PROGRESS REPORT NUMBER EIGHTEEN

STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
GERALD E. EDDY, DIRECTOR

GEOLOGICAL SURVEY DIVISION
WILLIAM L. DAOUST, STATE GEOLOGIST

NOTES ON THE DEVONIAN-SILURIAN IN THE SUBSURFACE OF SOUTHWEST MICHIGAN

BY

GARLAND D. ELLS

APRIL 1958

STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
Gerald E. Eddy, Director

GEOLOGICAL SURVEY DIVISION
William L. Daoust, State Geologist

NOTES ON THE DEVONIAN-SILURIAN IN THE SUBSURFACE OF SOUTHWEST MICHIGAN

Garland D. Ells
Petroleum Geologist

April, 1958

CONTENTS

Page

INTRODUCTION 1

General Extent of Subsurface Studies 2

Subject Matter 4

Nomenclature 5

Unconformities Associated with Devonian-Upper Silurian Rocks 7

Devonian-Silurian Unconformity 14

Base of the Devonian in Southwest Michigan 19

Upper Silurian Bass Island-Salina Subsurface Nomenclature 20

Bass Island-Salina Strata in Southwest Michigan 24

Middle Silurian-Niagaran 34

Structural Relationship of Basal Salina and Top of the "Niagaran" 35

Leaching of Salina Salt and Collapse of Overlying Rock 38

Structural Geology 41

Salina Oil and Gas Production in Southwest Michigan 47

References Cited 54

TABLES

Page

1 - Thickness of Devonian-Upper Silurian Rocks from Bay County to Berrien County 7

2 - Salina-Niagaran Oil Pools and Gas Pools 51

3 - Wells Referred To and Used in Cross Sections 52

ILLUSTRATIONS

Figure		Page
1 -	Salina-Niagaran Oil and Gas Pools	3
2 -	Generalized columnar section of formations and units referred to in this report	6
3 -	Thickness map of rocks from the top of the Traverse Formation to strata of Upper Silurian age	8
4 -	Thickness map of Bass Island-Salina rocks	9
5 -	Structure contour map of the surface of Silurian age rocks beneath strata of Devonian age	10
6 -	Distribution of Silurian Bass Island-Salina units beneath rocks of Devonian age	26
7 -	Devonian-Silurian unconformity, Ottawa County to Kalamazoo County	27
8 -	Cross section Kent County to Berrien County	31
9 -	Cross section Newaygo County to Berrien County	32
10 -	Sketch of basal Salina-Niagaran structural relationship	39
11 -	General distribution of Salina B, A-2, and A-1 Salt beds	48

INTRODUCTION

Interest has increased in the exploration for oil and gas in the Upper Silurian Salina rocks of southwest Michigan. Good shows of oil and gas have been reported from these rocks in many wells drilled in this part of the state. Interest is focused on this region because of the very successful development of the Overisel-Salina gas pool and the successful development of the Dorr-Salina oil and gas pool in Allegan County.

The Salina formation seems to have good oil-and-gas potential in southwest Michigan and in other areas of the Michigan Basin marginal to the Salina salt beds. For several years subsurface studies of the region have been conducted by members of the Petroleum Geology Section of the Geological Survey. This report is by no means complete but it is hoped that it will be of interest and of practical value to persons engaged in the search for gas and oil in the Salina rocks of this region. Some viewpoints are offered as a small contribution to better understanding of Devonian-Upper Silurian rocks in the subsurface in southwest Michigan. The report also points out several stratigraphic and structural problems that are within this region of the state.

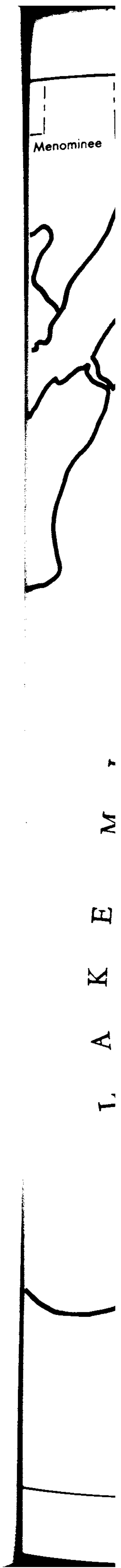
Thanks and appreciation is expressed to Miss Helen M. Martin, geologist, Research Section, for her continuous encouragement and valuable assistance in preparing this report. Thanks are also due to the geologists and members of the Survey staff, especially Messrs. R. E. Ives, W. E. Mantek, and H. J. Hardenberg for valuable comments and assistance received in certain phases of the subsurface studies.

GENERAL EXTENT OF THE SUBSURFACE STUDIES

Subsurface geology and the relationship of strata from the Mississippian System to strata of Middle Ordovician age in the counties of southwest Michigan (Figure 1) has been reviewed and studied. But this report and the conclusions stated are based primarily upon comprehensive study of well cuttings rather than on a reinterpretation of logs.

Nearly every set of rock cuttings from wells that penetrated Upper Silurian or deeper strata within the area have been used in this work. Practically all the older deep tests referred to in previous subsurface work have been re-studied. In a number of the older deep tests, reinterpretation of various units have been made and formational or unit boundaries have been changed accordingly. Well cuttings were not available for about 5 per cent of the wells studied, therefore, for these wells, interpretation was based on well logs. Deep wells outside the areal limits of the project have been studied and considered in formulating conclusions resulting from this investigation.

Stratigraphic analysis by chemical and statistical methods have been applied to Michigan Mississippian-Devonian rocks (McGregor, 1954, pp. 2324-56) and recently to Silurian rocks (Melhorn, 1958, pp. 816-38). This type of study has considerable value in interpretation of regional sedimentation and environmental tectonics for a given system or series of rocks, but it has no direct application in tracing and correlating the oil and gas producing units of the Devonian and Silurian systems. The actual and potential producing units of the Devonian and Silurian systems in Michigan are well known. Studies of this nature give neither indication of the areal limits of the oil and gas producing units nor their structural



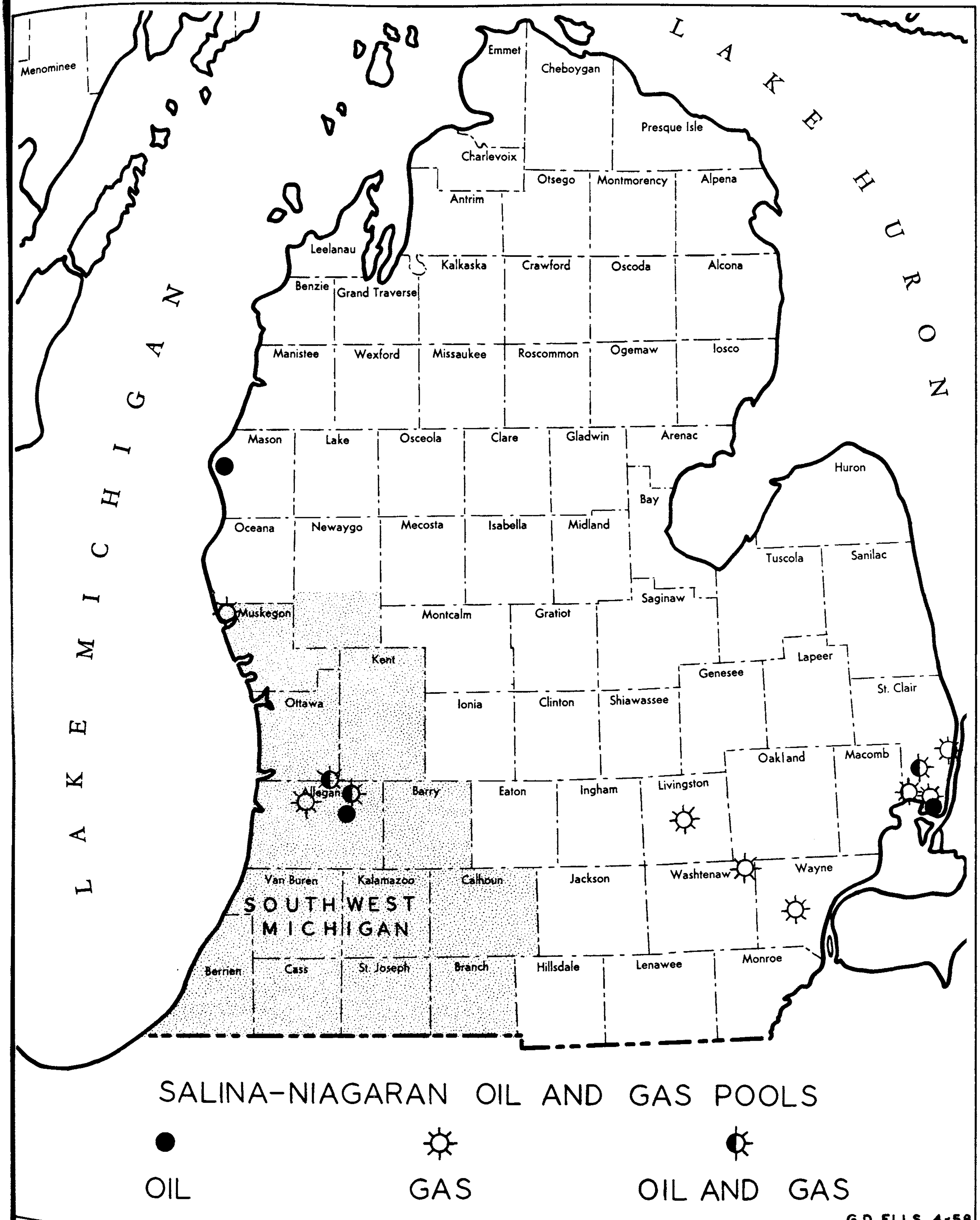

LAKE MICHIGAN
LAKE HURON
Menominee
Emmet
Cheboygan
Presque Isle
Charlevoix
Otsego
Montmorency
Alpena
Antrim
Leelanau
Kalkaska
Crawford
Oscoda
Alcona
Benzie
Grand Traverse
Manistee
Wexford
Missaukee
Roscommon
Ogemaw
Iosco
Mason
Lake
Osceola
Clare
Gladwin
Arenac
Huron
Bay
Oceana
Newaygo
Mecosta
Isabella
Midland
Tuscola
Sanilac
Muskegon
Montcalm
Gratiot
Saginaw
Kent
Lapeer
Genesee
Ottawa
Ionia
Clinton
Shiawassee
St. Clair
Oakland
Macomb
Allegan
Barry
Eaton
Ingham
Livingston
Van Buren
Kalamazoo
Calhoun
Jackson
Washtenaw
Wayne
SOUTHWEST MICHIGAN
Berrien
Cass
St. Joseph
Branch
Hillsdale
Lenawee
Monroe
SALINA-NIAGARAN OIL AND GAS POOLS
OIL
GAS
OIL AND GAS
G.D. ELLS 4-58

FIGURE I.

relationship to units above and below. Ultimately, the subsurface geologist must work with the oil-and-gas bearing rock units which are but a small part of the total thickness of any given series of sediments.

In general, the project has been a study of the lithology and of stratigraphic units in southwest Michigan. But the lithology and structural relationships of other areas, i. e., southeast Michigan, have not been ignored. Observations and correlations have been based on microscopic examination of well cuttings. Cuttings were affixed to scaled strip logs and direct comparison was made between formations and their component units by use of the binocular microscope. Notations were made of the several lithologies and their accessory particles such as chert, sand grains, fossil content, and other characteristics of value in correlation. No petrographic or statistical work was done.

SUBJECT MATTER

It is beyond the scope of this report to fully discuss all phases of investigation that have been made concerning the subsurface geology of southwest Michigan. The major intent of this report is to:

(1) Discuss and describe the nature of the Devonian-Upper Silurian unconformity in southwest Michigan and its relation to the rocks of both systems.

(2) Demonstrate the occurence of a wide spread but probably irregular area of possible Garden Island (?) equivalent within the region and to illustrate its relationship to the Sylvania and Bass Island formations.

(3) Summarize the lithology and formational limits of the Bass Island-Salina formations in the subsurface of this region.

(4) Illustrate the possible structural relationship of the upper Niagaran rocks to basal members of the Salina formation in Allegan County.

The cross sections illustrating this report outline formation tops from the Coldwater "Red Rock" of Mississippian age to the top of the Trenton formation of Ordovician age. No attempt is made to illustrate the lithology of all formations shown on the cross sections as they are described in detail in numerous publications (see References cited). The top of the "Traverse formation" or base of the Antrim has been used as the reference datum in constructing the cross sections. The gray to dark gray, calcareous shales underlying the hard, black, spore-bearing Antrim shale are referred to as "Traverse formation" and have been classified as basal Antrim (Cohee and others, 1954). The gray shales and very argillaceous limestones of the "Traverse formation" are unlike the Antrim shales in many respects and are believed to be more closely related to the Traverse Group. In this report, they are classified as strata of the Traverse Group.

NOMENCLATURE

The nomenclature used is essentially the nomenclature shown for 1954 on Sheet II, "Development of the Stratigraphic Nomenclature of Michigan Rock Formations, 1837-1956", a part of Publication 50, Michigan Geological Survey, 1956.

Basis for the lithologic description and definitions of the various formations from the top of the Detroit River Group through the Bass Island-Salina formations are to be found in the list of references.

