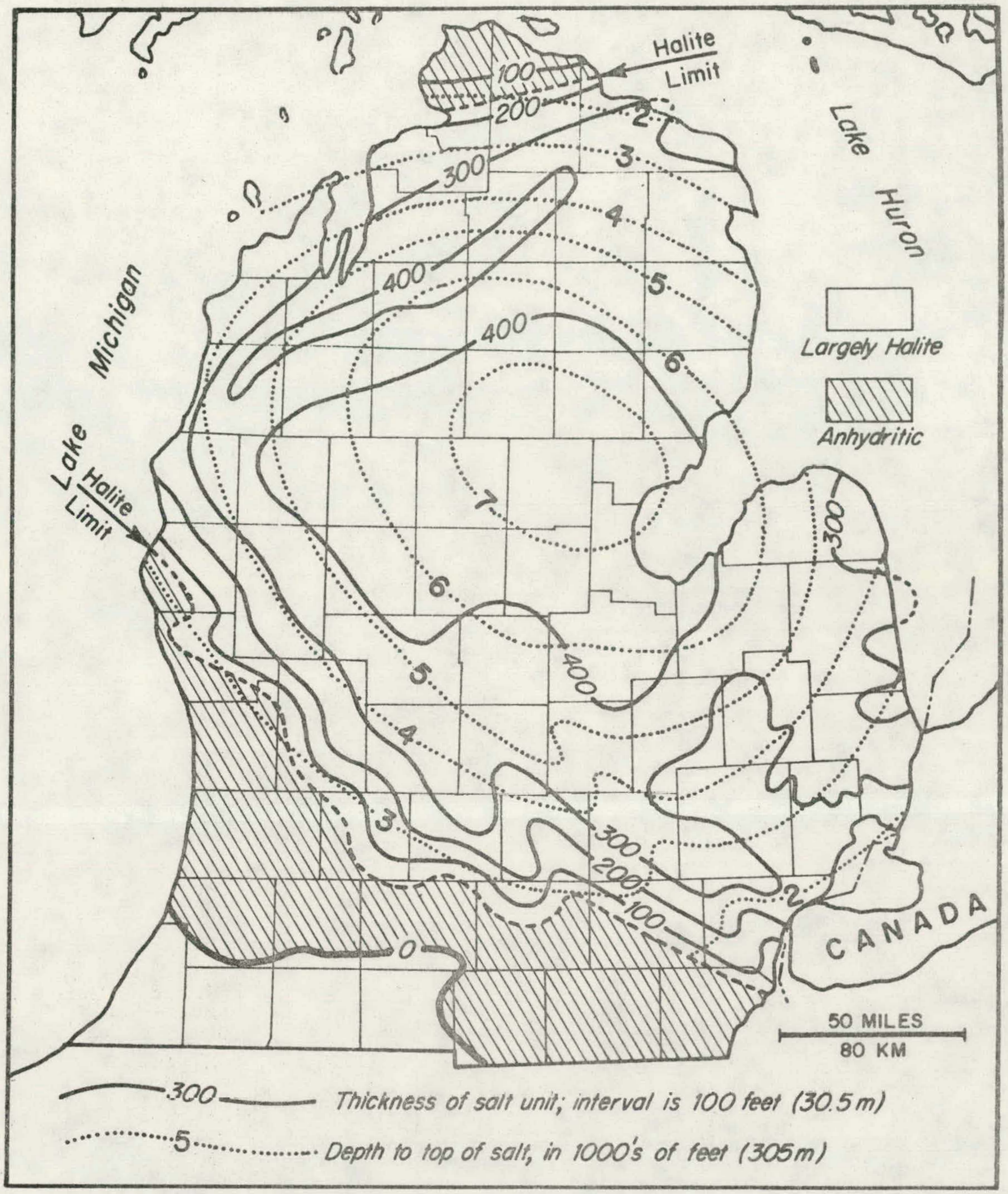


Figure 13. Map showing thickness and approximate depth to top of B salt unit in Salina Group. Thickness data from Mesolella and others (1974).

D Salt

The D unit consists of two moderately thin salt beds separated by a thin medial dolomite bed (fig. 10). Total thickness of the unit ranges from 40 to 100 feet, and thus it clearly is too thin to be considered as a host rock for storage of radioactive waste.

F Salt

The F unit is a succession of pure and impure salt beds interbedded with shale, dolomite, and anhydrite (fig. 10). It contains the youngest (shallowest) salts of the Salina Group in the Michigan basin.

The F salts, like others in the Salina, are thickest in the central part of the basin. Total thickness of the F unit is a maximum of nearly 970 feet in Ogemaw County, but it thins toward the margin of the basin due chiefly to depositional thinning of the salt beds (Ells, 1967). In some parts of the basin the salt has been removed by pre-Devonian erosion, and in other areas some of the salts may be thin or missing due to dissolution by ground water.

Most of the individual salt beds in the F unit are only 5 to 20 feet thick, but the two bottom beds and the top bed commonly are massive salts 30 to 60 feet thick (locally as much as 100 feet thick).

Inasmuch as the F unit is the youngest salt in the Salina Group, its depth below ground level is the same as that of the Salina (fig. 8). The top of the F salts is less than 3,000 feet deep along the southern and northern margins of the basin.

Detroit River Group

The Detroit River Group of Devonian age contains the youngest salts in the Michigan basin (figs. 5 and 9). Salt occurs in many separate units (fig. 14) that are interbedded with anhydrite, limestone, and dolomite (Gardner, 1974). The salt beds are 20 to 80 feet thick, although the uppermost salt reaches 115 feet thick in Kalkaska and neighboring counties.

Aggregate thickness of salts in the Detroit River Group ranges from 100 to 500 feet in much of the northern part of the Michigan basin (fig. 15). The thickness decreases towards the margin of the basin, partly due to depositional thinning of the salts and partly due to dissolution of the salt (mainly in the northern part of the salt area).

The depth to the top of the Detroit River salts is as much as 4,000 feet in the central part of the basin, but moderately thick salts are only 2,000 to 3,000 feet below the surface in the north.

Salt Dissolution

It is clear that in parts of the Michigan basin dissolution of salt beds has occurred in the past. Abrupt thinning and termination of some salt units near the edge of the basin, and development of salt-cored anticlines within the basin have been attributed mainly to dissolution of Salina (and perhaps Detroit River) salts in Silurian and/or Devonian time (Ells, 1967; Landes, 1959). Dissolution and removal of the salts caused overlying rock units to become brecciated as they

