SUBSURFACE ANALYSIS OF THE MIDDLE DEVONIAN SYLVANIA SANDSTONE IN THE MICHIGAN BASIN

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RYAN GLENN KEMPANY

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ABSTRACT

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By

Ryan Glenn Kempany

The Sylvania sandstone is of Lower Middle Devonian age and represents a basal transitional formation into the overlying Detroit River Group of lower Michigan and northwestern Ohio. Wild (1958) was the last person to attempt research on this stratigraphic unit but the most extensive study was completed by Grabau and Scherzer in 1907. In view of the availability of additional sample data as well as mechanical logs, a restudy of the unit was considered advisable, especially as increased interest is being shown on the part of some petroleum/gas companies.

Information for analysis was acquired by examination of well cuttings, gamma ray-neutron logs and printed driller-geologist logs supplied by the Michigan Geological Survey. Regional isopach and structure contour maps were constructed employing approximately one hundred control wells. Tops are derived predominantly from samples but when drill cuttings were not available for key wells, gamma ray-neutron logs were used to supplement the data.

Lithofacies trends were delineated from subsurface samples and displayed as sand, carbonate, chert and evaporite percentage maps, and also as a clastic ratio map generated to determine the paleoenvironment and history during Sylvania time.

From this investigation it can be concluded that fluvial and perhaps some eolian processes supplied sand to the seaway where it was reworked, redistributed and redeposited by marine currents and waves within a persistent shore line environment, predominately along with carbonates of the Sylvania age sea. The St. Peter sandstone of Lower Middle Ordovician age in the Wisconsin Highland area to the northwest, the Findlay Arch area to the east and southeast, and the Canadian Shield area to the northeast are considered to be chief sources for the Sylvania sandstone.

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A THESIS

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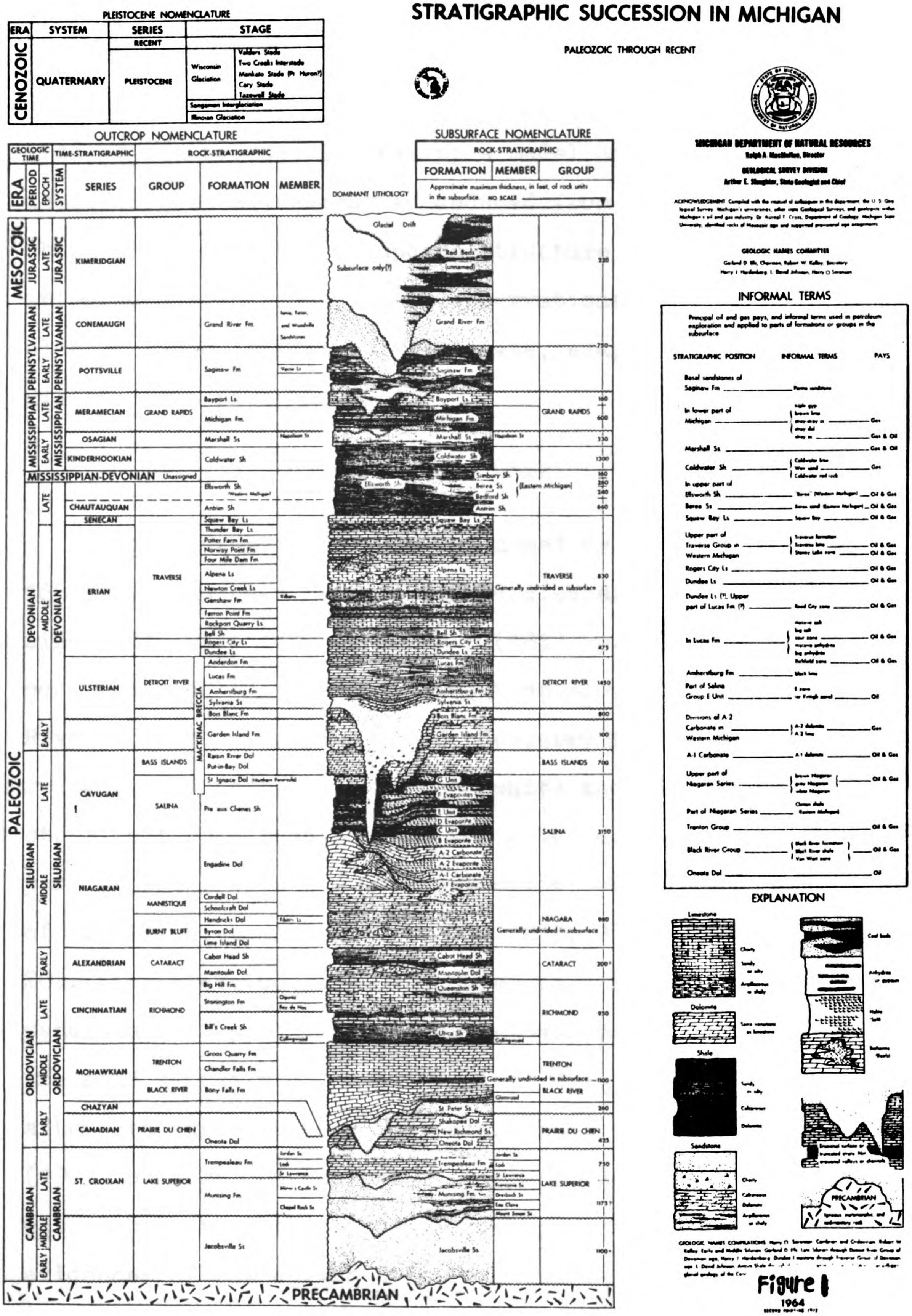
INTRODUCTION

Scope and Purpose of Investigation

The Sylvania sandstone is of Lower Middle Devonian age and represents a basal transitional formation into the overlying Detroit River Group in southeast Michigan and northwest Ohio (Figure 1). Recent wells drilled, involving the sandstone, are encountering difficulty in determining the contact relationships and stratigraphic position relative to underlying units. In addition, lateral gradations are questionable. Wild (1958) was the last person to attempt research on this thus-far economically unproductive formation and the only truly extensive study was completed by Grabau and Scherzer in 1907. Since that time, the Sylvania sandstone has been discussed only as a component part of the Detroit River Group to which it belongs.

In view of additional sample data as well as mechanical logs the Sylvania sandstone needs restudy. The purpose of this investigation has therefore been to: 1) establish subsurface relationships of the sandstone to the underlying Bois Blanc and Bass Island disconformable units, 2) analyze the lithology and determine the distribution


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
TIME-STRATIGRAPHIC
ROCK-STRATIGRAPHIC
ERA
PERIOD
EPOCH
SYSTEM
SERIES
GROUP
FORMATION
MEMBER
DOMINANT LITHOLOGY
SUBSURFACE NOMENCLATURE
ROCK-STRATIGRAPHIC
FORMATION
MEMBER
GROUP
Approximate maximum thickness, in feet, of rock units in the subsurface. NO SCALE
MESOZOIC
JURASSIC
LATE
KIMERIDGIAN
Glacial Drift
Red Beds (unnamed)
Subsurface only(?)
PENNSYLVANIAN
CONEMAUGH
Grand River Fm
POTTSVILLE
Saginaw Fm
MISSISSIPPIAN
MERAMECIAN
GRAND RAPIDS
Bayport Ls
Michigan Fm
OSAGIAN
Marshall Ss
KINDERHOOKIAN
Coldwater Sh
MISSISSIPPIAN-DEVONIAN
Unassigned
Ellsworth Sh
Sunbury Sh
Berea Ss
Bedford Sh
(Eastern Michigan)
DEVONIAN
CHAUTAUQUAN
Antrim Sh
SENECAN
Squaw Bay Ls
ERIAN
TRAVERSE
Thunder Bay Ls
Potter Farm Fm
Norway Point Fm
Four Mile Dam Fm
Alpena Ls
Newton Creek Ls
Genshaw Fm
Ferron Point Fm
Rockport Quarry Ls
Bell Sh
Rogers City Ls
Dundee Ls
Generally undivided in subsurface
ULSTERIAN
DETROIT RIVER
Anderdon Fm
Lucas Fm
Amherstburg Fm
Sylvania Ss
Bois Blanc Fm
Garden Island Fm
MACKINAC BRECCIA
SILURIAN
CAYUGAN
BASS ISLANDS
Raisin River Dol
Put-in-Bay Dol
St Ignace Dol
SALINA
Pte aux Chenes Sh
G Unit
F Evaporites
E Unit
D Evaporite
C Unit
B Evaporite
A-2 Carbonate
A-2 Evaporite
A-1 Carbonate
A-1 Evaporite
NIAGARAN
Engadine Dol
MANISTIQUE
Cordell Dol
Schoolcraft Dol
BURNT BLUFF
Hendricks Dol
Byron Dol
Lime Island Dol
NIAGARA
ALEXANDRIAN
CATARACT
Cabot Head Sh
Manitoulin Dol
ORDOVICIAN
CINCINNATIAN
RICHMOND
Big Hill Fm
Stonington Fm
Bill's Creek Sh
Queenston Sh
Utica Sh
Collingwood
MOHAWKIAN
TRENTON
Groos Quarry Fm
Chandler Falls Fm
BLACK RIVER
Bony Falls Fm
CHAZYAN
St Peter Ss
CANADIAN
PRAIRIE DU CHIEN
Shakopee Dol
New Richmond Ss
Oneota Dol
CAMBRIAN
ST. CROIXAN
LAKE SUPERIOR
Trempealeau Fm
Munising Fm
Jacobsville Ss
PRECAMBRIAN
PALEOZOIC
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY DIVISION
GEOLOGIC NAMES COMMITTEE
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
EXPLANATION
Limestone
Dolomite
Shale
Sandstone
PRECAMBRIAN
Figure 1
1964

pattern, 3) establish a relationship of the Sylvania to the overlying carbonate section, 4) gather information adding to a better understanding of the nature and direction of the source, 5) develop a model concerning the depositional environment as deduced from composition and physical properties, 6) update structure and isopach interpretations, and 7) make observations concerning clastic ratio, sandstone, carbonate, evaporite, and chert distribution patterns.

Previous Work

The Sylvania sandstone was named by Edward Orton in 1888, but has been recognized and discussed in literature since 1837 when John L. Riddell (1837, p. 9) reported the occurrence of a calcareous sandstone along the Maumee River in Ohio. In 1896, J. S. Newberry (1870, p. 16) recognized a correlation of the white saccharoidal sandstone, not more than 20 feet thick in the northwestern part of Ohio, with the Oriskany sandstone, lowest member of the Devonian in New York. In 1888, Orton (1888, pp. 18-20), then State Geologist of Ohio, considered the Sylvania sandstone an Upper Silurian sandstone, correlated it with the sand deposits of Monroe County, Michigan, but named it after its exposure near Sylvania, Ohio. A. W. Grabau (1907, p. 832), on the basis of field work in Michigan with Scherzer on the Sylvania and Upper Monroe, presented evidences of the eolian origin of the Sylvania sandstone and included it as part of the Monroe formation. This formation (Lane, Prosser, Sherzer, and Grabau, 1908, pp. 553-556) was divided into the Lower Monroe, represented by the Bass Island series; the Middle Monroe, represented by the Sylvania sandstone; and the Upper Monroe, represented by the Detroit River series. The age of the Monroe formation was given as Silurian (Sherzer and Grabau, 1908, pp. 540-553). They also postulated a northwestern and eolian origin for the Sylvania sandstone which possessed such purity and rounding it was considered to "out-Sahara the Sahara." In 1927, J. E. Carman (1927, pp. 481-506) concluded on the basis of geographical distribution of the members, stratigraphical relations, and faunas, that the Upper and Middle Monroe were of Lower Devonian age. Carman (1927, p. 506) further stated that the Sylvania is stratigraphically and faunally so closely related to the overlying Detroit River formation that both must be included in the same age.

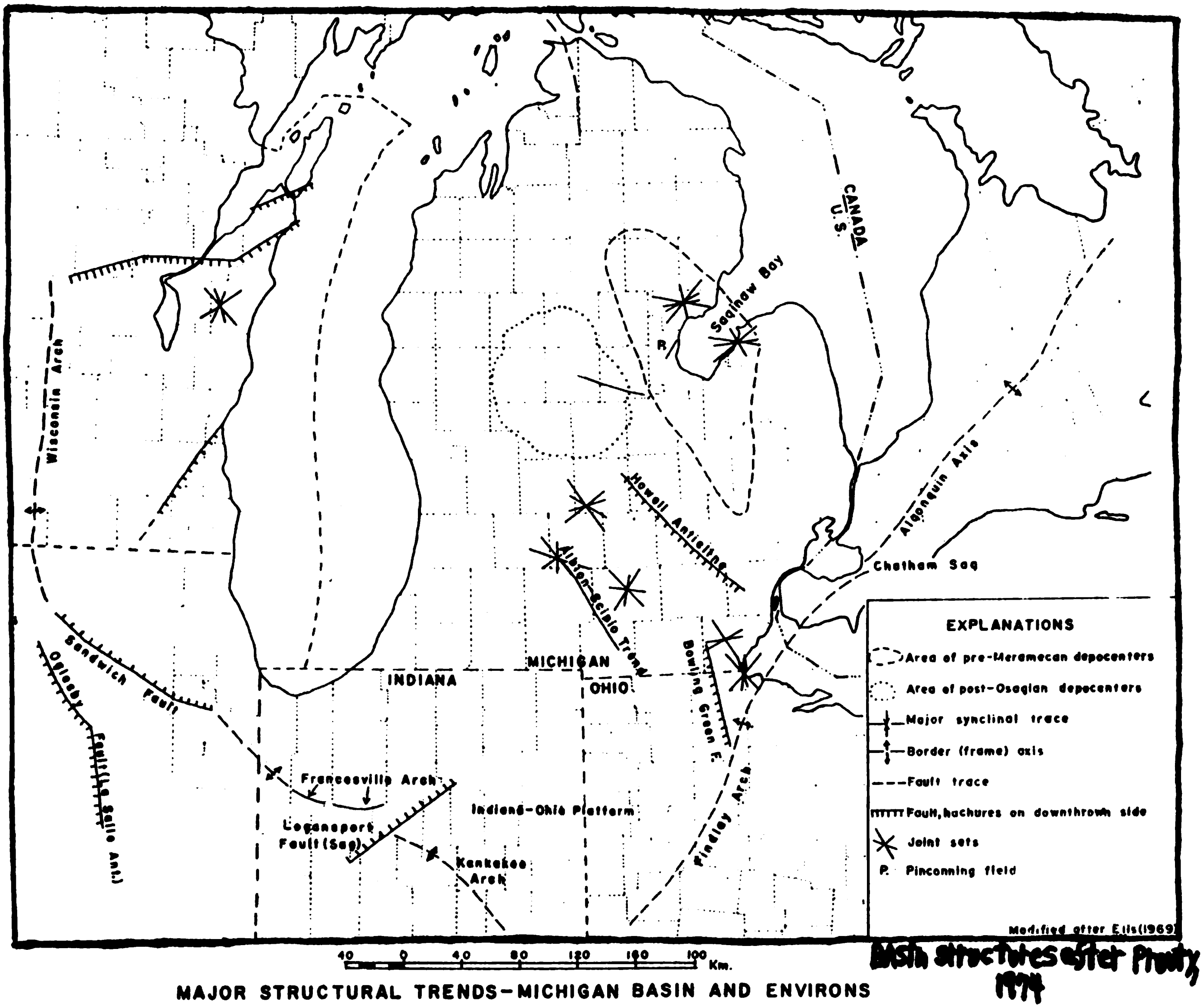
S. W. Alty (1932, pp. 289-300) studied the heavy mineral content of the Sylvania rocks from Michigan oil wells and found that the heavy minerals seemed to decrease from southeast to northwest. Carman (1936, pp. 253-266) studying the Sylvania sandstone of northwestern Ohio postulated that the Sylvania represents the basal member of the Detroit River dolomite in a transgressive overlap by the Sylvania sea toward the southeast. He thus questioned the eolian origin of the Sylvania as proposed by Grabau and Sherzer giving evidence for marine deposition of the Sylvania.