System	Series	Group	Group, Formation	Thickness from Cross Sections	Lithology
Mississippian System	Lower		Coldwater Shale		Shale, siltstone
			Coldwater "Red Rock"		Limestone, shale
			Sunbury Shale	0-70 FT.	Shale
			"Berea" Dolomite		Dolomite, oolitic LS.
			Ellsworth Shale	240-520 FT.	Shale, dolomite lentils
	Upper		Antrim Shale	85-245 FT.	Shale
Devonian System	Middle	Traverse Group	"Traverse Formation"		Shale
			"Traverse Limestone"	65-475 FT.	Limestone Cherty limestone Shaly limestone
			Bell Shale		Shale
			Rogers City-Dundee	0-85 FT.	Limestone, dolomite
		Detroit River Group	"Reed City Anhydrite"		Anhydrite
			"Reed City Pay Zone"		Dolomite
			Lucas Formation	75-615 FT.	Dolomite, anhydrite
			Amherstberg Fm.	0-120 FT.	Dolomite
			Sylvania SS. Member		Sandstone Dolomitic sandstone
			Disconformity		
			Bois Blanc Fm.	0-58 FT.	Cherty dolomite
			Disconformity		
	Lower		Garden Island (?)	0-105 FT.	Sandy dolomite, dolomite Sandy shale
			Disconformity		
Silurian System	Upper		Bass Island (H Unit)	0-120 FT.	Dolomite
		Salina Formation	G Unit	0-120 FT.	Shale, shaly dolomite
			F, E, D Units	0-290 FT.	Dolomite, shaly dolomite Shale, anhydrite, salt
			C Unit	0-100 FT.	Shale, shaly dolomite
			B Salt	0-250 FT.	Salt
			A-2 Dolomite	0-205 FT.	Dolomite, limestone
			A-2 Limestone	50-190 FT.	Limestone, dolomite
			A-2 Salt	0-385 FT.	Salt
			A-1 Dolomite	40-130 FT.	Dolomite, limestone
			A-1 Salt	0-295 FT.	Salt
			"Brown Niagaran"	0-40 FT.	Limestone, dolomite
	Middle	Niagara	Guelph-Lockport "Niagaran"	40-390 FT.	Dolomite
			Clinton		Shale, dolomite

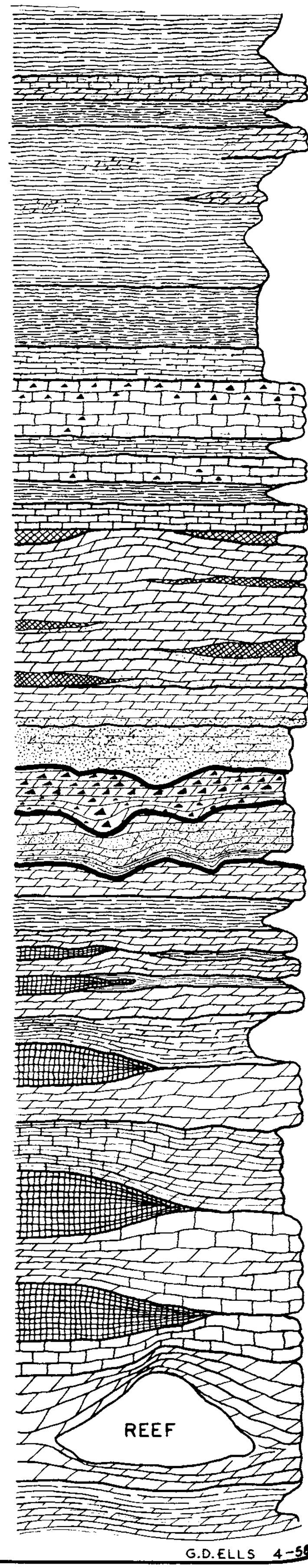


FIGURE 2. GENERALIZED COLUMNAR SECTION OF FORMATIONS AND UNITS REFERRED TO IN THIS REPORT.

UNCONFORMITIES ASSOCIATED WITH DEVONIAN-UPPER SILURIAN ROCKS

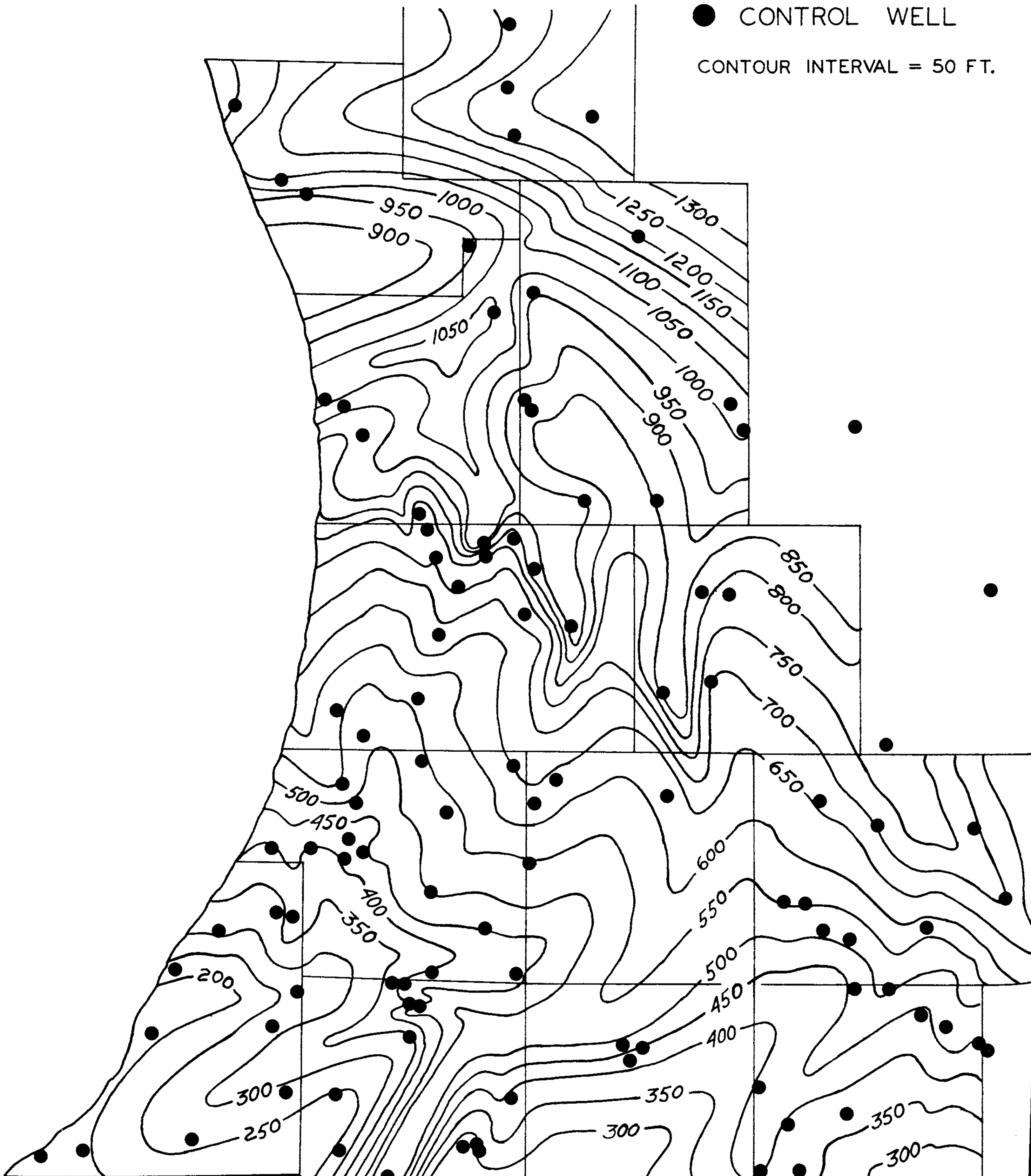
Most of the subsurface formations and units (Figure 2) within the deeper part of the Michigan Basin are recognized in southwest Michigan. However, the areal extent and thickness of certain formation differs considerably within this region. The total thickness of the Devonian-Upper Silurian strata increases basinward but regionally and locally some sediments thicken and/or thin (Figures 3 & 4).

The following tabulation of thickness data from four wells on an approximate northeast-southwest line from Bay County to Berrien County more clearly illustrate the thinning of Devonian-Upper Silurian sediments from the deeper part of the basin toward southwest Michigan. Two of the wells are in the Basin District and two are within the area of this study. The base of the Antrim shale is arbitrarily chosen as the top of the Devonian.

Table 1

THICKNESS OF DEVONIAN-UPPER SILURIAN FROM BAY COUNTY TO BERRIEN COUNTY

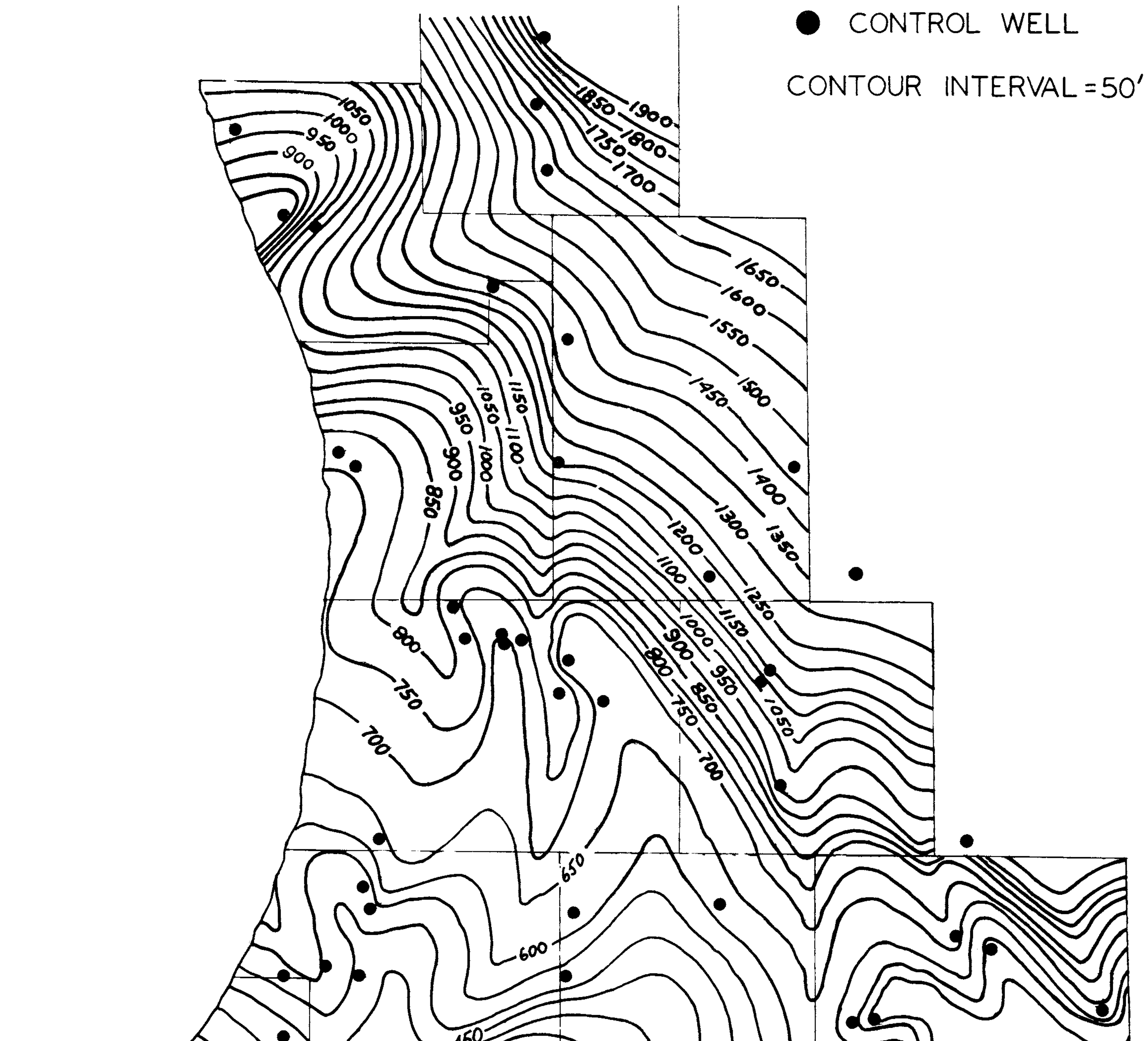
DEVONIAN	Well No. 34 Bay County Thickness	Well No. 35 Clinton Co. Thickness	Well No. 5 Kalamazoo Co. Thickness	Well No. 14 Berrien Co. Thickness
Traverse Gp.	680 ft.	398 ft.	270 ft.	116 ft.
Dundee Fm.	385 "	75 "	48 "	0 "
Detroit River Gp.	1405 "	805 "	312 "	170 "
Bois Blanc Fm.	320 "	75 "	0 "	0 "
UPPER SILURIAN				
Bass Island Fm.	670 ft.	290 ft.	50 ft.	0 ft.
Salina Fm.	2790 "	1726 "	580 "	114 "
TOTAL THICKNESS	6250 ft.	3369 ft.	1260 ft.	400 ft.



THICKNESS MAP OF ROCKS FROM THE TOP OF THE TRAVERSE FM. TO STRATA OF UPPER SILURIAN AGE

G.D. ELLS 5

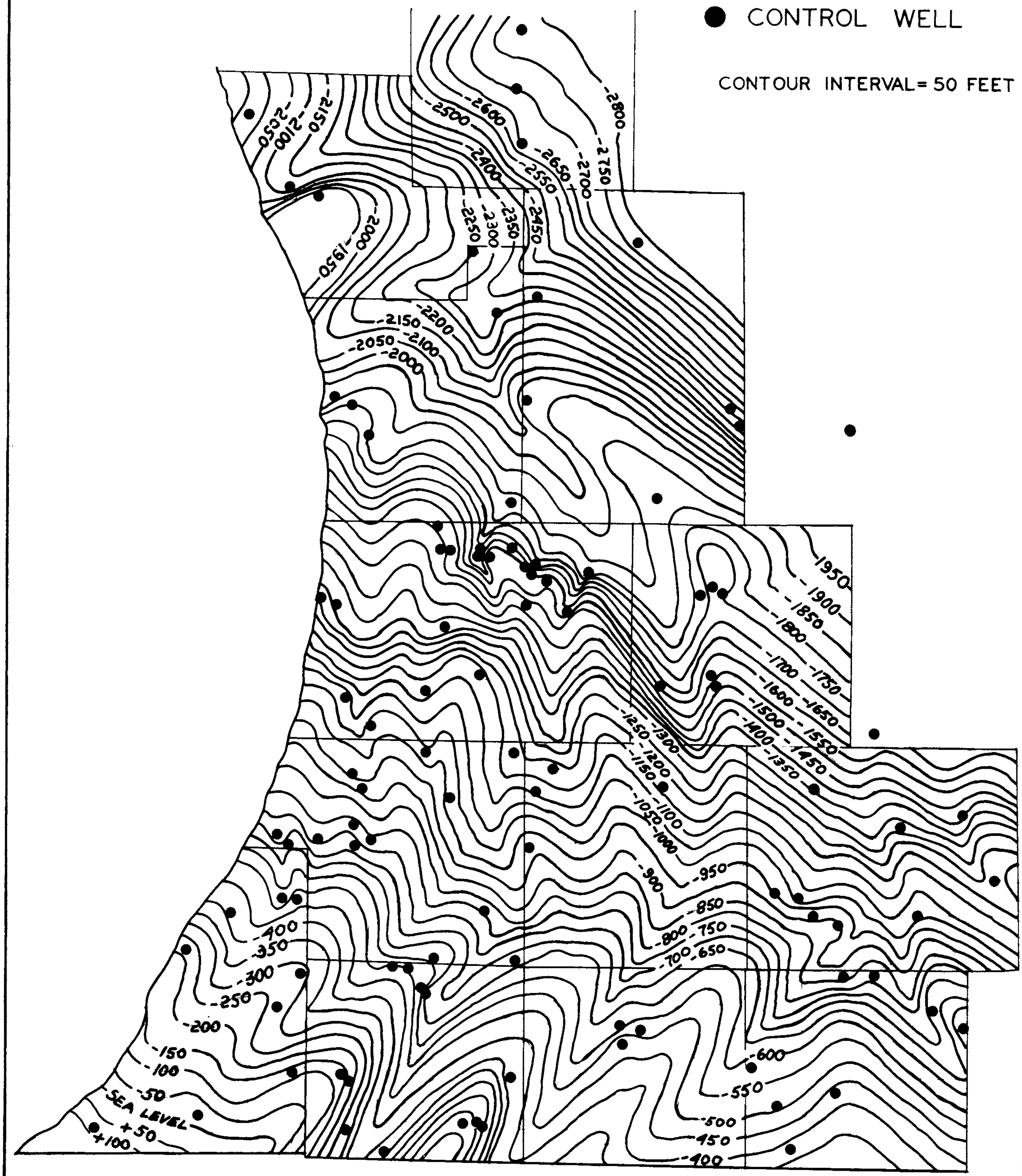
FIGURE 3.