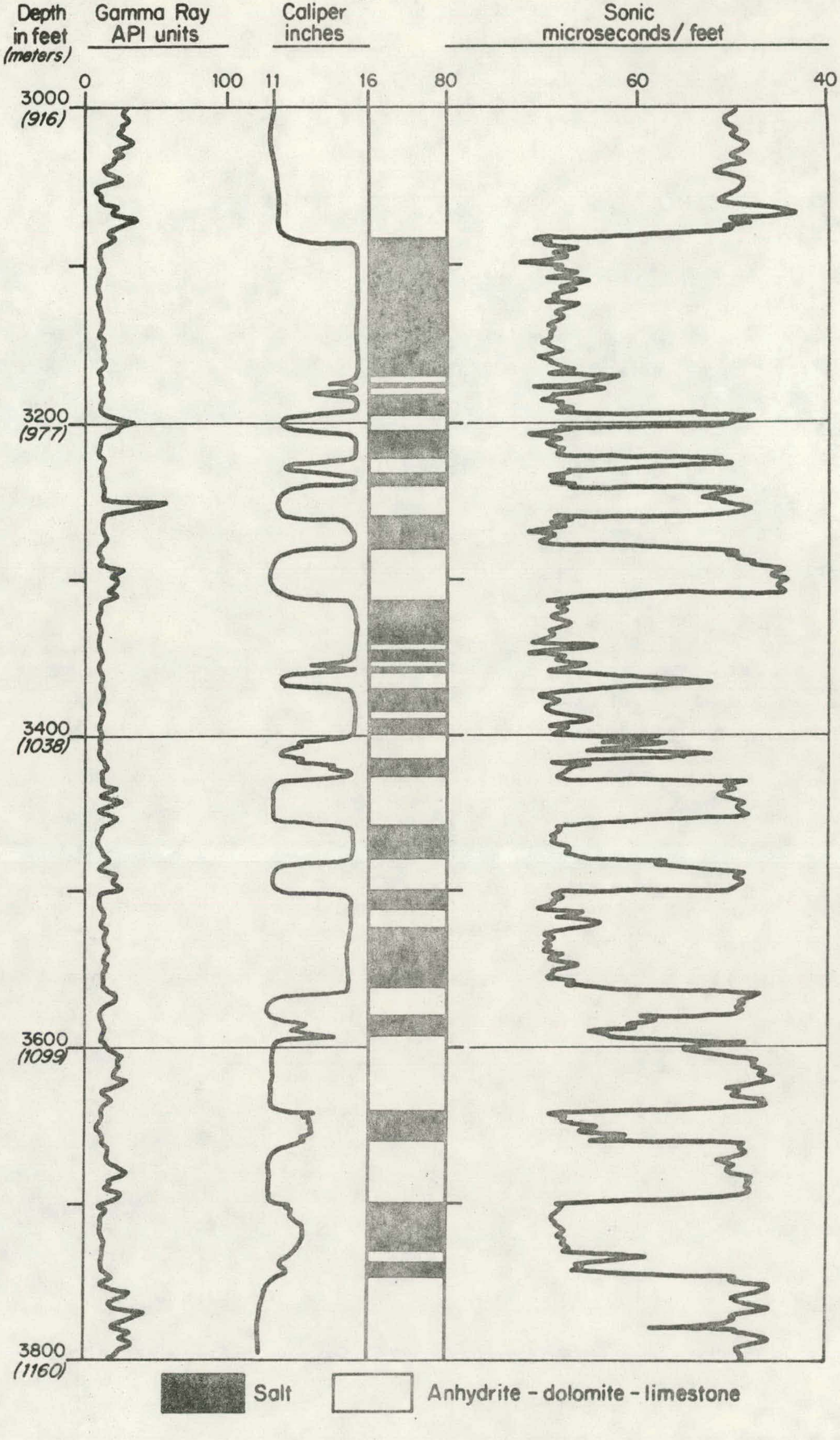


Figure 14. Lithology and mechanical logs of salt-bearing strata in Detroit River Group. Logs of Shell Oil Co., Shell Kerr No. 1-4, sec. 4, T. 28 N., R. 4 W., Crawford County. Lithology interpreted from mechanical logs.

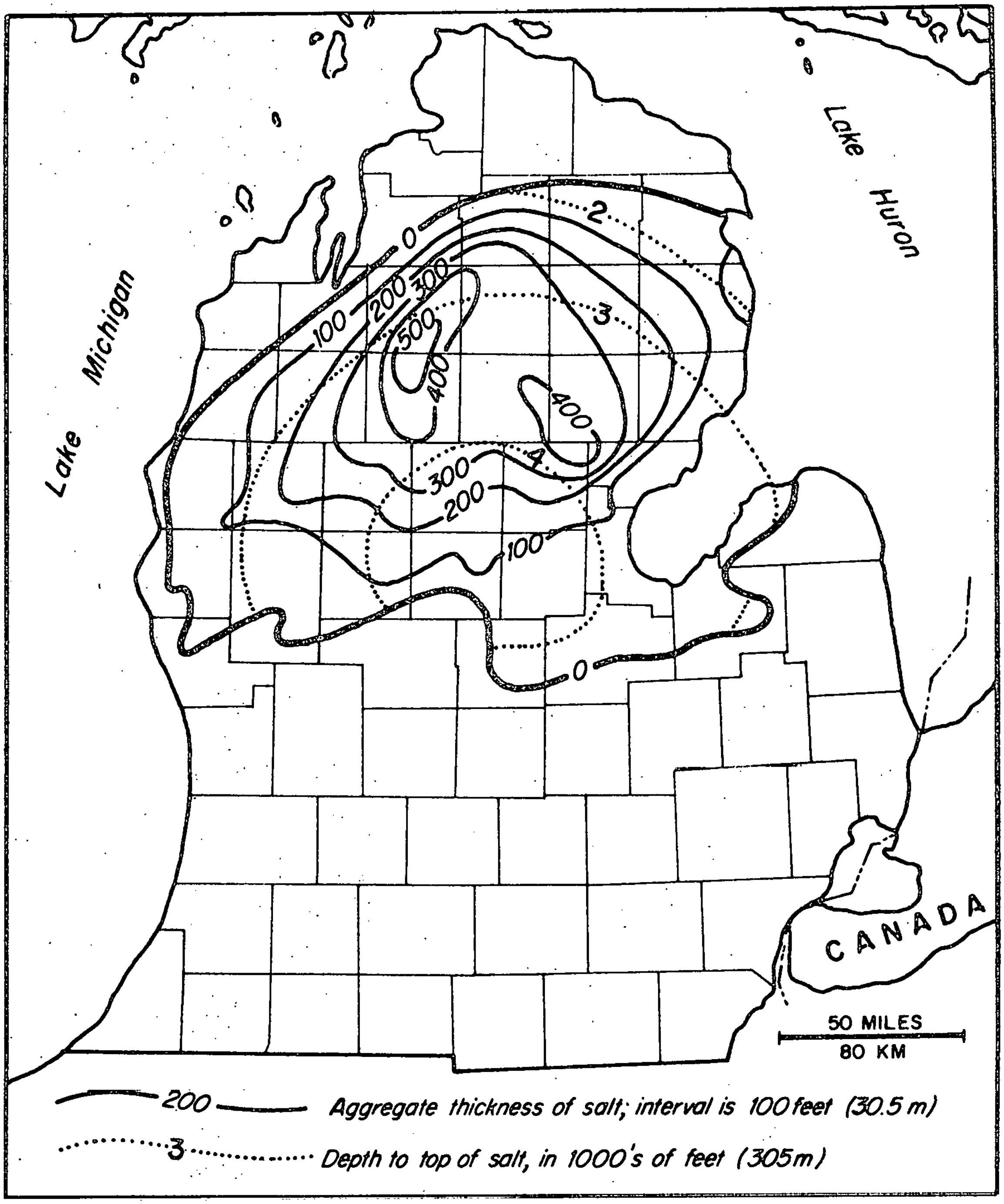


Figure 15. Map showing aggregate thickness and depth to top of salt beds in Detroit River Group (Devonian). Modified from Michigan Geological Survey (no date, a and b).

collapsed into the solution cavities, thus forming units such as the Mackinac Breccia (Landes, 1959).

In addition to areas where dissolution has occurred shortly after salt deposition, there may be other areas in the Michigan basin where salt beds are currently being dissolved. Where salt deposits are near the land surface, ground waters can migrate through the surrounding rocks and dissolve the salt. Such solutioning water must continue to move through the system, otherwise, by remaining in contact with the salt, the water becomes saturated and further solution is not possible. The movement of water occurs through aquifers (porous layers of limestone, dolomite, or sandstone) and also through fractures, joints, sinkholes, collapse features, and other openings that enable vertical interconnections between formations. Subsequent studies should establish the exact extent to which salt dissolution is now occurring because of the possible adverse effect this phenomena would have on the long-term safe isolation of high-level radioactive waste in underground salt beds.

