Geological Survey Division
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STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
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STRUCTURES ASSOCIATED WITH THE ALBION - SCIPIO OIL FIELD TREND

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May, 1962

CONTENTS

ABSTRACT 2
INTRODUCTION 2
Field names and field development 3
Previous investigation 3
Scope of investigations 4
Source of data 4
Presentation of data 4
Geologic framework of the Michigan Basin 5
Silurian-Devonian unconformity 6
General stratigraphy 6
Cal-Lee Field 8
- Type Log 8
- Ordovician system 8
- Silurian system 9
- Devonian system 12
- Mississippian system 12

Albion Field 15
- Type Log 15
- Ordovician system 15
- Silurian system 16
- Devonian system 17
- Mississippian system 17

Pulaski Field 23
- Type Log 23
- Ordovician system 23
- Silurian system 23
- Devonian system 24
- Mississippian system 24

Development of structure along the Trend 26
Development of Trenton structure or "Syncline" 29
Summary 30
Formation lithologies 31
References 32

TABLES

1 - Comparison of thickness intervals from type logs 7
2 - Wells used in Figure 6 32
3 - Oil and gas production - Michigan Trenton-Black River pools 32

ILLUSTRATIONS

1 Albion-Scipio Trend 2
2 Michigan Basin 6
3 Paleogeologic map of Silurian-Devonian unconformity 6
4 Generalized columnar section of Michigan 7
5 Geological map - lower half of Southern Peninsula 7
6 Structure section: top of "Bois Blanc" to Clinton" 11

CAL-LEE FIELD

7 Structure: "Black River shale" and Trenton 12
8 Structure: Utica shale and Cincinnatian 13
9 Structure: "Clinton" and Niagaran 13
10 Structure: A-1 carbonate and A-2 carbonate 13
11 Structure: C Unit; Thickness: A-2 carbonate to "Clinton" 13
12 Structure: "G" Unit and "Bois Blanc" 14
13 Structure: "Traverse Limestone" and Sunbury shale 14
14 Trace of major synclinal depressions 14
15 Structure profiles of formation tops 14

ALBION FIELD

16 Structure: Trenton 17
17 Structure: Utica shale 17
18 Structure: Utica shale 18
19 Structure: Cincinnatian 18
20 Structure: "Clinton" 18
21 Structure: "A-2 carbonate" 18
22 Thickness: "A-2 carbonate" to "Clinton" 19
23 Structure: C Unit 19
24 Structure: "G" Unit 19
25 Structure: "Bois Blanc" 19
26 Thickness: "Bois Blanc" to "G" Unit 20
27 Structure: "Traverse limestone" 20
28 Thickness: "Traverse limestone" to "Bois Blanc" 20
29 Structure: Sunbury shale 20
30 Thickness: Sunbury to "Bois Blanc" 21

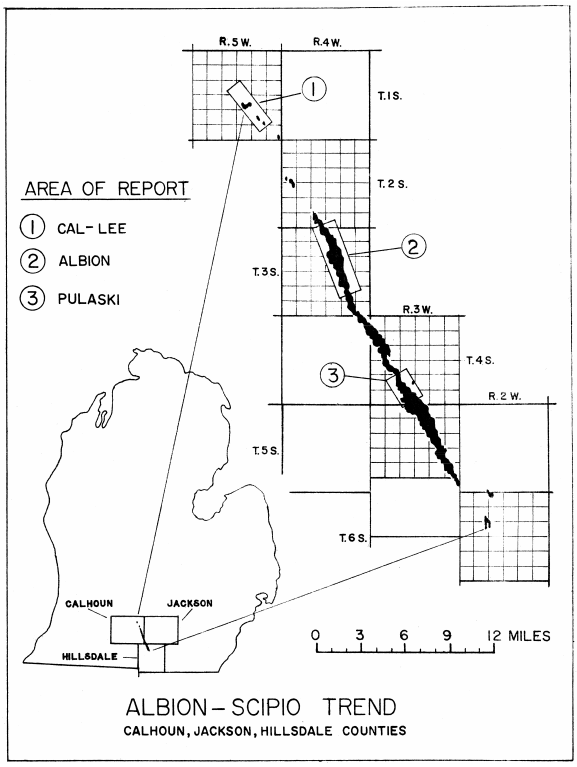
31 Thickness: Sunbury to Trenton.....21
32 Thickness: "Clinton" to Trenton 21
33 Trace of major synclinal depressions 21
34 Trace of major synclinal depressions 22
35 Trace of major synclinal depressions 22
36 Structure profiles of formation tops.....22
PULASKI FIELD
37 Structure: Trenton and Utica shale.....24
38 Structure: Cincinnatian and "Clinton".....25
39 Structure: "A-2 carbonate"; Thickness: "A-2" to "Clinton"25
40 Structure: C Unit and "G" Unit 25
41 Structure: "Traverse limestone" and Sunbury shale 25
42 Trace of major synclinal depressions 26
43 Structure profiles of formation tops.....26

ABSTRACT

The discovery of commercial oil production in Middle Ordovician rocks in Hillsdale County in 1956, in Calhoun County in 1958, and in Jackson County in 1959 led to the subsequent development of the largest Trenton-Black River oil pool found to date within Michigan. Hundreds of oil wells and many dry holes have been drilled along a linear, dolomitized fracture zone that extends for nearly 35 miles. Oil and gas accumulations are associated with synclines rather than anticlines.

Rocks of Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician age are penetrated in drilling to the oil and gas reservoirs. Detailed structure studies of numerous Paleozoic formations disclose a close association of numerous small folds and synclines nearly en echelon arrangement. The almost perfect alignment of the structural features suggests that the deformation is keyed to a pre-existing basement fault, but there is no direct information to substantiate the assumption.

Structural deformation appears to have begun in post-Middle Ordovician time and continued intermittently at least into Mississippian time. Middle Silurian reefs complicate the regional geology and are important factors in formation of structure in later Silurian rocks and in Devonian and Mississippian formations.



[1. Albion-Scipio Trend]

INTRODUCTION

The Albion-Scipio Trend, often referred to as simply "the Trend," extends for about 35 miles in a northwest-southeast direction across parts of Hillsdale, Jackson, and Calhoun counties in southern Michigan (Fig. 1). It contains the greatest accumulation of Ordovician oil and gas discovered to date in Michigan. Compared with other Trenton-Black River fields in Michigan, the oil pools of the Trend are unique in geological aspects and in the amount of oil and gas produced. Since the first discovery well in 1956, over 420 producing oil and gas wells have been drilled. By the end of 1961, the pools associated with the Trend had produced more than 21,740,000 barrels of oil and over 11 billion cubic feet of gas. Prior to 1956, five Trenton-Black River oil fields, the oldest dating back to 1920, had produced a little over a half million barrels of oil.

The Trend is comprised of several narrow, linear oil fields located on, or along, a probable deep seated fault or fracture zone. Oil and gas are produced from a dolomitized fracture zone in the Trenton and Black River formations of Middle Ordovician age. Several hundred wells have been drilled in the fields and in adjacent areas. In the fields the wells have been drilled one well to twenty acres, thereby making it possible to observe detailed structural and stratigraphic features over a distance of many miles. In drilling to these formations, rocks of the Pennsylvanian, Mississippian, Devonian, and Silurian systems are penetrated.

Since the discovery and development of the fields along the Trend, extensive seismic, gravity-meter, and other types of surveys and studies have been made in the fields and throughout a large part of the lower half of the southern Peninsula. Several scores of wildcat tests, many of them based on geophysical or subsurface studies, have been drilled in the vicinity of the Trend in hopes of finding another fracture zone. Although several "one-well" Trenton-Black River fields have been discovered, all have been found by random drilling. To date, no structure similar or comparable to the Albion-Scipio Trend has been found. Certainly other fields of

similar geologic history and structure should exist within the Michigan basin.

The writer thanks the members of the Petroleum Geology section, and members of the clerical staff for valuable assistance during the compilation of this report. Certain parts of the report were presented at the Albion-Scipio symposium sponsored by the Michigan Basin Geological Society in April, 1961. A more complete presentation was made before the Society in October, 1961.

FIELD NAMES AND FIELD DEVELOPMENT

Shows of oil and gas had been encountered in various formations in a number of wells drilled in Hillsdale County prior to 1957, but no commercial production had been established. The first oil well discovery for the Trend was drilled in Scipio Township, Hillsdale County in 1956. It produced oil and gas from Ordovician reservoir rocks of the Trenton-Black River formations and was finally completed in 1957 after several off-set wells with gusher type production had been drilled and completed. The field was called Scipio after the township name.

Gusher production stimulated further wildcat drilling in nearby localities of southern Michigan. Late in 1958 another Trenton oil well discovery was made in Albion Township, Calhoun County, about 12 miles northwest of the Scipio field. This well was drilled about if miles south of an earlier Trenton test in what was then called the Albion gas field, the gas having been produced from a shallow Devonian pay. The earlier Trenton test had been cored, showed some fracturing and oil saturation in dolomitized Trenton rock, but was plugged and abandoned without further testing as a dry hole in the Trenton formation (Ives and Ells, 1959). The Albion gas field had been abandoned in 1948. With the completion of the new Trenton producer, the field was called Albion. Subsequent Trenton development encompassed all the area that was originally included in the Albion gas field.

At about the same time as the Albion discovery well was being drilled, another Trenton test was underway about midway between the Albion field and. the Scipio field. This well, drilled in Pulaski Township, Jackson County, was completed in January, 1959, as a new Trenton-Black River oil discovery. The new field was called Pulaski. With the excellent lineation of the Albion-Pulaski-Scipio fields quite apparent, further wildcat drilling "on Trend" resulted in spectacular outpost discoveries. Subsequent discoveries were made by "trend" drilling which resulted in the southern-most extension in Adams Township, Hillsdale County in 1959, and the northernmost extension, the Cal-Lee field, Calhoun County in 1960. By mid-1961 ensuing field development had merged the original Albion-Pulaski-Scipio fields into a narrow, linear oil field extending for more than twenty-one miles. The southern and northern producing areas have not yet been joined to the central producing part of the Trend. Nearly all the producing wells are confined to a dolomitized area less than one mile wide at greatest developed width.

The line of fields is often referred to as the Albion-Scipio Fault Trend. The name is derived from the excellent lineation and narrow width of the fields and from the general belief that the dolomitized reservoir rocks are associated with a fault or series of faults. Although wells in some parts of the Trend are completed In the Trenton formation and in other parts in the Black River formation, it seems apparent from geological and reservoir considerations that all the designated fields along the Trend are related to the same fracture or fracture system. Because of the independent discoveries, different field names have become established for localities along the Trend. The field names: Scipio, Albion, Pulaski, and Cal-Lee, were used by the Michigan Geological Survey in its "Summary of Operations, Oil and Gas Fields" for 1957, 1958, and 1959. The use of individual field names was discontinued in the 1960 Summary. Statistical data for these fields are now listed under the term "Albion-Pulaski-Scipio Trend," with the production and other data designated by township. The field names, Albion, Pulaski, Scipio, and Cal-Lee, are retained for general area designation in this report.

PREVIOUS INVESTIGATION

The fields along the Trend have generally been classified as "syncline-type" oil traps, or as porosity traps associated with faulting. Early in the development of the Scipio field, structure contours on the top of the Trenton formation indicated the producing wells to be structurally low relative to dry-hole outpost wells (Ives and Ells „ 1958). Later, as more wells were drilled, the field was presented as a shallow syncline plunging in a north-westerly direction. Structure contours on the top of the Cataract ("Clinton") formation of Early Silurian age also indicated a shallow syncline markedly similar to the Trenton structure, lounger formations showed a slight indication of structure. The age of deformation was suggested to be at least post-Early Silurian and possibly as late as Devonian time (Ives. 1958). With the discovery and development of the Albion and Pulaski fields, it became evident that these fields were structurally similar and would probably be related to a common fracture or fault zone (Ells and Ives, 1959). Criteria for classifying the oil fields along the Trend as fault trap reservoirs were summarized by Ives and Ells (1960).

Burgess (1960) referred to the Albion-Scipio field as being situated along a linear syncline of about 30 feet relief and having a productive length of about 23 miles. The fields were described as synclinal type stratigraphic traps. The syncline was believed to have been formed as a result of normal faulting with very minor vertical displacement, and the subsequent shrinkage of the Trenton-Black River sequence by dolomitization. The dolomitization and subsequent shrinkage supposedly

superimposes a shallow syncline on the normal fault zone. Formation of the synclinal trend was believed to have occurred between Ordovician and Devonian time, Burgess compared the Albion-Scipio fields with the Dover and Colchester fields which also have characteristics of syncline type stratigraphic traps (Fig. 2).

SCOPE OF INVESTIGATIONS

A small amount of structural data has been published for the oil and gas fields along the Trend. The published data are limited to the structural configuration of the top of the Trenton formation for the original Scipio field and to a general regional portrayal of the Trend as it relates to the regional structural aspects of the Trenton (Ives and Ells, 1959). Some suggestions have been made as to the structure of formations younger than Trenton, but no data have been published. It has been suggested that the faulting or deformation of the rocks occurred sometime between Ordovician and Devonian time but data to support this suggestion have not previously been published.

The report is not a comprehensive presentation of all Important areas of study such as sedimentation, reservoir characteristics, porosity, etc. Structure and formation thickness maps, and other data, are presented to illustrate the relationships of various Paleozoic formations in selected parts of the Albion-Scipio Trend. The structural aspects of the various formations in the parts not mapped are similar to those of the mapped portions, but the geology varies because of Middle and Upper Silurian rocks which complicate an otherwise nearly conformable sequence of formations. Middle Silurian reef development has had an influence on the regional deposition and distribution of certain Late Silurian formations, on the development of structure In these rocks, and possibly on the structure in rocks as young as the Sunbury formation of Mississippian age.

The amount of well control within the fields along the Trend is consider able, but the amount of "wildcat" well control adjacent to the margins is relatively small. Exactly how the Trend relates to the adjacent areas cannot be illustrated at present because of low well density. It is probable that the fields are related to a common deformational cause. The mapped portions are Illustrative of the general nature of the deformation.

SOURCE OF DATA

The data used in this report were obtained from well records, maps, and unpublished studies kept and maintained by the Geological Survey Division, Michigan Department of Conservation.

Structural and formation thickness data were obtained solely from the Interpretation of radioactivity - neutron logs. This type of mechanical log has been run on perhaps 95 percent of the wells drilled in and along the Trend. Most of the formations in the Michigan basin are generally an alternating sequence of carbonates, argillaceous carbonates, shales, and evaporites. The radioactivity - neutron log, where related to the known stratigraphic succession, is an excellent tool for correlation. Many of Michigan's rock divisions are based on lithologic characteristics and fortunately many formation boundaries are especially well defined on radioactivity logs. Certain curves on these logs have been related to and have become associated with, for purposes of correlation, rock units of group, formation, or member status. There are also many distinctive and consistent curves that define numerous unnamed lithologic breaks that may be used in local or regional correlation, but there are also some formation breaks that are poorly defined on the logs.

Descriptive lithologic logs are available for all wells, and a large number of well sample sets are available for wells in the fields and vicinity.

PRESENTATION OF DATA

Structural data for several formations and structural contour maps of the Trenton formation for the entire Albion-Scipio Trend have been maintained since the initial discovery well in Hillsdale County. Preliminary investigations have been made along much of the Trend but it is not feasible to present the entire area in detail. The Scipio, Pulaski, and Albion fields have been merged together by the drilling of producing oil or gas wells, and the original limits of the fields no longer apply. The areas of detailed study were arbitrarily limited and the names given to these regions may include more or less area than the original limits of the fields. Thus reference to Albion on charts and diagrams, for example, means the area of study as shown in Figure 1 and not to the limits of the field as it may be understood by operators and others having interests in the Trend.

Each area of study is presented as a separate unit. A "type" radioactivity log for each area is listed for reference. The correlation points or formation tops as indicated by the log are designated. The correlation points are the same for all three areas of study except for certain units within the Salina sequence. The correlation points for the Salina sequence are noted by area of study. Only those wells for which mechanical logs were available are shown on the maps. Wells for which mechanical logs were not available are practically all edge wells. Although data for these few wells may alter the structural features on the edges of the fields, it is believed that the general structure will not be affected. All wells shown on contour and thickness maps for the Albion, Pulaski, and Cal-Lee fields were drilled into the Trenton formation or deeper.

The nomenclature used on the maps and charts are the common field terms generally used by the oil and gas industry of Michigan. Some of the formations or stratigraphic markers appear in quotation marks to designate the units that have been confined and limited

for purposes of this study. In general, the formation tops correspond to the same points chosen by the majority of subsurface geologists working in southern Michigan.

The geographic distribution of other Trent on-Black River oil fields, except those located in the Indiana and Ohio part of the Michigan basin» are shown in Figure 2.

The structure associated with the Trenton-Black River reservoir rocks in the fields along the Trend has been referred to as a depression or as a syncline. Depending upon the contour interval used, the structural aspects may be portrayed as a continuous syncline, a series of synclines, or a long, narrow sync line containing a number of closed depressions. The term "synclinal depression" is used for convenience in referring to the central part of the Trend. It refers to the structurally lowest areas on the surfaces of the various formations mapped and illustrated. It is not a singular feature and it may include several structurally low areas considered important in the interpretation of the Trend development.