THICKNESS MAP OF BASS ISLAND-SALINA ROCKS

G.D.ELLS 4-58

FIGURE 4.



STRUCTURE CONTOUR MAP OF THE SURFACE OF SILURIAN AGE ROCKS BENEATH STRATA OF DEVONIAN AGE

FIGURE 5.

Thinning of these sediments has been generally attributed to numerous subaerial or submarine erosional cycles or to non-deposition. Several students of Michigan surface or subsurface geology have stated or have implied that unconformities separate every group or formation within the Devonian-Upper Silurian sequence of rocks: At the top of the Traverse Group; Rogers City formation; Dundee formation; Lucas and Amherstberg formations of the Detroit River Group; the Bois Blanc formation; the Garden Island formation; and the Bass Island formation or top of the Upper Silurian. The opinions and criteria regarding the postulated unconformities are well summarized and amplified by Cohee and Underwood (1945); Cohee (1944, 1945); Landes (1945, 1951), and Ehlers and Landes (1945). Basis for most of these unconformities seems well established at the outcrop or type locality of the formations, all of which are on the edge or margin of the Michigan Basin.

In the subsurface, particularly in the deeper parts of the basin, a logical break so far as subaerial erosional contacts are concerned seems absent or is very obscure. This is especially true of all Devonian formations above the Bois Blanc formation. The formations above the Bois Blanc appear conformable and seem to grade upward nearly everywhere without a sharp break in formational boundaries or the presence of criteria which might be used to delineate a subaerial unconformity. This absence of a break may be only apparent and due to inaccurate or imperfect sampling of the well cuttings. Many cores that have cut so called erosional contacts within the Devonian system lack criteria diagnostic of subaerial erosion. However, such absence may be due to the small area of contact that can be observed in the ordinary small sized core.

Within the area discussed in this report, three disconformities are recognized in the subsurface:

(1) The disconformity at the top of the Upper Silurian rocks. (St. Ignace formation of the Bass Island Group, Mackinac Straits region, Ehlers, 1945; Landes, 1945, 1951). The St. Ignace formation is now referred to as St. Ignace dolomite and is placed with the Pte. aux Chenes shale in the Salina group (Ehlers and Kesling, 1957, pp. 23-24).

(2) The disconformity at the top of the Garden Island formation (Ehlers, 1945; Landes, 1945, 1951).

(3) The disconformity at the top of the Bois Blanc formation (Ehlers, 1945; Landes, 1945, 1951).

The significance of these disconformities in the interpretation of the Devonian-Silurian angular unconformity in southwest Michigan cannot be adequately expressed without some discussion of these formations outside the areal limits of this district.

It is believed by the writer, that the Garden Island (?) formation is present and may be identified over a considerable area of southwest Michigan. It is also postulated that this formation is in places overlain by the marginal edges of the Sylvania sandstone or Sylvania formation. The sandstone and sandy dolomite phase of the Garden Island (?) is similar to the marginal areas of the Sylvania sandstone or Sylvania formation. Because of this similarity, it is difficult to establish a boundary between the Sylvania and Garden Island (?) formations where the Bois Blanc formation is missing. Therefore, in some areas, the Garden Island (?) formation cannot be mapped satisfactorily because the upper limit cannot be established. The Garden Island (?) formation is seldom identified in the subsurface in the hundreds of well logs that have been submitted to the Geological Survey. Yet this little known formation may account for some of the difficulty in recognizing the upper limits of Silurian age rocks in a large area of southwest Michigan.

Several writers have described the Bois Blanc formation and its limits at the outcrops and in the subsurface, but it is apparent from the well logs submitted to the Survey that some confusion exists in identifying this formation in the subsurface.

Garden Island formation. Since identification of the Garden Island formation at the outcrops (Ehlers, 1945) very little information has been published concerning this Lower Devonian formation. It is the oldest Devonian strata so far observed in Michigan and contains a Lower Devonian Oriskany fauna. It is above the Upper Silurian St. Ignace dolomite and below the cherty Bois Blanc formation of Lower or Middle (?) Devonian age (Ehlers, 1945; Ehlers and Kesling, 1957, pp. 24 and 31). Where it outcrops at the type locality on Garden Island, the Garden Island has been described as follows: "light buff, dolomitic sandstone, with frosted quartz grains, buff dolomite having a few frosted quartz grains, and very hard buff gray to dark gray dolomite with a few chert nodules and an apparent absence of quartz grains" (Ehlers, 1945, p. 74). In the subsurface it has been variously described as: "a brownish limestone with a few sand grains" (Landes, 1945, p. 163): "characteristically a dolomite which may be very sandy in places" (Landes, 1951, p. 12). Rocks of this description were tentatively classified as Garden Island because of their lithologic similarity and stratigraphic position. The formation has been reported in several wells in the northern part of the Southern Peninsula of Michigan and is believed to be patchy in distribution. A definite unconformity seems evident at the top and at the base of this formation.

Bois Blanc formation. The Bois Blanc formation is well exposed at the surface in the vicinity of the type locality, Bois Blanc Island, in the region of the Straits of Mackinac. At the outcrops, it is typically a very fossiliferous, light gray to buff, dolomite or limestone. In the Mackinac Straits region it rests unconformably upon Upper Silurian-St. Ignace dolomite. It is overlain unconformably by rocks of the Detroit River Group. In the subsurface, the Bois Blanc has been described as: "gray limestone; cherty limestone; cherty dolomite; or a fossiliferous, cherty limestone or dolomite". The Bois Blanc was divided into three members, not all of which were present throughout the area covered by Bois Blanc formation (Landes, 1945, pp. 163-166). Later, some members of the Bois Blanc formation were placed in the Detroit River Group (Landes, 1951, p. 7). Many geologist now engaged in the exploration for oil in Michigan limit the Bois Blanc formation to the cherty limestone or dolomite that is beneath the Sylvania sandstone; or, where the Sylvania is absent, to the cherty limestone or dolomite beneath the Amherstberg or Lucas formations. The base of the Bois Blanc is generally placed above the light colored dolomites of the Bass Island formation. An unconformity at the top and at the base of the Bois Blanc formation seems well established.

DEVONIAN-SILURIAN UNCONFORMITY

The strata of the Devonian and Silurian systems thin and the unconformity at the top of the Upper Silurian rocks, and the unconformities at the top of the Garden Island (?) and Bois Blanc formations converge up the slope of the Basin in southwest Michigan and produce a rather complex set of conditions. The evaporite bearing rocks of the Lucas formation of the Detroit River Group are everywhere in this region. However, the underlying Amherstberg formation, and the Sylvania sandstone, if restricted to the area shown by Landes (1951, p. 15), does not extend everywhere throughout the region. The Bois Blanc formation is missing, due to erosion, from a large area. Its area of distribution is essentially the same area described by Landes (1945; 1951, p. 17).

Because of the difference in lateral extent of some units of the Detroit River Group, and the erosional unconformities at the top of the Bois Blanc, the Garden Island (?), and the Bass Island-Salina formations, the normal sequence of these units is interrupted from place to place (Figures 7, 8, 9).

Garden Island (?) formation in southwest Michigan. A bed of white to grayish white, non-sandy to very sandy dolomite is in many square miles of this region. The quartz sand grains in the dolomite are milky white to clear in color, and subrounded to very well rounded in shape. Most of the sand grains are frosted and etched. At or near the base of the sandy dolomite in many wells is an unusually smooth textured shale. The color of this shale is nearly everywhere a vivid green of different hues but in places it is greenish gray or gray with a faint tinge of red. In a few wells, a brownish red shale with minute subrounded pellets of red or reddish brown ferruginous material are associated with the green shale. In the Knoblock well (Figure 7, Well 33) a thin, black, bituminous shale bed is in association with the green shale and sandy dolomites. Little of the shale exhibits grain size or any descernable lamination. Most of the shale examined has conchoidal fracture in spite of the fact that it is very soft. In general appearance, some shale resembles chert and in some well logs has been erroneously identified as chert. Much of the shale contains sand grains as described above and a large amount of pyrite. It is almost impossible to measure the exact thickness of this shale unit (or units) because of the nature of well cuttings. The shale apparently ranges in thickness from thin partings to a probably maximum of 10 feet. Because of its structural characteristics, it is an incompetent bed and flakes of this shale may therefore be found intermixed with the Bass Island or Salina rocks upon which it lies unconformably. The white sandy dolomite and green shale sequence is found in many wells from Van Buren County to Branch County and from Kent to St. Joseph County although the shale decreases and thins away from the central part of southwest Michigan. The dolomite-shale sequence has also been identified in well cuttings from northern Indiana where it is at the approximate horizon of the (Pendleton sandstone?).

This described sequence of sandy dolomite and green shale is believed to be essentially the sequence described by Landes, (1945), who referred to it as "non-sandy Sylvania" and correlated it with the Sylvania sandstone body. Both the Sylvania sandstone body and the "non-sandy Sylvania" were mapped as a unit and referred to as the Sylvania formation. In the publication "Detroit River Group in The Michigan Basin", (Landes, 1951, p. 1), the Sylvania was redefined as the basal member of the Amherstberg formation owing to the fact that the sandstone body grades upward into the overlying Amherstberg formation. The areal limits of the Sylvania sandstone were then redrawn to exclude all the counties included within this report in southwest Michigan. The rocks previously mapped as Sylvania or non-sandy Sylvania were then apparently included within and mapped as Amherstberg (Landes, 1951). The green shale was then said to be "probably Bass Island in age, but it may have been deposited in Garden Island (Oriskany) time," (Landes, 1951, p. 14). Apparently the basis for this placement was the appearance of this same shale beneath Bois Blanc formation in the Sherk well (Figure 8, Well 2). But inspection of the samples from this well failed to disclose shale of the character associated with the white to gray white sandy dolomite discussed in this report. In the Sherk well, the shale underlying Bois Blanc formation is classified as Salina.

Several wells recently drilled in Allegan County have penetrated a dark gray to white, sandy dolomite and green shale sequence below cherty Bois Blanc formation and immediately above light tan or buff dolomite classified as Bass Island. In the Knoblock well (Figure 7, Well 33) the sequence is well developed. The overlying Bois Blanc formation is a very cherty, gray to brown dolomite. The chert contains fossil fragments and a few minute black spheres or spores (?). This cherty dolomite can be traced basinward and may be correlated with the thicker part of the Bois Blanc formation. The underlying sandy dolomite and green shale section can be traced south and correlated with the same section in many other wells within the area. Where this section is not overlain by the Bois Blanc formation, as it is nearly everywhere, it may be overlain by the Amherstberg or Lucas formation and underlain by Bass Island dolomites or dolomites of the Salina formation. Traced eastward, the sandy dolomite and green shale section extends beneath sandstone and white to grayish white, sandy dolomites of the margins of the Sylvania sandstone or Sylvania formation and there it is impossible to separate the section from the overlying Sylvania formation.

The sandy dolomite and basal green shale of this district cannot logically be classified as Bass Island if any consistancy is to be maintained in describing the subsurface lithology and limits of the Bass Island rocks. Investigation has shown that the sandy dolomite-green shale sequence is stratigraphically higher than any similar dolomite-shale sequence such as the E, F, and G units (subsurface nomenclature) of the Bass Island-Salina.

It lies above the H unit or Bass Island, but since an angular unconformity is at the top of the Upper Silurian rocks in this region, the sand, dolomite and green shale section overlies several older and stratigraphically lower units of the Bass Island-Salina sequence of rocks at several localities within this region. Because the sandy dolomite-green shale sequence is beneath the Bois Blanc formation and above the H unit, or Bass Island, the writer tentatively classifies and correlates this sequence with the Garden Island formation on the basis of its stratigraphic position and lithologic similarity, although green shale is not reported at the type locality nor included in the type description.

The Garden Island formation at the outcrop is identified primarily on its fossil content and is, therefore, a biostratigraphic unit. Fossils of Oriskany or Garden Island age have been definitely identified from well cores in southeastern Antrim County according to Landes (1951, p. 12), and are the same species as in the Garden Island formation at the type locality. The rock containing the Garden Island fossils is reported to be a gray limestone or dolomitic limestone (Well 39). No fossil material is available from the Garden Island (?) of southwest Michigan.

Garden Island lithology in the subsurface apparently differs considerably laterally, and probably vertically. The lithology referred to in this report as Garden Island closely approximates the lithology of the type section in so far as can be determined from written description. The shale and sandy shale of this region may represent the initial deposits of Garden Island (?). The clay and sand may represent reworked residual soil accumulated or derived from weathered Bass Island or Salina rocks.

Rocks classified as Garden Island (?) in this report are in many wells over a large area. However, it is not stated nor implied that this lithology is everywhere within the area of this report. It is probable that this lithology will not be found in many places. Garden Island (?) remnants may be in areas that were structurally low at the time of Garden Island erosion. Attention is called to this unit because of its similarity and proximity to the marginal edges of the Sylvania sandstone body. It is but one of a number of stratigraphic problems in this region, and the unit must be considered in detailed investigations of the rocks above and below the Devonian-Silurian unconformity. From an economic standpoint, many gas shows have been recorded in or at the base of the dolomite-shale section.

BASE OF THE DEVONIAN IN SOUTHWEST MICHIGAN

Throughout the subsurface investigations, the sandy dolomite-green shale sequence, wherever it occurs, has been placed in the Devonian system and classified as Garden Island formation. The base of this formation is placed at the first buff to light buff dolomite characteristic of the Bass Island formation in this district; or, the gray, dolomitic shales and gray, argillaceous dolomite characteristic of the Salina formation. Elsewhere in this district, the base of the Devonian has been established on the "typical" Bass Island or Salina lithology beneath Bois Blanc, Sylvania, or Detroit River rocks. Because erosion has removed Bass Island and Salina rocks from a large area of this district, different Devonian strata overly Upper Silurian rocks of Bass Island to lower Salina age. (Figures 7, 8, & 9).