HYDROLOGY

Surface Water

Surface drainage in the Southern Peninsula consists of streams and rivers that flow toward Lake Michigan and Lake Huron (fig. 1). The headwaters and drainage areas are within the State, except in the south where some of the streams flow through parts of Ohio and Indiana. Principal rivers in the State include: St. Joseph, Grand, Muskegon, Manistee, and Au Sable Rivers. Numerous lakes also are present in the Lower Peninsula.

Nearly all the water in the streams, rivers, and lakes comes directly from precipitation and runoff, but some is derived from springs emerging from glacial drift and bedrock. Small amounts of excess or used water produced from water wells adds to the discharge slightly. Average annual precipitation ranges from 26 to 36 inches: it is 26 to 30 inches in most parts of the northeast, and is 30 to 36 inches in most of the southwest.

Water from the Great Lakes is used extensively by municipalities and industries located near these water bodies. Inland from the Great Lakes, the many lakes and rivers are a major source of fresh water for municipal, industrial, and rural use.

Ground Water

In most parts of the Southern Peninsula that are remote from Lake Huron or Lake Michigan, glacial drift is the common source of fresh ground water for urban, industrial, and rural water supplies (fig. 16). Thickness of the drift ranges from 50 to more than 800 feet in most parts of the State (fig. 6). Where it is thick and chiefly consists of sand, it is easily recharged by precipitation. In those areas, large volumes of fresh ground water are stored and water wells provide good yields for long periods of time. Where the drift is thin and consists mostly of clay, little water infiltrates into the drift, and well yields are small or nonexistent.

The yields of water wells in glacial drift range from 10 gpm (gallons per minute) to more than 500 gpm in many parts of the Southern Peninsula (fig. 17). The areas of highest yield generally coincide with the areas of thickest drift. Yields of less than 10 gpm can be expected in several large areas of thin drift in the south-central, east-central, and northern parts of the region.

Water in the glacial deposits is generally of good quality, but it is moderately hard. It commonly contains between 200 and 500 ppm (parts per million) of total dissolved solids, and its hardness (expressed as $CaCO_3$) is 175 to 350 ppm (Piper, 1972). In the lowest part of the drift, or through most of its thickness where the drift is thin, water quality decreases due to an increase in calcium (Ca) and sulfate (SO_4) ions and, locally, in sodium (Na) and chloride (Cl) ions. This increase in dissolved solids near the lower part of the drift results from mixing between the more-saline waters of the underlying bedrock and the fresh waters in the drift.

Limestone, dolomite, and sandstone bedrock underlying the glacial drift provide fresh ground water in some parts of the Southern Peninsula,

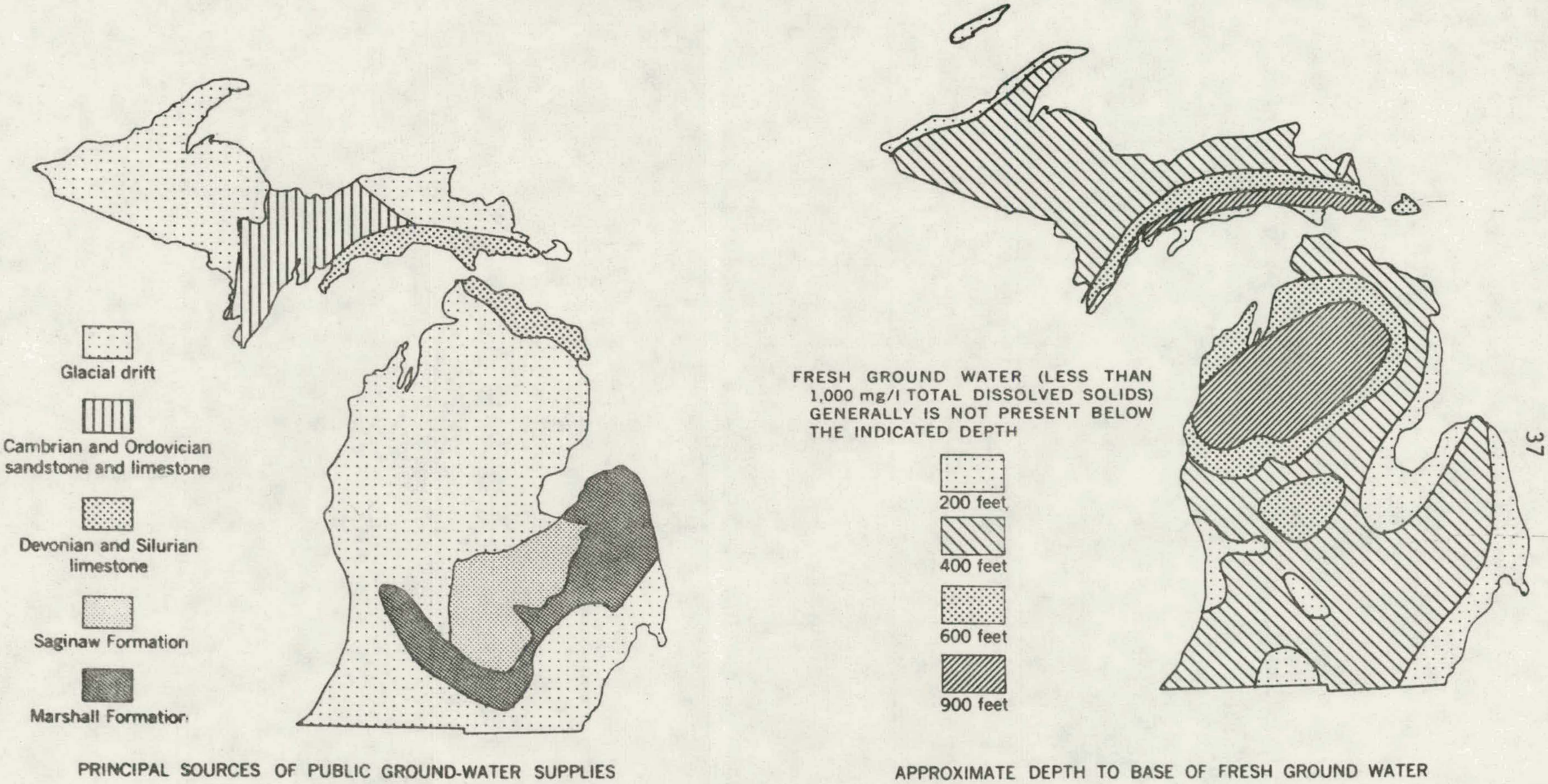


Figure 16. Principal sources of public ground-water supplies and approximate depth to base of fresh ground water in Michigan. Reproduced from U.S. Geological Survey pamphlet on Water Resources Investigations in Michigan.