The Cal-Lee field is presented first because it is the most basin-ward extension of the fracture zone and because it is near the edge of the Salina evaporite beds. The Trend traverses a thick section of Middle Silurian rocks which, where best developed, have characteristics of a barrier reef. The reef complex is related to platform areas on the southern rim of the basin. The section thins basinward and is represented by more or less isolated "pinnacle" type reefs. The reef complex is overlain by the Salina group. The evaporites of the Salina group blanket the zone of pinnacle reef development but do not extend far up the slope of the barrier reef. The Cal-Lee part of the Trend intersects the depositional edge of the Salina evaporite beds and the basinward edge of the reef complex. Certain carbonate beds of the Salina thin, or pinch-out entirely, against the reef complex as Late Silurian sediments eventually overlap Middle Silurian rocks. The southern part of the Trend is well outside the depositional limits of the Salina evaporite beds. The thinning and pinch-out of some of the Salina units, and the increasing rim-ward thickness of the Niagaran section is shown in Figure 6.

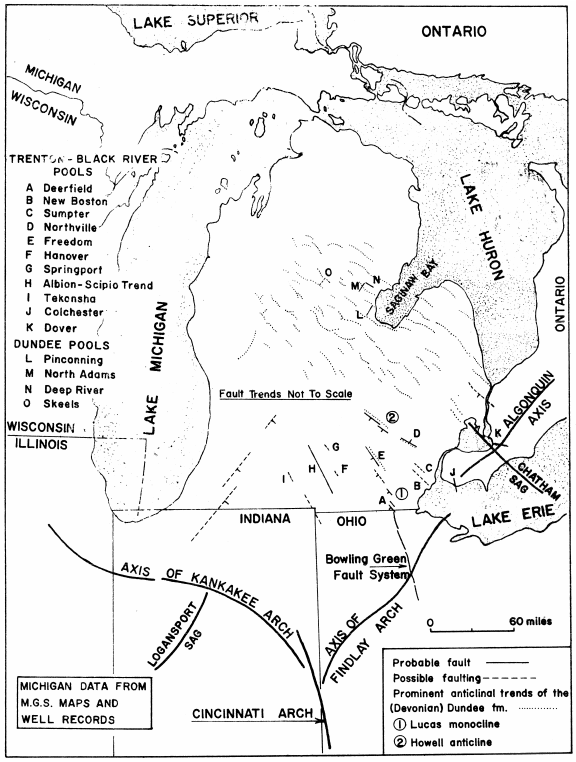
GEOLOGIC FRAMEWORK OF THE MICHIGAN BASIN

The Michigan Basin (Fig. 2) has been referred to as an intracratonic basin or autogeosyncline. It is nearly oval in shape„ with the longer axis trending in a northwest-southeast direction. The deepest part of the basin is probably in the Saginaw Bay, Clare, and Midland County area in central Michigan. Here the Precambrian rocks are overlain by an estimated 14,000-15,000 feet of Paleozoic sediments. In cross section from southwest to northeast, the basin is asymetrical with the steeper slope to the northeast. The basin is bordered, on the north by the Ontario portion of the Canadian Shield; on the east by the Algonquin axis in Ontario, Canada; on the south by the Findlay arch in northwestern Ohio and the Kankakee arch in northern Indiana; and on the west by the Wisconsin arch in central Wisconsin. According to some investigators, these major features have had an important part in the development of the Michigan basin proper.

Pirtle (1932) and Newcombe (1934) are of the opinion that the basin began to form in late Precambrian time. They, and Locket (1947), also suggest that the Kankakee arch is a southeastward extension of the Wisconsin Dome, Locket (1947) has suggested that a very early mountain chain extended from Canada through western Ohio and on south, and that the reflection of this mountain chain is manifest in the sedimentary rocks as the Cincinnati arch and presumably the Findlay arch. According to Sanford and Quillian (1957, p. 48) the Algonquin axis, the Canadian extension of Locket's early mountain range, has no relationship to the Findlay arch. The Algonquin axis (Algonquin arch) is said to be a basement high. The regional structure of southeastern Ontario is said to be controlled by this Precambrian feature. In Locket's opinion, the dominant structural features flanking the southern edge of the basin are underlain by cores of Precambrian mountains which have remained more or less positive features during the entire Paleozoic era, while the principal movement has been a continued subsidence of the negative areas such as the Michigan basin, the Illinois basin to the southwest, and the Pittsburgh-Huntington basin to the southeast (Locket, 1947, pp. 431-436).

Although other ideas have been expressed concerning the age and importance of the major features flanking the southern part of the basin (Bardley, 1951), (Green, 1957), opinion seems to favor a Precambrian or early Ordovician age for most of these features. The positive features, including the Canadian Shield and the Precambrian region of Wisconsin, set the framework for the Michigan basin and may to a large extent control the development of structural and fracture systems within the basin.

Structural features of lesser magnitude within the Michigan basin include the Chatham Sag (Kay, 1942), the Battle Creek Trough (Melhorn, 1958), the Howell anticline system (Newcombe, 1933), and the Lucas monocline (Carman and Stout, 1934, pp. 523-25). The dominant anticlinal trends of the Dundee formation of Devonian age in the central part of the basin are northwest-southeast. Known or suspected faults or fractures in these rocks strike northwest-southeast and northeast-southwest. Known anticlines or faults in Ordovician rocks trend northwest-southeast. The areal Geologic map (Fig. 5) reveals the pre-Pleistocene erosion surface and a few of the larger regional structures such as the Howell anticline system. Comparison of this map with Figure 2 illustrates the association of the known or suspected, Ordovician fracture zones with the regional deformational pattern of southeastern Michigan.



[2. Michigan Basin]

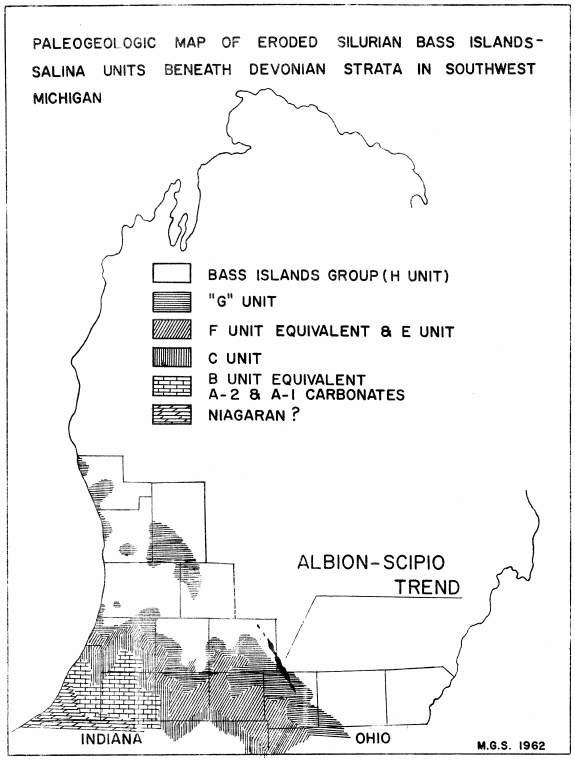
SILURIAN-DEVONIAN UNCONFORMITY

Surface and subsurface studies by numerous workers in Michigan geology have indicated the presence of several erosional unconformities within the Devonian sequence and within the sequence of Late Silurian rocks. An angular unconformity of considerable magnitude occurs between the Silurian and Devonian systems on the edges of the Michigan basin, but is not readily recognized in the deeper parts of the basin. Recognition and mapping of the formations involved in the unconformity is useful in dating the periods of deformation and possible fault movement along the Trend (Fig. 3).

Late Silurian Salina and Bass Islands rocks are thickest in the central part of the Michigan basin. From this region they thin outward toward the rim of the basin. In Ogemaw County, east-central Michigan, more than 3100 feet of Salina-Bass Islands rocks are present in the Lawton, State-Rose No. 1 (sec. 49 T.24N.-R.3E.). In Berrien County in the southwestern corner of Michigan, the equivalent section of rock is less than 100 feet thick and it may even be entirely absent in the southern part of this county. The thinning of this thick section of sediments is generally attributed to pinch out of the thick salt beds, to several periods of erosion, and to non-deposition of some of the Salina units.

Truncation of Salina and Bass Islands rocks is pronounced over a considerable part of southwestern Michigan. The Albion-Scipio Trend lies approximately along the edge of the eroded Bass Islands dolomite. Bass Islands dolomite is found in some wells at the southern end of the Trend but it is usually a thin section that has been preserved. To the southwest of the Trend some thin Bass Islands outliers are encountered, but to the north and northeast these rocks increase in thickness fairly rapidly and are found in all wells.

The oldest Devonian rocks encountered in the region of the Trend are those of the Bois Blanc formation which generally overlie Bass Islands dolomite. The Bois Blanc formation is thickest in the central basin district and, like the Bass Islands-Salina formations, it thins to the southwest. An erosional unconformity is believed to be present at the top of this formation. The Bois Blanc has been completely removed from most of southwestern Michigan, but some outliers are located near the erosional edge which is nearly coincident with the erosional edge of the Bass Islands dolomite. Bois Blanc formation is present in most of the wells along the Trend except at the southern end. In extreme southwestern Michigan, Devonian rocks younger than Bois Blanc may lie directly on rocks of the reef complex.



[3. Paleogeologic map of Silurian-Devonian unconformity]

GENERAL STRATIGRAPHY

At the north end of the Trend, the stratigraphic succession of formations includes rocks of the Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian systems. Within the confines of the oil fields, the oldest rocks penetrated to date are those of the Prairie du Chien group of Early Ordovician age. At the north end of the Trend, the first bedrock penetrated may be of Pennsylvanian age. Southeastward,

successively older formations of the Mississippian system are encountered. In general, the various formations dip northward toward the center of the basin. Except for rocks of Middle Silurian age, most formations increase in thickness basinward. Table 1 illustrates the variation in formation thickness along the Trend.

Table 1

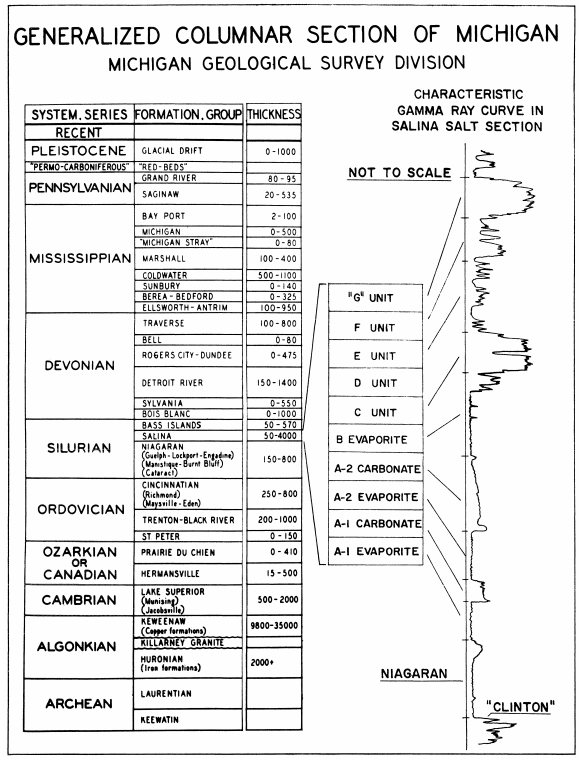
COMPARISON OF THICKNESS INTERVALS FROM TYPE LOGS

ND - not determined.	PULASKI	ALBION	CAL-LEE
Pleistocene glacial drift	225	73	50
Michigan Formation	0	0	50
Marshall Fm. to Coldwater Fm	120	300	340
Coldwater Fm. to Sunbury Fm	986	1004	1020
Sunbury Fm. to "Traverse limestone"	287	313	316
"Traverse limestone" to "Bois Blanc"	492	556	627
"Bois Blanc" to "G" unit	18	154	125
"G" unit	59	63	67
F unit	44	47	50
E unit	91	100	117
D unit not present			
Base of "G" unit to top of C unit	135	147	167
C unit	84	63	99
B unit	84	130	100
A-2 carbonate	ND	ND	151
A-2 evaporite	0	0	36
A-1 carbonate	0	0	71
A-1 evaporite	0	0	27
Niagaran to "Clinton"	562 (?)	444 (?)	242
"A-2 carbonate" to "Clinton"	621	542	527
"Clinton" to Cincinnatian	119	115	113
Cincinnatian to Utica	347	334	348
Utica shale	313	299	280
Trenton to "Black River shale"	360	352	376
"Black River shale" to "Glenwood"	249	231	243
Total depths of wells	4354	4513	4901

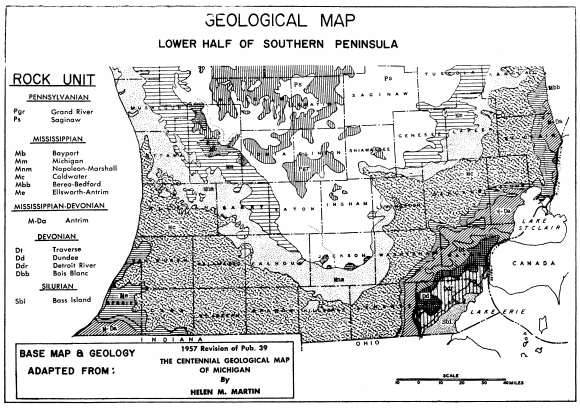
A generalized columnar section of Michigan is shown in Figure 4. The terminology and rank of rock units shown on the chart are those most commonly used by the oil and gas industry in Michigan. The terminology used to describe Salina rocks in the subsurface is shown on the right side of the chart. The thickness of formations or groups as indicated on the chart are the approximate thickness ranges for the Michigan basin and do not necessarily apply to the stratigraphic succession in the fields along the Trend.

The rocks of Middle and Late Silurian age are of special significance since the former are believed to be a reef and biostrome complex and the latter largely a marine evaporite sequence. The Niagaran Series is thickest in the shelf regions of the basin and thins basinward. The upper part of the Niagaran, sometimes called Guelph-Lockport, has been identified with reef and inter-reef facies of a regional reefal complex which is concentrated around the margins of the Michigan basin.

The Niagaran rocks appear to be conformably overlain by the evaporite sequence of the Salina group, which has been divided into a number of lithologic units that are traceable over most of the basin (Landes, 1947; Ells, 1958). The underlying reefal complex of the Niagaran appears to have had considerable influence on the deposition of evaporites and associated sediments. Southward along the Trend, the Salina evaporites pinch-out and certain of the A carbonate units thin considerably, or pinch-out entirely. In some areas where the evaporites are not present, it is often difficult to determine the exact limits of the A units.



[4. Generalized columnar section of Michigan]



[5. Geological map - lower half of Southern Peninsula]

The general bedrock geology of southern Michigan is shown in Figure 5. The region is almost everywhere covered with Pleistocene glacial drift and only a few scattered rock outcrops are encountered. The map illustrates the general extent of pre-Pleistocene truncation of successively older formations from the central part of the basin outward toward the rim.

Typical lithologies associated with the various formations penetrated in the Trend region are indicated by the descriptive log of a well in the Cal-Lee field. Except for certain units of the Salina and for thickness variations, the log is representative of the lithologies encountered throughout the fields. Refer to page 78 for the lithologic log.

CAL-LEE FIELD

The Cal-Lee field is the northernmost extension of the Albion-Scipio Trend. It was discovered in 1960 by using "trend" geology; that is, projecting the lineation of the Albion-Pulaski-Scipio fields and selecting a location on the projected trend. Oil and gas are produced from a narrow dolomitized zone in the Trenton formation. The field appears to be related to the main fracture zone but there is a possibility that it may be related to an associated minor fracture. In this respect it would be similar to the producing area in section 4, T.6S., R.2W., Adams Township, Hillsdale County (Fig. 1). Numerous dry holes have been drilled in attempting to extend this field laterally and along the strike of the Trend. Two Niagaran pinnacle reefs are associated with this field. The one to the northeast produces oil from a single well. The pinnacle to the southwest has one producible gas well.

Type log:

Schlumberger Well Surveying Corporation

Gamma Ray - Neutron log

State well permit number 22386

Sun Oil Company - H. H. Sundberg No. 1

SE NE NW section 26, T.1S., R.5W., Lee Twp., Calhoun County

Depths measured from K. B. at 948.0 feet above sea level.

NWD means there is not always a consistent or distinctive gamma ray curve definitive of the formation top or base, or of the correlation point. For correlation points not well defined on the log, well cuttings must be used in conjunction with the log to determine formation tops.

Standard formation tops or correlation points used for mapping various rock units and intervals in the Cal-Lee field.