UPPER SILURIAN BASS ISLAND-SALINA SUBSURFACE NOMENCLATURE

Many published reports are available that describe the evolution of the terminology and discuss the lithology of Bass Island-Salina rocks. The most recently published subsurface studies of these rocks appear to be those of Melhorn (1958). His work was principally a chemical and statistical analysis of Bass Island-Salina rocks. The most comprehensive subsurface studies in attempt to trace and correlate the various units of the Bass Island-Salina rocks were made by Landes (1945). Detailed studies were made of cuttings from wells along a line roughly parallel to the eastern coast line of the Southern Peninsula of Michigan. Correlations were made with Bass Island-Salina outcrops in the Straits of Mackinac to the north, and with Bass Island-Salina outcrops in Ohio to the south. As a result of these investigations it became apparent that Bass Island-Salina rocks can be divided into a number of units or beds which can be traced over a wide area of the Michigan Basin.

These units were labeled A thru H. The A beds are the oldest and are the basal beds of the Salina formation. The H bed was believed to be of Bass Island age. This classification of Bass Island-Salina rocks, with certain modifications, is used by most members of the petroleum industry in identifying Bass Island-Salina rocks in the subsurface in the Michigan Basin.

Figure 2 illustrates the terminology as it is commonly related at present to Bass Island-Salina rocks throughout the Michigan Basin. Some beds, especially those lying between the G and C units, are frequently unidentified. The H unit is practically always referred to as Bass Island. The G bed is referred to as "Salina" or "Salina shale". The F, E, D, and C beds are infrequently identified or reported. Whenever present, the B unit (salt) is identified as such, but the B unit may be identified as an anhydrite bed or series of anhydrites that seem to be in this zone on the margin of the B salt bed. The terminology of the A beds seems to have been modified considerably and is similar to the terminology of Evans (1950). The upper A dolomite has been subdivided into two units: The A-2 dolomite and the A-2 limestone. The A-2 limestone is characteristically a gray, shaly, argillaceous limestone that directly underlies the brown to buff anhydritic A-2 dolomite. The A-2 limestone appears to be a consistant unit but on the margin of the salt beds or outside the limits of Salina salt deposition it appears as a gray, shaly, argillaceous dolomite. The salt bed immediately underlying the A-2 limestone is referred to as A-2 salt (upper A salt of Landes, 1945). Beneath the A-2 salt is a generally dark dolomite. On the margin of the Salina salt beds or outside the limits of Salina salt deposition, this bed is nearly everywhere a dolomite. The salt bed underlying the A-1 dolomite is referred to as the A-1 salt or anhydrite. Where the salt is not present, this zone contains anhydrite beds of an aggegate thickness much less than the thickness of the salt. A bed of brown to buff dolomite or limestone is below the basal Salina salt or anhydrite bed in a large area. This bed is commonly identified as "Brown Niagaran" or "Guelph". The "Brown Niagaran" or "Guelph" is placed in the Salina for practical purposes.

It cannot be stated that the Bass Island-Salina units identified and used in this report are exactly equivalent to the original subdivisions of the Bass Island-Salina rocks in the subsurface. It is a fact that where the salt units of the Salina are not present, it is difficult to establish some rock units with absolute certainity. Establishment of units that can be easily identified and traced by everyone is sometimes difficult. A number of the original units established and adopted for these formations contained more than one type of lithology from well to well. The lower part of the H unit, or Bass Island, was correlated with the St. Ignace formation of the Bass Island Group in the original subsurface work (Landes, 1945). The St. Ignace formation is now called St. Ignace dolomite and is assigned with the Pte. aux Chenes shales to the Salina Group in the Mackinac Straits region (Ehlers and Kesling, 1957, p. 3; p. 29). Rocks of the Bass Island Group are apparently, then, not present in the Mackinac Straits region. Rocks believed to be Bass Island in age are exposed in the type region of the original Bass Island (s) group in southeastern Michigan and in Ohio. These rocks are represented by the Put-in-Bay dolomite and Raisin River dolomite (Ehlers and Kesling, 1957, p. 29). It is apparent that the status of Bass Island-Salina rocks has not been definitely established due to lack of abundant fossil evidence suitable for correlation purposes.

In the subsurface, the several rock types, particularly the shales and dolomites in the upper part of the Salina, are very similar. The light colored dolomites of the Bass Island phase of the Upper Silurian are also similar or nearly identical to some dolomites at different stratigraphic levels within the Salina. Just where to place the base of the Bass Island dolomites in the subsurface is a matter of speculation, especially if we are to include gray shaly beds that are no different from gray shaly beds within the Salina formation. In the deeper part of the Basin, where the Bass Island is several hundred feet thick (Well 34), and in wells in southeastern Michigan, gray shale beds of considerable thickness have been included within the H unit or Bass Island.

The "stereotype" Bass Island lithology is light cream to buff colored, dense dolomites. Light buff to brown dolomites are practically everywhere beneath rocks assigned to the Devonian System in the deeper parts of the Basin. In some areas, where the Silurian rocks are at a relatively shallower depth, as in southwest Michigan, gray dolomites and gray dolomitic shales are in places found beneath rocks assigned to the Devonian System. The buff, the gray, the highly argillaceous dolomites, and green shales underlying Devonian strata were designated as Bass Island and all strata below Devonian age rocks were mapped as Bass Island (Landes, 1945, 1951). In the Bateson well (Well 34) Bay County, more than 3,400 feet of Upper Silurian Bass Island-Salina sediments were penetrated. In southwestern Berrien County the total thickness of Upper Silurian sediments is a little over 100 feet; yet the sediments below Devonian strata in this region have previously been assigned to the Bass Island in spite of the belief that Bass Island rocks have been uplifted and eroded several times. It should be of considerable importance to know the approximate stratigraphic position that these various dolomite and shaly members found below Devonian strata occupy within the Bass Island-Salina sequence.

Because of apparent descrepancies in describing Bass Island-Salina rocks in the subsurface, an investigation of these rocks was made throughout southwest Michigan. No attempt was made, initially, to reconcile rock units of this district with the described and defined units of the Bass Island-Salina. Several deep wells in northern Kent County and southern Newaygo County were studied and used as "type wells". They apparently penetrate as complete a section of Bass Island-Salina rocks as has been found in this region. The readily identified rock units, other than salt, were identified and assigned letters. Correlations were made from well to well beginning with the basal rocks of the Salina. Correlations were made upward within the section and from the deeper part of the basin outward and up the regional dip.

BASS ISLAND-SALINA STRATA IN SOUTHWEST MICHIGAN

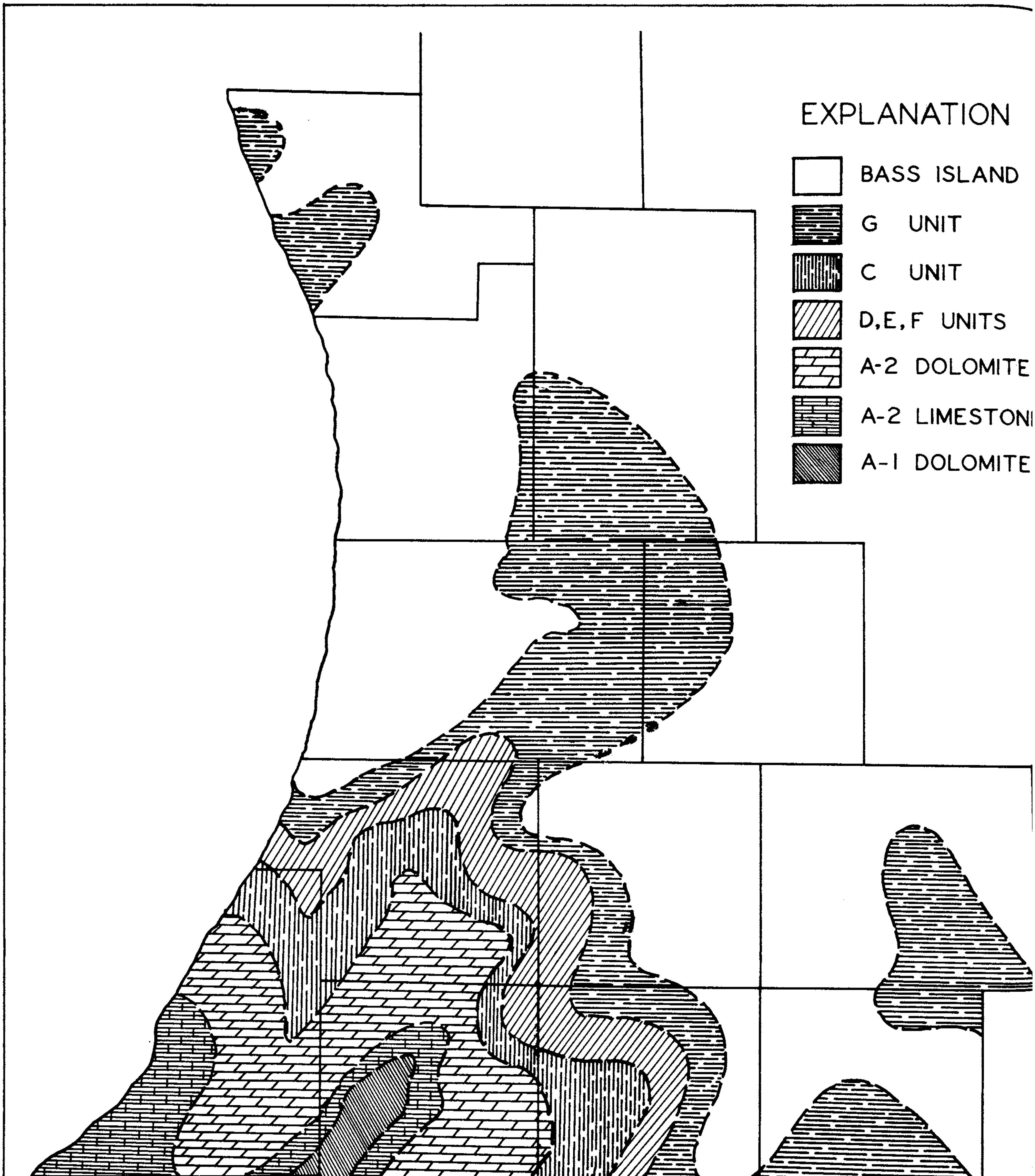
Independent investigation of Bass Island-Salina rocks has indicated that these rocks may be divided into rock units that can be traced over most of southwest Michigan. A comparison of the units in this district was made with cuttings from wells in the vicinity of the Northville field, Wayne and Washtenaw counties, and with type wells used in the original subdividing of Bass Island-Salina rocks in the subsurface. Comparison indicated that many units in southwest Michigan may be correlated with like units in the eastern half of Michigan. This seems evident for all units except the D, E, and F beds. The units are best identified in cable tool well cuttings, but are readily identified in good rotary samples where drilling mud, pumping, and sampling techniques have been satisfactorily maintained.

In is reasonable that rock types, such as shales and carbonates with the thicknesses they have in the Salina, should have a wide lateral extent and, generally, have more lateral continuity then evaporites have. In the district under consideration, which is mainly outside the area of evaporite deposition, the shale and carbonate beds have wide lateral spread. The units established for correlation within the district are rock units having a certain gross lithology. Color, structural, and textural features differ somewhat vertically and laterally within most units. In general, dark colored and highly argillaceous carbonates become lighter in color and less argillaceous from the deeper part of the basin toward the southwest out of the area of evaporite deposition. Shaly units maintain their general character but may differ somewhat in color and textural features. The lower units of the Salina thicken and thin locally, perhaps due to the presence of "Niagaran" reefs.

Within the approximate northern half of the district, all units or equivalent beds of the Bass Island-Salina formation are present. In tracing these units (identified for this district) southward into the southernmost counties, it can be demonstrated that the uppermost part of the Bass Island, as known in the subsurface, and also many beds assigned to the Salina have been truncated by erosion in a large area (Figures 7, 8, & 9). Because of the indefinite placement of the base of the Bass Island and the inconsistant inclusion of different rock types within the subsurface Bass Island, the buff and brown dolomites, and the gray argillaceous dolomites, have frequently been identified as Bass Island when actually they are member beds of the Salina formation. The subsurface terminology of the Bass Island-Salina is applied in this report to units described for this district as far as is possible.

H unit, or Bass Island dolomite. Within the area covered by this report, the H unit or Bass Island is everywhere characteristically a light buff to brown, dense dolomite with some oolitic lenses. In some northern wells within the district, the Bass Island is much darker in color and in places contains some anhydrite. No gray argillaceous dolomites or shale is identified within Bass Island rocks in the district. The H unit is believed to be typically and exclusively a light to brown colored, dense dolomite. In places the unit was apparently completely removed, or was eroded to a very thin unit over a large area (Figures 7, 8, & 9).

G unit or Salina shale. The G unit is a gray, very argillaceous dolomite or dolomitic shale, with many partings of pink anhydrite and with minute crystals of selenite which appear as flakes of mica. Some micaceous material may be in this unit. In Newaygo County (Figure 9, Well 31) this unit is directly below the Bass Island and above the highest salt beds in



DISTRIBUTION OF SILURIAN BASS ISLAND–SALINA UNITS
BENEATH
ROCKS OF DEVONIAN AGE

FIGURE 6.