R. L. Enyert (1949) on the basis of sedimentary analysis of outcrop samples, subsurface well samples, and well logs concluded that the Sylvania sandstone is the product of a wind-transported, water reworked sand probably deposited in a marine environment. The St. Peter sandstone, of Lower Ordovician age, in the Wisconsin Highlands to the northwest was considered to be the chief source of the Sylvania sandstone. Landes (1951) placed this sandstone within the Detroit River Group, and considered it to be a member of the Amherstburg formation because of the general transition between the sandstone and the overlying limestone or dolomite of the Amherstburg at the outcrop and in well samples. Landes further considered the sand of the Sylvania as having accumulated by current action like modern beach and barrier sands. R. C. Wild (1958) also showed the Sylvania sandstone to be marine in origin with waves and currents selectively distributing, reworking, and sorting the sand, but whose major source area was to the southeast of lower Michigan.

TECTONIC FRAMEWORK OF THE MICHIGAN BASIN

Regional Structures

The Michigan Basin is a slightly irregular circular structural depression, regarded as the type example of an autogeosyncline (Kay, 1951) or an intracratonic basin. Its center is located near the central part of southern Michigan and contains approximately 14,000 feet of Paleozoic rocks overlying Precambrian igneous and metamorphic units. The Basin's flanks are essentially located in eastern Wisconsin, northeastern Illinois, northern Indiana, northwestern Ohio, southwestern Ontario, and northern Michigan. Several arches border the Basin including the Algonquin Arch to the northeast, the Findlay Arch to the east and southeast, the Wisconsin Arch to the west, the Kankakee Arch to the southwest, and the Cincinnati Arch to the south (Figure 2). Prior to Sylvania deposition, a sag developed in the Findlay Arch (Chatham Sag) which persisted during Sylvania time. The deepest portion of the Chatham Sag was near the Lake St. Clair region of Michigan and Ontario. To the west, in central Wisconsin, a positive feature referred to as the Wisconsin dome was uplifted following the deposition of Silurian beds in Michigan. To the north, northeast, and east are exposed Precambrian rocks of the North American Shield whose three



MAJOR STRUCTURAL TRENDS–MICHIGAN BASIN AND ENVIRONS

Figure 2

provinces meet under the Michigan Basin and comprise the basement rocks (Stonehouse, 1969).

Intrabasinal Structures

The structure contour map (Figure 3), based on the top of the Sylvania sandstone, illustrates that the Basin has a symmetrical oval shape with a slight northwest-southeast elongation and many structural features follow this major trend. The deepest part of this pre-Mississippian Basin is in Clare, Gladwin and Midland Counties. The regional dip into the center averages 30 to 35 feet (9 to 11 meters) per mile (1.6 Kilometers) with minor structural variations. Contours show a relief of about 5000 feet (1,500 meters).

The largest feature shown on the structural contour map is the Howell anticline, a northwestward plunging fold trending through Livingston and Monroe Counties of south-eastern Michigan. It is an asymmetrical anticline with the steeper dips on the southwestern flank. Structural relief on the Howell anticline is about 1000 feet (300 meters). Three minor southward trending synclines are discernible in Lapeer, Lenawee, and Barry Counties.

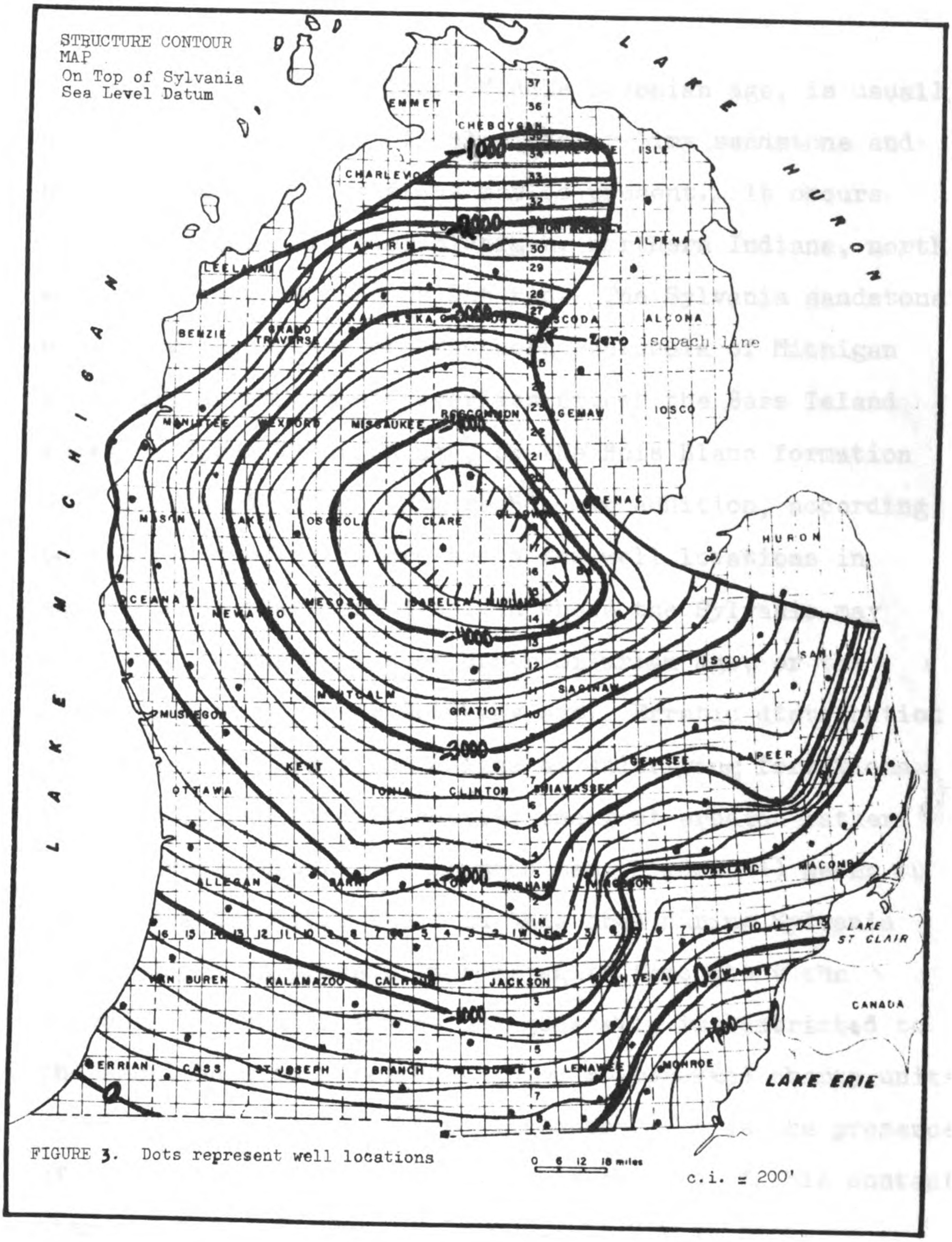


FIGURE 3. Dots represent well locations

GENERAL STRATIGRAPHY

The Sylvania, of Lower Middle Devonian age, is usually a sandstone, but beds of dolomitic or limy sandstone and sandy dolomite or limestone may be present. It occurs throughout most of lower Michigan, northern Indiana, northwestern Ohio, and eastern Ontario. The Sylvania sandstone extending throughout the Southern Peninsula of Michigan generally unconformably overlies either the Bass Island rocks of Upper Silurian age, or the Bois Blanc formation of Lower Onondaga age (Figure 5). In addition, according to descriptive logs there are a few well locations in south and southwestern Michigan where the Sylvania may also overlie the Salina of Upper Silurian age, or the Garden Island of Lower Oriskany age. Erratic distribution of the Garden Island and Salina as underlying formations is probably due to differential emergent erosion rather than nondeposition. The isopach map (Figure 11) seems to indicate a low lying shelf in this area during Sylvania time. Chert is present in some wells throughout the Sylvania's vertical extent but generally is restricted to the basal beds as a representation of reworked cherty units of the underlying Bois Blanc formation. It is the presence of this basal chert that offers a more identifiable contact than exhibited by the overlying carbonate section.

The Sylvania sandstone, where present, is stratigraphically closely related to the overlying Detroit River formation and in most places grades upward into the carbonate rocks without a sharp break as observed in the subsurface and at the outcrop. It will typically change into a dolomitic or limy sandstone, then into arenaceous limestone or dolomite, then a dolomite or limestone, not as a uniformly gradual change but with alternating layers of more sandy and less sandy material in a general upward decrease of the sand content. In one area only (Hillsdale County of southern Michigan), where the Lucas formation rests conformably on the Sylvania sandstone (Landes, 1951), it is not overlain by carbonate rocks of the Amherstburg.

The Sylvania sandstone crops out in quarries of Monroe and Wayne Counties in southeastern Michigan, and Lucas County in northwestern Ohio, and represents the oldest exposed formation of the Devonian System. The outcrop area varies in width from one to two miles at the northernmost exposure in Wayne County, to less than 200 yards at the southernmost exposure at the Maumee River in Lucas County. The sandstone beds dip toward the center of the Michigan Basin with a maximum depth of 4,400 feet below sea level occurring in Clare and Midland Counties.

In the subsurface, evidence of the Sylvania sandstone can be found throughout most of lower Michigan but it predominantly occupies a linear trough trending northwest-southeast with a maximum depth of at least 410 feet, partially eroded during pre-Sylvania time in the underlying Bass Island and Bois Blanc rocks. As indicated by the sand percentage map (Figure 12), this linear pattern extends from southeast Michigan into the northern half of the lower Peninsula where it terminates in Missaukee County. The sandstone thins from this area and grades laterally into the surrounding carbonates. Figure 5 shows the areal distribution of the Sylvania sandstone and its relationship to the underlying beds.

Pre-Sylvania Geologic History

The pertinent history of the Sylvania sandstone begins with Bass Island time. When the Bass Island sea withdrew, the area was covered with the youngest sedimentary rocks of the Bass Island dolomite. These late Silurian deposits were wide spread. During the period of emergence prior to the encroachment of the earliest Devonian sea there was some erosion that removed sediments of the Bass Island either completely or in part. Therefore, in isolated areas the underlying uppermost Salina Group was exposed. By the time the earliest Devonian sea spread over the area that is now the Southern Peninsula of Michigan the topography was moderately rolling and the rocks of different ages were exhibited from place to place. The earliest Devonian sea, Oriskany, deposited the Garden Island formation. Emergence occurred later and erosion removed the Garden Island formation everywhere in Michigan

Nomenclature of Michigan Formations

Lane, Prosser, Sherzer, and Grabau--1909

Upper Silurian	Monroe Formation	Upper Monroe or Detroit River Series	Lucas dolomite Amherstburg dolomite Anderdon limestone Flat Rock dolomite
		Middle Monroe	Sylvania Sandstone
		Lower Monroe or Bass Island Series	Raisin River dolomite Put-in-Bay dol. Tymochtee beds Greenfield dolomite

Classification Used in This Study

Middle Devonian Ulsterian Series (Onondaga)	Detroit River Group	Anderdon limestone FM.
		Lucas dolomite FM.
		Amherstburg dolomite FM.
		Sylvania Sandstone
		Disconformity
		Bois Blanc
		Disconformity
Early Devonian Oriskany		Garden Island
		Disconformity
Upper Silurian Cayugan Series	Bass Island Group	Raisin River dolomite
		Put-in-Bay dolomite
	Salina Group	St. Ignace dolomite
		Pt. Aux Chenes shale

FIGURE 4.

except for patches on Garden Island and elsewhere on the northern flank of the Basin in addition to those areas shown in southwestern Michigan on Figure 5. The post-Oriskany emergence and erosion interval was followed by widespread inundation by the Onondage sea. In Michigan, the Bois Blanc was deposited on the floor of this sea, covering both remnants of the Garden Island formation and the twice-eroded Bass Island Group. The withdrawal of the Onondaga sea from this area subsequently produced erosion of such magnitude that the Bois Blanc formation was completely removed from the flanks of the Kankakee and Findlay arches (Landes, 1951).

The areal geology at the time of the inundation by the Sylvania age sea is shown on the pre-Sylvania geologic map (Figure 5). The limit of the Bois Blanc formation and the locations of the Bass Island, Garden Island, and Salina formations vary in position from place to place owing to pre-Sylvania structural and erosional variability. This moderately rolling subsurface thus accounts for the differential thicknesses exhibited by the Sylvania sandstone isopach map (Figure 12). A downwarp and erosional surface along a northwest-southeast axis from central Michigan across southeastern Michigan into northern Ohio permitted the entrance of marine waters through the Chatham Sag which marked the beginning of Sylvania time. It was during this period that the Sylvania sandstone began deposition throughout most of lower Michigan.