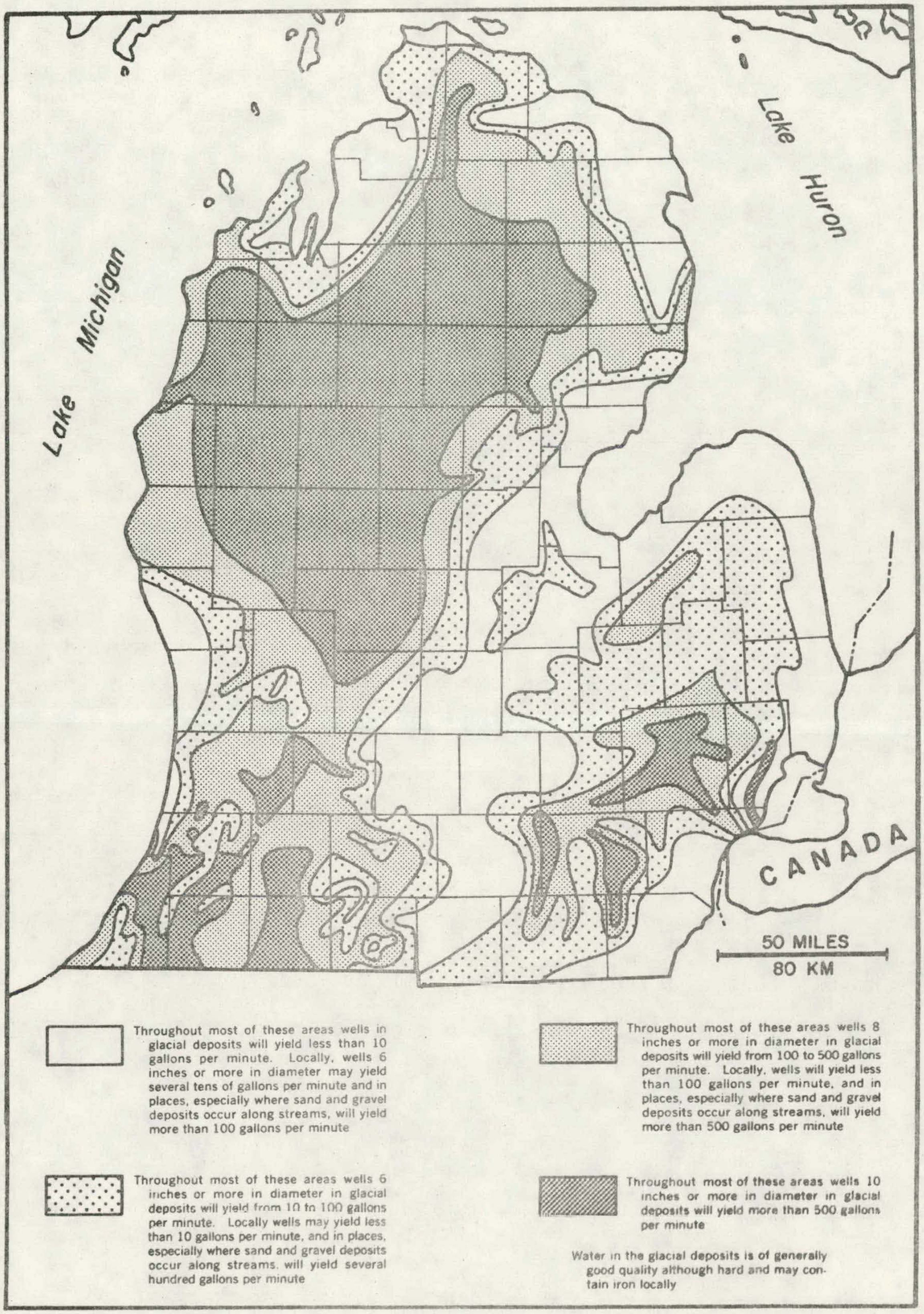


Figure 17. General availability of ground water in glacial drift deposits in Michigan's Southern Peninsula (after Twenter, 1966a).

particularly in the south-central, east-central, and northeast areas (fig. 16). Yields of less than 100 gpm are fairly common, but a few wells have recorded yields in excess of 500 gpm (fig. 18). The higher yields are commonly from sandstones and some of the limestones, whereas the lowest yields (less than 10 gpm) are from the shales.

Principal bedrock aquifers in the Southern Peninsula include the Saginaw Formation (Pennsylvanian) and Marshall Sandstone (Mississippian) in the south-central and eastern parts of the region, and a series of Devonian limestones and dolomites (Traverse Group, Dundee Formation and Detroit River Group) in the northeast (fig. 16). These, and other, bedrock aquifers yield ground water of good quality at many places where they are within several hundred feet of the land surface.

All bedrock formations in the basin contain saline or mineralized water at depth. The base of the fresh-water zone in these aquifers ranges from less than 200 feet to more than 900 feet in different areas (fig. 16). Below these depths, the water is generally too saline for any practical water-related use. Natural brines are, however, commercially obtained in certain areas and are processed for mineral commodities.

Another geohydrologic application which has been widely instituted in the Michigan basin is development of industrial-waste-disposal wells (Ives and Eddy, 1970; Warner and Orcutt, 1973). Subsurface saline aquifers, where sufficiently permeable and thick and overlain by an effective impermeable seal, have been utilized for disposal through injection of a variety of process brines, chemical effluents, and other liquid wastes. In fact, the first industrial-waste-disposal well approved and regulated