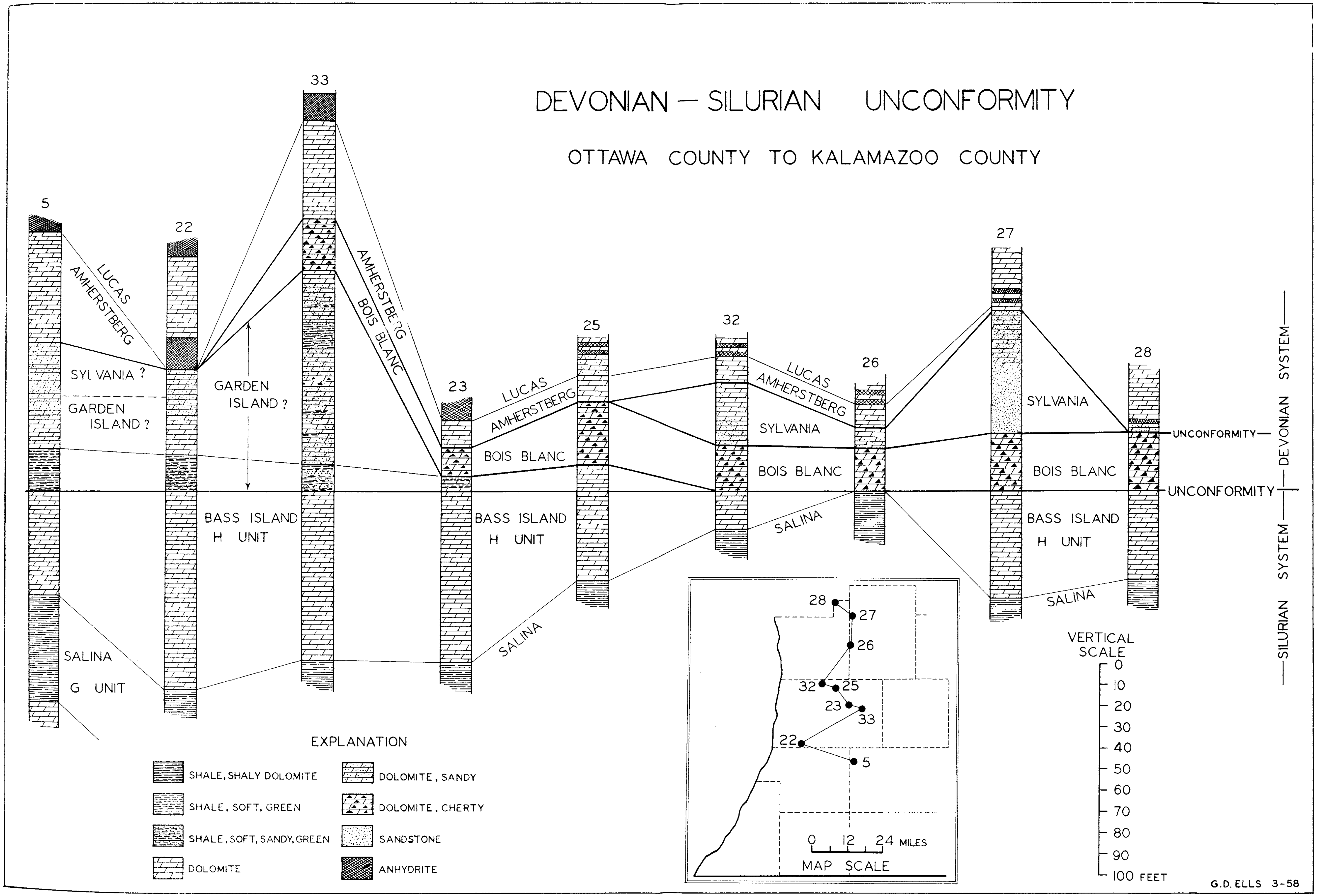

DEVONIAN — SILURIAN UNCONFORMITY
OTTAWA COUNTY TO KALAMAZOO COUNTY
5
22
33
23
25
32
26
27
28
LUCAS
AMHERSTBERG
SYLVANIA ?
GARDEN ISLAND ?
GARDEN ISLAND ?
AMHERSTBERG
BOIS BLANC
LUCAS
AMHERSTBERG
BOIS BLANC
LUCAS
AMHERSTBERG
SYLVANIA
BOIS BLANC
SYLVANIA
BOIS BLANC
UNCONFORMITY
UNCONFORMITY
BASS ISLAND H UNIT
BASS ISLAND H UNIT
BASS ISLAND H UNIT
SALINA G UNIT
SALINA
SALINA
SALINA
DEVONIAN SYSTEM
SILURIAN SYSTEM
EXPLANATION
SHALE, SHALY DOLOMITE
SHALE, SOFT, GREEN
SHALE, SOFT, SANDY, GREEN
DOLOMITE
DOLOMITE, SANDY
DOLOMITE, CHERTY
SANDSTONE
ANHYDRITE
MAP SCALE
0 12 24 MILES
VERTICAL SCALE
0
10
20
30
40
50
60
70
80
90
100 FEET
G.D. ELLS 3-58

FIGURE 7.

the Salina. From a large area the buff dolomites of the Bass Island have been removed or reduced to a thin unit by erosion and the underlying G unit is directly overlain by Devonian age rocks. Southward, the G unit was completely removed by erosion over some areas (Figures 6, 8, & 9). The G unit appears prominent on most gamma ray-neutron logs.

F, E, and D units. The salt beds of these units elsewhere in the Michigan Basin are not in the greater part of this region. The salt beds and green and red anhydritic shales of these units are identified in wells in the southern part of Newaygo County. South of Newaygo County, they have not been identified, and appear to be represented by thin beds of anhydrite. However, a series of dolomite and shale beds may correlate with these units. The sequence consists of an alternating set of buff to brown dolomite and gray shaly dolomite or gray argillaceous dolomite. This sequence is overlain by the gray dolomite of the G unit and has the gray shaly C unit at the base. In the southern part of the district these beds have also been truncated and are overlain by Devonian rocks (Figures 6, 8, & 9).

C unit. The C unit is a gray dolomitic shale or gray argillaceous dolomite very similar to the G unit. It may be traced southward for a considerable distance. This bed has also been removed by erosion in a large area to the south and is directly overlain by Devonian rocks (Figures 6, 8, & 9). The C unit is readily distinguished on most gamma ray-neutron logs.

B unit. The B unit is a salt bed of varying thickness. In many well cuttings, this salt bed seems to be entirely composed of salt and is so mapped. But core descriptions and electric logs indicate that the bed has numerous thin dolomite, shale, and anydrite partings distributed throughout. The B salt is overlain by the C unit and underlain by the A-2 dolomite. The B salt pinches out to the south and may be continued by thin anhydrite and shaly units which may be traced for some distance. When the B salt pinches out, the overlying C unit and the underlying A-2 dolomite converge.

A-2 dolomite. The A-2 dolomite is a buff to brown dense to crystalline dolomite or limestone beneath the B salt. Where the B salt is absent, the dolomite is overlain by the gray C unit. The unit contains some anhydrite lenses near the top; but outside the areal limits of the B salt, the anhydrite seemingly increases slightly and becomes more evenly distributed throughout the unit. Cores from the Overisel field, Allegan County, show that this unit is fractured. No evidence of displacement is apparent and fractures in some cores were completely resealed with anhydrite. The A-2 dolomite contains gas and oil pays.

A-2 limestone. The A-2 limestone is generally readily distinguished from the A-2 dolomite which lies immediately above. The limestone is gray, shaly and argillaceous, and nearly everywhere grades upward into the A-2 dolomite without a sharp break. In some areas, parts of this unit split into thin "poker chip" laminae. Outside the margins of salt deposition, this unit is a gray, shaly, argillaceous dolomite rather than a limestone. Southward it becomes much less argillaceous and lighter in color. Where the underlying A-2 salt is missing, the A-2 limestone lies upon the A-1 dolomite. To the south in this district, the A-2 limestone is overlain by Devonian age rocks (Figures 6, 8, & 9).

A-2 salt. The A-2 salt is one of the thickest salt bodies of the Salina within this district. In most well cuttings, this bed, like the B salt unit, seems to be a homogenous salt unit and is so mapped. However, it contains thin lenses of dolomite, limestone, anhydrite, and shale. Southward, it thins and pinches out but may be represented by a zone of thin anhydrites and shales which may be traced for some distance. The A-1 dolomite is immediately below the A-2 salt. Where the A-2 salt is missing, the A-2 limestone is in contact with the A-1 dolomite.

A-1 dolomite. The A-1 dolomite is a dark carbonate, shaly in places. The unit differs in character vertically and laterally. Within the area of salt depositon, it may be entirely dolomite or limestone, or both dolomite and limestone. It is mainly brown or almost black in color and may range from a sublithographic limestone or dolomite to a finely crystalline limestone or dolomite. Phases of this unit are often referred to as "poker chip shale". Cores of certain members within the unit split readily or easily into thin wafers an eighth of an inch or less in thickness. Splitting is along very thin more carbonaceous parting planes. Some of the "poker chips" are composed of minute laminae of dark brown, finely crystalline dolomite separated by even thinner partings of carbonaceous material. Many of the dolomite laminae are porous. The unit may also contain thin beds of dark anhydrite. Southward, away from the area of salt deposition, the A-1 unit becomes much lighter in color and more homogenous in lithology, outside the area of salt deposition, it is entirely a dolomite. The A-1 dolomite contains gas and oil pays.

A-1 salt. The A-1 salt is the basal evaporite unit of the Salina formation. It has the greatest lateral extent of all the Salina salt beds within the district. This salt bed also contains thin lenses of dolomite, limestone, anhydrite, and shaly material. Southward it pinches out, abruptly in places, and is replaced by thin anhydrites and shales that may be traced for some distance. In much of this area, the A-1 salt overlies a brown to buff, crystalline limestone or dolomite frequently referred to as "Brown Niagaran" or "Guelph" which frequently contains vugs filled with salt or anhydrite.

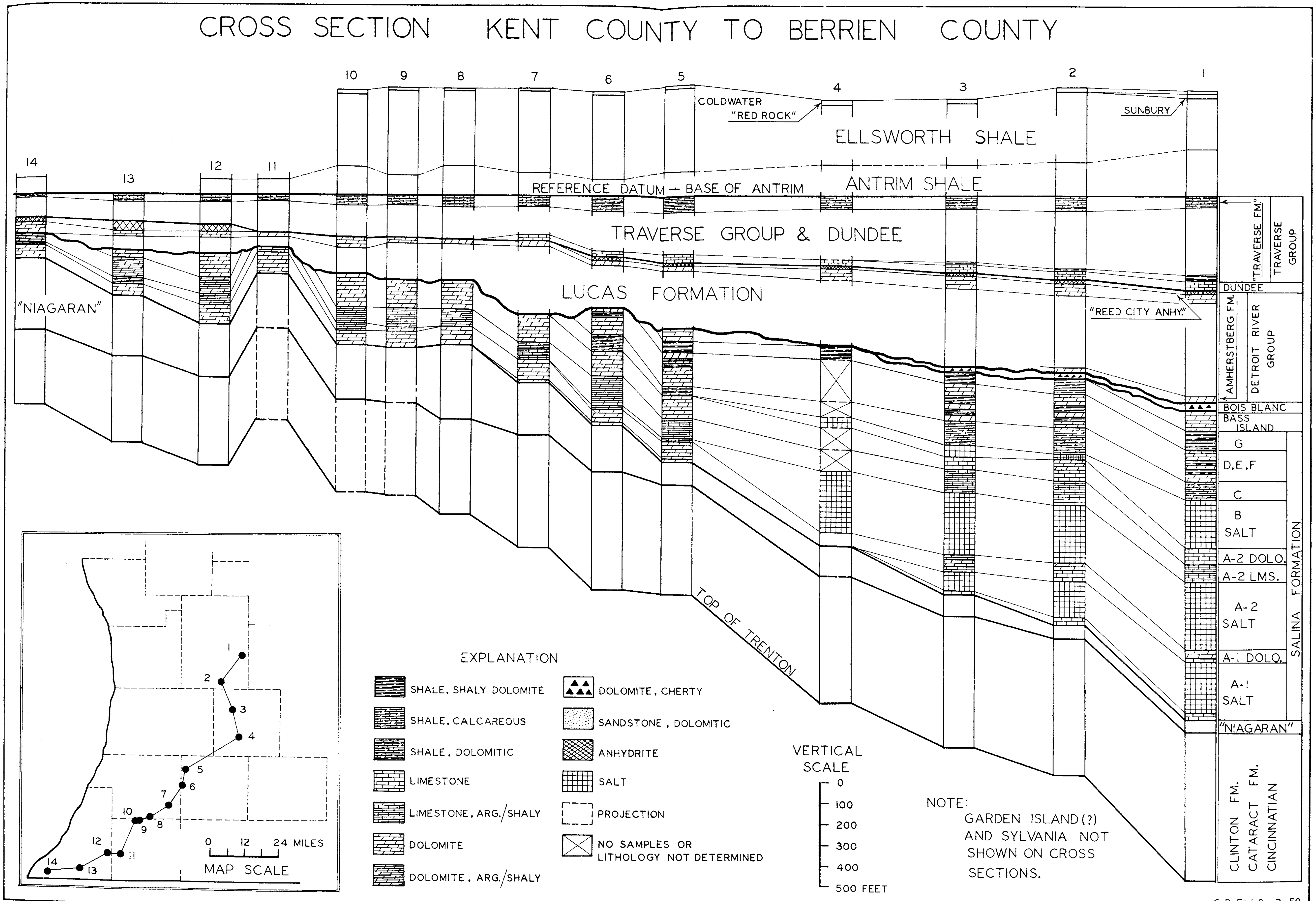

CROSS SECTION KENT COUNTY TO BERRIEN COUNTY
COLDWATER "RED ROCK"
SUNBURY
ELLSWORTH SHALE
REFERENCE DATUM – BASE OF ANTRIM
ANTRIM SHALE
TRAVERSE GROUP & DUNDEE
LUCAS FORMATION
"NIAGARAN"
"REED CITY ANHY."
TOP OF TRENTON
"TRAVERSE FM."
TRAVERSE GROUP
DUNDEE
AMHERSTBERG FM.
DETROIT RIVER GROUP
BOIS BLANC
BASS ISLAND
G
D, E, F
C
B SALT
A-2 DOLO.
A-2 LMS.
A-2 SALT
A-1 DOLO.
A-1 SALT
SALINA FORMATION
"NIAGARAN"
CLINTON FM.
CATARACT FM.
CINCINNATIAN
EXPLANATION
SHALE, SHALY DOLOMITE
SHALE, CALCAREOUS
SHALE, DOLOMITIC
LIMESTONE
LIMESTONE, ARG./SHALY
DOLOMITE
DOLOMITE, ARG./SHALY
DOLOMITE, CHERTY
SANDSTONE, DOLOMITIC
ANHYDRITE
SALT
PROJECTION
NO SAMPLES OR LITHOLOGY NOT DETERMINED
VERTICAL SCALE
0
100
200
300
400
500 FEET
NOTE:
GARDEN ISLAND (?) AND SYLVANIA NOT SHOWN ON CROSS SECTIONS.
0 12 24 MILES
MAP SCALE
G.D. ELLS 3-58

FIGURE 8.