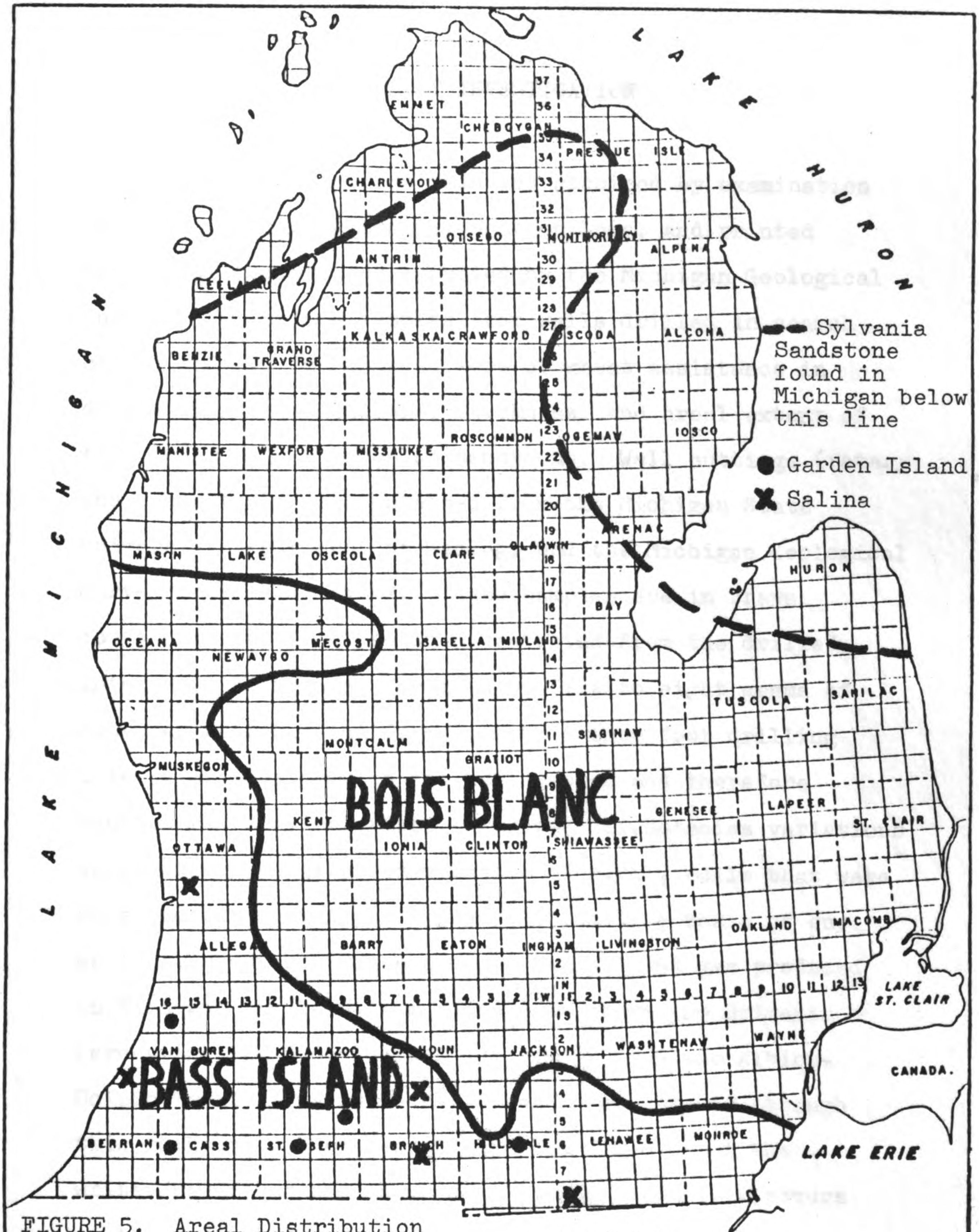


FIGURE 5. Areal Distribution of Formations Beneath the Sylvania Sandstone

METHOD OF INVESTIGATION

Information for analysis was acquired by examination of well cuttings, gamma ray-neutron logs, and printed driller-geologist logs supplied by the Michigan Geological Survey. Subsurface samples from wells drilled in search of oil and gas in Michigan were of great assistance in determining the lithology, thickness, and areal extent of this Lower Middle Devonian sandstone. Well cuttings (rotary and cable tool) were obtained from the Michigan State University Department of Geology and the Michigan Geological Survey sample libraries. These samples are in trays containing phials of sediment selected from the drilled interval. Each phial consists of five to eight grams of cuttings representing from five to twenty foot drilling intervals. The samples are well washed and therefore contain few clay materials. Regional lithofacies variations were determined after examination of eighty wells that were selected throughout the State on a limiting basis of one well per section. Since most of the oil and gas produced in Michigan has been from formations above the Sylvania (excepting the Ordovician producers as from the Albion-Scipio Trend), few wells have penetrated into or through this rock unit. Because of this limiting factor the writer has found the major concentration of wells occurs in the southern half of lower Michigan, thus resulting in somewhat poor geologic control in the North. Every available northern Sylvania sample interval was used in this investigation.

Examination of well cuttings was achieved through the use of a reflected light binocular microscope with a magnification range between 7X and 40X. A Micrometer Occular was used to determine quartz grain size frequencies and the percentages of sample constituents. Where a mixed lithology, as sandy dolomite, was encountered, the percentages of sand and dolomite for the sample interval were estimated and placed within their respective grade size categories. By totaling the percentage of each rock type from individual phials and dividing by the total number of phials for each well sampled, an average was computed for the amount of rock constituents. From this data, percentage maps showing major lithologies from the Sylvania were constructed. Quartz properties examined included color, grain size, shape, degree of sorting, type of cementation, and presence of frosting or pitting. For carbonate facies, semi-quantitative acid analyses (Colorado School of Mines Technique) were used for lithologic determinations. By this method samples were tested using cold hydrochloric acid, diluted with distilled water, at a water to acid ratio of 7:1. The lithology of the intervals for each well was recorded with conclusions based largely on these data. Sylvania tops indicated in the descriptive logs were previously established by the Michigan Geological Survey but were modified as deemed necessary from sample analyses.

Regional isopach and structure contour maps were constructed employing about one hundred control wells from a possible one hundred thirty-five. Where drill cuttings were not available for key wells, gamma ray-neutron logs were used to supplement the sample study. In addition, tops picked by microscopic sample analyses were compared to those appearing on the logs to achieve greater accuracy. Gamma ray-neutron logs measure and record emanations from strata traversed. All rocks contain small but measurable amounts of gamma ray-emitting radioactive elements, and in most cases a detectable increase or decrease of radioactive intensity occurs at each formation boundary. Identification of different rock types can be made where a lithologic change occurs at the contact of two formations. Upper and lower contacts were picked in accordance with the manner adopted by the Geologic Survey. The top of the Sylvania formation is usually picked as being higher in deflections compared to the overlying carbonate section. A black limestone marker bed, producing a distinctively large outward kick, is usually located within eighty feet above the Sylvania sandstone and may be used as a general reference to orientation of the Sylvania top. The bottom of the sandstone is usually identified by shorter deflections compared to the underlying carbonate section as exhibited by cross-sections (Figures 7 and 8). Cross-sectional well locations are indicated by Figure 6.

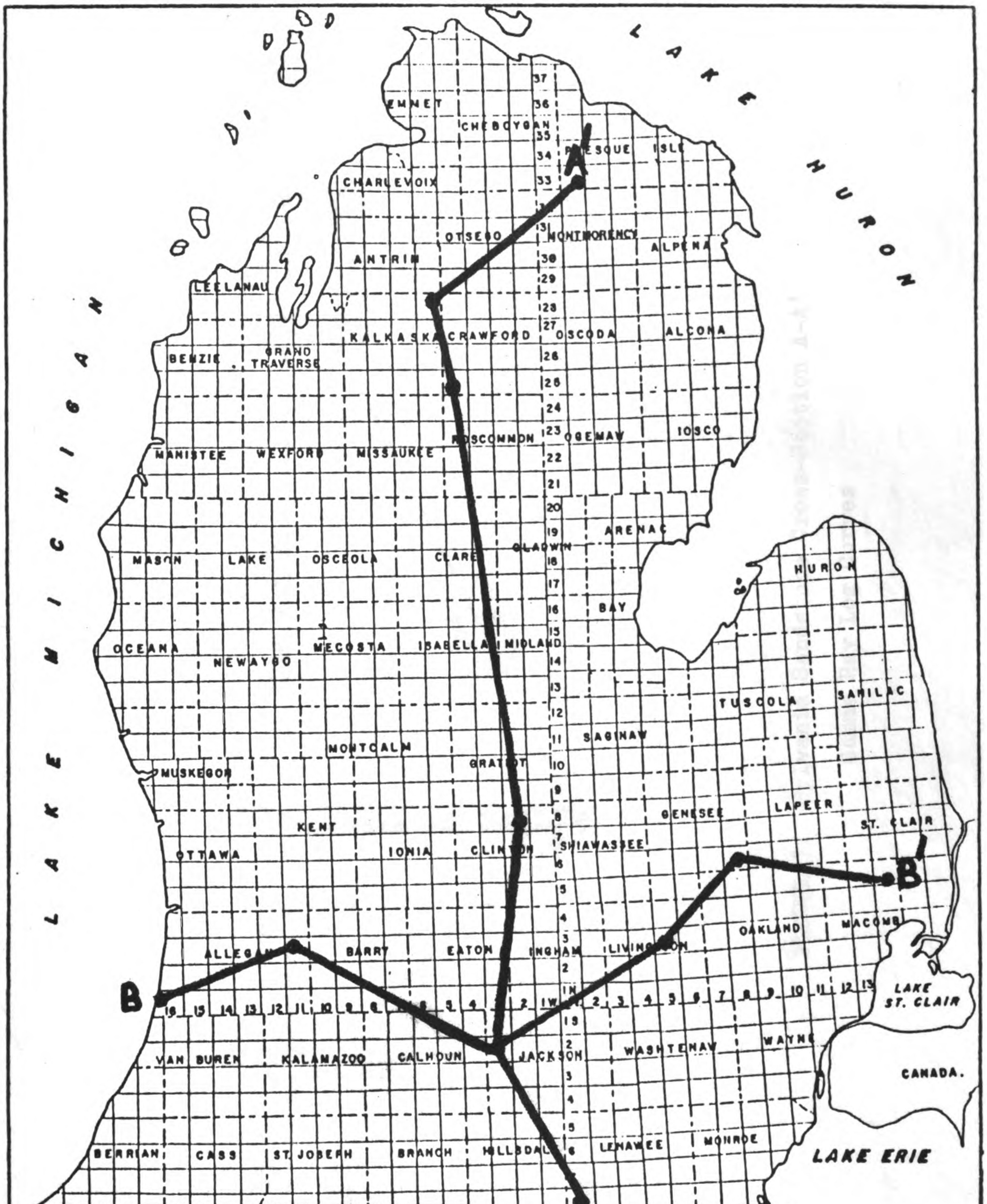


FIGURE 6. Sylvania Cross-Sectional Locations

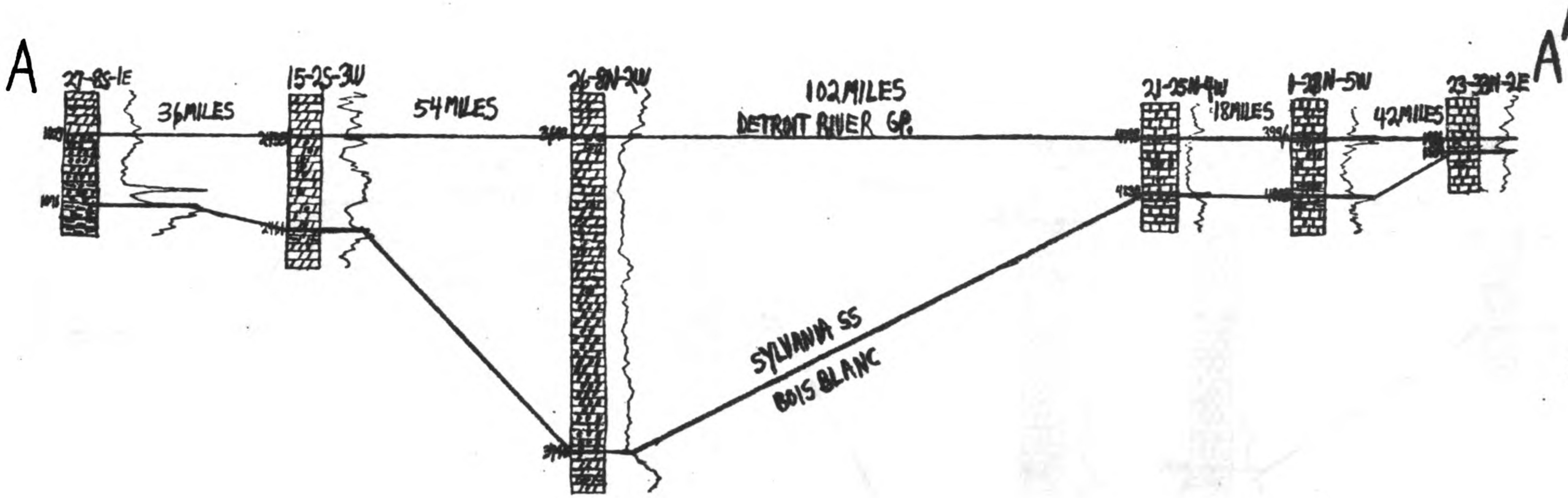


FIGURE 7. Sylvania Sandstone Cross-Section A-A'

Gamma Ray Log Curves

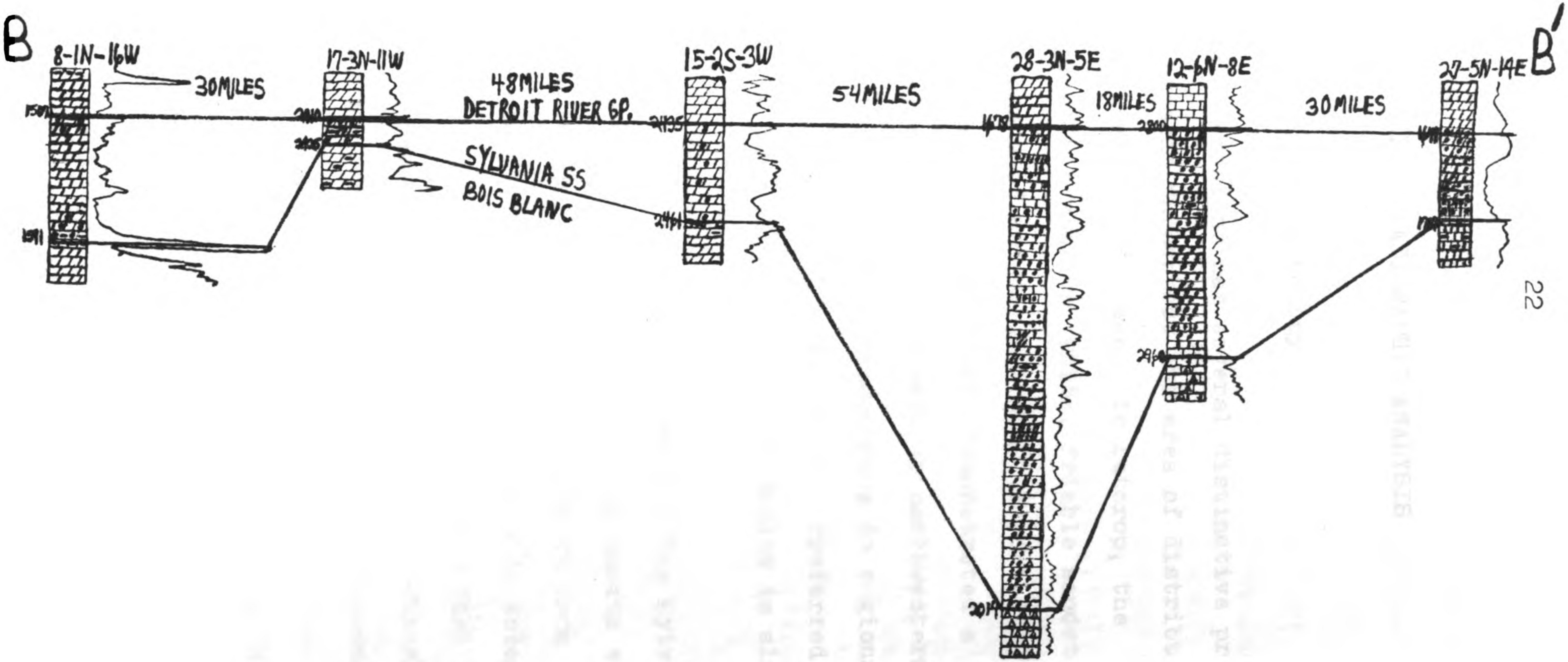


FIGURE 8. Sylvania Sandstone Cross-Section B-B'

Gamma Ray Log Curves

DETAILED STRATIGRAPHIC ANALYSIS

Lithology

The Sylvania sandstone has several distinctive properties which are present throughout its area of distribution in the Lower Peninsula of Michigan. In outcrop, the Sylvania is typically a massive, white, friable sandstone, with variable amounts of dolomitic cement (Enyert, 1949). Hatfield, Rohrbacker, and Floyd (1968) demonstrated a northwestward inclination of cross beds in northwestern Ohio and southeastern Michigan corresponding to regional dip and thickening into the Michigan Basin. Preferred orientation of the long dimensions of the grains is also in that direction.