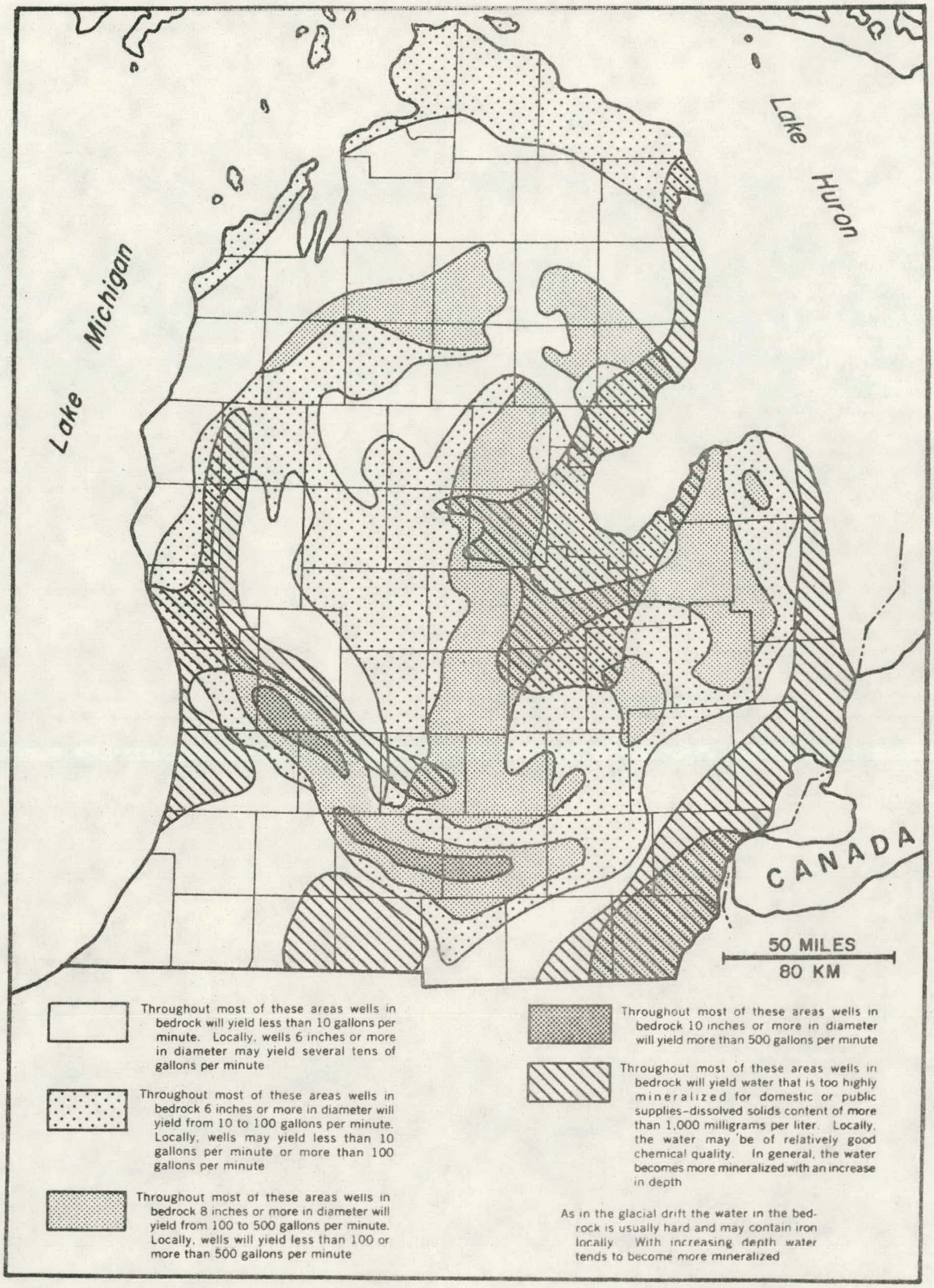


Figure 18. General availability and quality of ground water in the bedrock deposits in Michigan's Southern Peninsula (after Twenter, 1966b).

by a state was installed in Michigan in 1950. Several different disposal horizons within the Paleozoic rock sequence have been utilized; the largest concentration of these disposal systems is in the Midland area.

SEISMIC ACTIVITY

Recorded seismic activity in the Michigan basin and surrounding areas is low, compared to most other parts of the United States. Earthquakes having a Modified Mercalli Intensity of V (MM V) or greater are sparse in the region (Coffman and von Hake, 1973), except in northwestern Michigan and in western and northeastern Ohio (fig. 19). Earthquakes in nearby parts of Canada with an Instrumental Magnitude of 3.5 (M_L 3.5) or greater are sparse, according to Smith (1966). The entire Michigan basin is within zone 1 (expected minor damage) on the seismic-risk map prepared by S. T. Algermissen (ESSA/Coast and Geodetic Survey, 1969).

Only two earthquakes of MM V or greater have been recorded in that part of the Michigan basin underlain by the Salina salt sequence, and both these events were in the southern half of the area. Thus, the northern half of the Michigan basin appears to be more favorable seismically than other parts of the basin for the terminal storage of radioactive waste in salt.

The four earthquakes of MM V or MM VI recorded in Michigan's Lower Peninsula occurred in the south (Coffman and von Hake, 1973). Earthquakes occurred near the head of Saginaw Bay in 1872 (MM V), in southeast Michigan in 1877 (MM IV-V), near Kalamazoo in 1883 (MM VI), and in south-central Michigan in 1947 (MM VI). Other earthquakes recorded in Michigan have been located in the Upper Peninsula, and include events at Menominee in 1905 (MM V), at Calumet in 1905 (MM VI),

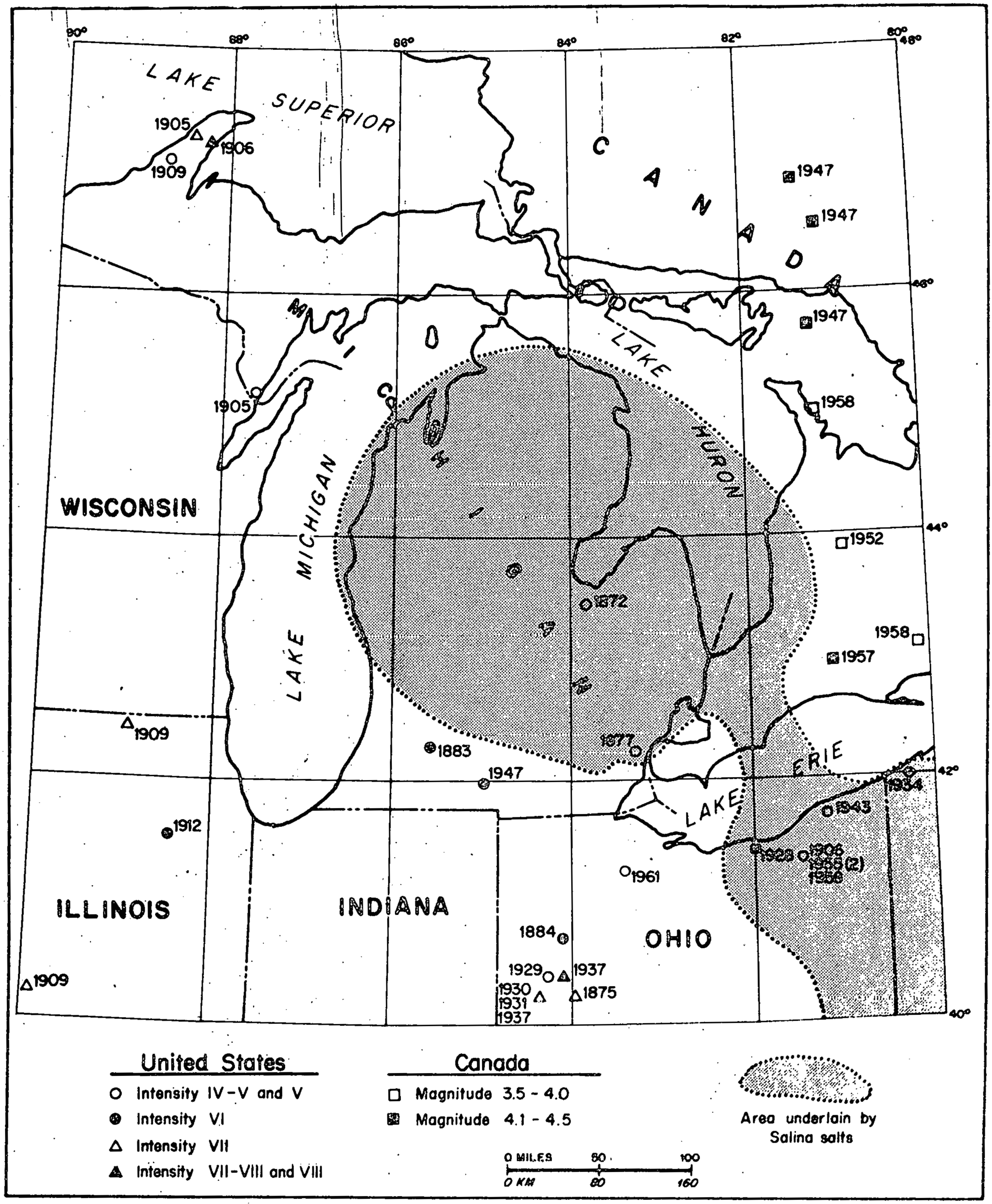


Figure 19. Map showing epicenters of earthquakes of (at least) MM V or M_L 3.5 in Michigan and surrounding areas. United States data through 1970 (Coffman and von Hake, 1973) and Canadian data through 1959 (Smith, 1966).

on the Keweenaw Peninsula in 1906 (MM VIII), and at Houghton in 1909 (MM V).

Two areas of more-frequent seismic activity are in western and northeastern Ohio. The cluster of earthquakes in western Ohio, including those near Anna, occurred in 1875 (MM VII), 1884 (MM VI), 1929 (MM V), 1930 (MM VII), 1931 (MM VII), 1937 (MM VII), and 1937 (MM VII-VIII). Those in the Cleveland area of northeastern Ohio included one event of MM IV-V, in 1943, and five events of MM V in 1906, 1928, 1955 (2), and 1958. The only other events greater than MM VI in the United States part of the region (fig. 19) are two events that occurred in 1909 (MM VII) in central and north-central Illinois.