	Depths in feet to Top	and Base
PLEISTOCENE:		
Base of glacial drift		50
MISSISSIPPIAN:		
Michigan formation	50	100
Marshall formation	100	440
Coldwater formation	440	1460
Sunbury formation	1460	1470
Berea-Bedford formations	1470	1485
MISSISSIPPIAN - DEVONIAN:		
Antrim formation	1485	1725
DEVONIAN:		
"Traverse formation"	1725	1776
"Traverse limestone" (base Traverse group at 1993)	1776	1993
Dundee formation	1993	2052
Detroit River group (including Sylvania ss. at base)	2052	2403
"Bois Blanc" formation	2403	NWD
SILURIAN:		
Bass Islands dolomite (H unit)	NWD	2528
"G" unit (Salina) (includes part of F unit)	2528	2595
F unit (salt beds not present)	2595	2645
E unit	2645	2763
D unit (not present)		
C unit	2763	2862
B unit (most of the salt not present)	2862	2962
A-2 carbonate (includes A-2 limestone)	2962	3113
A-2 evaporite (largely anhydrite)	3113	3149
A-1 carbonate	3149	3220
A-1 evaporite (A-1 evaporite equivalent)	3220	3247
Niagaran	3247	3489
"Clinton" (top of Cataract group)	3489	
Cabot Head shale (upper formation of Cataract group)	3489	3561
Manitoulin dolomite (lower formation of Cataract group)	3561	3602
ORDOVICIAN:		
Cincinnatian	3602	3950
Utica shale	3950	4230
Trenton formation	4230	4577
Black River formation	4577	4849
"Black River shale" (within the Black River formation)	4606	
"Glenwood shale"-St. Peter sandstone	4849	4871
Prairie du Chien group	4871	

Total depth of the log . . 4901 in the Prairie du Chien

ORDOVICIAN SYSTEM

Lower Ordovician

Prairie du Chien group. The oldest rocks drilled so far in this field are those of the Prairie du Chien group which includes in ascending order, the Oneota, New Richmond sandstone, and Shakopee formations. The Shakopee and New Richmond formations are believed to have been removed by erosion throughout most of this district (Cohee, 1945). Light colored, sometimes arenaceous, and often porous crystalline dolomites of the Oneota formation are encountered beneath a thin unit generally called the St. Peter sandstone.

Middle Ordovician

St. Peter sandstone. According to lithologic well logs a thin sandstone with characteristics of the St. Peter is encountered in some wells. The sandstone is overlain by a greenish gray or black shale containing fine to medium well rounded, frosted, clear quartz sand grains. This unit together with the underlying sandstone is often called "Glenwood" or "Glenwood-St. Peter."

"Glenwood shale." This dark colored sandy shale is sometimes referred to as the "base" of the Black River formation. It is well defined on radioactivity logs and may be used as a correlation or reference point for subsurface mapping. Data on the surface of this unit suggest a shallow syncline similar to that of the "Black River shale" which lies approximately 245 feet above.

"Black River shale." (Fig. 7) This is a thin shaly bed in the upper part of the Black River formation. It is indicated as a distinctive curve on the radioactivity logs and is a widely used point for mapping. Structure contours on this surface indicate a shallow, northwest plunging syncline flanked on the northeast by a narrow anticlinal ridge or fold. The thickness interval from the "Glenwood shale" to the "Black River shale," ranges from 239 feet to 247 feet, and averages about 244 feet. There appears to be no pattern of thickening of this interval within the syncline.

Trenton formation. (Fig. 7.) Contours on the Trenton formation indicate a structural feature similar to that of the underlying "Black River shale." The thickness interval from Trenton to "Black River shale" ranges from 376 feet to 380 feet, and averages about 378 feet. The thickness interval appears fairly uniform with no indication of thickening within the syncline.

Upper Ordovician

There are several mappable units within this series. The lower half is a thick shale unit generally called Utica shale by most geologists. The upper half is a sequence of dolomite, argillaceous dolomite, and shales similar to those of the lower half.

Utica shale. (Fig. 8) This is a thick sequence of gray, grayish green to black, hard, fissile shale, with a few thin stringers of shaly dolomite near the top. Structure contours on the top of the Utica shale indicate a shallow syncline of about the same magnitude as that of the underlying Trenton formation. The thickness of this unit ranges from 272 feet to 281 feet and averages about 277 feet. Distribution of the thickness intervals indicates a slight increase of more than 5 feet within the syncline.

Top of Cincinnatian. (Fig. 8) The upper half of the Cincinnatian Series is a sequence of light to dark colored dolomites, argillaceous and shaly dolomites, and shales similar to those of the Utica shale. Structure contours on the top of the Cincinnatian indicate a shallow syncline of about the same magnitude as that on the underlying Utica shale. The thickness intervals from the top of the Cincinnatian to the top of the Utica shale range from 345 feet to 357 feet. The thickness data indicate a thinner section within the syncline and a thicker section (about 7 feet) along the western flank of the syncline. Wells that outline the anticlinal fold to the east appear to have a thinner section.

SILURIAN SYSTEM

Lower Silurian

Cataract group. The Cataract group includes the Manitoulin dolomite formation and the overlying Cabot Head shale formation. The Cabot Head formation and the Manitoulin dolomite are sometimes mapped together and termed Cataract formation. In the Albion-Scipio Trend region and elsewhere within Michigan, the top of the Cataract group is often referred to as the top of the “Clinton." Figure 9 illustrates the structure on the top of the "Clinton" (top of the Cabot Head shale of the Cataract group). Again the configuration of the surface is that of a shallow syncline very similar to that shown for the top of the Cincinnatian Series. The thickness intervals from the top of the "Clinton" to the top of the Cincinnatian Series range from 104 feet to 123 feet and average about 112 feet. The thinnest intervals are in the southeast of section 22 where the interval averages about 107 feet. In section 26 the interval averages about 115 feet. The intervals for the wells in sections 23 and 24 are 114 feet, and 123 feet respectively. An increase in thickness within the syncline is not readily apparent.

Middle Silurian

Niagaran series. The rocks of the Niagaran series are predominantly light colored dolomites with minor amounts of chert and shale. Group names and formation names for surface exposures of this series are not often applied to the rocks in subsurface studies. In the subsurface, the rocks have been mapped as the "Niagara group" composed of the Guelph-Lockport and Clinton formations (Cohee, 1948). Although the upper part of the Niagaran series is sometimes called Guelph-Lockport, it is a common practice for most geologists in the oil and gas industry of Michigan to divide the Niagaran into several units based primarily on color and textural differences. The uppermost unit is called "Brown Niagaran" and is approximately equivalent to the Guelph. The rocks below this unit are commonly called "white" or "gray" Niagaran.

The upper units of the Niagaran are associated with reef and inter-reef facies of a reefal complex distributed around the margins of the Michigan basin. The thickest section of Niagaran occurs on the margins of the basin. From the margins, the section thins basinward. The Niagaran series is overlain by the evaporite sequence of the Salina group of Late Silurian age. The top of the Niagaran is generally called at the base of the lowest salt or anhydrite of the Salina group. The relationship of the Salina rocks to the underlying Niagaran reef complex in a line sub-parallel to the Trend is illustrated in Figure 6. The Cal-Lee field lies basinward from the thicker part of the reef complex and near the edge of the lower evaporite units of the Salina group. At least two pinnacle reefs are associated with the Cal-Lee field. Because the lowermost evaporite of the Salina is present in this region, the top of the Niagaran may be readily recognized except on the highest parts of the pinnacle reefs.

Niagaran. (Fig. 9) Structure contours on the top of the Niagaran indicate a depression similar to that on the top of the underlying "Clinton." However the depression is flanked on both sides by pinnacle reefs which have about 175 feet of relief. The reefs are elongated approximately parallel to the strike of the underlying syncline on the top of the "Clinton” and appear to be related to the higher part of the "Clinton" structure. The thickness of rock from the top of the Niagaran to the top of the "Clinton" varies due to reef development in the upper part of the Niagara. In the NW¼ SW¼ SE¼ of section 22, the thickness interval from the top of the Niagaran to the top of the "Clinton" is 431 feet; opposite this well, in the SE¼ NW¼ SE¼ of section 22, the thickness interval is 252 feet. Similarly the thickness interval in the NW¼ SE¼ SE¼ of section 22, is 253 feet; and in the well to the northeast in the SE¼ NE¼ SE¼ of section 22, the Interval is 436 feet. The height of the

reefs above the surrounding Niagaran surface, on either side of the depression, is about 180 feet. Elsewhere in the Cal-Lee field the thickness intervals from the top of the Niagaran to the top of the "Clinton" are less but vary according to the amount of reef build-up.

Upper Silurian

Cayugan series. Cayugan rocks Include In ascending order, the Salina group, and the Put-in-Bay and Raisin River formations of the Bass Islands group. The Salina group is largely an evaporite sequence composed of shales, carbonates and argillaceous carbonates, halite, and anhydrite. For purposes of subsurface Identification and correlation, the classification (with some modification) as devised by Landes (1945) is used by most stratigraphers in Michigan. In the subsurface, the Cayugan rocks have been divided into a number of stratigraphic units which may be traced over most of the Michigan basin. The thickness of the units varies depending on geographic position in the basin, proximity to the reef complex and Individual pinnacle reefs, sub-aerial or submarine erosion of certain units, leaching and removal or non-deposition of salt units, and the supply of sediments contributing to individual units.

The informal stratigraphic units of the Cayugan as used in this report are as follows:

H unit (Bass Islands dolomite): Largely buff colored, dense dolomites

“G” unit: Top of the Salina formation, gray shaly dolomite and argillaceous dolomite. Includes part of F unit shales and dolomites.

F unit: Uppermost salts of the Salina formation; contains thick salt beds separated by shale, shaly dolomite and dolomite in the deeper part of the basin. Salt beds not present in the Trend.

E unit: Gray shaly dolomite, argillaceous dolomite, and dolomite; contains an oil and gas pay called “E" zone or "Kintigh zone.”

D unit: Salt separated by a thin bed of argillaceous dolomite. Not present in the Trend region.

C units: Gray shaly dolomite, argillaceous dolomite, similar to “G" unit.

B unit: Nearly pure salt with thin dolomites and argillaceous dolomites in the upper half of the unit.

A-2 carbonates: Buff to brown dolomite or limestone. Over a large part of the basin, the lower part of this unit is a gray dolomite or limestone which is sometimes called “A-2 limestone.”

A-2 evaporite: Almost pure salt with anhydrite beds. Near the rim of the basin and within the inner margin of the Niagaran reef complex, the salt grades laterally into, or is represented by, an anhydrite bed.

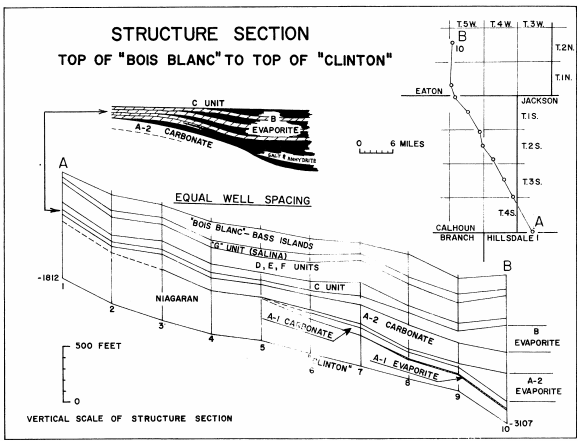
A-1 carbonate: Buff to brown dolomite or limestone.

A-1 evaporite: Almost pure salt. Near the rim of the basin and within the inner margin of the Niagaran reef complex, this salt also apparently grades laterally into, or is represented by, an anhydrite bed.

The Niagaran reef complex appears to have had considerable influence on the deposition of the Salina A units. The lowest unit, the A-1 evaporite, is largely a salt over most of the basin but near the inner margin of the reef complex the salt grades laterally into an anhydrite bed which in turn pinches out against the reef complex. The A-1 evaporite thins or is entirely absent over the higher parts of the pinnacle reefs. The A-1 carbonate thins and is often not present over the higher parts of the pinnacle reefs. The A-1 carbonate, traced from the belt of pinnacle reef development outward toward the basin rim and area of thick reefal complex, thins against this barrier and apparently pinches out. The A-2 evaporite also thins and pinches-out against the reef complex. The A-2 carbonate may also thin over the higher parts of the pinnacle reefs and it progressively thins as it overlaps the reef complex. The B evaporite, a thick salt with thin shale and dolomite beds in the upper half also thins over the reef complex. The salts of the B unit pinch-out gradually and the B unit is then represented by the convergence of the dolomites contained in the upper part. Figure 6 illustrates the thinning and overlap of the A and B units against and over the reef complex.

Most units of the Salina formation are represented in the Cal-Lee region. Structure maps and some thickness data are presented for several of the units.

A-1 carbonate. (Fig. 10) The structure on the top of the A-1 carbonate clearly reflects the underlying pinnacle reefs. The underlying A-1 evaporite, or its representative, an anhydritic dolomite, is present in most wells. It is best developed in the depression between the pinnacle reefs. On the higher part of the reefs the A-1 evaporite is absent. The overlying A-1 carbonate lies directly on the reef and is less than half as thick as it is in off-reef wells. The thinning of the A-1 evaporite and A-1 carbonate over the higher parts of the pinnacle reefs may be illustrated by the following data. In the NW¼ SW¼ SE¼ of section 22, the A-1 evaporite is absent and the A-1 carbonate is about 20 feet thick. Opposite this well, in the SE¼ NW¼ SE¼ of section 22, the A-1 evaporite is 18 feet thick and the overlying A-1 carbonate is 45 feet thick. In the NW¼ SE¼ SE¼ of section 22, the A-1 evaporite is about 27 feet thick and the A-1 carbonate is 61 feet thick, but to the northeast, in the SE¼ NE¼ SE¼ of section 22, the A-1 evaporite is absent and the A-1 carbonate is about 10 feet thick. Elsewhere in the Cal-Lee field the thickness of the A-1 evaporite and A-1 carbonate varies according to position on the reef.



[6. Structure section: top of “Bois Blanc” to Clinton”]

A-2 carbonate. (Fig. 10) Structure contours on the top of the A-2 carbonate clearly reflect the underlying A-1 carbonate structure and the Niagaran pinnacle reefs. The amount of relief on this surface Is about half the amount shown on the surface of the A-1 carbonate. The A-2 evaporite lies below the A-2 carbonate and above the A-1 carbonate. The A-2 evaporite Is principally an anhydrite in the Cal-Lee field and general vicinity. Thickness of this unit ranges from 30 feet to 57 feet, and averages about 40 feet. There appears to be a general increase in thickness basinward, but no conclusive evidence of thinning over the higher parts of the reefs.

Thickness: Top of A-2 carbonate to top of "Clinton." (Fig. 11) This interval includes the A-2 carbonate; A-2 evaporite; A-1 carbonate; A-1 evaporite; and all the Niagaran rocks down to the top of the "Clinton." The thicker section on each side of the depression is indicative of the Niagaran pinnacle reefs. In the Albion and Pulaski fields, where the base of the A-2 carbonate and the limits of the A-1 carbonate cannot be readily determined in all wells from logs or well cuttings, it was necessary to map the entire interval from the top of the A-2 carbonate to the top of the "Clinton." The interval for the Cal-Lee field is included for comparison with a similar interval in the Albion and Pulaski fields.

B unit (not illustrated). The B unit (B evaporite) farther basin-ward is a thick salt section which lies above the A-2 carbonate and below the C unit. The upper half of this unit includes thin dolomites and thin shale beds of unusual lateral continuity. In the vicinity of the Cal-Lee field, the lower half of the B unit is largely represented by an anhydrite bed. The upper half of the B unit is represented by the convergence of the thin dolomites , shales and anhydrites within the upper part of the B unit. The thickness of the B unit in the Cal-Lee field is about 100 feet. Figure 6 illustrates the thinning and convergence of the B unit.

C unit. (Fig. 11) The C unit is a persistent stratigraphic unit over most of the Michigan basin. Structure contours on the surface of this unit reflect the structure on the top of the A-2 carbonate and the depression between the pinnacle reefs. On the northeastern flank of the depression in section 22, about 50 feet of relief is noted, but on the southwestern flank of the depression in section 26, nearly 120 feet of relief is indicated. The greater amount of relief in section 26 is due to a thicker section of C unit. Over the pinnacle reefs, the C unit averages about 87 feet thick. Throughout most of the depression, with the exception of the five southern-most wells in section 26, the unit averages about 101 feet thick. The five southernmost wells have G units ranging from 148 feet to 183 feet. The average thickness for the five well area is about 165 feet. The extra section of C unit is found in a few other wells in southern Michigan.

D unit (not illustrated). The D unit (D salt) does not appear to be present in the Cal-Lee field and vicinity. Farther basinward the D unit is identified as two salt beds separated by a thin argillaceous dolomite bed.

E unit (not illustrated). The E unit is essentially a series of shales and thin dolomites located below the lowest F unit salt and above the D unit salts. It is a persistent and recognizable rock sequence over much of the Michigan basin. In the Cal-Lee field, it is about 120 feet thick. The E unit contains the “Kintigh porosity zone,” or “E zone” as it is sometimes called.