Results of subsurface analyses show that the Sylvania is commonly a clear, white or light gray pure quartz sandstone, but may be brown, orange or yellow due to iron staining. Grains are often loosely cemented with dolomite, silica, or calcite, although they are so friable that loose grains are quite common. Samples show that the Sylvania is very well sorted, with great variation both horizontally and vertically in the maximum frequency of grain size. Although there is marked change, the average medium diameter appears to be slightly more than a quarter millimeter, but any given well may contain a range of between one-sixteenth and one millimeter in diameter. Usually grains less than one-eighth or greater than three-fourths of a millimeter will represent 20 percent or less of the sample, with another 20 percent falling between one-eighth and one-fourth millimeter grain size. There is a slight tendency toward smaller quartz sizes downward stratigraphically. Deviations toward larger grains occur in southeastern and western Michigan where appreciable quantities of coarse sandstone (up to one millimeter) may be found (Figure 9).

The Sylvania sandstone might have all gradations from a sandstone, through dolomitic sandstone and arenaceous dolomite to dolomite; or from a sandstone, through limy sandstone and arenaceous limestone to limestone. Figure 10 shows the sandstone occurring with limestone in northern and eastern Michigan but with dolomite in western and southern Michigan. There is a general decrease upward of sand percentages. A correlation is noted between the percentage of carbonate and the size of the sand grains in some wells. Generally the higher the percentage of carbonates the smaller the clastic grain size. This is particularly observable in northwestern Michigan, around Kalkaska County, where limestone approaches an average of 97 percent and silt grains of approximately one-fortieth of a millimeter occur (Figure 9). This is normal if it is assumed that clastic grain size percentage, and proportions of magnesium salts decrease away from a postulated southeastern source.

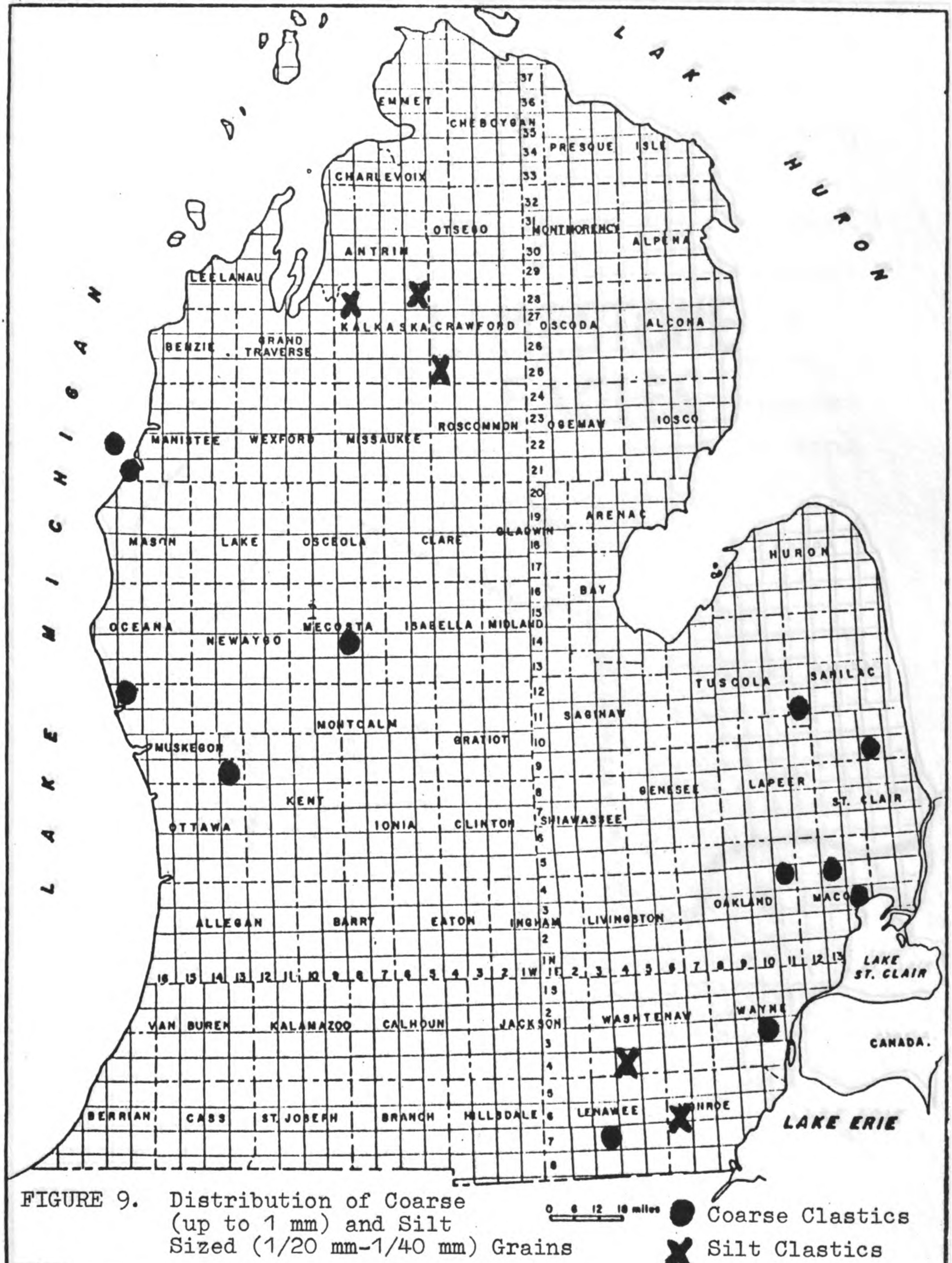


FIGURE 9. Distribution of Coarse (up to 1 mm) and Silt Sized (1/20 mm-1/40 mm) Grains

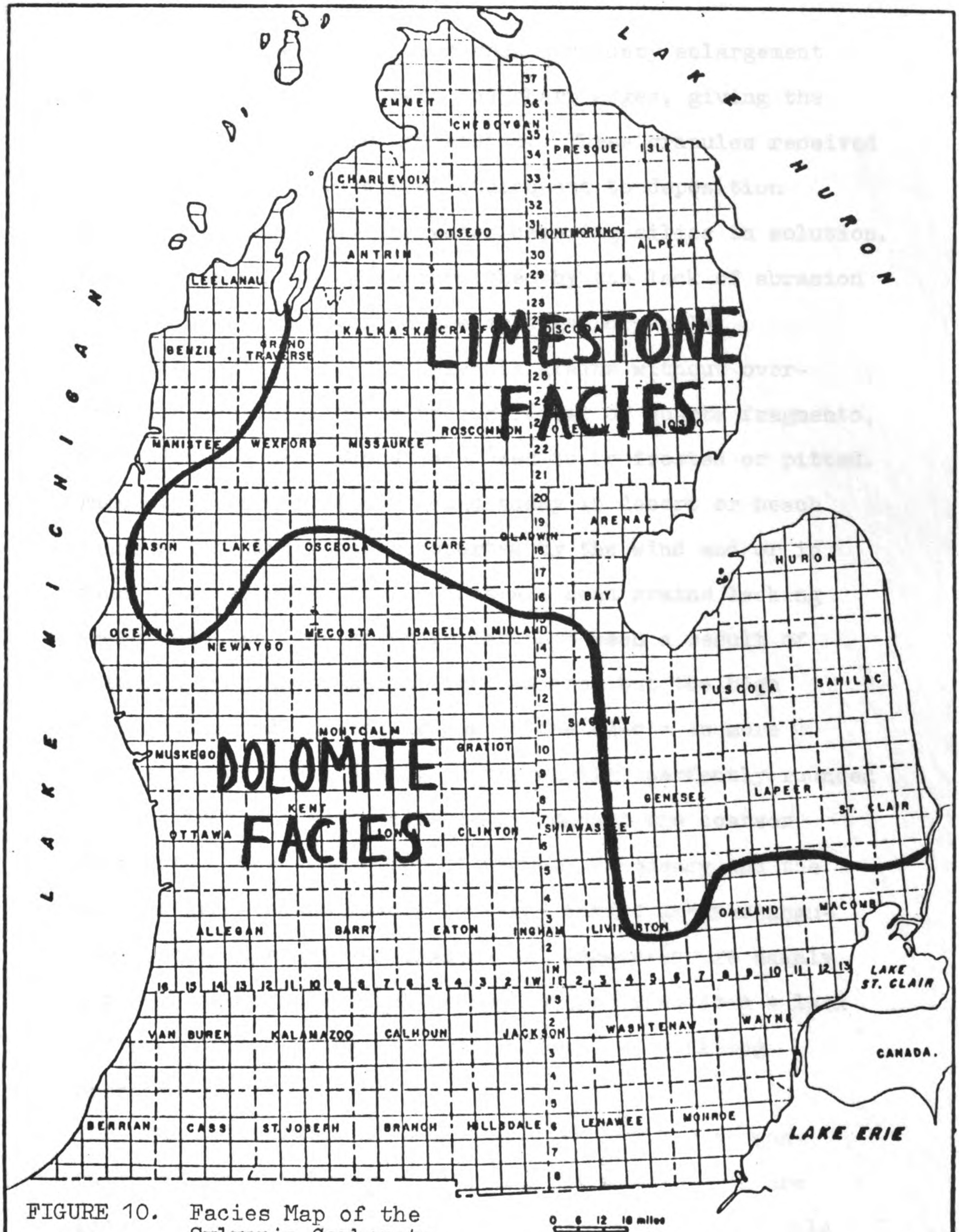


FIGURE 10. Facies Map of the Sylvania Carbonate Fraction

Many of the sand grains show secondary enlargement with perfect crystal facets and sharp edges, giving the sand a fresh sparkling appearance. These granules received their secondary enlargement subsequent to deposition probably from percolating water carrying silica in solution. Evidence of this view is furnished by the lack of abrasion on the faces and edges of the enlarged crystals.

The surfaces of the Sylvania grains without overgrowth do not show the vitreous luster of quartz fragments, but under the microscope, are seen to be frosted or pitted. This is a characteristic found today in desert or beach sands which have been transported by the wind and/or in dune phase at some time. Since all sand grains lacking overgrowth are frosted, this may have been a result of chemical etching by percolating waters, but the high degree of rounding and sorting of the quartz is more indicative of beach sands. Occasionally, perfectly rounded grains are to be seen, especially amongst the coarser fragments. The sand sizes of highest frequency and the smaller grade sizes have a tendency toward greater angularity than the coarser fragments. Angularity is mainly a result of secondary enlargement rather than from a lack of transporting distance or as a result of drilling operations.

The Sylvania is a very pure quartz sandstone containing only a few grains of other minerals, which are located mostly in southeastern Michigan. Heavy minerals that do occur become more prominent toward the base of the formation. The persistent minerals, in decreasing order of importance, include chert, gypsum, anhydrite, pyrite, tourmaline, hornblende, epidote, zircon and limonite. Chert is present in some wells throughout the whole vertical section, but generally it is restricted to the basal beds. The lower units often contain a high percentage (up to 35 percent) of weathered chert probably representing the reworked cherty beds of the underlying Bois Blanc formation. In southern Michigan chert persists throughout the section as indicated by the chert percentage map (Figure 15). S. W. Alty (1932, pp. 289-300) studied the heavy mineral content in oil well samples and found that the heavy minerals seemed to decrease from southeast to northwest.

Sylvania fossils exist predominantly in the gradational limy sandstones and arenaceous limestones of eastern lower Michigan. The fossils occurring in these transitional beds, and even those near the base of the sandstone, are the same as those in the overlying member of the Detroit River formation and are not related to the fossils of the underlying Bois Blanc and Bass Island formations (Carman, 1936). Fossils observed in this investigation include pelcypod shells, crinoid stems, bryozoans, foraminifera, ostracods, cephalopods-tentaculities, fossil corals, and brachiopods.

To attempt to establish typical limestone or dolomite lithologic characteristics within the Sylvania sequence would be unproductive. Individual sandstone beds cannot be traced for any distance, except in a few areas where the beds are traceable between two or three closely spaced wells (Figures 7 and 8). Even within a single vertical column (Table 1), a wide variation in limestone and dolomite color, crystallinity and percentage relationships with quartz is observable and it becomes difficult to identify a classic Sylvania unit.

Contact Relationships

The Sylvania sandstone lies stratigraphically between the Lower Middle Devonian Amherstburg formation of the Detroit River Group above, and the lower Onondaga age Bois Blanc formation or late Silurian Bass Island Group below (Figures 1 and 4). Deviations from this regional pattern occur in southwestern Michigan where thin units of the Sylvania are overlain by the Lucas formation of the Detroit River evaporite section and in a few isolated locations where the sandstone may overlie the early Devonian Garden Island formation or late Silurian Salina Group (Figure 5). The sandstone is generally conformable with the overlying carbonate or evaporite sequence, but unconformably overlies either the Bass Island or Bois Blanc carbonates. Where the Sylvania is absent along the northern flank of the Michigan Basin, the Bois Blanc is overlain by the Amherstburg.