The larger earthquakes in Canada include events during 1947 near Sudbury (M_L 4.4), near Laforest (M_L 4.3), and in Georgian Bay (M_L 4.5), and a later event in 1957 near London (M_L 4.2).

MINERAL RESOURCES

Oil and Gas

Oil and gas are produced in the Michigan basin from reservoir rocks of Ordovician, Silurian, Devonian, and Mississippian age (Ells and others, 1974; Netherland, Sewell and Associates, 1975). Most of the oil and gas fields in central and southwestern Michigan produce from reservoirs above the Silurian salt deposits (fig. 20). These fields generally produce from structures located along salt-cored anticlines that trend northwest to southeast. More than 20 major anticlines are present in this part of the state. Many dry holes have been drilled along these folds in order to connect the productive areas, and in recent years drilling in this province has decreased.

Fields producing from Silurian (Niagaran) reefs are concentrated in distinct bands or clusters: one is the northeast-southwest band across northwestern Michigan; another is the east-west band across the south-central part of the state; and the third is a cluster in the southeast. The fields in these bands are prolific and produce from the pinnacle reefs that developed in the shelf area that rimmed the Michigan basin in Niagaran time. Reefs have not been found in the central portion of the basin where the northwest-southeast trending post-Silurian fields are located.

The first commercial oil well in the pinnacle reefs of northern Michigan was completed in 1952 in Mason County (Mesolella and others,

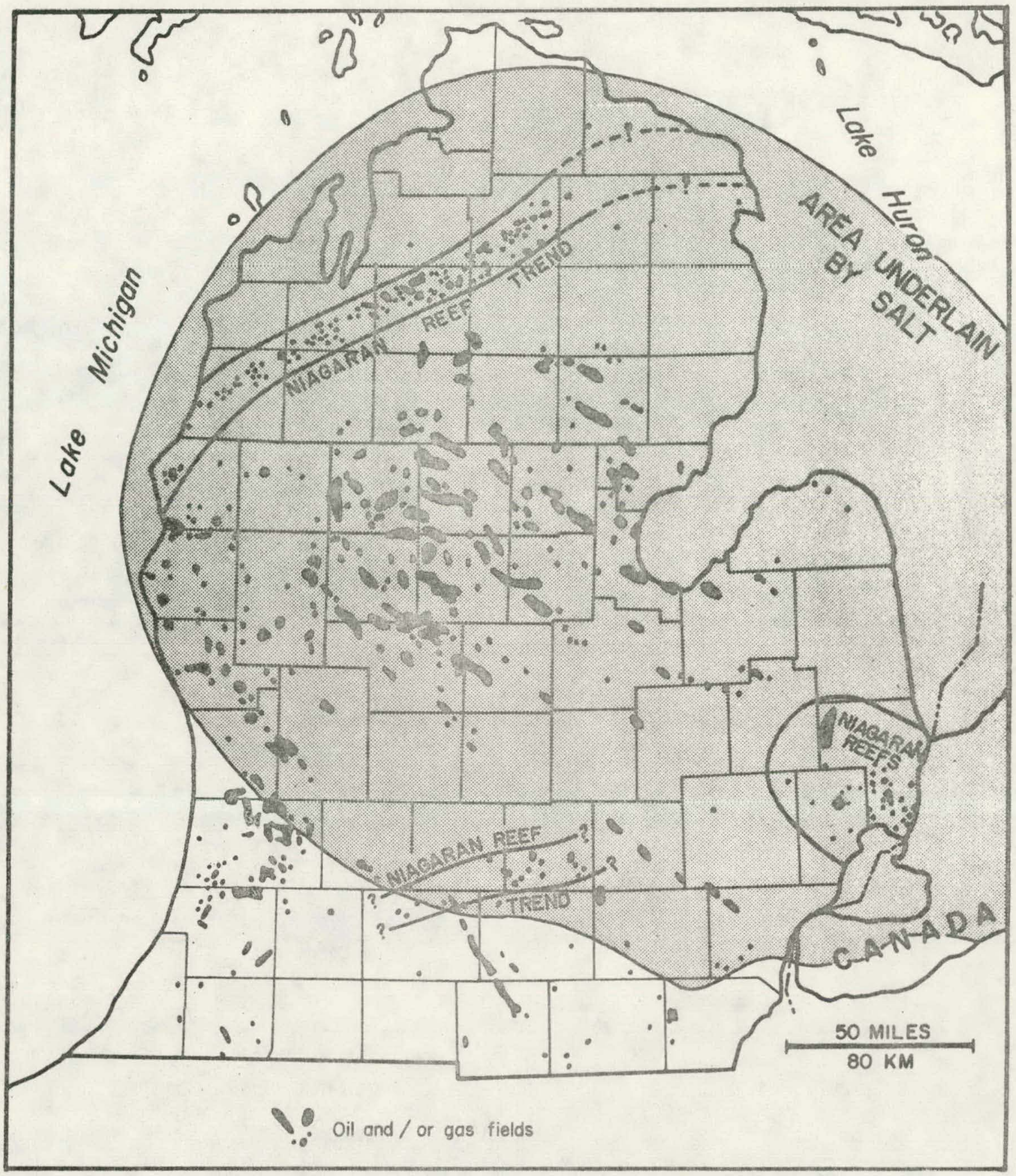


Figure 20. Map of oil and gas fields in Michigan (after Ells and others, 1974; Netherland, Sewell and Associates, 1975).

1974). Other tests that penetrated the Niagaran and Salina carbonates commonly exhibited noncommercial shows of hydrocarbons. In 1969, however, three exploration wells confirmed the presence of commercial quantities of petroleum within Niagaran reefs, and this precipitated a boom of drilling activity that resulted in completion of many commercial oil and gas wells within the northeast-trending band of reefs. The "fairway" in which the pinnacle reefs occur is about 10 miles wide and now extends 160 miles from Mason County on the southwest to Presque Isle County, and it is believed (Briggs and Briggs, 1974; Mantek, 1973) that this trend extends eastward through southern Presque Isle County (fig. 20).

Fields producing from Ordovician reservoirs are those near the southern border of the State, and they generally lie outside the area underlain by thick salts in the Salina Group.

Petroleum production for the State during 1974 amounted to 18 million barrels of oil and 70 billion cubic feet of natural gas (fig. 21), and the value of petroleum production was nearly 20% of Michigan's total mineral output for the year.

Although a considerable number of oil and gas tests have been drilled in Michigan, the majority of these tests is concentrated in specific areas and along specific trends (Netherland, Sewell and Associates, 1975). Therefore, sizeable areas of the Michigan basin contain only a few boreholes, and there are other sizeable areas where no wells (other than shallow water wells) have been drilled (fig. 22).