“G” unit. (Fig. 12) The “G” unit (uppermost beds of the Salina) as identified in most of the southern counties of Michigan comprises, in the author’s opinion, more than the uppermost beds of the Salina. The “G” unit as generally identified apparently represents the convergence of the G unit and several shale beds of the underlying F unit. When the “G” unit is traced from the southern counties basinward to where the Salina is better developed and much thicker, the "G” unit splits and contains as many as 3 salt beds. In the classification of Landes, all of these salts are classified as belonging to the F unit. Thus the "G” unit as mapped in the southern counties includes part of the F unit. Nevertheless, the "G" unit is a distinctive, mappable bed of rock which is readily identified on radioactivity logs and in well cuttings.

The structure on the surface of the "G” unit is similar to the structure of the C unit. In section 26, the amount of structural relief (approximately 130 feet) on this surface is about the same as the relief on the surface of the G unit for the corresponding area of section 26. Elsewhere, the amount of relief on the surface of the "G” unit is considerably less than on the C unit.

H unit (Bass Islands dolomite). Not illustrated. The H unit is almost always referred to as Bass Islands dolomite. Bass Islands dolomites are light colored, dense, and very similar to the light colored dolomites of the Salina group. In the center of the basin the Bass Islands dolomite is several hundred feet thick but in the vicinity of the fields along the Trend it has been completely removed or reduced to a thin unit.

DEVONIAN SYSTEM

"Bois Blanc." (Fig. 12) The top part of the rock unit here-in mapped as "Bois Blanc" is often called the "black lime," the "unconformity," or the Bois Blanc. The upper part of this unit is a thin, dark brown to nearly black carbonate which often overlies cherty dolomite characteristic of the Bois Blanc formation with which it seems to be related. The thin, dark carbonate bed is represented by a distinctive "break" on nearly all radioactivity logs in the Albion-Pulaski-Scipio region. The Bois Blanc is the oldest Devonian formation recognized in the Cal-Lee field.

In the deeper part of the basin, the Bois Blanc formation may be several hundred feet thick. It is characteristically a very cherty limestone and dolomite sequence. South and southwestward the formation thins by depositional thinning and by post-Bois Blanc erosion. The Bois Blanc formation has been removed from most of southwestern Michigan by one or more periods of erosion, but outliers or remnants may be encountered southward from the truncated edge.

In the Cal-Lee field the Bois Blanc may be as much as 40 feet thick in some wells but may be entirely absent in nearby wells. The combined interval from the top of the Bois Blanc to the top of the Salina "G" unit includes Silurian Bass Islands rocks. The thickness of this interval in the individual wells is shown in Figure 12.

The structure on the erosional surface of the "Bois Blanc" is similar to the structure on the surface of the "G" unit, but there is considerably less relief, especially in section 26.

"Traverse limestone." (Fig. 13) The "Traverse limestone" is a thick carbonate section within the Devonian Traverse group of the southern and western parts of Michigan. Structure contours on the surface of this section indicate a shallow depression or syncline similar to that on the surface of the "Bois Blanc" formation which lies from 610 to 650 feet beneath the "Traverse limestone."

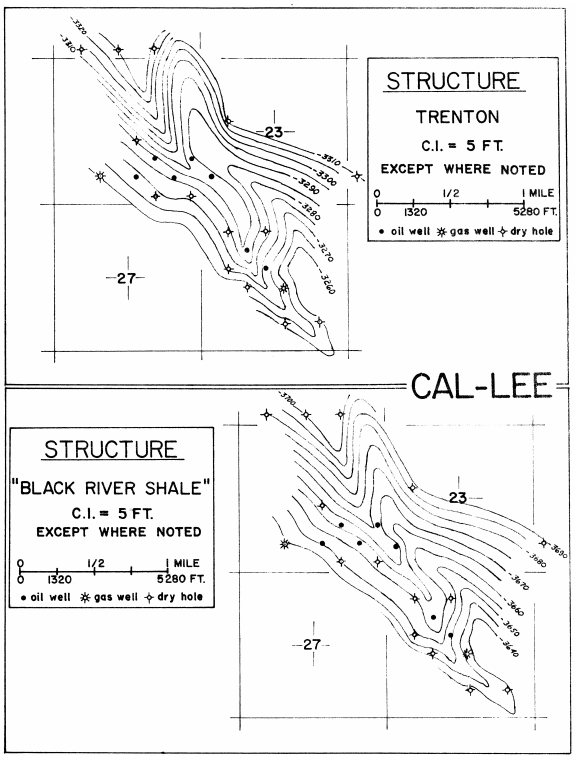
The interval from the top of the "Bois Blanc" to the top of the "Traverse limestone" includes in ascending orders the Sylvania sandstone, the carbonate and anhydrite rocks of the Detroit River group, the Dundee limestone, and the carbonates and thin shales of the Traverse group up to the top of the "Traverse limestone." The interval is thickest within the syncline and is thinnest on the low relief anticlines flanking the syncline. The thickness interval also increases from the southern part of the field to the northern end. Part of the thickness increase occurs within each of the rock divisions from the "Bois Blanc" up to the top of the "Traverse limestone."

MISSISSIPPIAN SYSTEM

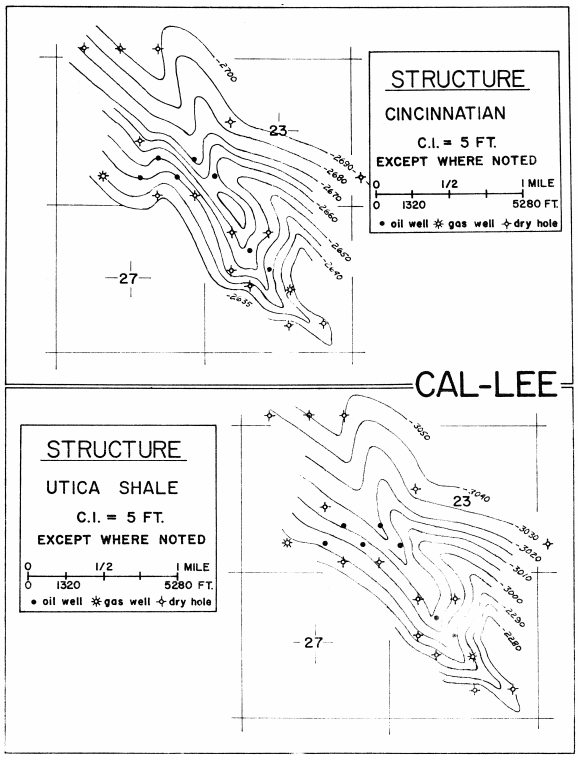
Sunbury shale. (Fig. 13) The Sunbury shale is the youngest Mississippian formation mapped in this field. It lies about 310 feet above the Devonian "Traverse limestone." Structure on the top of the Sunbury conforms closely to that of the "Traverse limestone." The depth of the syncline is about the same as that of the "Traverse limestone."

The interval from the top of the "Traverse limestone" to the top of the Sunbury includes in ascending order: the "Traverse formation," consisting of calcareous shale and thin limestones, the Antrim shale, the Bedford-Berea formations, and the Sunbury shale. The mapped thickness of the interval ranges from 310 feet at the south end of the field to 317 feet at the northern end. There appears to be no significant increase in thickness within the syncline. Some regional increase in thickness from south to north is indicated.

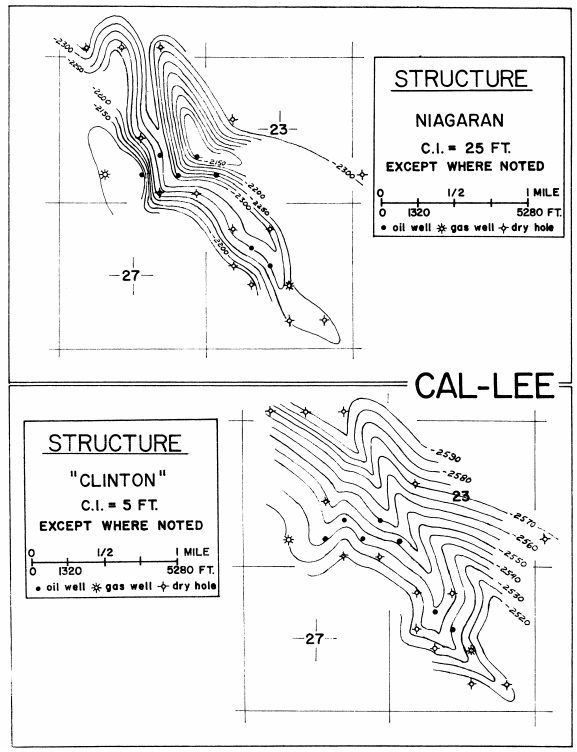
Structure profiles off formation tops. (Fig. 15) Structure profile sections at several points along the Cal-Lee field show the general structural relationship of formations from lower Middle Ordovician time to the end of Mississippian Sunbury time. The influence of Middle Silurian Niagaran reefs on the structure and thickness of rock units overlying the Niagaran is clearly evident.



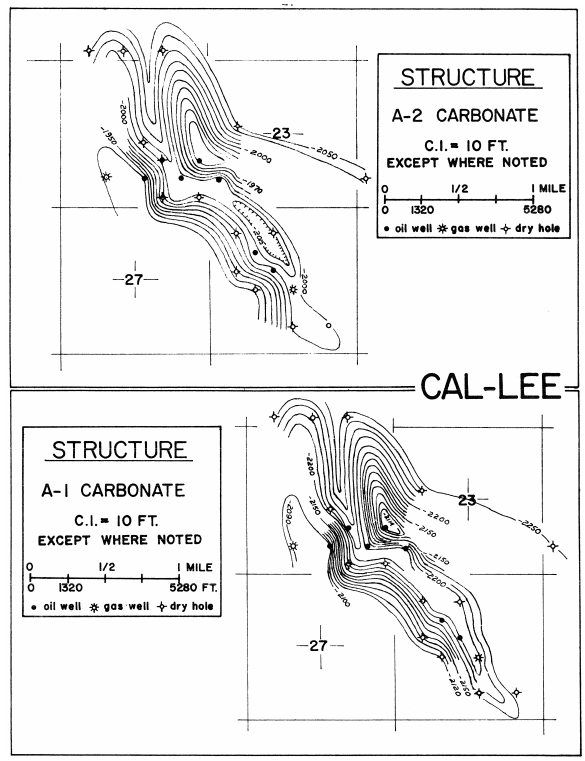
[7. Structure: "Black River shale" and Trenton]



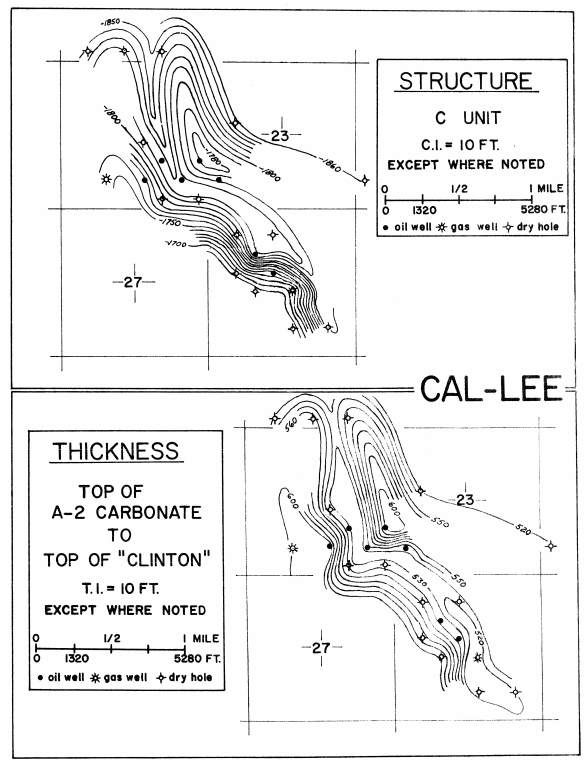
[8. Structure: Utica shale and Cincinnatian]



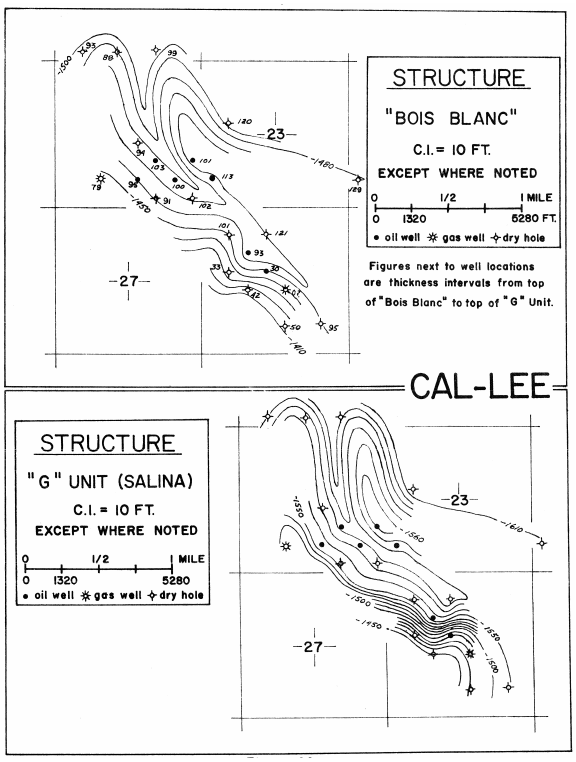
[9. Structure: "Clinton" and Niagaran]



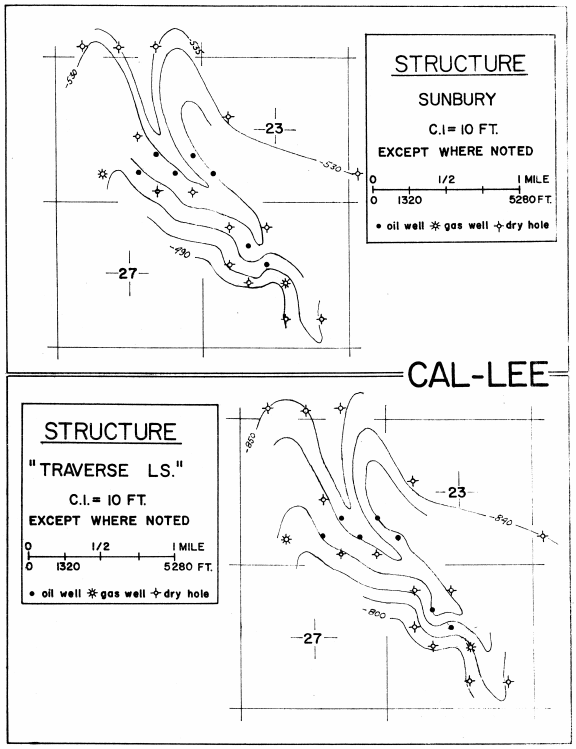
[10. Structure: A-1 carbonate and A-2 carbonate]



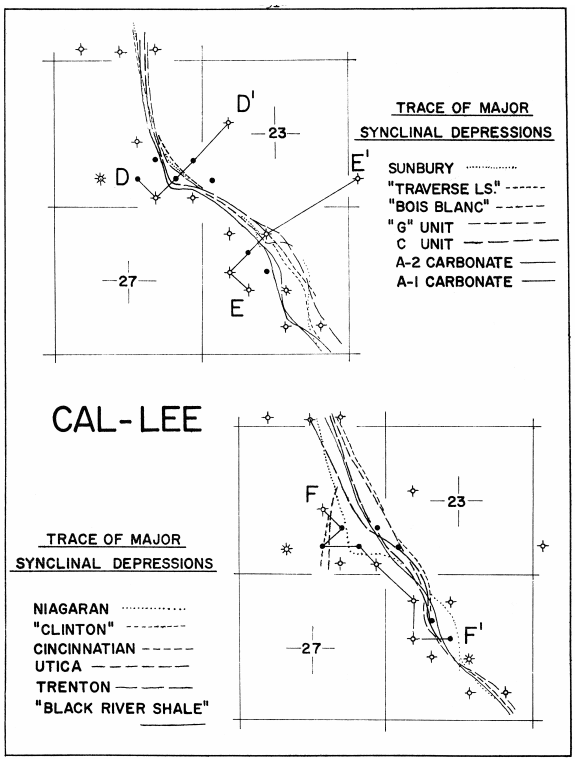
[11. Structure: C Unit; Thickness: A-2 carbonate to "Clinton"]



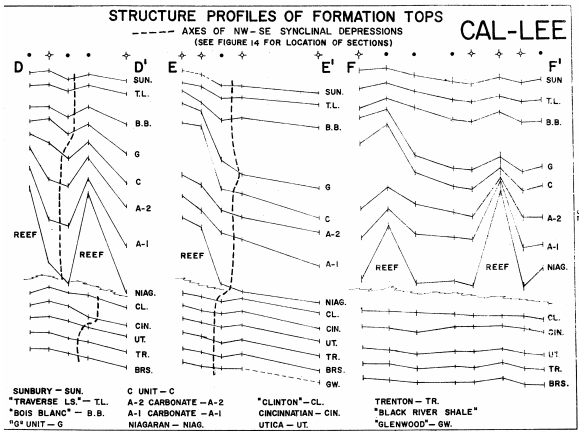
[12. Structure: “G” Unit and “Bois Blanc”]



[13. Structure: “Traverse Limestone” and Sunbury shale]



[14. Trace of major synclinal depressions]



[15. Structure profiles of formation tops]

ALBION FIELD

The Albion field, discovered in 1958, was the second field found on what is now known as the Trend. After this discovery, extensions were made to the north and to the south in fairly rapid succession.