TABLE 1

Sylvania Sandstone Lithologic Column

T4N-R8E-22 Permit No. 13072

Detroit River-Amherstburg

Unit		Depth (Feet)
1.	Dolomite, calcitic, brown to gray, sucrosic, medium grained, 90 percent; limestone, dark to light brown, aphanitic, fine grained, soft, 10 percent; trace of sandstone, frosted, subrounded, 1/2 mm.	3480-3498
	Upper Contact-Sylvania	
2.	Dolomite, calcitic, dark brown to brown, medium grained, 85 percent; limestone, white, aphanitic, fine grained, 8 percent; sandstone, white, frosted, subrounded to well rounded, fairly well sorted, 1/2 mm - 1/4 mm, mostly 1/4 mm, 7 percent, a few aggregates contain dolomite cement, a few grains approach sphericity; trace chert, white, porcelain; trace gypsum, white, soft.	3499-3550
3.	Dolomite, calcitic, light brown to gray, medium sucrosic, 60 percent; limestone, gray to white, fine sucrosic, fine grained, 15 percent; sandstone, white, frosted, well rounded, well sorted, 1/8 mm - 3/4 mm, mostly 1/4 mm, 23 percent; chert, white, porcelain, 3 percent.	3550-3590
4.	Limestone, dolomitic, light gray to brown, sucrosic, 55 percent; dolomite, calcitic, tan to gray, finely crystalline, fine grained, 15 percent; sandstone, grayish white, clear, subangular due to secondary enlargement, poorly sorted, most 1/4 mm, 28 percent; chert, white, weathered, traces of pyrite inclusions, 2 percent.	3590-3630

TABLE 1 (Continued)

Unit		Depth (Feet)
5.	Limestone, dolomitic, brown to white, medium sucrosic, 100 percent; trace chert, white; fossil crinoid stems, bryozoans, brachiopod fragments.	3630-3660
6.	Limestone, dolomitic, brown to white, medium sucrosic, fine grained, 50 percent; sandstone, clear, subrounded to subangular, secondary enlargement, moderate sorting, mostly 1/2 mm, 50 percent; trace chert.	3660-3690
7.	Sandstone, clear, subrounded to subangular, moderate sorting, 1/4 - 1/2 mm, mostly 1/4 mm, 99 percent; limestone, dolomitic, brown to white, sucrosic, 1 percent; trace chert, white.	3690-3770
8.	Limestone, dolomitic, gray to light brown, fine sucrosic, 44 percent; dolomite, calcitic, tan to gray, dense, 32 percent; sandstone, white, frosted, moderately sorted, well rounded, 1/4 mm - 1 mm, mostly 1/2 mm, 20 percent; chert, milky white, porcelain to weathered, a few dolomite rhom inclusions, 4 percent; trace shale.	3770-3795
	Bois Blanc-Contact	
9.	Dolomite, calcitic, light brown to light gray, very finely crystalline, some pore filling gypsum crystals, 50 percent; limestone, dolomitic, light gray, medium sucrosic, 6 percent; chert, white, all weathered, dolomite rhom inclusions, 44 percent; trace pyrite.	3795-3810

One of the chief problems in the Sylvania section is its relationship with the Detroit River sequence. The contact of the Sylvania sandstone with the overlying dolomite and limestone is difficult to determine, because few lithologic changes and some sandy beds are present in the basal part of the overlying carbonate rocks. Because the contact is gradational, the carbonate rocks are considered to be conformable with the Sylvania and, therefore, the Sylvania is included in the carbonate sequence of the Detroit River Group.

The basal Amherstburg is primarily composed of limestone with lesser amounts of dolomite in the northern and eastern parts of the Southern Peninsula of Michigan. It becomes a dolomite in the western and southern parts of the lower peninsula with the exception of the southwestern corner where the Detroit River evaporite section directly overlies the Sylvania. The characteristic feature of the basal Amherstburg carbonate rocks is a relatively darker color in contrast to the somewhat lighter colored underlying arenaceous Sylvania carbonates. Many geologists have referred to the Amherstburg as the "Black Lime" because of its dark color. This peppered dark brown appearance was only observed in the basal units of the northern lower peninsula. Upper contacts were chosen on the basis of slight color changes and significant differences in quartz percentages with the exception of southwestern Michigan where the light colored dolomites offered little lithologic color change. In northern and northwestern Michigan the uppermost Sylvania sandstone is typically a light brown to brown, dense, arenaceous limestone that grades into the overlying peppered dark brown, finely sucrosic limestone of the Amherstburg. In eastern Michigan the upper Sylvania is represented by a very arenaceous limestone that is often dark gray or brown to buff, dense, and may contain a trace of chert. This normally grades upward into a slightly arenaceous limestone that becomes dark brown to brown, aphanitic, with an absence of chert. Chert is rarely present in the basal beds of the Detroit River carbonate section. The upper contact in central and southeastern Michigan shows two types of lithologic breaks. There may be a sharp break from a pure white sandstone unit into a calcitic dolomite which is brown to buff and microcrystalline. Secondly, there is a gradational change from a gray to buff, microcrystalline, arenaceous calcitic dolomite into a dark gray to brown, dense, calcitic dolomite. Definite, easily recognizable lithologic breaks between the Sylvania and overlying Amherstburg only occur in the high sandstone percentage zones of central and southeastern Michigan. Southern Michigan shows a gradual change from a light gray to white, dense, dolomite into a buff to medium-brown dolomite. Because quartz grains are of small quantity in southwestern and western Michigan, in addition to carbonate units showing no lithologic differences, upper contacts are based upon a total absence of sand in the overlying Detroit River carbonate section to the west or evaporite sequence in the southwest. In southwestern Michigan, a green sandy shale with interbedded gray dolomite represents a facies of the Sylvania and in the western area it is typically a brown to buff, dense, arenaceous dolomite.

At or near the top of the Detroit River carbonate sequence is a black limestone or dolomite. The black limestone has proved to be a reliable marker bed when tracing the Sylvania sandstone from gamma ray-neutron logs. According to Landes (1945, p. 68) this marker bed is present throughout Michigan. The top of the "black limestone" is 200 to 300 feet above the base of the Detroit River carbonate section in eastern and northern Michigan, and 20 to 100 feet above the base in western and southern Michigan. In wells where the contact between the Sylvania and the overlying carbonate bed cannot be readily determined, the "black limestone" serves as a marker on gamma ray-neutron logs from which the contact can be roughly estimated.

The lower contact of the Sylvania is easily determined when the cherty section of the underlying Bois Blanc is present. The Sylvania basal beds often contain white weathered chert representing the reworked cherty units of the underlying formation. Bois Blanc subsurface samples show a substantial increase in the presence of chert compared to the overlying sandstone units. The upper five feet of the Bois Blanc is typically a gray sandy cherty dolomite. The sand residue is usually poorly sorted and often subangular to angular in all size fractions.

In western Michigan, the underlying brown, buff and gray dolomites are called Bois Blanc if chert is present, or Bass Island if the carbonate is not cherty. Bois Blanc and Bass Island carbonates, therefore, are differentiated on the basis of chert content. The locations where Garden Island or Salina are subjacent to the Sylvania were taken from the Michigan Geological Survey descriptive logs, and occur in small isolated patches to the south and southwest of the Basin. The feather edge of the Bois Blanc formation varies widely along its border due to local variations in the depth of erosion (Figure 5). In these areas where the Sylvania sequence overlies Bass Island, Garden Island or Salina rocks, the contact between the two is difficult to distinguish in the subsurface since color changes are rare. The break was chosen as the point where the sandstone became absent below the Sylvania beds.

Distribution and Thickness

The Sylvania sandstone appears to be restricted to an area north and west of the Findlay Arch. On the basis of the isopach map (Figure 11) it can be seen that the sandstone thins southward in southeastern Michigan and the zero thickness location does not extend far into northern Ohio, indicating that the Findlay Arch probably formed the southern shore of the Sylvania age sea. In the subsurface, the Sylvania sandstone is found throughout most of the Southern Peninsula of Michigan with the exception of the extreme northern and northeastern regions. The sandstone is also found in northern Indiana, northwestern Ohio and eastern Ontario, with outcrops occurring in southeastern Michigan and northwestern Ohio. The outcrop area varies in width from one to two miles at the northernmost exposure in Wayne County, Michigan, to less than 200 yards at the southernmost exposure at the Maumee River, Lucas County, Ohio. The Sylvania sandstone dips toward the center of the Michigan Basin from the outcrops at an average rate of 30 to 35 feet (9 to 10 meters) per mile (1.6 Kilometers) and in Clare, Midland, and Gladwin Counties the structure contour map (Figure 3) shows a depth of about 4,400 feet (1,320 meters) below sea level and a structural relief of approximately 5,000 feet (1,500 meters).

The isopach map shows a shallow linear trough lying in a northwest-southeast axis extending from northwestern through southeastern Michigan toward northern Ohio. Most of the Sylvania sandstone accumulated in this "trough." Thickness lines indicate that very little of the sandstone has been eroded in the outcrop area. Within this large linear basin the isopach map (Figure 11) shows maximum thicknesses occurring in Sanilac County to the east, Clare County in the central area, and Livingston County to the southeast. Each of these counties represents

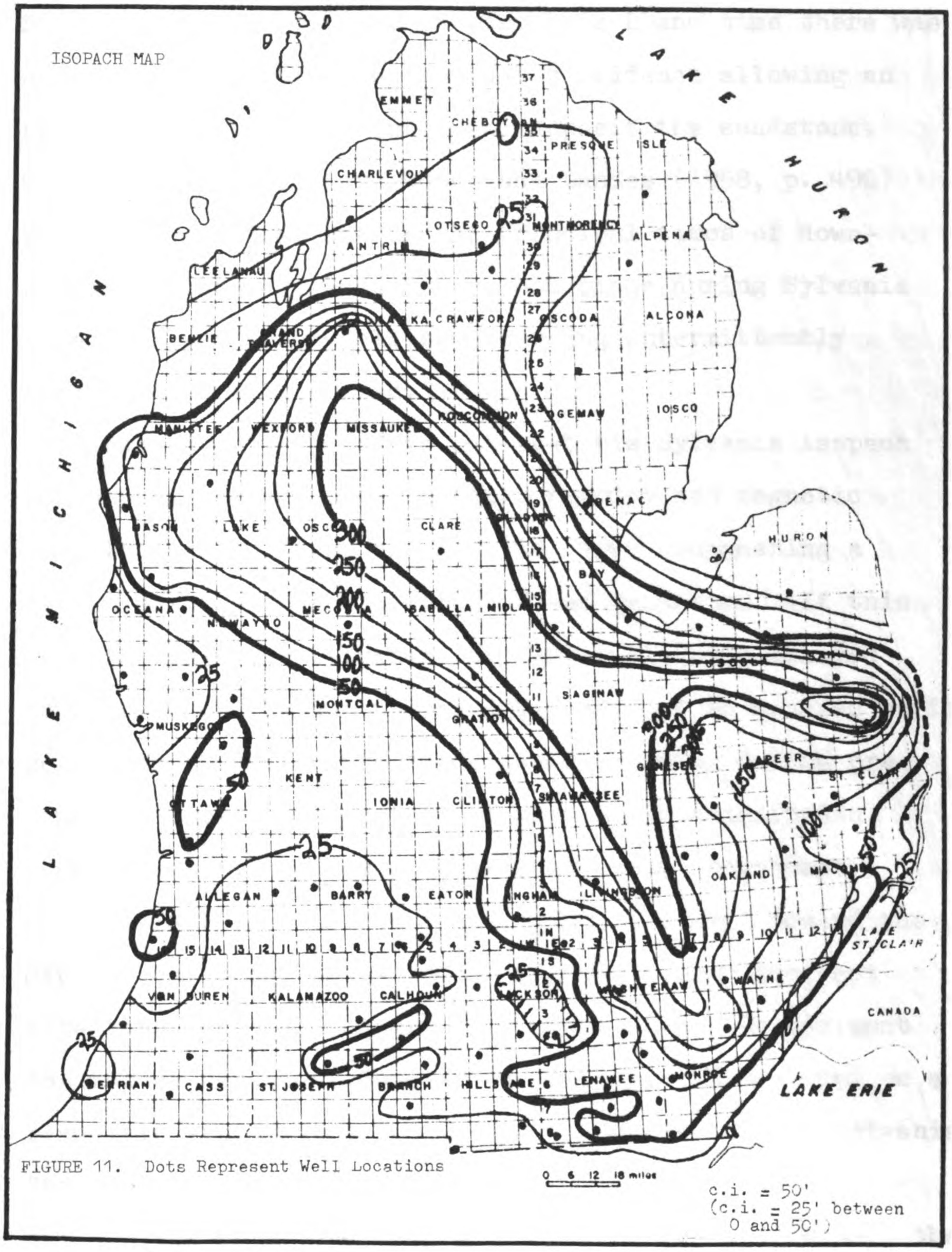


FIGURE 11. Dots Represent Well Locations

a thickness of 410, 328+, and 336 feet, respectively, reflecting greater subsidence along the "trough" into the Bois Blanc. Apparently, in post Bois Blanc time there was a northwestward trending basinal subsidence allowing an epicontinental sea to enter and deposit the sandstone. This is compatible with Cohee and Landes (1958, p. 490) who point out that one of the principal times of down-warping in the Michigan Basin took place during Sylvania time with incipient folding occurring intermittently throughout the Paleozoic.

Gardner (1974) points out that his Sylvania isopach shows parallelism to the Bouguer gravity and magnetic anomaly maps of Kinze and Merritt (1969) suggesting a pre-existing basement control of sedimentation. If this were the case the Sylvania "trough" would be a delayed isostatic sinking due to the added mass of Keweenawan mafic rocks incorporated into the basement complex during pre-Cambrian time. Depocenters of most pre-Mississippian isopach maps also show a general northwest-southeast orientation; however, they are offset eastward toward the Saginaw Bay area. This would indicate a very indirect effect to the Mid Michigan high, but along with sediment loading by sandstone deposition it cannot be excluded as a plausible explanation for downwarp movement of the Sylvania "trough."

To the north and east of the sandstone depocenter, the Sylvania thins rapidly from 300 to 400 feet to zero in

Charlevoix, Ogemaw and Huron Counties. The southern thickness is more gradual as thinning continues into northwestern Ohio. To the west the sandstone decreases to 50 feet in Clinton County and continues in a thickening and thinning pattern throughout all of western and southwestern Michigan. Within this area are several isopach highs and an isopach low, generally trending in northwest to southeast and northeast to southwest directions. Structural patterns in the Michigan Basin often show these alignments denoting possible zones of weakness in the basement along which folding or sinking has taken place. Therefore, isopach thicknesses are mainly a result of partial subsidence with perhaps prior erosion occurring on the pre-Sylvania surface, and thins appear to have been structurally controlled by subsurface folding.

The isopach would imply that the trough has a relief of 300 feet throughout its northwest-southeast lineation with a central diameter of approximately 55 miles broadening to over 70 miles to the northwest and southeast. The southeastern area develops a tributary-type pattern with extensions to the east and south. Such an outline might be attributed to entrenchment of the subsiding trough by the encroaching Sylvania age sea. Since the southeastern tributary extension occurs over the present day Howell Anticline, this would imply the absence of that structure, and activity shaping its development must have been in post-Sylvania time. Kilbourne (1947), in his study on the origin and history of the Howell Anticline, pointed out there had been a local trough in this area throughout the early and middle Paleozoic. He further assumes sediments collected in this trough until the beginning of Coldwater time as all formations thin out in a southwesterly direction, as the isopachs imply.

The lithologic cross sections (Figures 7 and 8) show that although upper and lower contacts of the Sylvania sandstone can be located throughout the lateral extent of the Michigan subsurface, individual sandstone lenes are not easily traceable and do not extend laterally for any appreciable distance except between closely spaced wells.

Mineral Variation Maps

Facies changes represent lateral variations in a rock unit. One of the most effective ways of portraying variation is by the use of percentage maps. Subsurface sample analysis indicates that there is a close relationship between the carbonate and quartz grain content (Figures 12 and 13). The percentage maps are identical in pattern, but directly opposite in numerical values, implying an inverse relationship throughout the Sylvania areal extent. The most noticeable feature is the gradual decrease of quartz and increase of carbonate northwestward, with changes more quickly in all other directions.