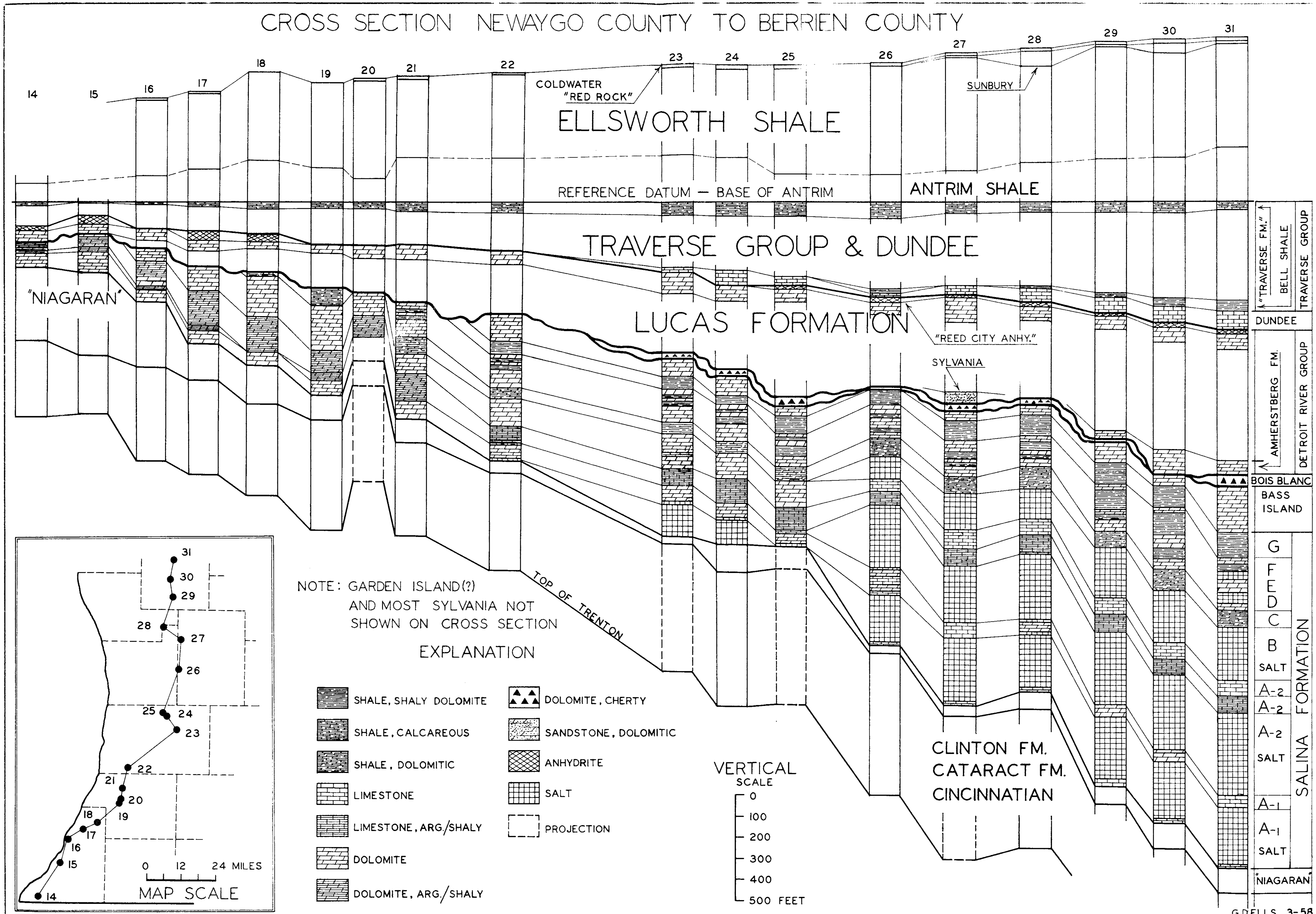

CROSS SECTION NEWAYGO COUNTY TO BERRIEN COUNTY
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
COLDWATER "RED ROCK"
SUNBURY
ELLSWORTH SHALE
REFERENCE DATUM — BASE OF ANTRIM
ANTRIM SHALE
TRAVERSE GROUP & DUNDEE
"NIAGARAN"
LUCAS FORMATION
"REED CITY ANHY."
SYLVANIA
"TRAVERSE FM."
BELL SHALE
TRAVERSE GROUP
DUNDEE
AMHERSTBERG FM.
DETROIT RIVER GROUP
BOIS BLANC
BASS ISLAND
G
F
E
D
C
B
SALT
A-2
A-2
A-2
SALT
A-1
A-1
SALT
SALINA FORMATION
"NIAGARAN"
TOP OF TRENTON
NOTE: GARDEN ISLAND(?) AND MOST SYLVANIA NOT SHOWN ON CROSS SECTION
EXPLANATION
SHALE, SHALY DOLOMITE
SHALE, CALCAREOUS
SHALE, DOLOMITIC
LIMESTONE
LIMESTONE, ARG./SHALY
DOLOMITE
DOLOMITE, ARG./SHALY
DOLOMITE, CHERTY
SANDSTONE, DOLOMITIC
ANHYDRITE
SALT
PROJECTION
VERTICAL SCALE
0
100
200
300
400
500 FEET
CLINTON FM.
CATARACT FM.
CINCINNATIAN
0 12 24 MILES
MAP SCALE
G.D.ELLS 3-58

FIGURE 9.

"Brown Niagaran" or "Guelph". The "Brown Niagaran" or "Guelph" dolomites or limestones seem to have affinities with the Salina formation and are placed in the Salina formation. Many samples show a reasonably sharp break between the base of this rock and the underlying light buff, white to blue gray Guelph-Lockport type lithology. However, cores and electric logs seem to demonstrate that the contact between Guelph-Lockport type dolomites of Middle Silurian age is gradational into overlying basal Salina rocks. The "Brown Niagaran" produces gas and oil, and much of the Silurian production in southeast Michigan is from this unit.

MIDDLE SILURIAN-NIAGARAN

"Niagaran" discussed in this report and indicated on the cross sections does not include beds of Clinton age and older. The term is applied to subsurface rocks that on a lithological basis have been traditionally, or commonly, considered as "Niagaran" or Guelph-Lockport. These are the thick white to blue gray, porous, crystalline dolomites of southwestern Michigan, and the buff, pink to reddish brown limestones immediately below Salina strata basinward and to the north in this district. In the northern part of this district, the pink to buff limestone, containing fossil fragments, especially crinoid debris, is correlated with a similar lithology in the basal part of the "Niagaran" to the south. Gray and greenish gray shales, argillaceous gray dolomites, and buff to brown, cherty dolomites of the Clinton (?)-Cataract formations are at the base of this unit. Northwest-southeast cross sections of the "Niagaran", with the top and base so restricted, indicate that this section is lenticular and that the thinnest sections are to the northwest and southeast. From southwest to northeast, the "Niagaran" tapers and thins basinward (Figures 8 & 9).

The upper part of the Niagaran Group, the Guelph-Lockport, has been correlated with reef bearing formations of equivalent age in the states contiguous to Michigan (summarized by Cohee, 1945, chart No. 33). That the thick white and blue gray dolomites of this region are part of the Illinois-Indiana upper Middle Silurian reef system seems probable. It is possible that the thick dolomite section is part of a barrier type reef system that grew on a submarine platform closely associated with buried pre-Trenton-Black River or Precambrian highs, but it may have been associated with the initiation of the Kankakee Arch. The surface and flanks of this platform would be the loci of reef development in this part of the Michigan Basin and would be contemporaneous with reef development in the Illinois-Indiana Basins.

No direct evidence is available to prove that the thick white and blue gray crystalline dolomites of southwest Michigan, and the southern rim of the Michigan Basin in general, are part of a barrier type reef system. Little, if any, evidence of organic material has been found in well cuttings of the Guelph-Lockport in this district. Excepting the red crinoidal limestone, the section seems to be nearly everywhere a crystalline, porous dolomite, devoid of all evidence of reef building organisms such as algae, stromatoporoides, corals, and other types of reef dwelling fauna. Some cores of the blue gray dolomites of the Guelph-Lockport show evidence of pentameroid type brachiopods. Some cores from the "Brown Niagaran" are fossiliferous. The scarcity of fossil evidence is probably due to the complete dolomitization of the Guelph-Lockport. Sediments at the base of the Guelph-Lockport and sediments in regions where a Guelph-Lockport lithology is not found, are similar in character to the inter-reef areas described by Lowenstam (1950, pp. 430-87) for the Illinois Basin and the Great Lakes region.

STRUCTURAL RELATIONSHIP OF BASAL SALINA AND TOP OF THE "NIAGARAN"

Recent drilling in Allegan County has disclosed some interesting structural conditions of basal Salina units and the underlying "Niagaran" dolomites. Some wells penetrated as much as 175 feet of A-1 salt but nearby wells encountered no A-1 salt. In some wells having no A-1 salt, the Niagaran and the A-1 dolomite have been structurally high in relation to control wells. The A-1 dolomite is in practical contact with the "Niagaran", and the beds above the A-1 dolomite appear structurally conformable. In other wells, structural relationships between the "Niagaran", the A-1 salt, and the beds above differ considerably. Data in a small confined area are not sufficient to indicate whether or not the "Niagaran" or Guelph-Lockport thickens locally due to reef building. Several wells were drilled completely through the section, but these wells are some distance apart. At least one well in the Dorr, Salem, and Overisel fields was drilled completely through the "Niagaran". But in fields producing Salina gas and oil, operating practice is to stop at the top or near the base of the pay section. Therefore, we do not have complete structural and thickness data for the underlying "Niagaran" section.

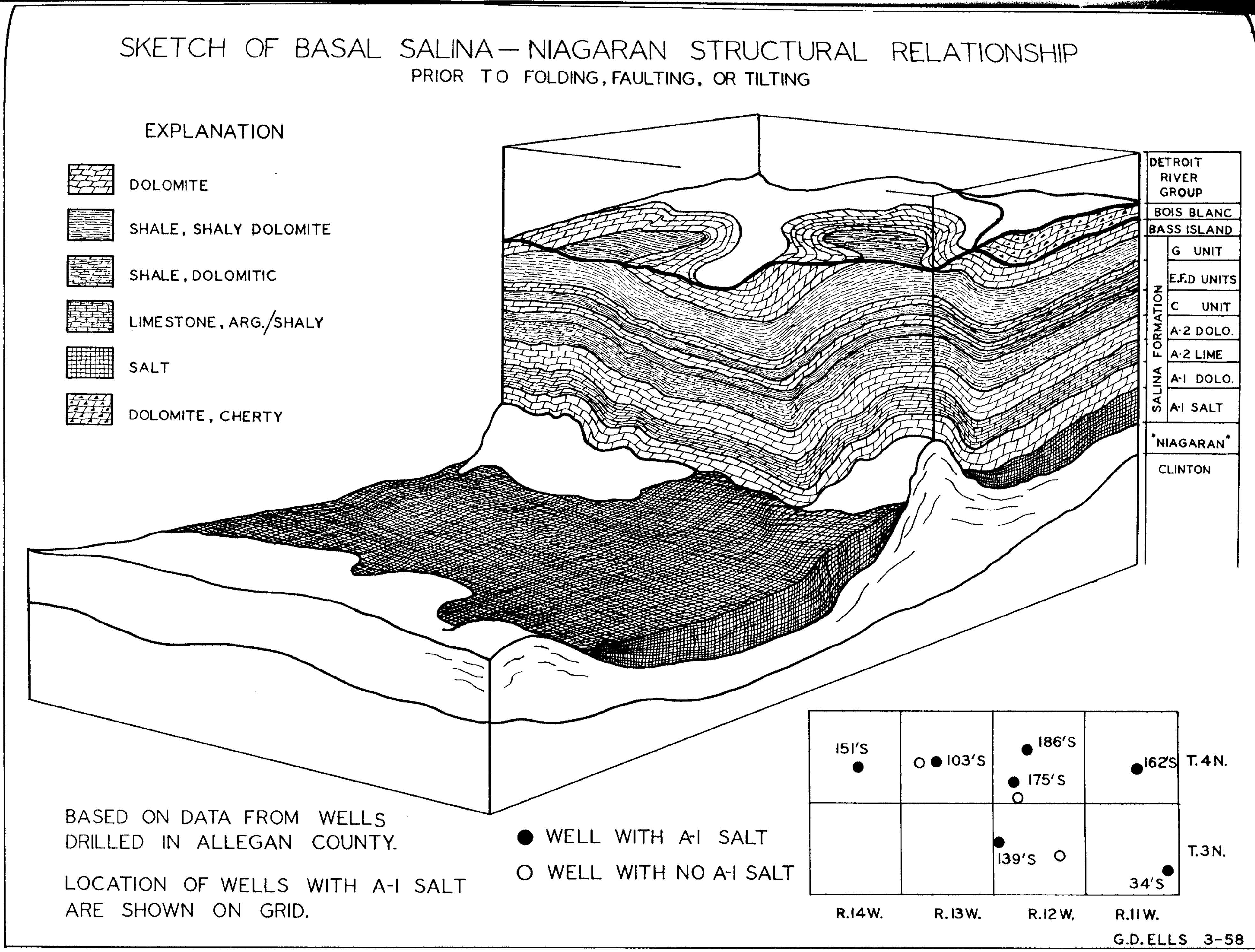
In southeastern Michigan, St. Clair County, similar structural conditions are found. In the Salina gas fields of St. Clair County, where enough wells have been drilled, thickness and structural relations of the lower salt and dolomite beds appear discordant relative to the Niagaran. Lower salt units thicken off structures in reference to the A-1 dolomite unit. Data are not complete in a confined area to definitely indicate thickening of the underlying Guelph-Lockport.

It is certainly a matter of speculation, but the data are suggestive that the "projections" of Guelph-Lockport in the southwest are reef type buildups, some of which were not completely buried by the initial A-1 salt beds. In Ontario, Canada, Guelph-Lockport formation is said to project upward into Salina formation as much as 400 feet (Sanford and Brady, 1955, p. 5). The evidence derived from cores and sample study does not indicate an erosional unconformity separating the Niagaran rocks from rocks of the Upper Silurian Bass Island-Salina. Lowenstam (1950, p. 485) and others, suggest that deposition of Salina evaporites in the interior of the Michigan

Basin may have been contemporaneous with reef development on the flanks of the basin. In other words, at least the lower part of the Salina may be of upper Niagaran Age in much of the Michigan Basin. No direct evidence seems to indicate Niagaran Age for basal phases of Salina evaporite deposition. The only evidence that might help to support such an hypothesis is the gradation of the Guelph-Lockport upward into sediments traditionally classified as Salina and the surrounding of Guelph-Lockport lithology by salt and anhydrite beds. It is possible that restriction of circulation within the Michigan Basin area became so acute that reef growth was completely halted by hypersaline waters. Precipitation of evaporites began and eventually the smaller fringing reefs on the flanks of the basin were covered or partially covered by the initial salt and anhydrite beds of the Salina. Perhaps no salt was deposited on the higher reefs. If salt was deposited over the reefs, compaction and folding of later sediments around the reef cores may have caused the salt to flow down and away from the reefs until adjustments were made. Following deposition of the A-1 salts and anhydrites, a carbonate, shale, and evaporite phase of deposition began which finally completely buried the Niagaran reefs. Deposition and compaction of Salina sediments over the buried reefs continued. It is possible that vertical and lateral compressional forces, acting at a later time upon the bedded sediments that covered the relatively incompressible and stable reef core, further accentuated the structure initiated by Niagaran reefs below Salina sediments. Faulting or slippage of the sediments flanking and covering the reef may have further accentuated the structure of the buried reef. Figure 10 illustrates possible basal Salina-Niagaran associations before folding, faulting, or regional tilting of the sediments.