Type log:

Schlumberger Well Surveying Corporation

Gamma Ray - Neutron - Lateralog

State well permit number 21356

Humble Oil and Refining Company - Farley Rosenau No. 1

NW SW NW section 23, T.3S., R.4W., Albion Twp., Calhoun County

Depths measured from K. B. at 1021 feet above sea level

NWD means there is not always a consistent or distinctive gamma ray curve definitive of the formation top or base, or correlation point. For correlation points not well defined on the log, well cuttings must be used in conjunction with the log.

Standard formation tops or correlation points used for mapping various rock units and intervals in the Albion field.

	Depths in feet to Top	and Base
PLEISTOCENE:		
Base of glacial drift		73
MISSISSIPPIAN:		
Marshall formation	73	300
Coldwater formation	300	1304
Sunbury formation	1304	1322
Berea-Bedford formations	1322	1360
MISSISSIPPIAN - DEVONIAN:		
Antrim formation	1360	1577
DEVONIAN:		
"Traverse formation"	1577	1617
"Traverse limestone"	1617	1809
Dundee formation	1809	1845
Detroit River group (including Sylvania ss. at base)	1845	2173
"Bois Blanc" formation	2173	NWD
SILURIAN:		
Bass Island dolomite (H unit)	NWD	NWD
"G" unit (includes part of the F unit)	2327	2390
F unit (salt beds not present)	2390	2437
E unit	2437	2537
D unit (not present)		
C unit	2537	2600
B unit	2600	
"A-2 carbonate" (mapping point at 2632 within the B unit)		2730 (?)
A-2 evaporite (not present)		
A-1 carbonate (may not be present)	NWD	NWD
A-1 evaporite (not present)		
Niagaran (?)	2730	3174

	Depths in feet to Top	and Base
SILURIAN (continued):		
"Clinton" (top of Cataract group)	3174	
Cabot Head shale (upper formation of Cataract group)	3174	3240 ?
Manitoulin dolomite (lower formation of Cataract group)	3240 ?	3289
ORDOVICIAN:		
Cincinnatian	3289	3623
Utica shale	3623	3922
Trenton formation	3922	4228
Black River formation	4228	4505
"Black River shale" (within the Black River formation)	4274	
"Glenwood shale"	4505	
Prairie du Chien group		

Total depth of log - 4513 in the St. Peter - Prairie du Chien

ORDOVICIAN SYSTEM

Lower Ordovician

Prairie du Chien group. The oldest rocks that have been penetrated in the Albion field are those of the Prairie du Chien group. An angular unconformity occurs at the top of this group. The Shakopee and New Richmond formations are believed to be absent in this region, thus the rock encountered beneath the “Glenwood-St. Peter" interval is commonly identified as Oneota formation. Tests penetrating Oneota formation are scattered and most are on the edges of the field. The wells are not numerous enough to afford information on the structure of the Oneota.

Middle Ordovician

"Glenwood-St. Peter." An interval of sandy shale and dolomite similar to- that of the Cal-Lee field also occurs throughout the Albion area. The sequence is often called "Glenwood shale,” St. Peter sandstone, for basal Black River. Tests penetrating these rocks are not numerous enough to warrant mapping.

"Black River shale." Wells penetrating this marker interval are more numerous but not sufficiently close together to warrant mapping, however, some indication of structure similar to the Trenton is apparent.

Trenton formation. (Fig. 16) Structure contours indicate the presence of a synclinal depression, off-set at several points, but running the length of the mapped area. Several depressions of lesser magnitude occur on the edge of the field but connect with the central depression. Narrow, low relief anticlinal folds flank the edges of the field, and several small anticlinal features are associated with the central part.

Upper Ordovician

Utica shale. (Fig. 17.) The structural features of the Utica shale are similar to those of the Trenton formation about 290 feet below the top of this unit.

Thickness: Utica shale. (Fig. 18) The Utica shale is decidedly thicker within the central synclinal depression and is thinnest over the anticlinal features.

Cincinnatian. (Fig. 19) Structure on the top of the Cincinnatian series conforms to that of the Utica shale which lies about 304 feet below the top of the Cincinnatian. The thickness interval from the top of the Utica to the top of the Cincinnatian increases slightly from the south end of the field to the north end. There appears to be no consistent pattern of increased thickness interval within the synclinal depression except at the northern end. Here the thickness is slightly greater within the central depression.

SILURIAN SYSTEM

Lower Silurian

Cataract group ("Clinton"). (Fig. 20) Structure on the top of the "Clinton" (the top of the Cabot Head shale of the Cataract group of Early Silurian age) clearly conforms to the structure of the Late Ordovician Cincinnatian series. The thickness interval from the top of the "Clinton" to the top of the Cincinnatian includes the Cabot Head shale and the underlying Manitoulin dolomite. The combined thickness interval ranges from 115 feet to as much as 136 feet, but averages about 124 feet throughout the field. No pattern of thickness variation is apparent.

Contact of Niagaran rocks with the lower units of the Salina. The lowermost units of the Salina (the A-1 evaporite, the A-1 carbonate, and the A-2 evaporite) are not present everywhere in the Albion field because of deposit ional pinch-out. The units begin to appear a few miles north of the Albion field, and in the region of the Cal-Lee field they are easily recognized. Figure 6 illustrates the thinning and pinch-out of the lower units of the Salina against the reef front. The basal part of the A-2 carbonate, which normally is somewhat darker in color and possesses some shale characteristics, appears to have been overlapped by the upper phase of the A-2 carbonate. The part of the A-2 carbonate which is present in the Albion field is similar lithologically to the uppermost part of the Niagaran. Because the basal beds of the A-2 carbonate do not appear to be present in every well, it is difficult to determine the contact between the Niagaran and the base of the A-2 carbonate in well cuttings as well as from radioactivity logs. For this reason, the top of the Niagaran has not been determined for the Albion field. As in the Cal-Lee field, the Niagaran section varies in thickness, and much of the thickness variation is probably caused by reefing in the upper part. Indication of the variable thickness of the Niagaran can be determined by mapping the interval from the top of the so-called "A-2 carbonate," to the top of the "Clinton."

"A-2 carbonate" in the Albion field. The top of the "A-2 carbonate" (often called A-2 dolomite) as generally identified and mapped for the Albion field does not appear to correspond stratigraphically with the top of the A-2 carbonate as determined for the Cal-Lee field and other regions where the overlying B unit evaporite is well developed.

The top of the "A-2 carbonate" in the Albion field, and elsewhere in those areas where the salt and anhydrite beds of the B unit are absent, is apparently within the thin carbonate and shale beds of the B unit. The top of this unit is actually "called" at the base of one of the thicker and more persistent shaly dolomite beds in the upper part of the B evaporite unit. Thus the "A-2" as determined for the Albion field, and for a large part of the Michigan basin margin, actually includes part of the B unit. The "A-2 carbonate" top as mapped for the Albion field is considered by the writer to be within the B unit and is bracketed with quote marks to distinguish it from the A-2 carbonate as defined for the Cal-Lee field. The "A-2 carbonate" is represented by a distinctive, easily recognized curve on practically all radioactivity logs. The base of the curve is an excellent mapping point over very large areas of southern Michigan.

Structures "A-2 carbonate." (Fig. 21) The structure on the top of the "A-2 carbonate" is very similar to that of the "Clinton" rocks several hundred feet below the top of the "A-2" except that the amount of relief is considerably greater. The several long, narrow anticlinal structures are nearly coincident with similar features of the "Clinton." The sharpness and greater relief are attributed principally to reefing in the upper part of the Niagaran. Structure in the "A-2" is a reflection of reef, and probably differential compaction, depositional thinning, and post-"A-2" deformation around the more ridged reef mass.

Thickness: Top of "A-2 carbonate" to top of "Clinton." (Fig. 22) This interval includes in ascending orders all the rocks of the Niagaran series; the A-2 carbonate; and the rocks of the B unit up to the base of the "A-2 carbonate" mapping point. The thinner interval of rocks is nearly coincident with the central synclinal depression of the "Clinton." The thicker intervals are attributed to reef development in the upper part of the Niagara. The reefs may have begun their growth on the anticlinal folds which had been formed in the lower Niagaran rocks prior to reef development.

C unit. (Fig. 23) The structural features of this unit are similar to the structure of the "A-2 carbonate."

B unit. Not mapped other than for the thin interval included within the "A-2 carbonate."

D unit. Not present in the Albion field and vicinity.

E and F units. Not mapped. Except for the salt and anhydrite beds, rocks representing these units are present in the Albion field and vicinity. The combined thickness of these units is 147 feet in the type log for the Albion field.

"G" unit. (Fig. 24) As was pointed out for the "G" unit in the Cal-Lee field, the "G" unit as herein mapped includes part of the F unit shales which, as defined for purposes of this report, make a mappable unit. The structural features of this unit are similar to those of the C unit which lies about 235 feet below the top of the "G" unit. The thickness of this unit ranges from about 60 feet at the south end of the field to about 70 feet at the north end. A few wells, however, have as much as 80 feet to as little as 33 feet of "G" unit. The anomalous intervals are not concentrated in any particular pattern but are scattered at random along the length and width of the field.

DEVONIAN SYSTEM

"Bois Blanc." (Fig. 25) The structure on the erosional surface of the Bois Blanc formation is similar to that of the Silurian “G” unit.

Thickness: Top of the "Bois Blanc" to top of “G” unit. (Fig. 26) The thickness interval includes rocks of Silurian and Devonian age. No attempt has been made to differentiate the Bois Blanc rocks from those of the Silurian Bass Islands dolomite. Both formations appear to vary in thickness. In general, the combined thickness is greatest in the central synclinal depression and several of the minor synclines. The thinnest intervals are coincident with the anticlinal features of the "Bois Blanc” surface and the Salina “G” unit.

Erosional unconformities are present at the top of the Bass Islands dolomite and at the top of the Bois Blanc formation. From the structure and thickness data at least one period of post-Bois Blanc deformation is evident.

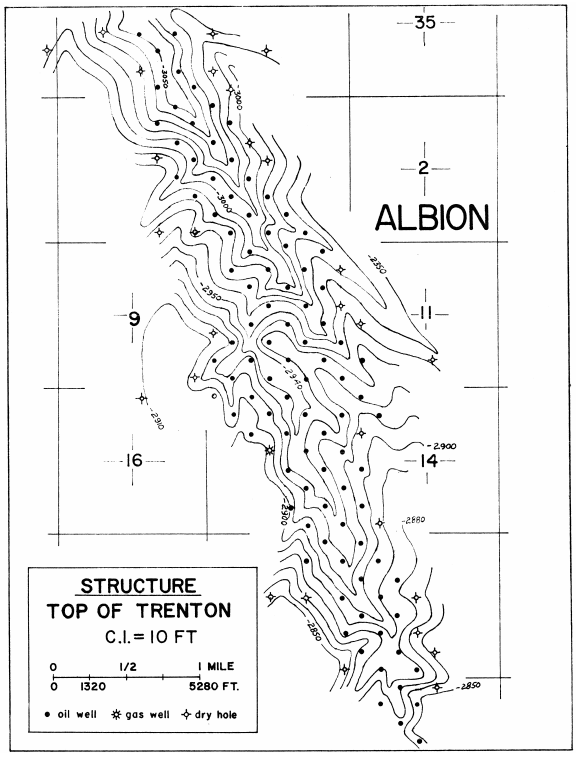
"Traverse limestone." (Fig. 27) The "Traverse limestone" is a thick carbonate section within the Traverse group of the southern and western parts of Michigan. Structure contours on the surface of this section of rock indicate structural features similar to those of the "Bois Blanc" formation. The "Bois Blanc” lies about 550 feet below the top of the "Traverse limestone" at the south end of the field, and about 620 feet below the top at the north end of the field.

Thickness: Top of "Traverse limestone" to top of "Bois Blanc." (Fig. 28) This thickness interval includes in ascending order: The Sylvania sandstone; the carbonate and anhydrite rocks of the Detroit River group; the Dundee limestone; and the carbonates and thin shales of the Traverse group up to the top of the "Traverse limestone.” The interval is thickest within the central synclinal depression and several of the minor synclines, and is thinnest over the anticlinal features. A regional increase from south to north is also evident. At the south end of the field the interval is about 550 feet at the north end of the field the interval is about 620 feet. In the Cal-Lee field, at the north end of the Trend, the corresponding interval is about 610 feet for the south end of the field and about 650 feet for the north end. As in the Cal-Lee field, part of the increase in thickness occurs within each of the rock divisions from the "Bois Blanc" formation up to the top of the "Traverse limestone."

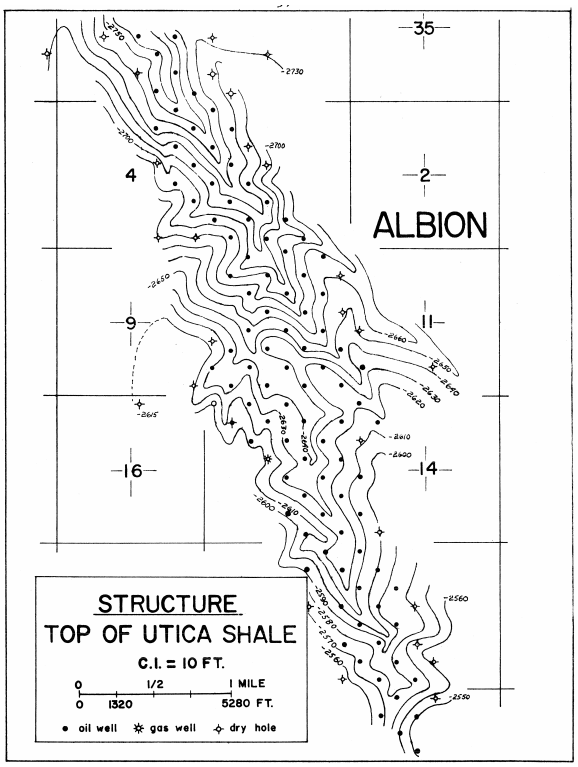
MISSISSIPPIAN SYSTEM

Sunbury shale. (Fig. 29) The Sunbury is the youngest Mississippian formation mapped in the Albion field. The Sunbury lies about 300 to 320 feet above the top of the "Traverse limestone." Structure contours on the top of this formation indicate structural features similar to those of the "Traverse limestone."

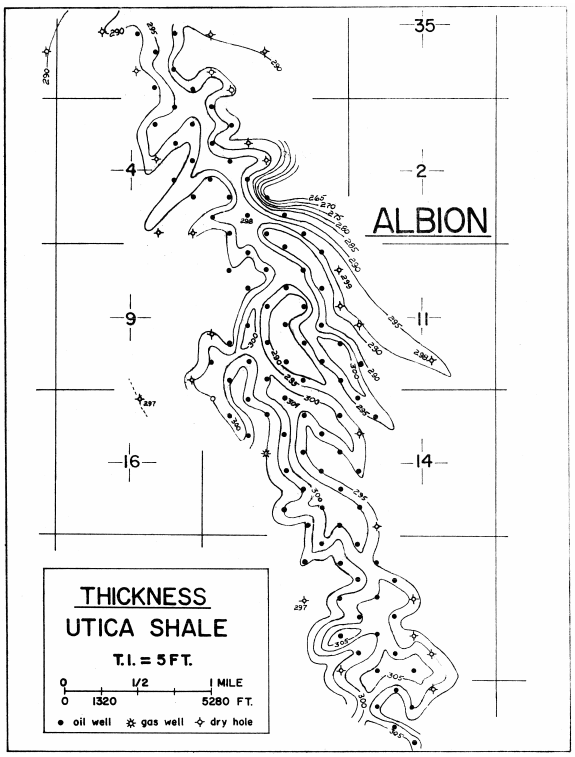
The interval from the top of the "Traverse limestone" to the top of the Sunbury includes, in ascending order, rocks of: the "Traverse formation," consisting of calcareous shale and thin limestones; the Antrim shale; the Bedford-Berea formations; and the Sunbury shale. The thickness interval increases from the south end of the field to the north end, and is thickest in the central synclinal depression at the north end of the field.