The clastic percentage map also shows considerable parallelism with the isopach map (Figure 11). Where the

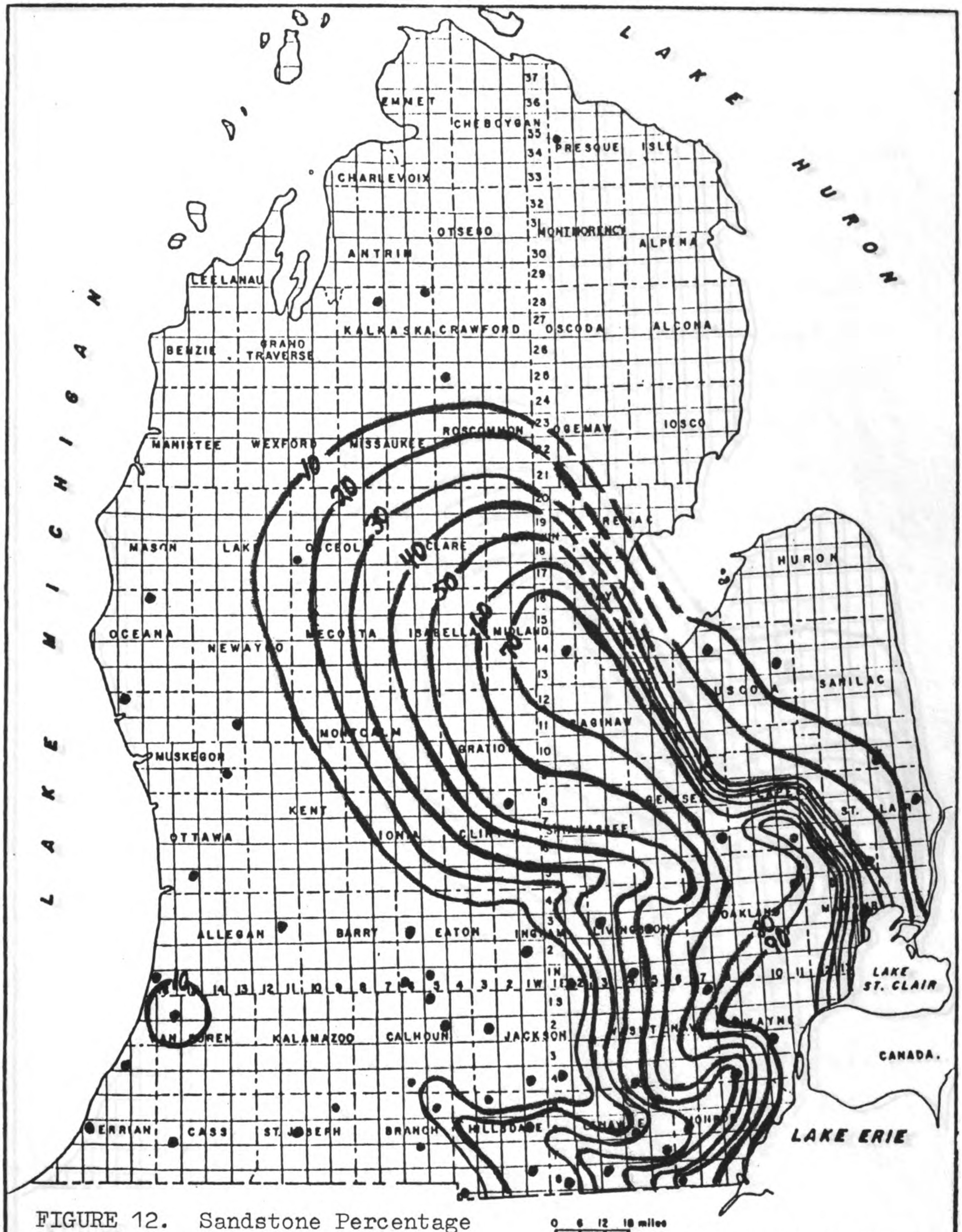


FIGURE 12. Sandstone Percentage Map

10 percent Interval

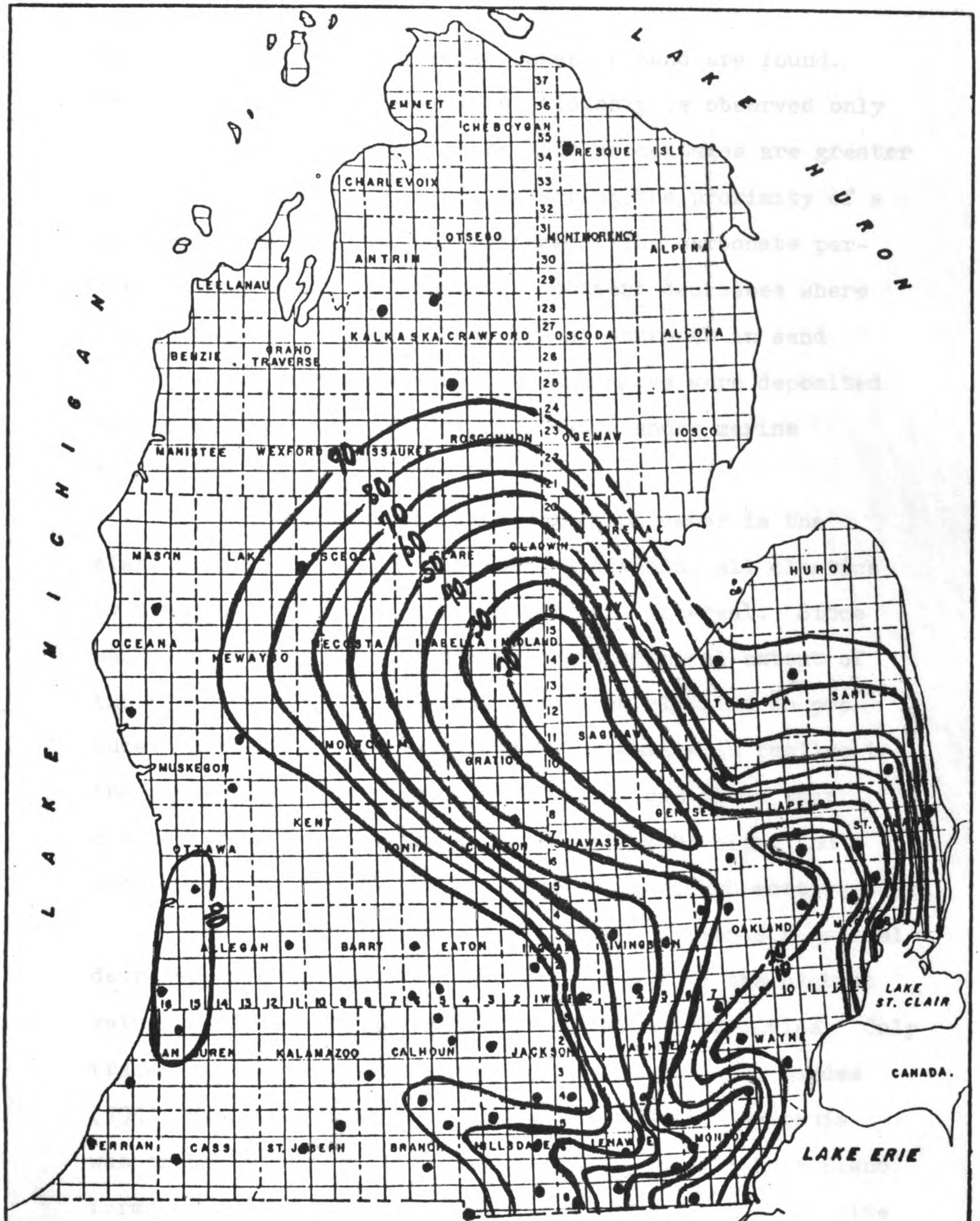


FIGURE 13. Carbonate Percentage Map

10 percent Interval

unit is thicker, higher percentages of sand are found. Departure from this general relationship is observed only in southeastern Michigan where sand percentages are greater with decreasing thicknesses, inferring the proximity of a sedimentary source to the southeast. The carbonate percentage map shows that carbonate content decreases where the formation is thicker and with an increase in sand content. At various times, the carbonates were deposited simultaneously with the Sylvania sands under marine conditions.

The most fundamental lithologic indicator is the clastic ratio, which is obtained by dividing all clastics by non-clastics within the desired well interval. Since sandstone and carbonates dominate the vertical extent of the Sylvania unit, these rocks would be expected to produce a clastic ratio map (Figure 14) similar in outline to the percentage maps of each. The ratio map shows that clastics are concentrated in southeastern Michigan and decrease quite rapidly in all directions except northwestward.

The chert percentage map (Figure 15) reveals a general decrease of chert in all directions away from the highest values recorded in Ingham, Eaton and Jackson Counties. Only traces of chert are found elsewhere in Michigan. Landes (1951) concluded that most of the chert in the Sylvania was probably derived from the underlying cherty Bois Blanc formation. The high chert concentration does not coincide with underlying areas of maximum Bois Blanc erosion (Figure 5). However, residual chert from the southwest and west where the Bois Blanc was completely removed as an underlying formation may have been carried eastward by stream and/or wind activity and incorporated into the Sylvania stratigraphic units. In addition, there may have been secondary silicious processes operating in chert production as would be indicated by the presence of quartz secondary enlargement. In view of the fact that most of the chert was of a weathered milky white appearance it would more likely be residual in nature. Chert concentrations also occur in an area of high carbonate percentage (Figure 13) with a similar distribution pattern, as well as an area relatively near the Sylvania Shore.

In the evaporite percentage analysis (Figure 16), wells investigated show relatively high evaporite values (greater than 2 percent) located to the east and southwest. This would seem to indicate these near-margin areas were sufficiently restricted to prove favorable for evaporite deposition. Jodry (1954) noted lagoonal conditions around the southwest Michigan area in the Traverse Group. He suggested lagoonal control based on the coincidence of the "West Michigan barrier" and the high regional gravity map of the area after Logue (1954). Runyon (1976) and Newhart (1976) produced dolomite percentage maps showing increases of magnesium toward the west from the postulated barrier during Traverse and Ordovician times, respectively. This