Netherland, Sewell and Associates (1975) concluded, based upon their preliminary study and the data in Figures 20 and 22, that certain

MINERAL PRODUCTION OF MICHIGAN - 1974

Compiled by the Geological Survey Division

				PERCENT CHANGE FROM 1973 IN:		RANK IN U.S. FOR 1973(Value
MINERAL	UNIT	QUANTITY	VALUE	Quantity	Value	
Iron Ore	Long tons (2240#)	11,530,796	257,943,788	-6.4	+43.2	2
Cement	Short tons	6,119,999	146,822,510	-5.7	+13.3	4
Petroleum	Barrels (42 gal.)	18,101,812	154,951,511	+24.6	+160.1	17
Sand & Gravel	St. Tons (2000#)	60,072,793	82,709,611	-4.0	+11.4	2
Nat. Salines (1)	Short Tons	1,406,650	112,349,792	+27.0	-7.2	1
Copper	Pounds	131,037,602	108,761,210	-13.6	+15.5	6
Salt	Short Tons	4,444,704	62,054,985	-7.7	+15.5	2
Stone (2)	Short Tons	28,139,838	47,625,238	+4.4	+16.8	14
Lime	Short Tons	1,528,157	30,036,238	-1.1	+15.3	4
Nat. Gas	Th. Cu. Ft. (MCF)	69,806,374	35,182,413	+59.7	+103.3	16
Gypsum (crude)	Short Tons	1,482,192	7,257,885	-21.3	+15.0	1
Clay & Shale (3)	Short Tons	2,160,928	4,073,629	+0.5	+23.3	8
Peat	Short Tons	244,223	3,811,397	+5.1	+75.5	1
Marl	Short Tons	151,298	258,007	+108.2	+225.6	1
Miscellaneous (4)			3,463,152		+23.2	
TOTAL			1,057,301,366		+29.4	

(1) Bromine, Magnesium compounds, Calcium-Magnesium chloride, and Iodine.

(2) Does not include 19,142,166 short tons of limestone & dolomite valued at $24,772,217 used in the manufacture of cement and lime.

(3) Tile brick, pottery, clay used for cement, lightweight aggregate, and miscellaneous.

(4) Sulfur, mineral pigments, silver.

Michigan's total mineral value of 1,057,301,366 in 1974, ranked Michigan as 15 in U. S.

Figure 21. Mineral production of Michigan during 1974 (reproduced from Lewis, 1975).

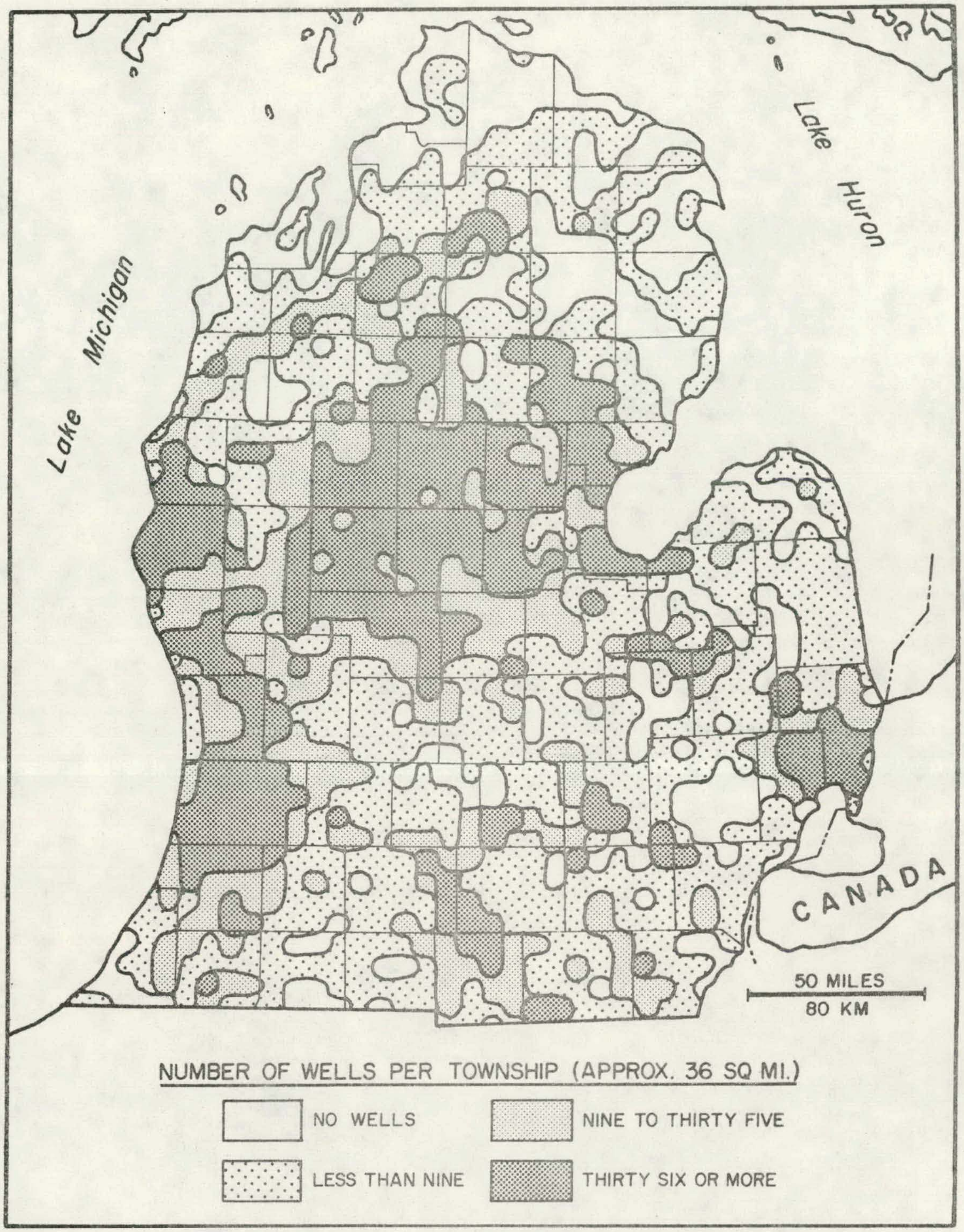


Figure 22. Map showing density of drilling of oil and gas tests in Michigan (after Netherland, Sewell and Associates, 1975).

areas in the Michigan salt basin can be identified where development along present and/or possible future oil and gas trends will not be interfered with by possible storage and high-level radioactive waste in the Salina salt deposits.

Salt

Salt resources of Michigan are vast and are limited stratigraphically to the Silurian (Salina Group) and Devonian (Detroit River Group) Systems. Salt or salt brines are produced at mines or brine-well plants at 10 localities in the southern and central parts of the State (fig. 23). In the southeast, three operations are active in Wade County and two in St. Clair County; in the center of the State, one producer is located in each of Midland and Gratiot Counties; and in the west, there are two facilities in Manistee County and one is in Muskegon County. Production of salt in Michigan during 1974 was 4,444,704 short tons (fig. 21), which amounted to about 10 percent of the total United States production.

With the vastness of salt resources in the State, it is unlikely that use of underground salt beds for radioactive-waste storage at one or several sites would have any significant impact on the present or future availability of adequate salt resources for this part of the United States. A waste repository should not be sited in salt deposits near these mines or brine wells because the long-term isolation of the repository might be jeopardized. This is especially important where solution-mining is being utilized to recover the salt in the form of artificial brines.