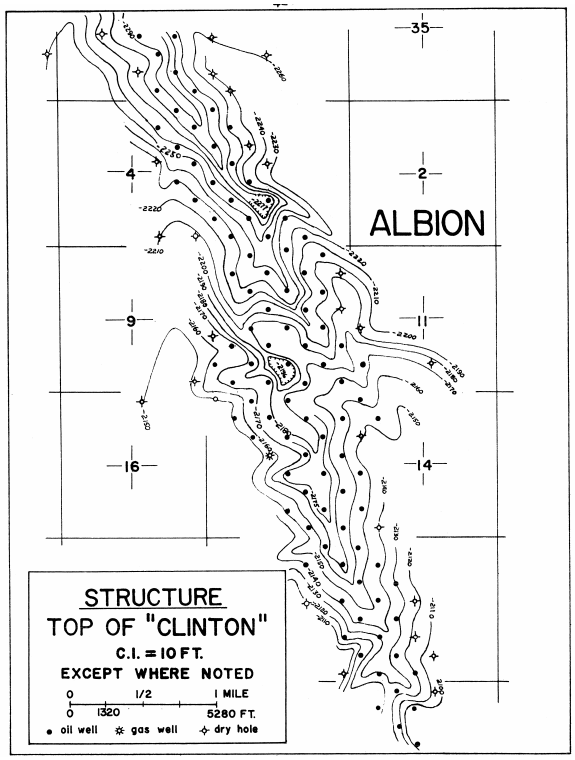
[16. Structure: Trenton]



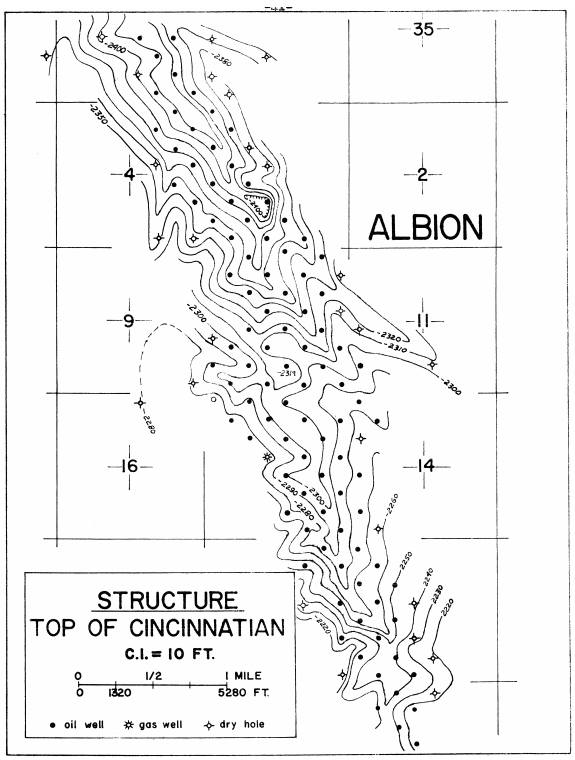
[17. Structure: Utica shale]



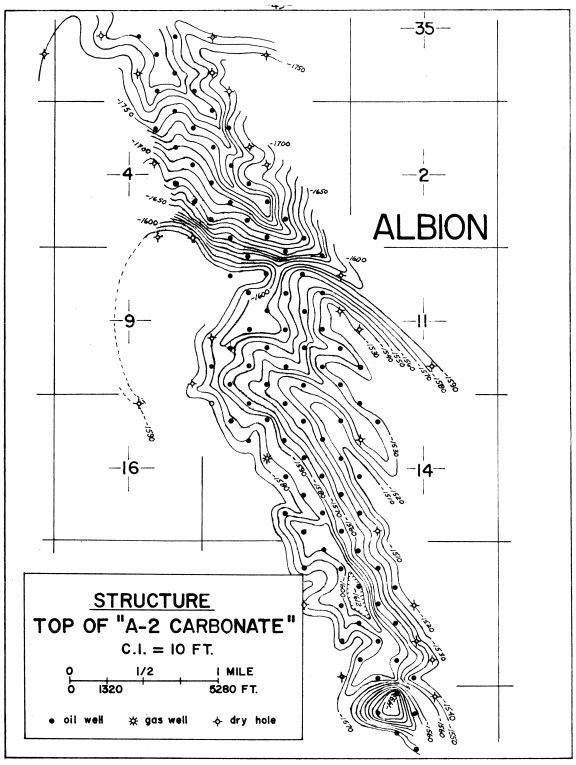
[18. Structure: Utica shale]



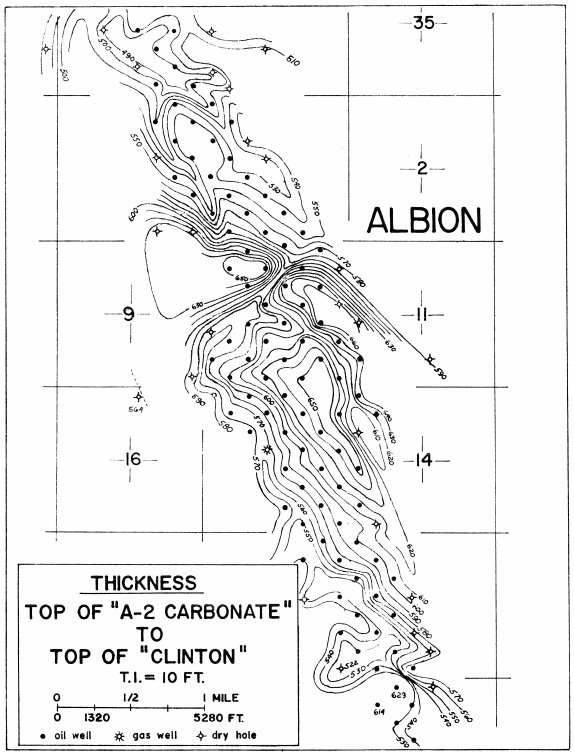
[20. Structure: "Clinton"]



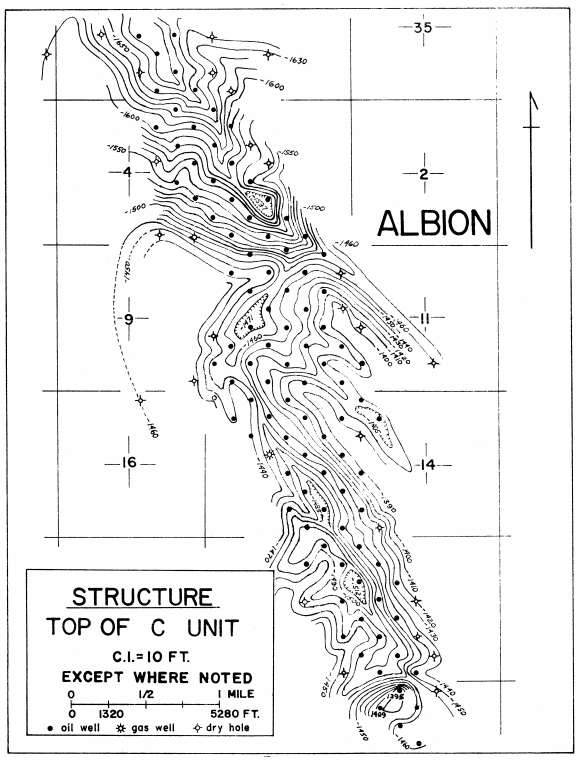
[19. Structure: Cincinnatian]



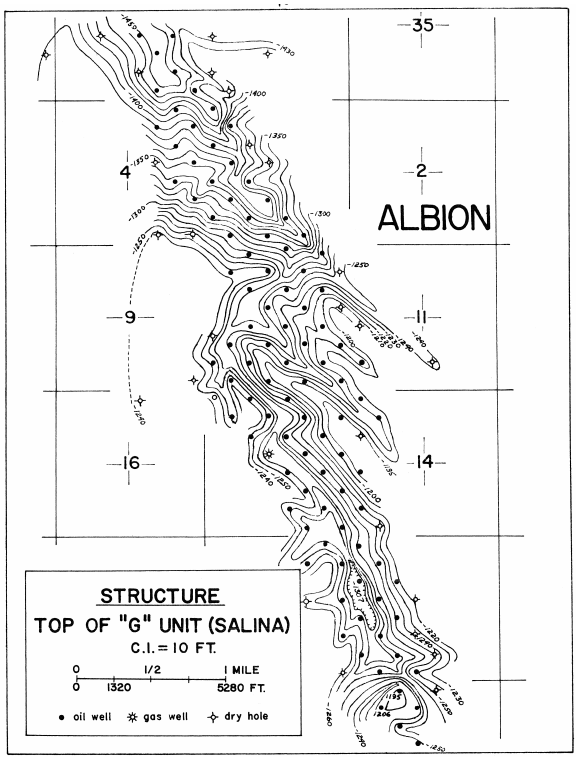
[21. Structure: "A-2 carbonate"]



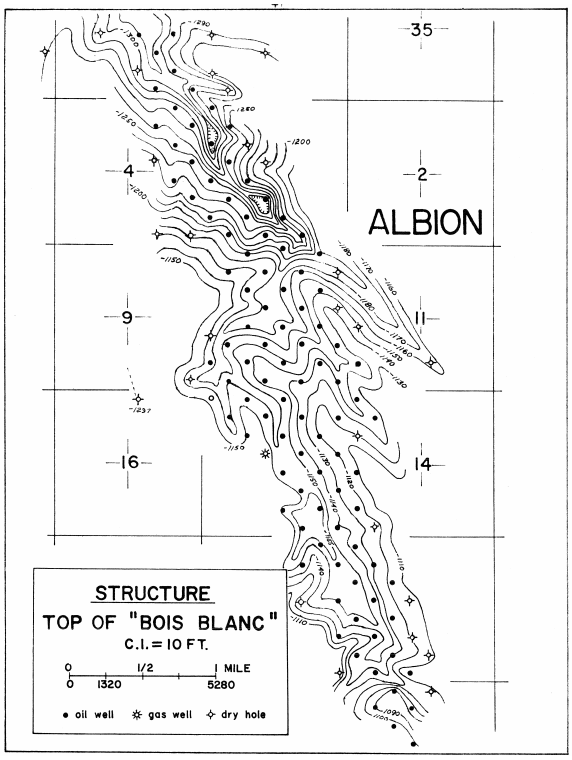
[22. Thickness: “A-2 carbonate” to “Clinton”]



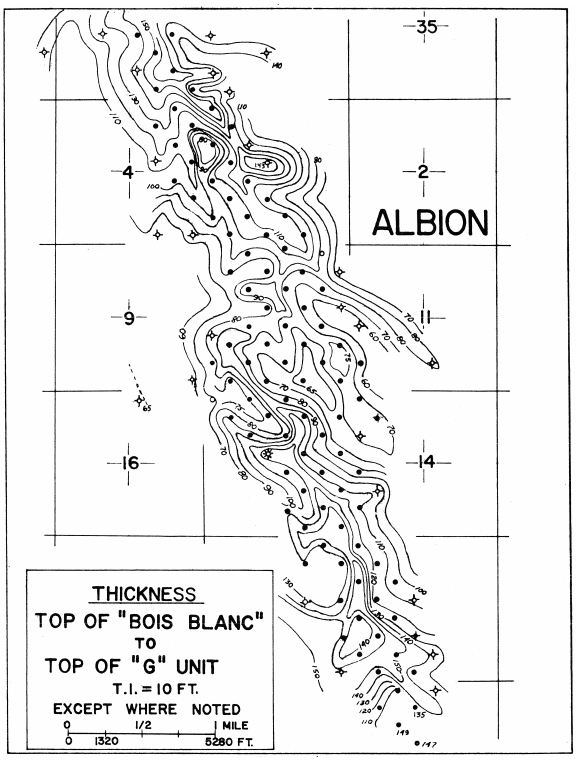
[23. Structure: C Unit]



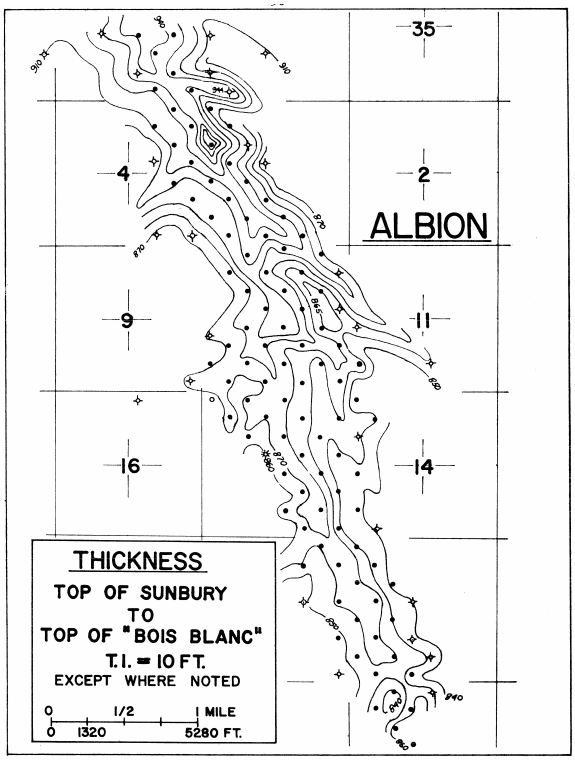
[24. Structure: “G” Unit]



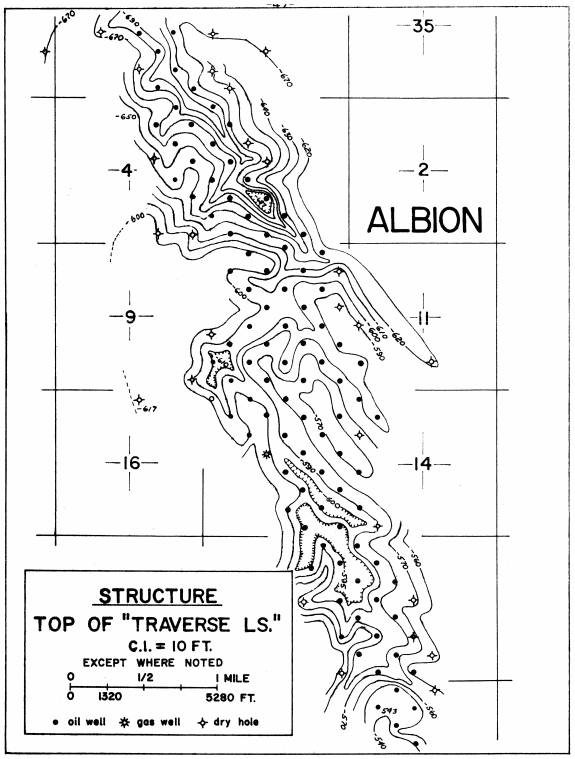
[25. Structure: “Bois Blanc”]



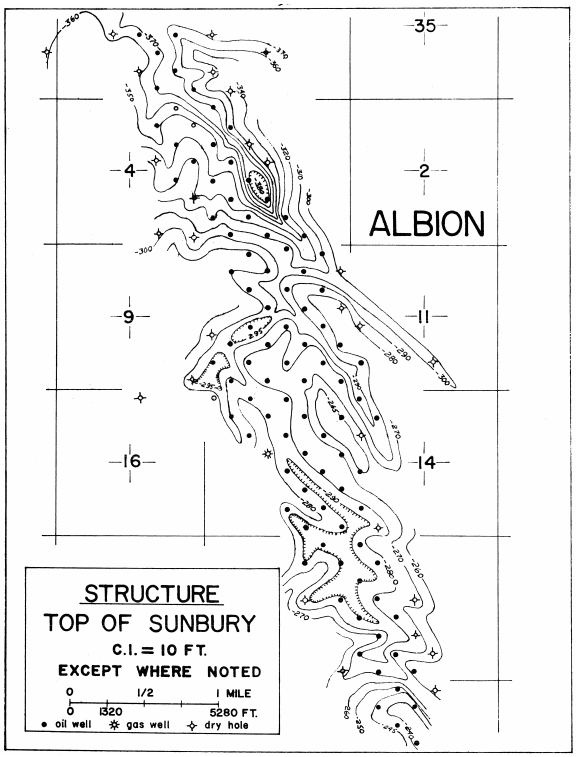
[26. Thickness: "Bois Blanc" to "G" Unit]



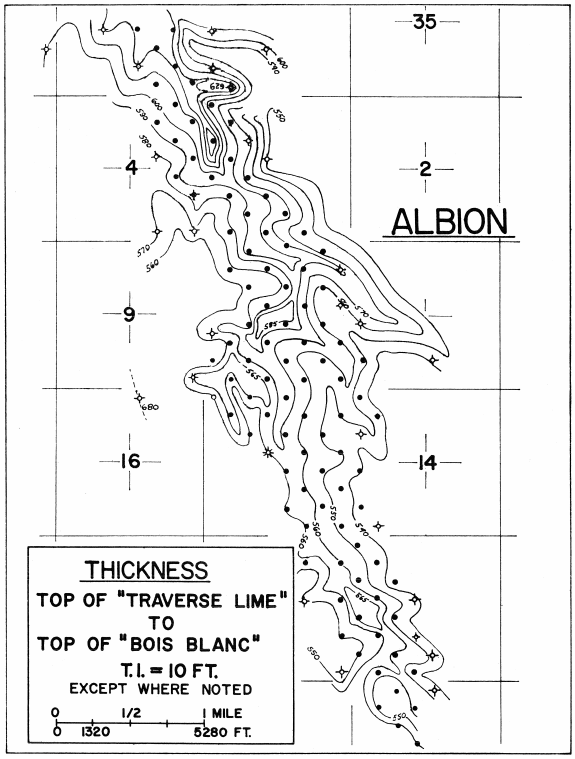
[28. Thickness: "Traverse limestone" to "Bois Blanc"]