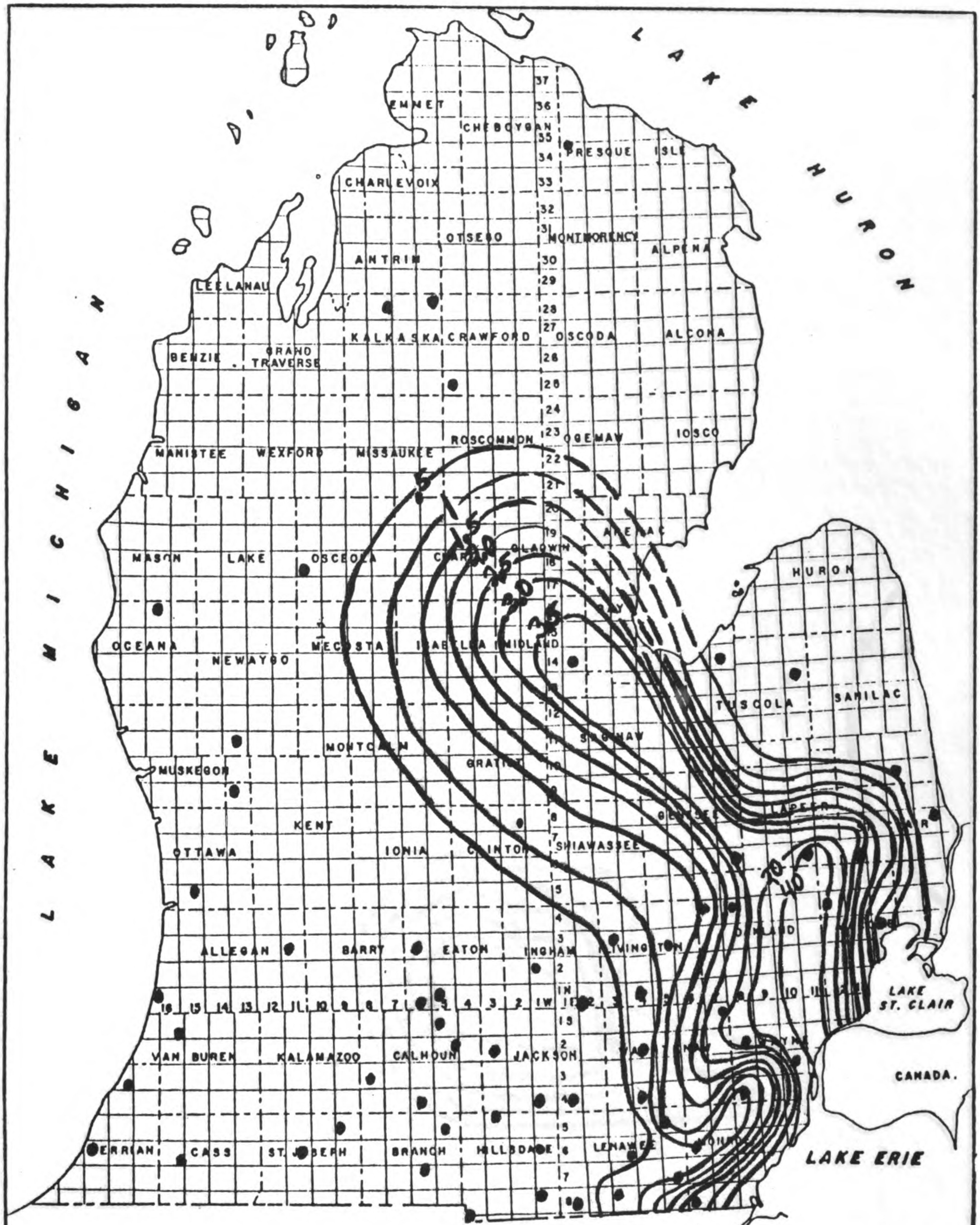


FIGURE 14. Clastic Ratio Map

Ratio Interval 0.5
up to 3.5 Above
3.5 Interval is 20

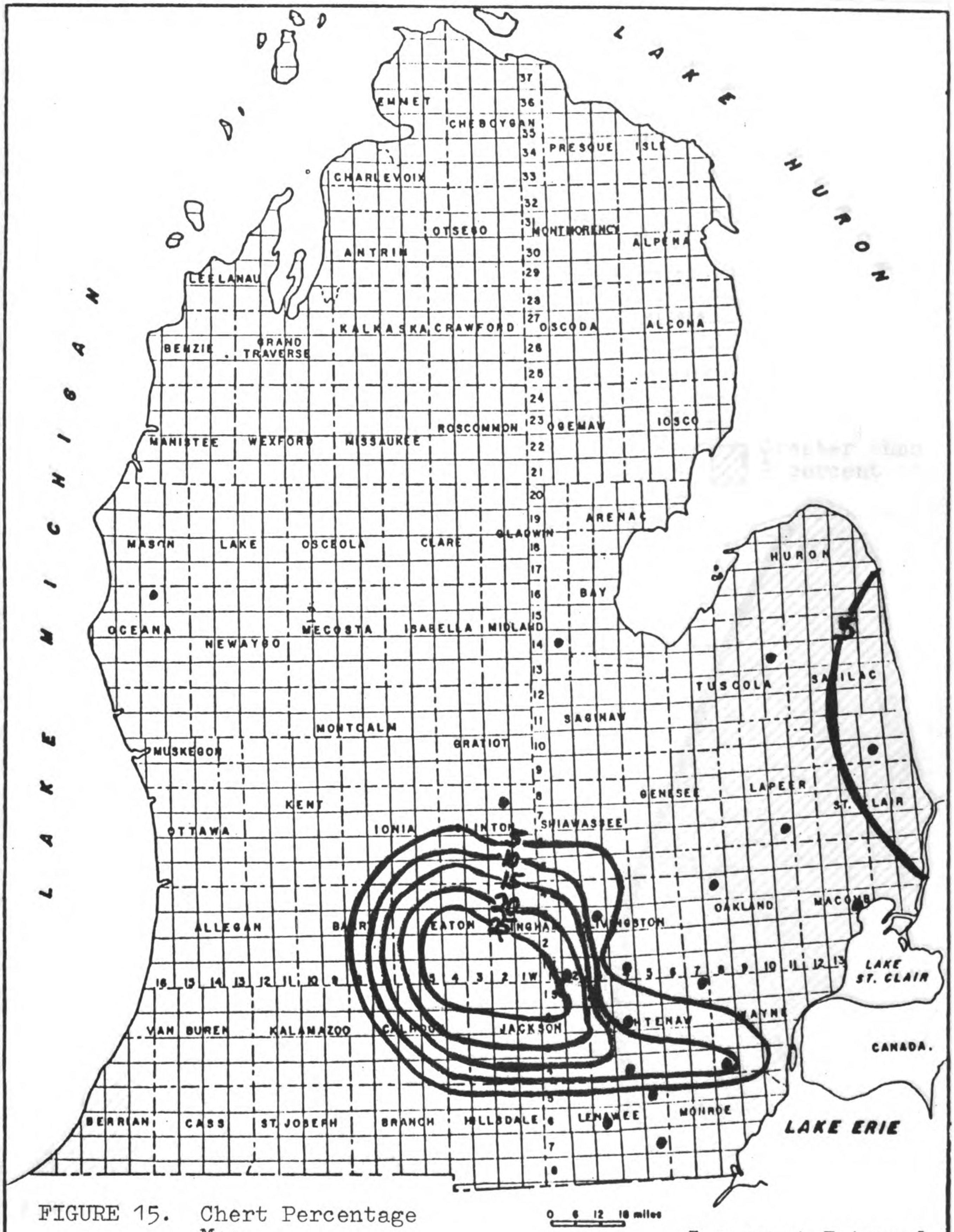


FIGURE 15. Chert Percentage Map

5 percent Interval

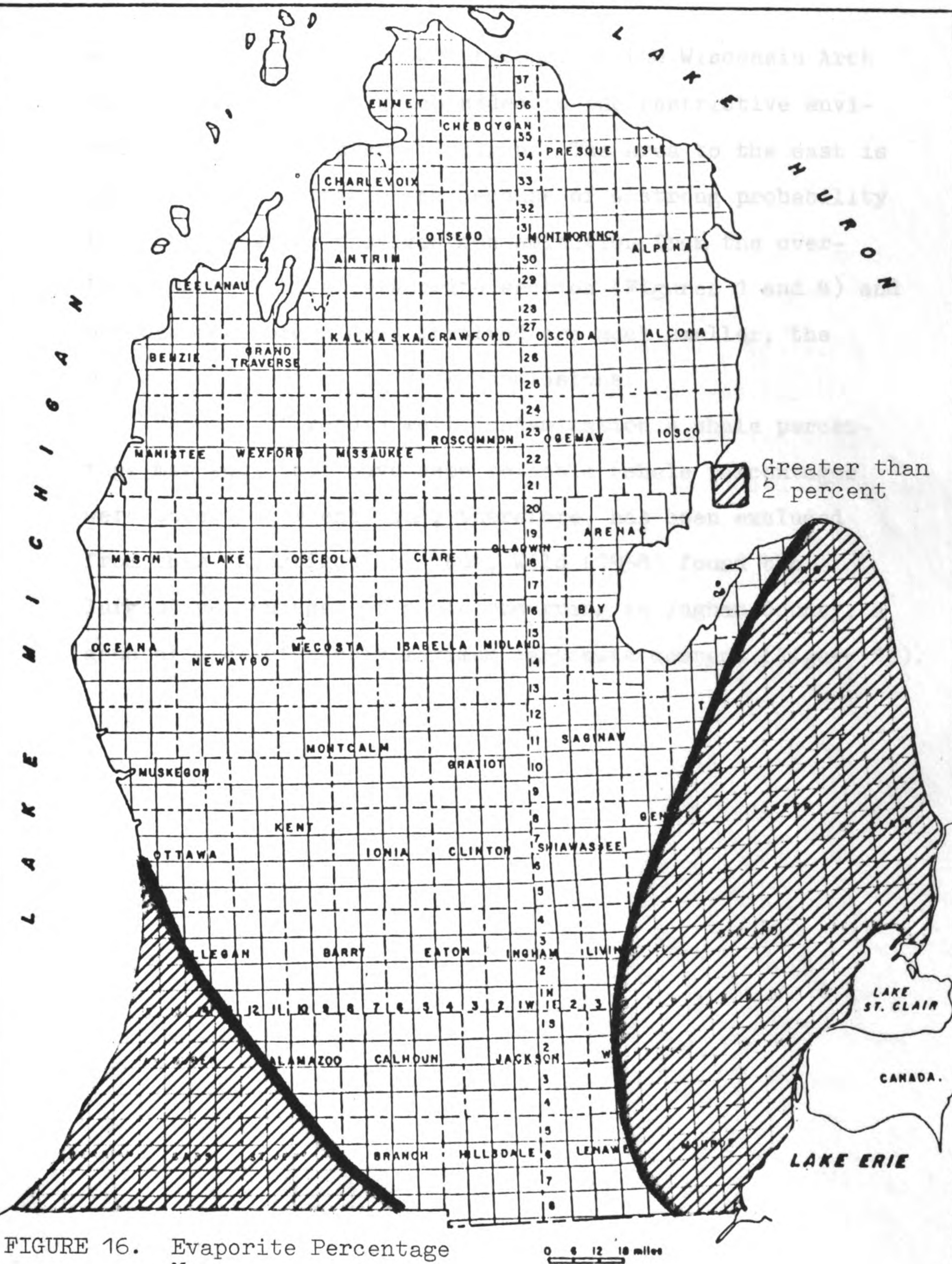


FIGURE 16. Evaporite Percentage Map

would seem to indicate the presence of the Wisconsin Arch during Sylvania time which added to the restrictive environment in southwestern Michigan. The area to the east is not easily explainable and because of a strong probability that rotary wells provided contamination from the overlying Detroit River evaporite section (Figures 1 and 4) and because the percentages involved are much smaller, the writer is reluctant to draw conclusions.

Because of rotary well contamination a shale percentage map would not have been reliable (shale percentages were under 4 percent) and, therefore, has been excluded from this investigation. But, Wild (1958) found the largest percentages of shale occurring in Ingham County, a general area of nearly maximum carbonate content (Figure 13).

ENVIRONMENTAL INTERPRETATION

Origin of Sediments

The origin of the Lower Middle Devonian Sylvania sandstone presents a problem which may be explored by an investigation of the sedimentary and lithologic characteristics, the areal distribution and thickness and the paleogeography at the time of deposition. From the writer's data it is apparent that the Sylvania may have been deposited in a near shore shallow carbonate producing marine environment migrating northwestward from the Chatham Sag and southeastern Michigan.

Indications for a southeastern source are exhibited by the following: (1) seven wells located in eastern and southeastern Michigan contain appreciable quantities of coarse quartz grains (up to 1 mm) within some units of the Sylvania sequence (Figure 9), indicating a closeness to source since large size grains do not occur elsewhere in Michigan, with the exception of wells located to the extreme northwest and west; (2) three wells located in and near Kalkaska County contain only silt size quartz (1/40 mm) exhibiting a lateral gradation of large to finer grains from southeast to northwest and away from the westerly source area; (3) the clastic ratio map (Figure 14) shows the highest clastic concentration occurring in southeastern

Michigan, which would be expected since more clastic material tends to be deposited closer to source; and (4) heavy mineral content decreases from the southeast toward the center of Michigan. This evidence is supported by Hatfield's (1969) observations regarding crossbedding with a northwestward inclination in the Sylvania in northwestern Ohio and southeastern Michigan, with preferred orientation of the long dimensions of grains also in that direction.

Some of the Sylvania sand may also have been transported by prevailing westerly winds and/or running water from a northwestern or western direction as indicated by the following evidence: (1) there are five wells located in western and northwestern Michigan which contain coarse quartz grains (up to 1 mm) indicating a closeness to source (Figure 9); and (2) these coarse grains are better rounded and sorted than those located in eastern and southeastern Michigan which might be resultant of a more persistent abrasion in beach phase but could conceivably imply reworking of older sandstone exposed in the Wisconsin Highland region. Paleogeographic maps suggest an arid climate in the area during Lower Devonian time so prevailing Westerlies and/or streams could easily have picked up this sand and redeposited it in the Michigan Basin.

There exist two possibilities as to the origin of these southeastern derived sediments. First, Chung (1973) in his study on the Coldwater Formation and Asseez (1969) in his analysis of the Bedford-Berea sequence indicate the presence of a rising eastern landmass during those periods. Chung (1973) created a paleogeographic map which depicts this as a low lying peninsula in the Findlay Arch area. In addition, in comparing isopach maps of the Bois Blanc and Sylvania formations produced by Brigham (1971) it can be seen that the zero thickness line closes in toward southeastern Michigan from western Ontario during Sylvania time. This would imply the existence of this low lying emergent area during Sylvania deposition. Second, the Canadian Shield to the northeast was exposed during Sylvania time and may have contributed sediments brought down by fluvial processes or beach transport along the Algonquin Arch.

Sedimentary and Geologic History

The pertinent sedimentary and geologic history of the Sylvania sandstone begins with the withdrawal of the Bois Blanc sea from the Michigan Basin. During the regression erosion completely removed the Bois Blanc formation from southwestern Michigan as well as from the flanks of the Kankakee and Findlay Arches. Closing this interval, subsidence of a northwest-southeast trending Sylvania "trough" occurred on the eroded Bois Blanc surface permitting entrance of marine waters through the Chatham Sag of the Findlay Arch. Sylvania sandstone deposition began throughout most of lower Michigan sometimes concurrently with carbonates. The sand may have been carried to the encroaching Sylvania sea by three delivery systems: (1) quartz grains may have been brought down from the eroding Canadian Shield area to the northeast by a fluvial or beach current transport system paralleling the Algonquin Arch; (2) the grains may have been eroded off a postulated low lying peripheral landmass surrounding the Findlay Arch area; and (3) wind and/or stream activity from the Wisconsin Highlands to the northwest may have carried sand from older eroding exposed sandstone into the Basin.

Typical characteristics of the sand grains are their exceptionally well rounded appearance, the uniformity of size, and extreme purity, the frosting and the high degree of sorting. These attributes all point to a long continued wind and wave abrasion probably in a shallow coastal environment. These qualities were developed in a beach phase while being transported downward along the Algonquin Arch and/or were created by the northwestward trending currents carrying sands into a persistently transgressive shore line zone where waves and possibly wind actively reworked and redeposited the sediments.

With further transgression of the Sylvania sea came additional carbonate accumulations (Figure 10). The Wisconsin, Kankakee and Findlay Arches and the "West Michigan Barrier" probably restricted the shallow marine environment in the western and southern areas of Michigan for dolomite deposition to predominate in the arid climate postulated. To the north and northeast a deeper sea and lower salinity environment produced fossiliferous limestone deposition. The zero thickness line located to the northeast on the isopach map (Figure 11) either indicates the Sylvania shoreline was here during this period or was further back and the limestone subsequently eroded. The zero thickness to the south would be indicative of the transgressing sea being limited southward by the Findlay Arch.

Following Sylvania sandstone deposition, the Basin probably subsided allowing the sea to transgress farther leaving a thick carbonate layer of the (Amherstberg) Detroit River Group. As the carbonate depositing marine waters spread over the Michigan Basin, the upper Sylvania sands were reworked and in most cases incorporated into the basal units of the overlying limestone and dolomite, resulting in a gradational upper Sylvania contact. The contact relations between the Sylvania sands and fossiliferous Amherstburg carbonates above and to Bois Blanc cherty carbonates below may be readily seen on the lithologic cross-sections (Figures 7 and 8). These provide an excellent example of the obvious predominate marine depositional environment of the sandstone and demonstrate interbedding with limestone and dolomite.

ECONOMIC CONSIDERATIONS

The purity of the Sylvania and superiority as glass sand has been recognized since the early reports of Houghton (1838, p. 7). It is the only glass sand produced from quarries in Michigan. Because of its extreme purity, averaging only 0.015 percent iron oxide, all sand used by the U.S. Government for optical purposes during the first World War (Martin, 1920, p. 172) was from Michigan. The Sylvania sandstone has also been discussed by Sherzer (1911, p. 256) as a source of water in and adjacent to the outcrop area in southeastern Wayne and northern Monroe Counties, Michigan.

The oil and gas fields presently discovered and produced commercially from the Detroit River Group are anticlinal accumulations within dolomites of the Lucas formation. The Sylvania sandstone member has yielded good showings of oil in several wells (Landes, 1945) but no production as yet. However, most wells penetrating the Sylvania sandstone have been off structure within the central area of the Basin. It would be reasonable to assume that many new fields in the Detroit River Group will be discovered by exploring the Detroit River sequence of rock from top to bottom, including the basal Sylvania sandstone, on anticlines, stratigraphic traps, due to porosity pinch outs in the dolomite zone, and also due to sand lenticularity are additional possibilities.

SUMMARY AND CONCLUSIONS

1. The Sylvania rests disconformably upon the eroded surface of the Bass Island and Bois Blanc formations.

2. It is concluded that there may have been three source areas for the Sylvania sandstone: first, the exposed Canadian Shield area to the northeast could have contributed sediments brought down into the Chatham Sag area by fluvial processes or beach transpost along the Algonquin Arch; second, erosion of a postulated low lying peripheral landmass around the Findlay Arch area may have deposited material into the encroaching sea; third, there is some minor evidence that the St. Peter sandstone from the Wisconsin Highland region to the northwest was carried into Michigan by prevailing westerlies and/or streams.

3. The lithologic percentage maps, clastic ratio map, isopach map and distribution of coarse and silt size grains map can be interpreted as evidence that sand carrying encroaching marine waters were coming into Michigan from the southeast.

4. Northwestward trending currents of these transgressive marine waters, which came through the Chatham Sag of the Findlay Arch, were an influential force governing

the distribution and deposition of the Sylvania sandstone in Michigan.

5. The marine phase probably resulted in transportation to a shallow coastal environment along the Sylvania Shoreline where wind, wave and current activity reworked, redistributed and continuously redeposited the sandstone, predominately along with carbonates of the sea.