LEACHING OF SALINA SALT AND COLLAPSE OF OVERLYING ROCK

Leaching of the upper Salina salt beds by circulating ground waters, and the subsequent collapse of overlying rocks, is indicated for some areas of Bass Island-Salina sediments (Landes, 1945, 1951). Within the area covered by this report, little or no evidence indicates collapse due to leaching of Salina salt beds. The upper salts (above the B salt) are not in the region excepting in the north (Figure 9). The B, A-2 and A-1 salts seem to gradually pinch out to the south and southwest. The basal A-1 salt in some places seems to pinch out rather abruptly but this fact is not attributed to leaching of salt. The carbonate and shale beds seem conformable and not "jumbled" together. In some sample sets used in this investigation, the thinner strata (F, E, and D units) appear to be mixed, but this is believed due to sampling procedure or drilling through unlike beds in a particular "run" and subsequent mixing of the two beds. In all wells, the lithology necessary to reconstruct a sequence of strata was found. However, the possibility of collapse is not precluded. The wells, wherein this condition was encountered, were nearly all outside the area of salt deposition. Movement or adjustment in Salina rocks is indicated in some areas of this region. In the Overisel field, Allegan County, cores of the A-2 dolomite showed fracturing of this bed but no apparent displacement was noted. All fractures observed appeared resealed, some sealed with anhydrite. In Kent County, Lowell Township (Well 36) cores of Salina units, believed to be the A-1 dolomite, are highly fractured. The fractures are vertical or parallel to the axis of the core and are filled with salt crystals. The salt is highly re-crystallized and is very similar in structure and texture to salt found in some salt domes. Similar fractures are in Salina rocks elsewhere. The



SKETCH OF BASAL SALINA — NIAGARAN STRUCTURAL RELATIONSHIP
PRIOR TO FOLDING, FAULTING, OR TILTING
EXPLANATION
DOLOMITE
SHALE, SHALY DOLOMITE
SHALE, DOLOMITIC
LIMESTONE, ARG./SHALY
SALT
DOLOMITE, CHERTY
DETROIT RIVER GROUP
BOIS BLANC
BASS ISLAND
SALINA FORMATION
G UNIT
E.F.D UNITS
C UNIT
A-2 DOLO.
A-2 LIME
A-1 DOLO.
A-1 SALT
"NIAGARAN"
CLINTON
BASED ON DATA FROM WELLS DRILLED IN ALLEGAN COUNTY.
LOCATION OF WELLS WITH A-1 SALT ARE SHOWN ON GRID.
● WELL WITH A-1 SALT
○ WELL WITH NO A-1 SALT
151'S
103'S
186'S
175'S
162'S
139'S
34'S
T.4N.
T.3N.
R.14W.
R.13W.
R.12W.
R.11W.
G.D.ELLS 3-58

FIGURE 10.

salt in the fractures has every indication of having been squeezed into the fractures sometime after lithification of the shale and dolomite rock. The anhydrite in the fractures in cores from the A-2 dolomite in the Overisel field seems to have been precipitated into the fractures.

STRUCTURAL GEOLOGY

The Michigan Basin has been referred to as an intracratonic basin or antogeosyncline (Kay, 1951, p. 20). The criteria for intracratonic basins and the shelf areas are set forth by Sloss, Krumbein, and Dapples, (1949, p. 100). The Michigan Basin has been a basin of deposition and subsidence throughout most of the Paleozoic. Much of southwest Michigan appears to have been a submarine platform or shelf with relief that is probably a reflection of buried Precambrian or pre-Trenton-Black River topography, but it may also be relief associated with the Kankakee Arch. Deposition of sediments and subsidence of the deeper part of the basin seems to have been continuous from Trenton time through Bass Island time in most of the Michigan Basin. Upper Ordovician and Lower Silurian sediments, when traced from the deeper parts of the basin, decrease in thickness southward and are thinnest over the higher parts of the platform. The Middle Silurian Guelph-Lockport, as restricted in this report, in thickest in this region and thins progressively basinward (Figures 8 & 9). Sediments of Upper Silurian age are thickest in the central part of the basin and thin outward toward the edge.

The thickening of Bass Island-Salina sediments basinward is due primarily to deposition of salt and anhydrite beds, (Figures 8 & 9). If the salt and anhydrite is excluded, the total thickness of the shale and carbonate beds of the Salina is fairly uniform. Estimates based on the thicker sections of Bass Island-Salina indicate a minimum thickness, prior to erosion, of 400 to 800 feet of shale and carbonate rock outside the area of evaporite deposition in southwest Michigan.

Deposition of Salina sediments was affected by the irregular structural features of the shelf region and by subsidence possibly due to down faulting of basement rock marginal to this area. Pre-Salina structure extending from southwestern Michigan basinward in a general north and northeast direction is evident. The most prominent pre-Salina structure extends northeast through Cass County into north central Barry County. From Barry County it trends northward into northwest Kent County where it appears to end. A thicker section of Bass Island-Salina sediments was deposited in the troughs flanking the structure.

Reef development over much of the platform is believed to have direct bearing on many Salina structures in southwest Michigan. Deposition and compaction of the relatively thin section of non-evaporite sediments over Niagaran reefs in this area resulted in structural conditions favorable for the entrapment of Salina oil and gas. Subsequent folding, faulting, and regional tilting modified the original structural relationships. The approximate structural relationships between Niagaran reefs and the Salina sediments are most clearly recognized in the zone marginal to the limits of deposition of the A-1 salt bed. In some areas the lower salt bed pinches out against the reef. The overlying A-1 dolomite and the beds above drape over the reef and result in a structural feature directly due to Niagaran reefing.

Locally, in this district, the structural attitude of the Salina rocks may bear no relationship to underlying Niagaran rocks. Re-adjustment of salt beds to compensate for compressional forces may have resulted in arching the strata above the salt with a consequent thickening of the salt below. Therefore, some structural features in the Salina beds may be due to incipient small salt domes or "salt swells", which did not completely perforate or move upward and beyond the overlying confining rock stratum. The amount of uplift due to thickening and movement of the salt is, of course, limited because of the relatively thin A-1 salt. This condition may exist in the proximity to reef build-ups. Data in any one locale are not sufficiently complete to substantiate this possibility, but the possibility is worthy of consideration in exploration for oil and gas in southwest Michigan.

The Salina section is believed to thicken beneath some Traverse structures in southwest Michigan. A-1 salt has been found beneath Traverse limestone structures. Off structure, in nearby wells, no A-1 salt has been found. This fact has lead to speculation that the A-1 salt may be localized beneath the Traverse structure (R. E. Ives, personal communication). In describing the geology of the Muskegon oil field, Muskegon County, Newcombe (1932, pp. 163-65) noted the thickening of the Salina salt series "on structure" of the Dundee limestone. He offered several theories to account for this. Newcombe's theory that best explained the structural discrepancies is: "the mechanical adjustment of structure with depth because of the divergence of the Monroe-Salina section, including the salt beds, into the center of the Basin. This tilted condition might cause a shallow fold to be represented in the lower beds by a terrace or plunging nose, with insufficient closure to trap any oil and gas." (Newcombe, 1932, p. 163). Possible flowage of incompetent salt beds to account for thickening of the salt series "on structure" was recognized but given little significance because of the thick competent beds beneath the salt and the gentle folds in the Muskegon field. Only two wells have been drilled in or close to the Muskegon field (Wells 37 & 38). Inspection of the samples from the Heinz and Savacool wells shows that Devonian rocks lie immediately above rocks of the Salina (Figure 6). Removal of Bass Island from this area may indicate a series of buried Niagaran reefs somewhere in the immediate vicinity. Study of the Salina section to the north in Muskegon County shows that the Salina salt beds pinch out southward against the Muskegon structure. A Salina-"Niagaran" relationship similar to their relationship in areas of Allegan County is postulated for this region.

Extensive deeper drilling to Salina rocks beneath two Traverse limestone pools has shown conformity of Traverse limestone structure and Salina structure. Over the Overisel structure, the Bass Island has been eroded to a thin unit and is overlain by a thin unit of Bois Blanc formation. Structural contours on beds of Devonian age are conformable to structural contours drawn on beds of Upper Silurian age. However, the producing closure of the Devonian Traverse limestone is limited to a smaller part of the total structure than the closure of the upper Silurian A-2 dolomite pay. Structural contours on the top of the Traverse limestone, Detroit River anhydrite, and Salina pay sections in the Dorr field also appear conformable. On other structures where few Salina tests have been drilled, Traverse limestone structure and Salina structure are apparently not conformable. But when more wells are drilled and more evidence obtained, it is believed that Salina-Devonian structures will be found to be generally conformable.

Conformity or similarity of Traverse limestone structures and underlying Salina structures could be explained by post-Devonian or post-Mississippian folding. Locally and regionally structures from the Coldwater "Red Rock" of Mississippian age down through most units of the Salina are generally conformable. On the Overisel and Dorr structures, no shift in axis of the structure from the top of the Traverse formation to the top of the A-2 dolomite is apparent. The highest closure on the A-2 dolomite is directly below the highest closure on the top of the Traverse limestone. Harmony in Devonian-Silurian structure in Allegan County may be accounted for by assuming post-Devonian folding. But this theory does not adequately consider the intervals of erosion after the deposition of the Bass Island, Garden Island, and Bois Blanc formations.

It is possible that a number of factors, unique to this region, have been in operation since pre-Trenton-Black River time and have resulted in perpetuation of regional and, in places, local structure. The more important factors to be considered are: (1) Buried pre-Trenton-Black River or Precambrian ridges and fault blocks. (2) Reef growth in Silurian times upon reflections of the buried highs. (3) Differential compaction and subsidence of sediments over and around the ridges and attendant Silurian reef growth. (4) Withdrawal of the sea at the end of Bass Island time and erosion of areas having greater relief. Higher relief of some areas was possibly due to buried Niagaran reefs. (5) Perpetuation of Bass Island-Salina highs beneath Garden Island (?) and Bois Blanc formations. (6) Reef development in Traverse time over these highs. (7) Post-Devonian folding around the remenant highs.

It is noted that areas of Devonian-Silurian structural conformity are also areas where Bass Island, Garden Island (?) and Bois Blanc rocks are present. This region is on the western flank of the relatively broad, north-south pre-Salina structurally high area postulated for this region (Figures 4, 5, & 6). A similar structure of different age assignment has been indicated for this general region by Newcombe (1933, pp. 77-79); Hale (1941, p. 714); and Jodry (1957, p. 2691). In the southernmost tier of counties in southwest Michigan the Bass Island-Salina rocks thicken and thin in several areas (Figure 4). The areas of thick and of relatively thin Bass Island-Salina compare favorably with areas of structure shown by contours drawn on the top of Upper Silurian rocks (Figure 5). In St. Joseph and Cass counties, structural contours on the top of the Upper Silurian rocks indicate a southwest trending structural low which is nearly coincident with the "Battle Creek Trough" of Melhorn (1958, Figure 7, p. 829). It is one of several structurally low areas that seem to trend into northern Indiana. To the west, in Cass County, a similar structurally low area of Upper Silurian rocks extends into northern Indiana. Immediately to the west of this structural low is an area of structurally high Upper Silurian rock. The axis of the structurally high Upper Silurian rocks trends southwest into Indiana and is roughly in alignment with the postulated northeast extention of the Kankakee Arch into the Michigan Basin (Melhorn, 1957, Figure 7, p. 829). Thickness maps (Figures 3 & 4) show that areas of thick Bass Island-Salina rock and thick areas of Devonian rock compare favorably with areas of structurally high and structurally low regions of Upper Silurian rock. From synthesis and re-evaluation of certain data used in many studies of the stratigraphy of this region, it is possible to conclude perpetuation of regional structure in most of southwest Michigan.

SALINA OIL AND GAS PRODUCTION IN SOUTHWEST MICHIGAN

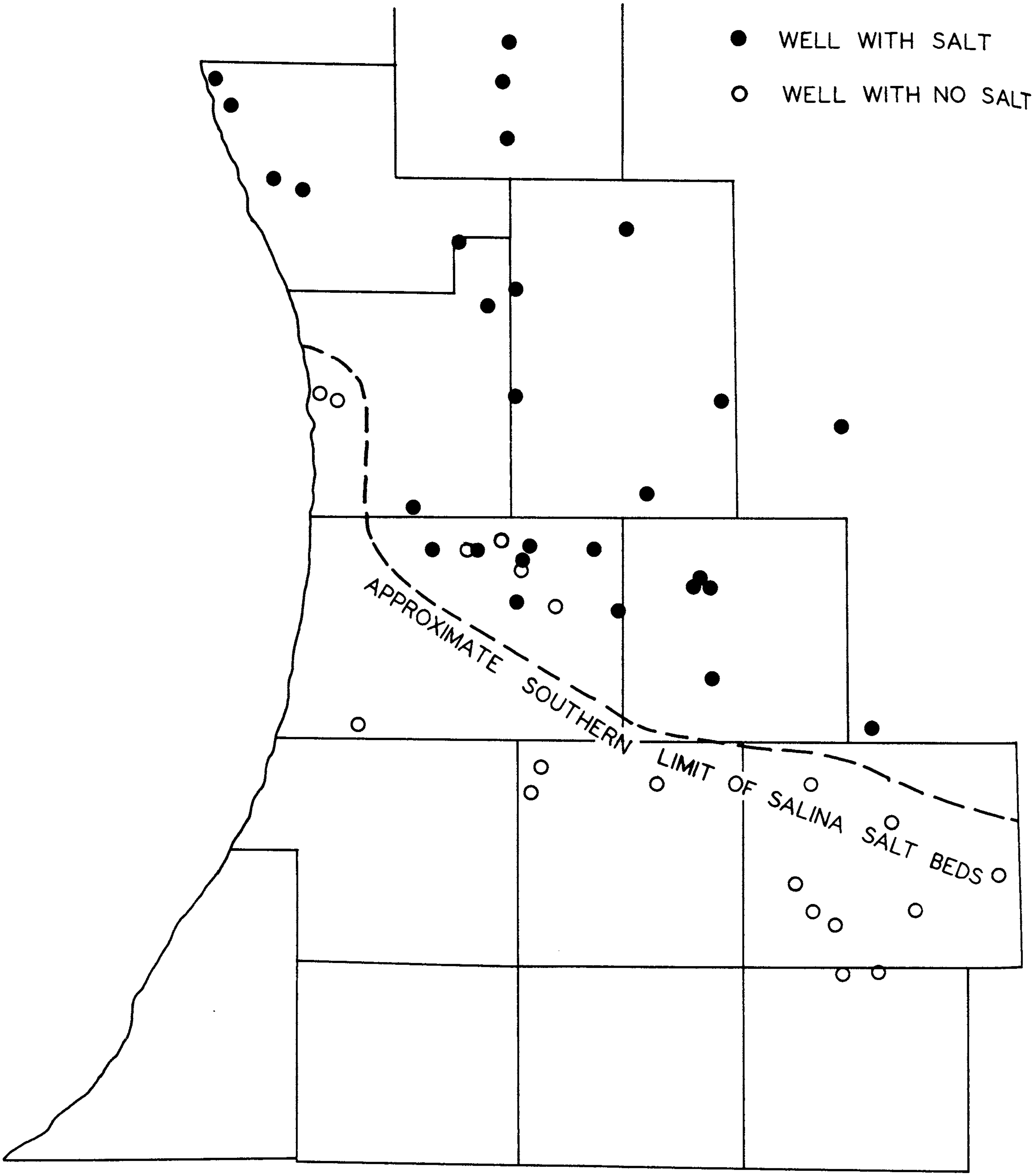
Commercial production of Salina gas and oil in southwest Michigan region, excepting northwestern Muskegon County has been, so far, confined to the structures in Allegan County. Production has been obtained from Salina rocks beneath several of the larger Traverse limestone pools on the Overisel and Salem structures. Production is also obtained from Salina rocks beneath or adjacent to the Dorr, West Hopkins, and Hilliards fields. Excepting the Dorr Field, these structures have not been adequately tested.