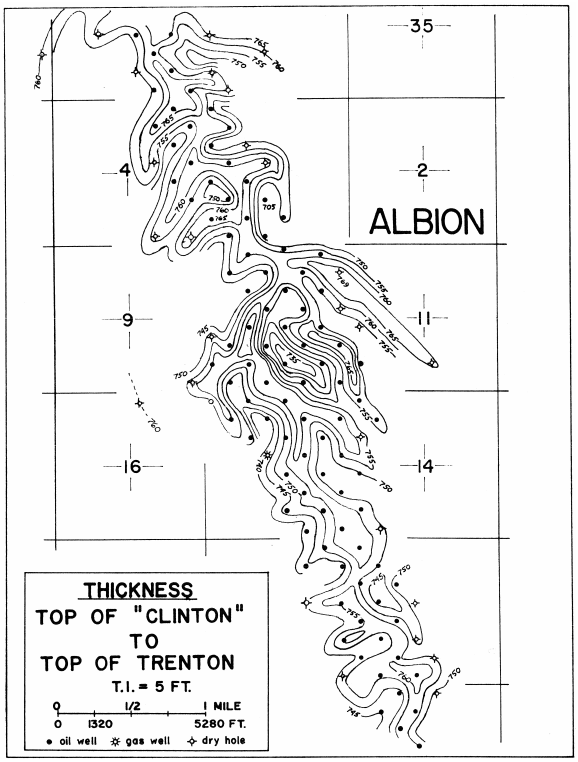
[27. Structure: "Traverse limestone"]



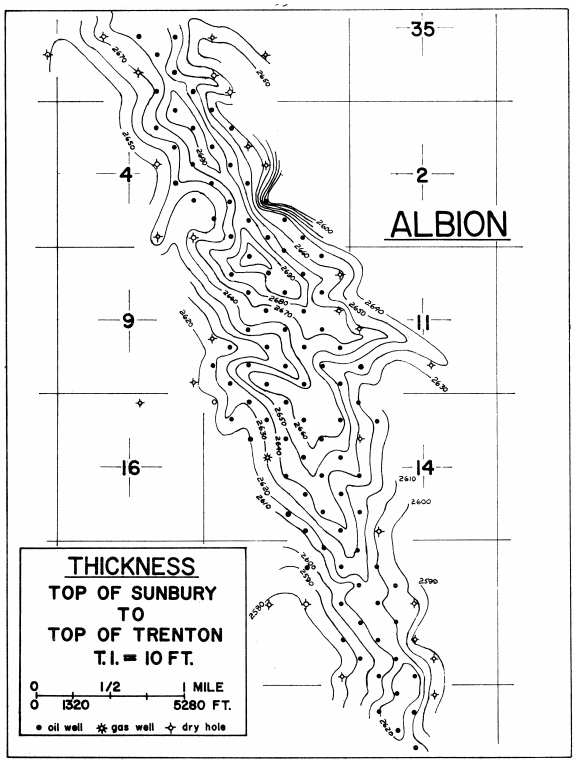
[29. Structure: Sunbury shale]



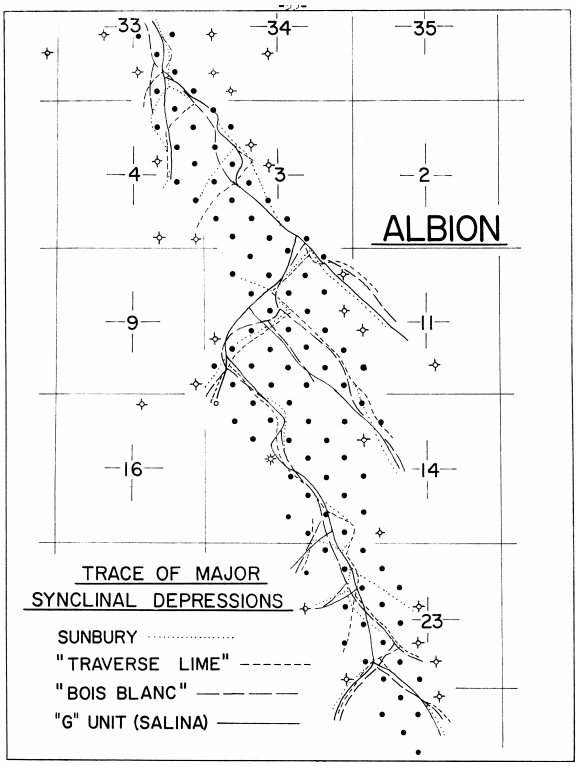
[30. Thickness: Sunbury to “Bois Blanc”]



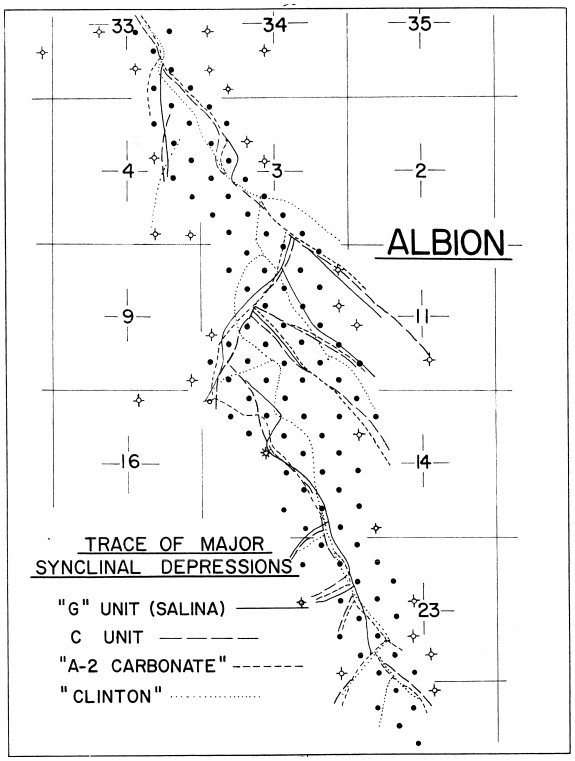
[32. Thickness: “Clinton” to Trenton]



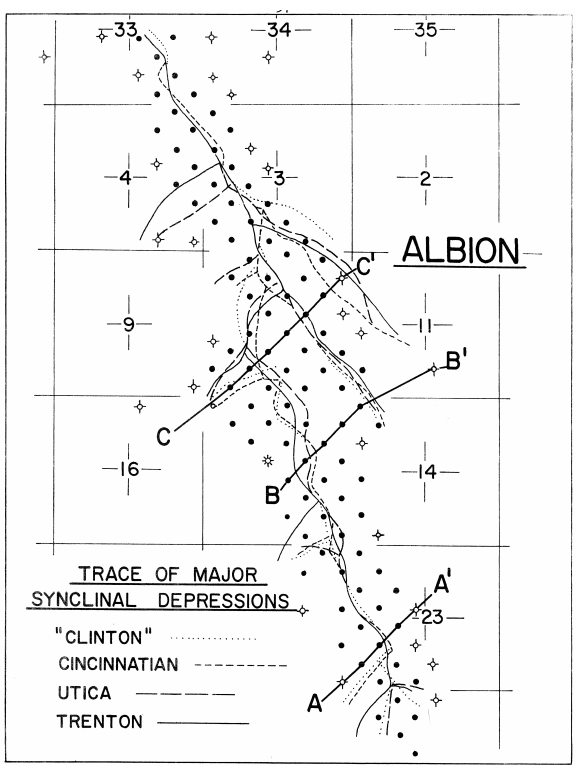
[31. Thickness: Sunbury to Trenton]



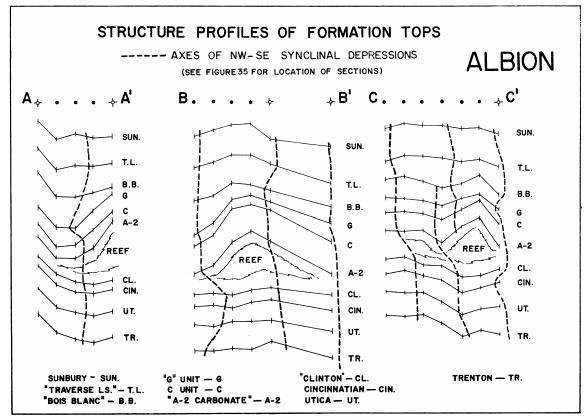
[33. Trace of major synclinal depressions]



[34. Trace of major synclinal depressions]



[35. Trace of major synclinal depressions]



[36. Structure profiles of formation tops]

Thickness: Top of Sunbury to top of "Bois Blanc." (Fig. 30) The thickness of rock from the top of the Mississippian Sunbury shale to the top of lower Middle Devonian “Bois Blanc" formation is consistently greater within the central synclinal depression, and is thinnest over the anticlinal features. Regional increase in thickness from south to north is evident.

Thickness: Top of Sunbury to top of Trenton. (Fig. 31.) This illustration shows the combined effects of Niagaran reefing, greater thickness coincident with the synclines, and thinner intervals over the reefs and folds.

Synclinal depressions. (Figures 33, 34, 35) These illustrations indicate the near coincidence of the central synclinal depression and the more prominent depressions that connect with it, through several geologic periods.

Structure profiles of formation tops. (Fig. 36) Structure profile sections at several points along the Albion field show the general structural relationship of the various rock units. The influence of Middle Silurian Niagaran reefs on the structure and thickness of rock units overlying the Niagaran is clearly evident.

PULASKI FIELD

Type log:

Schlumberger Well surveying Corporation

Simultaneous Gamma Ray - Neutron log

State well permit number 21985

Smith Petroleum Company - M. Zaremba No. 1

SE SE NE section 28, T.4S., R.3W., Pulaski Twp., Jackson County

Depths measured from K. B. at 1091 feet above sea level

NWD means there is not always a consistent or distinctive gamma ray curve definitive of the formation top or base, or correlation point. For correlation points not well defined on the log, well cuttings must be used in conjunction with the log.

Standard formation tops or correlation points defined for mapping various rock units and intervals in the Pulaski field.

	Depths in feet to Top	and Base
PLEISTOCENE:		
Base of glacial drift		105
MISSISSIPPIAN:		
Marshall formation	105	225
Coldwater formation	225	1211
Sunbury formation	1211	1226
Berea-Bedford formations	1226	1261
MISSISSIPPIAN - DEVONIAN:		
Antrim formation	1261	1466
DEVONIAN:		
"Traverse formation"	1466	1498

	Depths in feet to Top	and Base
DEVONIAN (continued):		
"Traverse limestone"	1498	NWD
Dundee formation	NWD	NWD
Detroit River group (including Sylvania ss. at base)	NWD	NWD
"Bois Blanc" formation	1990	NWD
SILURIAN:		
Bass Island dolomite (H unit)	NWD	NWD
"G" unit (Salina) - (includes part of the F unit)	2008	2067
F unit (salt beds not present)	2067	2111
E unit	2111	2202
D unit (not present)		
C unit	2202	2286
B unit (salt beds and major anhydrite beds not present)	2286	2333
"A-2 carbonate" (mapping point at 2321 within the B unit)	2321	NWD
A-2 evaporite (not present)		
A-1 carbonate (may not be present)		
A-1 evaporite (not present)		
Niagaran (?)	2380	2942
"Clinton" (top of Cataract group)	2942	
Cabot Head shale (upper formation of Cataract group)	2942	2995
Manitoulin dolomite (lower formation of Cataract group)	2995	3061
ORDOVICIAN:		
Cincinnatian	3061	3408
Utica shale	3408	3721
Trenton formation	3721	4051
Black River formation	4051	4330
"Black River shale" (within the Black River formation)	4081	
"Glenwood shale"	4330	4337
Prairie du Chien group	4337	

Total depth of log - 4354 in the Prairie du Chien

Most of the wells drilled in this part of the Trend (sometimes called South Pulaski) are completed in the Trenton Formation. The oldest rocks that have been penetrated in this part of the Trend are those of the Lower Ordovician Prairie du Chien group. These tests are scattered principally along the edges of the field, but are not sufficiently numerous to afford information as to the structure on the surface of the Prairie du Chien rocks. Similarly, tests penetrating through the "Black River shale" are not numerous enough to indicate the structure of the Black River rocks. Information from wells north of the mapped area suggest that the structure of the Black River rocks is similar to that of the Trenton Formation.

ORDOVICIAN SYSTEM

Trenton formation. (Fig. 37) Structure contours on the top of the Trenton indicate a central syncline similar to that of the Trenton in the Albion and Cal-Lee fields. Several anticlinal folds are on the northeastern edge of the central depression.

Utica shale. (Fig. 37) Structure on the top of the Utica shale conforms to that of the Trenton. The thickness of the Utica ranges from 308 to 342 feet, and averages about 320 feet. It tends to be thicker within the central depression and thinnest over the anticlinal features. No regional increase in thickness from south to north is apparent.

Cincinnatian. (Fig. 38) Structure on the top of the Cincinnatian conforms to that of the Utica shale. The thickness interval from the top of the Cincinnatian to the top of the Utica ranges from 321 to 354 feet, and averages about 345 feet. This interval of rock also tends to be thickest within the central depression, especially in the southern half of the mapped area. No regional increase in thickness from south to north is apparent.

SILURIAN SYSTEM

"Clinton." (Fig. 38) The structure on the top of the "Clinton" (top of the Cabot Head shale of the Cataract Group) conforms to that of the Cincinnatian. The thickness interval from the top of the "Clinton" to the top of the Cincinnatian ranges from as little as 113 feet at the south end of the mapped area to as much as 131 feet at the north end. The average thickness is about 122 feet. The interval increases about 10 feet from south to north and tends to be thicker within the central depression.

Contact of the top of the Niagaran with lower units of the Salina. Of the four lowermost divisions of the Salina Formation (the A-1 evaporite, A-1 carbonate, A-2 evaporite, and the A-2 carbonate) only the A-2 carbonate appears to extend southward into the Pulaski field. Here the A-2 carbonate is about 40 feet thick as compared to about 90 and 155 feet respectively in the Albion and Cal-Lee fields. The A-2 carbonate is in direct contact with the top part of the Niagaran. Because there are no evaporites and part of the A-2 is lithologically similar to the upper part of the Niagaran, it is not always possible to identify the contact between the Niagaran and Salina rocks on all Gamma Ray - Neutron logs in the Pulaski field.

"A-2 carbonate." In the Pulaski field the top of the "A-2 carbonate" corresponds to the "A-2 carbonate" as it is

generally called in the Albion fields but not to the top of the A-2 carbonate as it is identified in the Cal-Lee field and in those regions where the evaporites of the B unit are well developed. Because the top of the Niagaran cannot be consistently identified from gamma ray - neutron logs in this part of the Trend, the variable thickness of the Niagaran is demonstrated by mapping the structure of the "A-2 carbonate" and the thickness interval from this point down to the "Clinton."

Structure: "A-2 carbonate." (Fig. 39) The structure on the top of this unit is similar to that of the "Clinton." However, part of the structure of the "A-2 carbonate" is a reflection of probable small bioherm development in the upper part of the Niagaran. In this respect, the association of the "A-2 carbonate" structure with Niagaran reefs is similar to that of the equivalent section in the Albion field and elsewhere along the Trend. Reefs in the Pulaski region have considerably less relief than those farther out in the basin.

Thickness: Top of "A-2 carbonate" to top of "Clinton." (Fig. 39) This interval includes in ascending order all the rocks of the Niagaran, the A-2 carbonate, and the thin interval of B unit rocks up to the base of the mapping point referred to as "A-2 carbonate." In the Pulaski field, as in the Albion and Cal-Lee fields, the thickest interval is closely associated with the low relief anticlinal features of the "Clinton." The thicker section of rock is attributed to bioherm development in the upper part of the Niagaran. Bioherm development may have begun after the formation of anticlinal folds in the lower part of the Niagaran. The thinner intervals of rock are coincident with the central synclinal depression. A regional increase in interval from south to north is evident.

C unit. (Fig. 40) The structure of the C unit conforms to that of the "A-2 carbonate." There is a small amount of thickness variation in this unite but no definite pattern of variation is apparent.

D unit. Not present in this area of the basin.

E unit. Not mapped.

F unit. Not mapped.

"G" unit (Salina). (Fig. 40) This interval of rock corresponds to the "G" unit in the Albion and Cal-Lee fields. The structure of the unit conforms to that of the G unit. There is a small amount of thickness variation, but no particular pattern of variation is apparent.