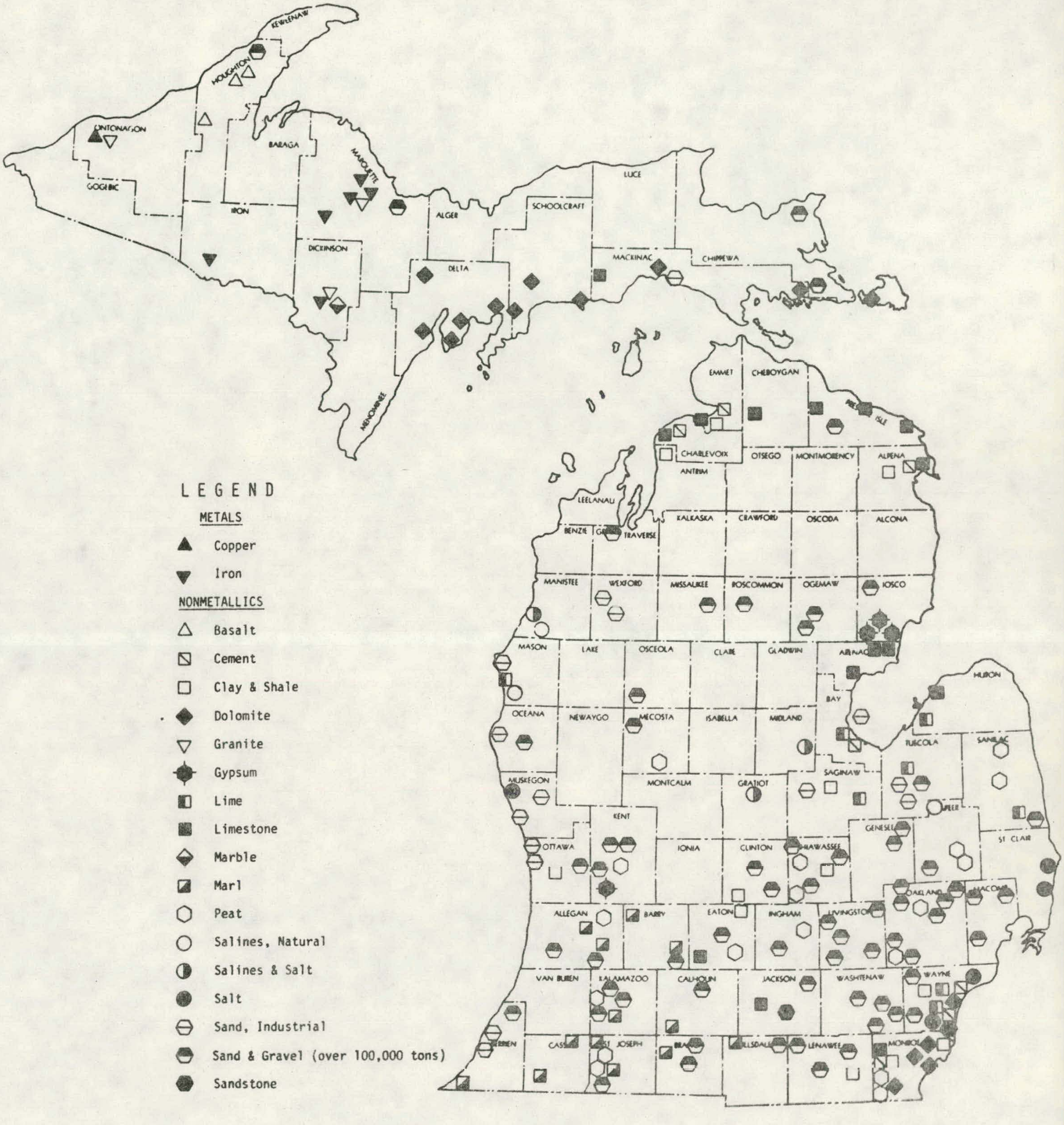


Figure 23. Map showing mineral operations in Michigan (reproduced from Lewis, 1975).

Natural Brines

Natural brines or salines produced from deep wells in the State have been a commercial source of such important chemicals as bromine, iodine, calcium chloride, and magnesium compounds (Lewis, 1975). The principal source beds for these brines are the Filer and Sylvania Sandstones in the Detroit River Group (Devonian), and thus they are younger than the Salina salt beds.

Michigan currently ranks first among the states in production of such natural brines. The 7 operating plants are located across the central part of the State in the following counties: Lapeer (1 plant), Midland (1), Gratiot (1), Mason (2), and Manistee (2).

Other Minerals

Other known mineral resources in Michigan (figs. 21 and 23) either are not commercially recoverable in areas that might be considered for radioactive-waste disposal, or they are being developed only by surface-mining techniques that would conflict with radioactive-waste storage only in the immediate vicinity of a storage site.

Major metallic resources (iron ore and copper) are recovered only in the Upper Peninsula, and thus the continued development of these reserves does not conflict with use of the salt deposits in the Lower Peninsula.

Gypsum resources of the State are great, and occur mainly in the Michigan Formation (Mississippian) and in the Detroit River Group (Devonian) (Briggs, 1970), and thus are younger than the Salina salt sequence. Five companies are producing gypsum: three quarries are active near Alabaster in Iosco County and two shallow mines are operated near Grand Rapids in Kent County (Lewis, 1975). Current production is about 1,480,000 short tons (fig. 21), or about 10 percent of United States output, and Michigan leads all other states in gypsum production.

Potash has recently been identified in the A-1 evaporite (Anderson and Egleson, 1970; Mathews, 1970), but it is apparently restricted to the central part of the Michigan basin where the A-1 salt and the overlying A-2 and B salts are too deep to be considered for radioactive-waste disposal. These potash deposits are not now being produced.

Stone is an important nonmetallic mineral resource that is produced from bedrock formations for a variety of uses. Limestone and dolomite are used as crushed stone for aggregate, cement, lime, flux, and for chemical and agricultural application. They also are recovered as dimension stone. Other types of stone, such as sandstone, basalt, and marble, are used primarily as aggregate and dimension stone. The many stone quarries in the Southern Peninsula are concentrated in the southeast, the north, and in the Saginaw Bay area (fig. 23).

Shale and clay deposits are widely distributed in Michigan's Southern Peninsula (Lewis, 1975). The resource, which occurs both in the bedrock and in the glacial drift, is used in the manufacture of cement, brick, drain tile, sewer pipe, and flower pots. Ten companies operate open pits in the southeast, central, and northern parts of the Southern Peninsula.

Sand and gravel probably comprise the most widespread mineral commodity in the State (Lewis, 1975). Most commercial deposits have been developed in glacial deposits such as outwash, kames, eskers, and glacial lake-shore sediments. Some of the resource is obtained from river terraces and deltaic deposits. More than 350 companies are producing sand and gravel from open pits in all parts of the State, and most of these pits are located near the expanding urban areas in the south.

CONCLUSIONS

As a result of this study of the Michigan basin, the Lower Peninsula of Michigan appears to have a geologic framework and a series of salt deposits that locally may be suitable for the underground storage of high-level radioactive waste. Thick deposits of massive rock salt (halite) are present at moderate depth; they are nearly flat lying and have not been structurally deformed or fractured in most parts of the basin. The region is characterized by tectonic stability. There have been few recorded earthquakes of MM V or greater in areas underlain by salt, and the entire State of Michigan lies within seismic-risk zone 1 (minor damage).

In addition to these regional characteristics that make the basin appear generally favorable, there are other geologic-hydrologic factors that bear upon the overall potential of the Michigan basin for possible repository consideration. Important ground-water resources underlie many parts of the region, but there are areas where the quantity and quality are low. Glacial drift is thick in much of the State, although there are some large areas where the drift is thin or absent. Although petroleum exploration and production are conducted in most parts of the basin, there are areas with few boreholes and low petroleum potential. Salt and natural brines are the only other resources produced from deep subsurface sources, and repository sites should not be considered in areas that would conflict with or be jeopardized by these mineral-recovery activities.

We recommend that the data presented in this summary be evaluated, along with other pertinent information that is available, to determine whether there may be specific areas in the State that are sufficiently favorable for radioactive-waste storage to warrant more-detailed study.

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