Salina production, where porosity and permeability are favorable, is now obtained from structures that are marginal to the edge of Salina salt deposition (Figure 11). The initial Salina salt bed, the A-1, extends into Allegan County but is locally absent. The A-2 salt and the B salt are not in this area but are believed to pinch out against the flanks of the pre-Salina structure to the north and northeast of Allegan County.

Complete production and reservoir data are not available for all the Salina pools in Allegan County. Production data and a small amount of reservoir data are available for the larger pools.

Salem Field. Salina gas has been produced from the A-2 dolomite in one well in this field since 1937. The accumulative gas production from the one well at the close of 1957 was nearly 324 million cubic feet. Rock pressure at the time of completion was reported to be 1150 psi. Gas and shows of black oil were reported in the A-1 dolomite section, but were plugged off and production was confined to the A-2 dolomite. A second well, about one and a half miles east of the discovery, was completed in 1957 as a shut in gas well. Initial production, natural, was reported to be about 76,000 cubic feet of gas per day.

Dorr Field. A small amount of oil was produced from the A-1 dolomite in the Dorr Field in 1942. The oil was a heavy, black, asphalt base crude of about 22 API



GENERAL DISTRIBUTION OF SALINA B, A-2, AND A-1 SALT BEDS

G.D. ELLS 5-58

FIGURE 11.

gravity. The well was abandoned in 1943. Commercial production was obtained from the Salina in 1956. Some oil and gas was produced from the A-1 dolomite but the bulk of present production is from the A-2 dolomite. Gas-oil ratios of individual wells within the field vary considerably. Production is obtained by pumping and by natural flow. Accumulative oil production at the end of 1957 was nearly 13,000 barrels of oil. Gas production amounted to over 45 million cubic feet. The bulk of the oil and gas has been produced from three of the seven wells completed in the field to the end of 1957.

Overisel Field. Gas production in the Overisel field was first obtained in 1956. By the end of 1957, 38 gas wells had been completed in the A-2 dolomite. Single point capillary pressure determinations were reported from a number of samples from different wells in the field. Permeability factors ranged from 0.9 Md. to 14 Md.; porosity ranged from 5.8 per cent to 18.6 per cent; wetting phase saturation at 1000 PSIA ranged from 4.9 per cent to as high as 25.4 per cent. Gas reserves were reported to be in excess of 60 billion cubic feet. The field was sold and will eventually be converted to a gas storage reservoir.

Gas and oil production from the Salina pays in the West Hopkins and Hilliards fields has been small. Discovery of the Salina pays in these fields was very recent, and development has been slow. Little is known about the oil and gas potential.

Table 2 lists the Salina-Niagaran oil and/or gas pools that were producing at the close of 1957. Field development has continued in the Dorr, Overisel, Salem, and Peters fields during 1958.

South of the lower half of the Van Buren County and west of St. Joseph County, the producing units of the Salina are believed to be directly overlain by Devonian rocks (Figure 6). Very few shows of oil and gas have been reported in Salina rocks in this area. In the few wells that have had oil and gas shows, the shows were in rocks immediately above or below the surface of unconformity separating the Devonian-Silurian systems. In some wells, gas shows were in the section referred to in this report as Garden Island (?). In many places, rocks at or near the surface of the unconformity contain bituminous or petroliferous material. Some petroliferous units of the Salina are believed to have been completely removed or thinned by erosion over a large part of this area. Shows of oil and gas in Salina rocks in this region have been few. It is possible that many structural traps in Salina rocks in this area are barren of gas and oil. Accumulation of oil and gas in various types of stratigraphic traps may be favorable, especially at or near the surface of unconformity.

Table 2

SALINA-NIAGARAN OIL POOLS (Producing at end of 1957)

Field	County	Discovery Date	Producing Unit	Depth to Pay	Cumulative Production (bbls.)	Producing Wells (1957)	Comments
Dorr	Allegan	1956	A-2 dolomite	2758	12,914	8	High GOR
Hopkins, West	Allegan	1956	A-1 dolomite	2864	690	1	
Hamlin	Mason	1952	Top of Niagaran (?)	4224	59,579	1	
Marine City	St. Clair	1955	A-1 dolomite	2176	3,126	1	
Peters	St. Clair	1957	A-1 dolomite "Brown Niagaran"	2615	4,905	1	

SALINA-NIAGARAN GAS POOLS (Producing at end of 1957)

Field	County	Discovery Date	Producing Unit	Depth to Pay	Cumulative Production (MCF)	Producing Wells (1957)	Comments
Overisel	Allegan	1956	A-2 dolomite	2650	Shut in	38	50-60 Billion Cubic Feet Gas Reserves
Salem	Allegan	1937	A-2 dolomite	2725	323,698	1	
Howell	Livingston	1935	"Brown Niagaran"	3920	20,475,888	14	
Montague	Muskegon	1953	"Brown Niagaran"	3734	7,139	2	
Boyd	St. Clair	1952	A-1 dolomite	2467	652,448	1	
Ira	St. Clair	1953	"Brown Niagaran"	2276	402,469	1	
Peters	St. Clair	1955	A-1 dolomite "Brown Niagaran"	2386	94,749	1	
St. Clair	St. Clair	1953	"Brown Niagaran"	2567	7,851	1	
Romulus	Wayne	1955	A-1 dolomite	1980	17,589	2	
Northville	Wayne Washtenaw	1937	A-1 dolomite "Brown Niagaran"	2905	2,311,226	5	

Table 3
WELLS REFERRED TO AND USED IN CROSS SECTIONS

Well No.	Company and Well Name	State Permit	County	Town-ship	Range	Sec-tion
1	J. E. Flannigan - Croff #1	3090	Kent	T.7N.	R.9W.	35
2	Smith Petro. Co. - R. Sherk #1	11540	Kent	T.5N.	R.10W.	21
3	Sun Oil Co. - W. L. Kidder #1	7873	Barry	T.3N.	R.9W.	8
4	McClure Oil Co. - Hibbard #1	20732	Barry	T.2N.	R.9W.	34
5	Reid-Norris - Caldwell #1	789	Kalamazoo	T.1S.	R.12W.	32
6	C. L. Hook - C. & M. Hook #1	13483	Kalamazoo	T.2S.	R.12W.	31
7	Ford Oil Co. - Potter & Stephayn #1	18559	Van Buren	T.4S.	R.13W.	5
8	Wolverine Oil & Expl. Syn.-Vought #3	449	Van Buren	T.4S.	R.14W.	32
9	Reed & Springsteen - Norton #1	62	Cass	T.5S.	R.15W.	2
10	L. T. Barber - N. P. Beebe #1	3803	Cass	T.5S.	R.15W.	3
11	Berrien Petro. Syndicate - Franz #1	837	Cass	T.7S.	R.16W.	3
12	R. M. Perry - Foster Est. #1	13879	Berrien	T.7S.	R.17W.	2
13	N. Nelson - Speckine #1	13779	Berrien	T.7S.	R.18W.	32
14	A. Violette - C. K. Warren #1	6364	Berrien	T.8S.	R.20W.	8
15	J. Nicosia - A. Wishart #1	19529	Berrien	T.6S.	R.19W.	4
16	Shelbow Oil Co.-Van Leute et al #1	7046	Berrien	T.4S.	R.19W.	35
17	Sprenger Bros. - G. Herwig #1	6126	Berrien	T.4S.	R.18W.	10
18	J. Warman - J. Warman #1	7815	Berrien	T.3S.	R.17W.	34
19	Whitehill & Drury-Amet & Webster #1	5229	Van Buren	T.2S.	R.16W.	35
20	Little Four Oil Co. - J. Getz #1	6679	Van Buren	T.2S.	R.16W.	23
21	Mich.-Cal. Oil Corp. - W. Piper #1	6352	Van Buren	T.1S.	R.16W.	36
22	Stevens - Starback #1	15327	Allegan	T.1N.	R.15W.	29
23	Oil Producers, Inc. - A. Schafer #1	20184	Allegan	T.3N.	R.12W.	18

Table 3 (Continued)

Well No.	Company and Well Name	State Permit	County	Town-ship	Range	Sec-tion
24	Regal Dutch Petro. Co. - Heasley #2	4402	Allegan	T.4N.	R.13W.	21
25	Muskegon Develop. Co. - Momey #2	4108	Allegan	T.4N.	R.13W.	17
26	Producers Committee - Riddering #1	9166	Kent	T.7N.	R.12W.	30
27	C. N. Crawford - C. Gillson #1	18027	Kent	T.9N.	R.12W.	32
28	Michigan Petro. Co. - C. Moe #1	537	Ottawa	T.9N.	R.13W.	6
29	Atlantic Exploration Co.- Brydges #1	788	Newaygo	T.11N.	R.13W.	12
30	Sun Oil Co. - G. Bradley #4	13816	Newaygo	T.12N.	R.13W.	11
31	Newaygo Gas & Oil Co. - Bates #1	411	Newaygo	T.13N.	R.13W.	12
32	Consumers Power Co. - Koopman #1	20115	Allegan	T.4N.	R.14W.	16
33	Hobson & Henry - Knoblock #1	20595	Allegan	T.3N.	R.12W.	23
34	Gulf Refng. Co. - Bateson #1	5441	Bay	T.14N.	R.4E.	2
35	Parsons Bros. - A. Sillman #1	19272	Clinton	T.8N.	R.4W.	27
36	Cities Service Oil Co. - L. P. G. #1	16734	Kent	T.6N.	R.9W.	12
37	Muskegon Oil Corp.-H. Heinz #5	309	Muskegon	T.10N.	R.16W.	8
38	Johnson Oil Refng. Co. - Savacool #1	168	Muskegon	T.10N.	R.17W.	2
39	Sun Oil Co. - State-Mancelona #A-1	11572	Antrim	T.29N.	R.5W.	36

REFERENCES

Cohee, G. V., 1944, "Thickness and character of the Traverse Group and Dundee formation in southwestern Michigan". U. S. Geological Survey, Oil and Gas Inv., Preliminary Chart No. 4.

___________, and Underwood, L. B., 1945, "Lithology and thickness of the Dundee formation and the Rogers City limestone in the Michigan Basin", U. S. Geological Survey, Oil and Gas Inv., Preliminary Map No. 38.

___________, 1947, "Lithology and thickness of the Traverse group in the Michigan Basin", U. S. Geological Survey, Oil and Gas Inv., Preliminary Chart No. 28.

___________, 1948, "Thickness and lithology of Upper Ordovician and Lower and Middle Silurian rocks in the Michigan Basin", U. S. Geological Survey, Oil and Gas Inv., Preliminary Chart No. 33.

___________, (Chairman), 1954, "Southern Peninsula of Michigan", Geologic Cross-section of Paleozoic rocks, Central Mississippi to Northern Michigan, American Association Petroleum Geol., pp. 20-29.

Ehlers, G. M., (and Landes, K. K.; Stanley, G. M.), "Geology of the Mackinac Straits Region", Publication 44, Geological Survey Division, Michigan Department of Conservation.

___________, and Kesling, R. V., 1957, "Silurian rocks of the Northern Peninsula of Michigan", Michigan Geological Society Annual Geological Excursion, 1957.

Evans, C. S., 1950, "Underground Hunting in the Silurian of Southwestern Ontario", Proc. Geol. Assoc. of Canada, Vol. 3.

Hale, L., 1941, "Study of Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan", Bull. Amer. Assoc. Petrol. Geol., Vol. 25, pp. 713-723

Jodry, R. L., 1957, "Reflection of possible deep structures by Traverse group facies changes in Western Michigan", Bull. Amer. Assoc. Petrol. Geol., Vol. 41, pp. 2677-94.

Kay, M., 1951, "North American Geosynclines", The Geological Society of American, Memoir 48.

Landes, K. K., 1945, "The Salina and Bass Island rocks in the Michigan Basin", U. S. Geological Survey, Oil and Gas Inv., Preliminary Map No. 40.

___________, 1945, "Geology and oil and gas possibilities of Sylvania and Bois Blanc formations of Michigan", U. S. Geological Survey, Oil and Gas Inv., Preliminary Map No. 28.

Landes, K. K. 1951, "Detroit River Group in the Michigan Basin", U. S. Geological Survey Circular 133, 23 pp.

Longwell, C. R., (Chairman), 1949, "Integrated Facies Analysis", The Geological Society of America, Memoir 39, pp. 91-123.

Lowenstam, H. A., 1950, "Niagaran reefs in the Great Lakes area", the Journal of Geology, Vol. 58, pp. 430-87.

Martin, H. M. and Straight, M. T., 1956, "An Index of Michigan Geology", Publication 50, Geological Survey Division, Michigan Department of Conservation, 461 pp.

Mc Gregor, D. J., 1954, "Stratigraphic Analysis of Upper Devonian and Mississippian rocks in Michigan Basin", Bull. Amer. Assoc. Petrol. Geol., Vol. 38, pp. 2324-56.

Melhorn, W. N., 1958, "Stratigraphic Analysis of Silurian rocks in Michigan Basin", Bull. Amer. Assoc. Petrol. Geol., Vol. 42, pp. 816-38.

Newcombe, R. B., 1932, "Geology of Muskegon oil field, Muskegon, Michigan", Bull. Amer. Assoc. Petrol. Geol., Vol. 16, pp. 153-168.

____________, 1933, "Oil and Gas fields of Michigan", Publication 38, Geological Survey Division, Michigan Department of Conservation, 293 pp.

Price, L. W., et al, (Compilers), 1957, "1957 Summary of Operations Oil and Gas Fields", Geological Survey Division, Michigan Department of Conservation, 39 pp.

Sanford, B. V., and Brady, W. B., 1955, "Paleozoic Geology of the Windsor-Sarnia Area, Ontario", Canada Department of Mines and Technical Surveys, Geological Survey of Canada, Memoir 278, 65 pp.