6. Most of the Sylvania sandstone was deposited in a southeast-northwest trending trough with sand percentage decreasing and carbonate percentage increasing in all directions away from this linear depression except southeastward.

7. The water-laid phase of the Sylvania grades conformably into the overlying Detroit River carbonates, which in this region is of Amherstburg age.

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APPENDICES

APPENDIX A

APPENDIX A

TABLE 2. Well data used for construction of structural contour and isopach maps. Elevations based upon feet above sea level.

Location	Permit No.	County	Elevation (Feet)	Top of Sylvania	Bottom of Sylvania
5-34N- 2E	None	Presque Isle	830	1050	1300
23-33N- 2E	28083	Presque Isle	881	1496	1504
18-32N- 6E	28061	Alpena	935	--	--
14-31N- 8W	28395	Antrim	1115	--	--
18-30N- 2W	28375	Otsego	1334	3493	3535
9-29N- 5E	28346	Aplena	1213	--	--
22-29N- 2W	28191	Otsego	1243	3723	3738
1-28N- 5W	28325	Kalkaska	1211	3996	4028
25-28N- 7W	28309	Kalkaska	1106	3952	3997
30-25N- 3E	28195	Oscoda	1183	--	--
21-25N- 4W	28110	Crawford	1239	4798	4830
20-23N-14W	29417	Manistee	758	2922	2960
6-22N-15W	29564	Manistee	781	2662	2718
9-21N-18W	29858	Manistee	718	2893	2952
3-20N- 3W	9590	Clare	1195	5620	5929+
11-20N-14W	9130	Lake	852	3780	--
26-19N- 3E	9468	Arenac	751	4337	4690
29-18N-10W	12802	Osceola	1133	4835	4890
8-17N- 4W	9904	Clare	988	5212	5540+
16-16N-16W	12194	Oceana	877	3094	3206
35-16N-18W	11889	Oceana	643	2660	2670
32-15N-12E	12199	Huron	723	--	--
23-15N-15W	220	Oceana	830	3248	3290
27-14N-2E	3664	Midland	616	4925	5147
10-14N- 5E	30125	Midland	591	4489	4579

Location	Permit No.	County	Elevation (Feet)	Top of Sylvania	Bottom of Sylvania
33-14N- 8E	29237	Tuscola	627	4022	4174
3-14N- 8W	11693	Mecosta	1019	4640	4823
16-13N-11E	10968	Tuscola	739	3498	3795
24-12N- 3W	5067	Barry	746	4490	4545+
14-12N-15W	27688	Muskegon	754	3030	3050
8-12N-17W	28931	Muskegon	754	2650	2665
7-11N-14E	22857	Sanilac	798	3035	3240
11-11N-13W	28137	Newaygo	888	3424	3464
2-10N-17W	24195	Muskegon	763	--	--
4- 9N- 8E	24079	Genesee	837	3269	3466
9- 9N-15E	11492	Sanilac	771	1866	2276
6- 9N-13W	537	Ottawa	704	2885	2951
26- 8N- 2W	24475	Clinton	728	3642	3740
1- 7N-16E	22615	St. Clair	657	1290	1390
12- 6N- 8E	24028	Genesee	915	2800	2960
25- 6N-11E	12933	Lapeer	941	2344	2454
14--6N-13E	22594	St. Clair	815	2021	2133
27- 5N-14E	22708	Macomb	770	1646	1707
11- 5N-15W	21529	Ottawa	649	2380	2452
9- 4N- 7E	22665	Oakland	1004	2454	2700
22- 4N- 8E	13072	Oakland	1024	2183	2490
11- 4N-11E	23072	Oakland	977	2057	2166
8- 4N-13E	24039	Macomb	724	1673	1767
3- 4N-15W	24281	Allegan	715	2232	2269
11- 3N- 3E	10990	Livingston	920	2565	2795
28- 3N- 5E	22853	Livingston	973	1678	2014
28- 3N-14E	21582	Macomb	590	1195	1295
22- 3N- 6W	22945	Eaton	896	2786	2820
12- 3N-10W	24504	Barry	775	2534	2542
17- 3N-11W	21613	Allegan	790	2410	2425
17- 2N- 1W	28299	Ingham	974	2945	3046
31- 1N- 2E	24470	Ingham	944	2839	2893
23- 1N- 4E	23073	Livingston	907	2253	2422

Location	Permit No.	County	Elevation (Feet)	Top of Sylvania	Bottom of Sylvania
18- 1N- 5W	21769	Eaton	900	2570	2588
28- 1N- 6W	429	Eaton	864	2465	2475
8- 1N-16W	22875	Allegan	672	1507	1591
3- 1S- 7E	19342	Washtenaw	1007	1488	1765
6- 1S- 5W	22489	Calhoun	922	2480	2510
36- 1S-16W	6352	Van Buren	650	1441	1468
33- 2S- 4E	19891	Washtenaw	918	1680	1865
25- 2S- 8E	3813	Wayne	658	610	765
15- 2S- 3W	21963	Jackson	1020	2435	2461
12- 2S- 5W	22880	Calhoun	943	2345	2368
29- 2S-16W	5977	Van Buren	665	1501	1541
7- 3S-10E	17574	Wayne	632	420	560
22- 3S- 8W	20241	Calhoun	961	1892	1915
36- 3S-18W	24368	Barrien	732	1165	1175
11- 4S- 1E	22066	Jackson	1006	2096	2113
28- 4S- 4E	18777	Washtenaw	859	1500	1585
26- 4S- 8E	19214	Wayne	637	150	378
18- 4S- 1W	17807	Jackson	1042	2050	2094
21- 4S- 6W	22476	Calhoun	941	1721	1816
17- 5S- 5E	22517	Lenawee	798	939	1047
10- 5S- 3W	21013	Hillsdale	1031	1797	1835
28- 5S- 5W	20322	Branch	1024	1740	1762
17- 5S- 9W	22242	St. Joseph	875	1510	1576
3- 5S-15W	3803	Cass	749	1225	1233
24- 6S- 3E	9766	Lenawee	803	1262	1346
19- 6S- 6E	2952	Monroe	681	190	200
18- 6S- 1W	21109	Hillsdale	1196	1796	1864
13- 6S-11W	7823	St. Joseph	866	1323	1334
35- 6S-16W	24642	Cass	810	960	969
4- 6S-19W	19529	Berrien	626	704	735
25- 7S- 3E	23087	Lenawee	753	985	1029
13- 7S- 5E	7870	Lenawee	682	115	178
2- 7S- 6W	21433	Branch	1026	1465	1504

Location	Permit No.	County	Elevation (Feet)	Top of Sylvania	Bottom of Sylvania
27- 8S- 1E	21916	Lenawee	831	1027	1071
17- 8S- 3E	23527	Lenawee	749	910	1005
31- 8S- 6E	22645	Monroe	695	226	278
5- 8S- 1W	22147	Hillsdale	944	1288	1308
5- 9S- 4W	21773	Hillsdale	1072	1245	1265

APPENDIX B

APPENDIX B

TABLE 3. Wells Used in Construction of the Percentage and Ratio Maps

County	Location	Permit No.	Carbon-ate%	Clastic Ratio	Quartz %	Chert %	Evaporite %	Mineral %
Presque Isle	5-34N- 2E	None	59.8	.1	6.4	33.8	--	--
Presque Isle	23-33N- 2E	28083	--	--	--	--	--	--
Alpena	18-32N- 6E	28061	--	--	--	--	--	--
Antrim	14-31N- 8W	28395	--	--	--	--	--	--
Otsego	18-30N- 2W	28375	--	--	--	--	--	--
Alpena	9-29N- 5E	28346	--	--	--	--	--	--
Otsego	22-29N- 2W	28191	--	--	--	--	--	--
Kalkaska	1-28N- 5W	28325	97.3	.01	1*	--	1.7	--
Kalkaska	25-28N- 7W	28309	97.7	.01	1*	--	1.3	--
Oscoda	30-25N- 3E	28195	--	--	--	--	--	--
Crawford	21-25N- 4W	28110	97.4	.01	1*	--	1.6	--
Manistee	20-23N-14W	29417	--	--	--	--	--	--
Manistee	6-22N-15W	29564	--	--	--	--	--	--
Manistee	9-21N-18W	29858	--	--	--	--	--	--
Clare	3-20N- 3W	9590	--	--	--	--	--	--
Lake	11-20N-14W	9130	--	--	--	--	--	--
Arenac	26-19N- 3E	9468	--	--	--	--	--	--
Osceola	29-18N-10W	12802	83	.2	17	--	--	--
Clare	8-17N- 4W	9904	--	--	--	--	--	--
Oceana	16-16N-16W	12194	92.1	.04	1.3	4.2	--	--
Oceana	35-16N-18W	11889	--	--	--	--	--	--
Huron	32-15N-12E	12199	--	--	--	--	--	--
Oceana	23-15N-15W	220	--	--	--	--	--	--
Midland	27-14N- 2E	3664	13.1	6.0	79.2	7.7	--	--
Midland	10-14N- 5E	30125	--	--	--	--	--	--
Tuscola	33-14N- 8E	29237	88.1	.1	6.9	--	1.1	--
Mecosta	3-14N- 8W	11693	--	--	--	--	--	--
Tuscola	16-13N-11E	10968	84.7	.2	14.6	.7	--	--

* Indicates 1 percent or less

County	Location	Permit No.	Carbon-ate	Clastic Ratio	Quartz	Chert	Evaporite	Mineral
Barry	24-12N- 3W	5067	--	--	--	--	--	--
Muskegon	14-12N-15W	27688	--	--	--	--	--	--
Muskegon	8-12N-17W	28931	95	.1	5	--	--	--
Sanilac	7-11N-14E	22857	--	--	--	--	--	--
Newaygo	11-11N-13W	28137	90.2	.1	1*	--	--	--
Muskegon	2-10N-17W	24195	--	--	--	--	--	--
Genesee	4- 9N- 8E	24079	60.4	.6	20.5	--	3.4	--
Sanilac	9- 9N-15E	11492	62.5	.5	10.6	9.0	--	--
Ottawa	6- 9N-13W	537	93.7	.05	3.4	--	1.7	--
Clinton	26- 8N- 2W	24475	39.1	1.5	55.4	3.3	--	--
St. Clair	1- 7N-16E	22615	97	.03	1*	--	--	--
Genesee	12- 6N- 8E	24028	20.5	3.9	77.5	--	--	--
Lapeer	25- 6N-11E	12933	.2	498.5	99.7	.1	--	--
St. Clair	14- 6N-13E	22594	23.2	2.7	25.9	--	3.7	--
Macomb	27- 5N-14E	22708	31.6	2.1	27.4	--	2.5	--
Ottawa	11- 5N-15W	21529	88.3	.1	1*	--	1.3	--
Oakland	9- 4N- 7E	22665	40.6	1.5	50.3	--	--	--
Oakland	22- 4N- 8E	13072	26.1	2.8	73.3	.6	--	--
Oakland	11- 4N-11E	23072	27	2.2	78	--	--	--
Macomb	8- 4N-13E	24039	2.4	39.8	95.6	--	--	2
Allegan	3- 4N-15W	24281	--	--	--	--	--	--
Livingston	11- 3N- 3E	10990	56.6	.6	34.8	7.5	.2	.9
Livingston	28- 3N- 5E	22853	40.9	1.39	52.2	--	6.9	--
Macomb	28- 3N-14E	21582	42.6	.9	46.9	2.9	7.6	--
Eaton	22- 3N- 6W	22945	99	.01	1*	--	--	--
Barry	12- 3N-10W	24504	--	--	--	--	--	--
Allegan	17- 3N-11W	21613	97.3	.3	1*	--	--	1.6
Ingham	17- 2N- 1W	28299	95.2	.03	1*	--	1.5	--
Ingham	31- 1N- 2E	24470	68.8	.1	3.6	24	--	--
Livingston	23- 1N- 4E	23073	53.6	.8	43.6	2.8	--	--
Eaton	18- 1N- 5W	21769	96.7	.03	1*	--	--	--
Eaton	28- 1N- 6W	429	99	.01	1*	--	--	--

County	Location	Permit No.	Carbon-ate	Clastic Ratio	Quartz	Chert	Evaporite	Mineral
Allegan	8- 1N-16W	22875	90.1	.02	1*	--	7.9	--
Washtenaw	3- 1S- 7E	19342	23.3	3.3	76.6	.1	--	--
Calhoun	6- 1S- 5W	22489	92.8	.1	1*	--	8	--
Van Buren	36- 1S-16W	6352	86.7	.3	133	--	--	--
Washtenaw	33- 2S- 4E	19891	50	.1	42	7.8	--	--
Wayne	25- 2S- 8E	3813	4.5	21.2	95.5	--	--	--
Jackson	15- 2S- 3W	21963	98	.01	1*	--	1	--
Calhoun	12- 2S- 5W	22880	94	.06	1*	--	--	--
Van Buren	29- 2S-16W	5977	--	.3	--	--	--	--
Wayne	7- 3S-10E	17574	2.5	39.0	97.5	--	--	--
Calhoun	22- 3S- 8W	20241	95.5	.04	2	--	--	--
Barrien	36- 3S-18W	24368	93	.05	5	--	--	2
Jackson	11- 4S- 1E	22066	98	.02	1*	--	--	--
Washtenaw	28- 4S- 4E	18777	44.1	.01	44.1	11.8	--	--
Wayne	26- 4S- 8E	19214	39.6	1.4	50.0	10.4	--	.1
Jackson	18- 4S- 1W	17807	94.7	.1	5.3	--	--	--
Calhoun	21- 4S- 6W	22476	86.4	.1	5.9	--	.9	--
Lenawee	17- 5S- 5E	22517	31.8	1.5	58.6	1	7.9	--
Hillsdale	10- 5S- 3W	21013	89.3	.1	5.7	--	--	--
Branch	28- 5S- 5W	20322	83.8	.2	15.1	--	--	--
St. Joseph	17- 5S- 9W	22242	94	.06	6	--	--	--
Cass	3- 5S-15W	3803	--	.5	--	--	--	--
Lenawee	24- 6S- 3E	9766	76.4	.3	20.2	3.4	--	--
Monroe	19- 6S- 6E	2952	50	1.0	40	--	--	2
Hillsdale	18- 6S- 1W	21109	74.6	.3	25.4	--	--	--
St. Joseph	13- 6S-11W	7823	91	.1	9	--	--	--
Cass	25- 6S-16W	24642	95	.01	1*	--	4	--
Barrien	4- 6S-19W	19529	96.8	.01	1*	--	2	.2
Lenawee	25- 7S- 3E	23087	--	10.9	--	--	--	--
Lenawee	13- 7S- 5E	7870	54.9	.8	35.6	1.7	--	--
Branch	2- 7S- 6W	21433	98	.01	1*	--	1	--
Lenawee	27- 8S- 1E	21916	69.9	.2	28.5	--	--	.4
Lenawee	17- 8S- 3E	23527	51.6	.9	46.4	--	--	.1
Monroe	31- 8S- 6E	22645	22.7	2.8	73	--	3.3	--
Hillsdale	5- 8S- 1W	22147	74.3	1.7	25	--	--	--
Hillsdale	5- 9S- 4W	21773	97	.03	3	--	--	--