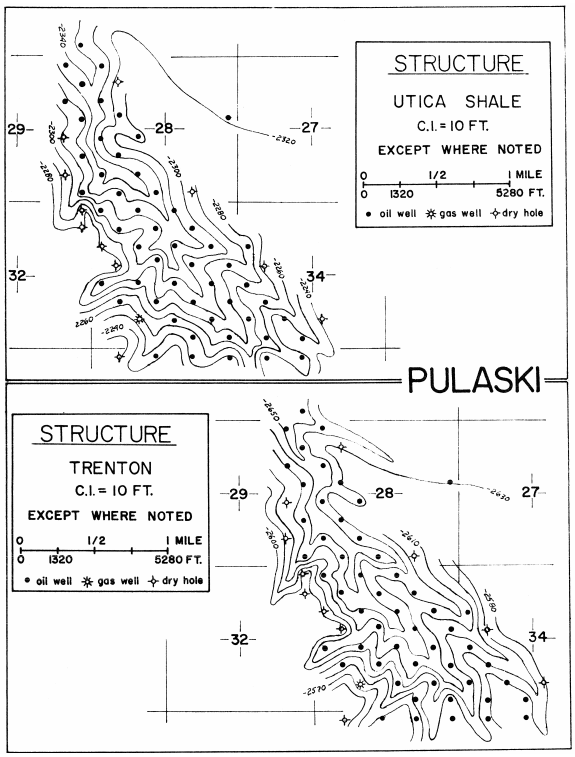
DEVONIAN SYSTEM

"Bois Blanc." Not illustrated. The thin section of rock referred to as "Bois Blanc," "black lime," or "the unconformity" is present in the Pulaski field. It correlates with the "Bois Blanc" of the Albion and Cal-Lee fields o The thickness interval from, the top of this marker down to the top of the Salina "G" unit ranges from 0 to as much as 40 feet. Some Bass Islands dolomite may be present in the thicker sections. As in the Albion and Cal-Lee fields, a thicker section of rock is present within the central synclinal depression, especially at the northern end of the mapped area. The thinner intervals are associated with the anticlinal features. Structure contours on the top of the "Bois Blanc" disclose structural features similar to those of the Salina "G" unit.

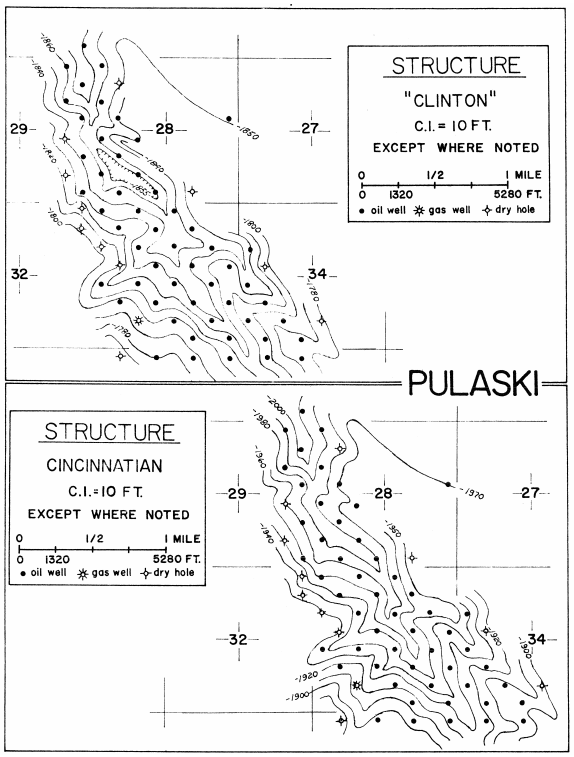
"Traverse limestone." (Fig. 41) Structure contours on the top of the "Traverse limestone" indicate structural features similar to those on the top of the "Bois Blanc" erosional surface. The interval from the top of the "Traverse limestone" to the top of the "Bois Blanc" includes in ascending order, the rocks of the Detroit River group including the Sylvania sandstone at the bases the Dundee formation, and all the rocks of the Traverse group up to the top of the "Traverse limestone." The combined thickness of these rocks in the Pulaski field is about 500 feet.

MISSISSIPPIAN SYSTEM

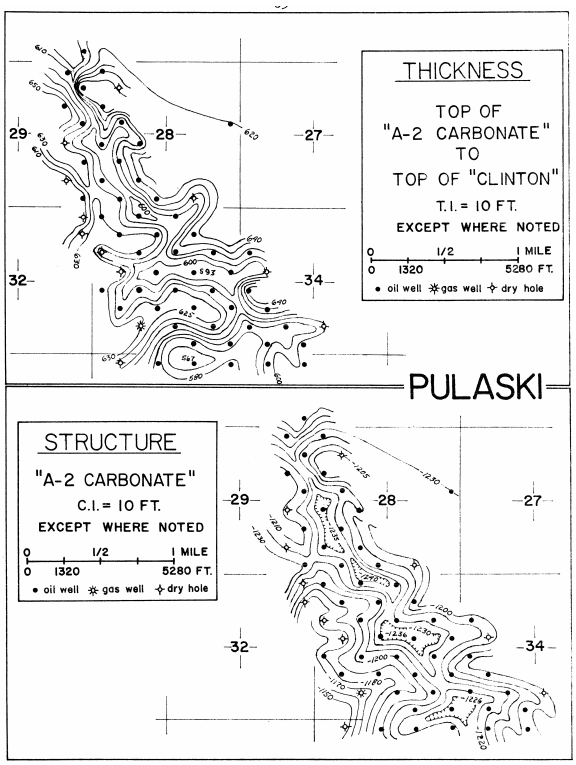
Sunbury shale. (Fig. 41) The Sunbury is the youngest Mississippian formation 'mapped in the Pulaski field. The structural features of this formation are similar to those of the "Traverse limestone." The interval from the top of the Sunbury down to the top of the "Traverse limestone" includes in ascending order the shales and thin limestones of the "Traverse formation," the Antrim shale, the Bedford-Berea formations, and the Sunbury shale. The combined thickness of these rocks is about 280 feet and is nearly constant throughout the mapped area.



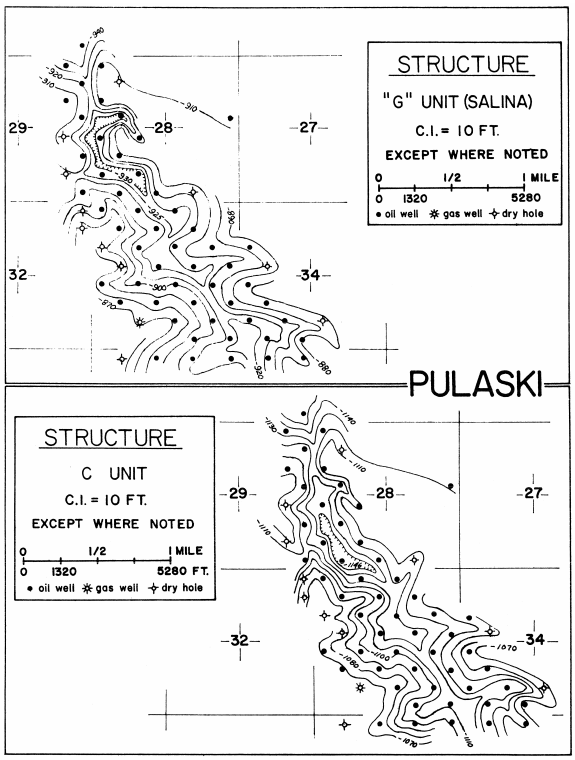
[37. Structure: Trenton and Utica shale]



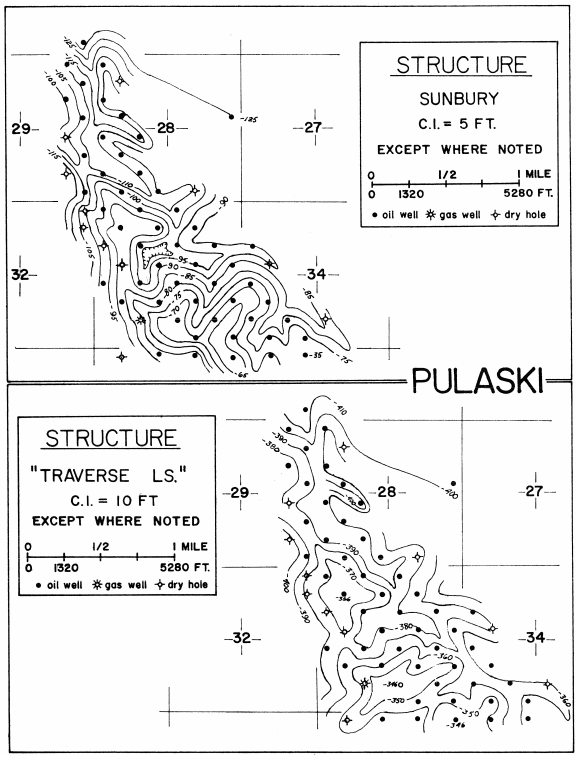
[38. Structure: Cincinnatian and "Clinton"]



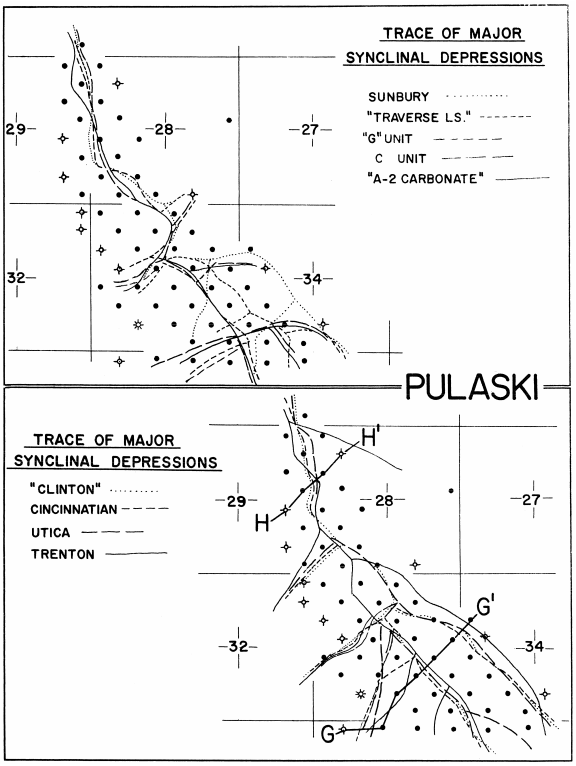
[39. Structure: "A-2 carbonate"; Thickness: "A-2" to "Clinton"]



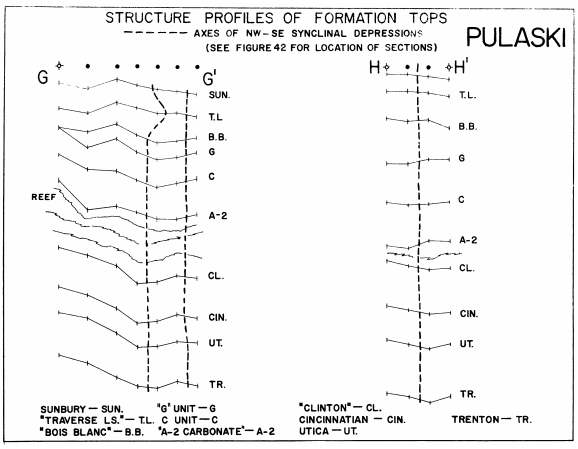
[40. Structure: C Unit and "G" Unit]



[41. Structure: "Traverse limestone" and Sunbury shale]



[42. Trace of major synclinal depressions]



[43. Structure profiles of formation tops]

DEVELOPMENT OF STRUCTURE ALONG THE TREND

Considerable information has been presented to illustrate the structural character and the structural relationships of selected formations in several areas along the Trend. The first published Trenton structure maps indicated the oil wells to be confined to a shallow syncline or depression plunging to the northwest; small anticlinal noses were associated with the syncline (Ives, 1958, pp. 216-17). Later, it was also pointed out that the Albion field discovery well was in direct line with the general lineation of the Scipio field about 12 miles to the south (Ives and Ells, 1959, p. 1206). Subsequent development has demonstrated the persistence of this structural pattern, wherever sufficient well control is available, everywhere along the Trend (Ells and Ives. 1959, pp. 137-39).

The development of structural features associated with the Trend may be explained, in part, by the sequence of events as concluded from structure and thickness data.

Ordovician System

Data for Ordovician formations suggest that deformation began after Trenton time and continued at a slow rate, or intermittently, throughout the Ordovician and into the Silurian.

"Glenwood shale" to top of Utica shale. After the deposition of the “St. Peter - Glenwood shale" sequence upon the eroded surface of Prairie du Chien rocks by a transgressing, early Black River seas the transitional beds were covered by the carbonate rocks of the Black River - Trenton formations. There appears to be no significant variation in thickness from the "Glenwood shale” to the "Black River shale,” and. from the "Black River shale" to the top of the Trenton formation. This indicates these strata were essentially flat-lying and uniform in thickness prior to deformation. Further evidence of post-Trenton deformation is indicated by similar structure and amplitude of folds on the "Glenwood shale," "Black River shale," and Trenton.

The contact between the Trenton and the Utica shale appears abrupt but otherwise conformable, with little or no evidence of erosional unconformity. The contact between the two formations has been cored in a few wells. Core descriptions indicate sealed fractures in Trenton rocks to extend to within a few inches of the base of the Utica shale but not into it. Most fractures are resealed with white crystalline dolomite or calcareous dolomite. In one case, a small fracture filled with crystalline anhydrite was encountered just below the Utica shale-Trenton contact. An individual well core may show horizontal, vertical, or inclined fractures, and sometimes brecciated intervals. Fractures range from "hairline" to fractions of an inch in width. The wider fractures have been filled with dolomite crystals which grew inward from opposite sides of the fissure and eventually sealed the opening. Some open fissures are noted in core descriptions. This may indicate a second period of fracturing which occurred sometime after the filling of the original fractures. Available core description data indicate no unusual deformation of strata which might suggest contemporaneous deposition and folding of Trenton-Black River rocks. Fracturing appears to have taken place after compaction and lithification.

The Utica shale is decidedly thicker within the synclines and is correspondingly thinner over the anticlines. The variation is not great if one considers the entire thickness of the shale unit. However, the distribution and pattern of thickness variation is significant because it coincides well with the deformational features of the underlying Trenton formation. Structure on the top of the shale conforms to that of the Trenton but the amount of relief is less. Slow deformation of the underlying Trenton-Black

River rocks during deposition of the Utica shale accounts for the thinner interval of strata over the anticlines and thicker section within the synclines. Thickness differences are attributed to differential compaction and perhaps to lesser deposition of sediments over the highs.

Utica shale to the top of the Cincinnatian series. The Ordovician rocks above the Utica shale are mainly dolomitic shales, thin dolomites, and argillaceous dolomites, with the proportion of carbonate beds increasing upward. Structure on the top of the Cincinnatian definitely reflects the structural features of the Utica shale. The thickness of rock from the top of the Utica to the top of the Cincinnatian is not consistent within the several areas studied. In the Cal-Lee field the interval is thinnest within the syncline and thickest near the flank, but a thinner interval also occurs at the crests of the folds. In the Albion and Pulaski areas, the thicker section is within the synclines, and the thinner intervals are associated with the folds. Deposition and slow deformation appears to have been contemporaneous during this Interval of Ordovician time. However, the amount of deformation and adjustment apparently was not uniform along the Trend.

Silurian System

Cataract group to the top of the Niagaran. Early Silurian rocks conformably overlie the Cincinnatian series. Structure on the top of the Cabot Head shale, the upper formation of the Cataract group, definitely reflects the important structural elements of the Cincinnatian surface. The combined thickness of the Cabot Head shale and the underlying Manitoulin dolomite is irregular In the Cal-Lee and Albion fields and no pattern of thickness distribution is apparent. In the Pulaski field the thickness interval increases northward along the Trend, and the thicker sections tend to be related to the synclines. The irregular thickness may be due, in part, to the development of small bioherms in the Manitoulin formation. Similarity of structure in Lower Silurian and Upper Ordovician rocks apparently is due to a continuation of deformation which began in Utica shale time.

Carbonate rocks of Middle Silurian age overly the Cabot Head shale. The carbonates of the Niagaran are mainly dolomites with associated biostrome and bioherm facies. Bioherms, or reefs, have been Identified in the upper part of the Niagaran, but they may occur at any interval within the sections Reef development in upper Niagaran rocks is evident throughout most of the Trend and some of the reefs, or reef-like masses, appear related to the deformational features. In the Cal-Lee field, for example, the thicker Niagaran section Is nearly coincident with the small folds and the thinner intervals are coincident with the syncline. It is presumed that reef growth began on the low relief folds which were slowly forming along the Trend, but the association of reefs with the folds is probably entirely a coincidence since reefs and reef-like masses are found throughout the Niagaran reef complex of this region. However, the orientation, shape, and size of the reefs may be directly related to the lineation and deformational pattern of the Trend.

Niagaran to the "Bois Blanc" Unconformity. Carbonates, dolomitic shales, and evaporite beds of Late Silurian age overlie Niagaran rocks. The structure in these formations is clearly a reflection of the underlying Niagaran surface. Uneven deposition of sediments, differential compaction of successive formations over and around reefs, together with intermittent movement or deformation along the Trend during Late Silurian time, accentuated and perpetuated the structural features.

Similar structure is repeated throughout the entire Salina sequence, and is also evident in the basal part of the Bass Islands dolomite. Most of the Bass Islands rocks have been removed by erosion and only a relatively thin section remains. Rocks of the Bois Blanc formation of Devonian age overlie the eroded Bass Islands. These rocks have also been eroded, and consequently only a thin section is generally found in most wells. A thicker section of Bass Islands rock Is found In the synclines, and a thinner section is associated with the folds or small anticlines. Structure on the surface of the "Bois Blanc" unconformity is remarkably similar to that of the Salina "G" unit; but the amount of relief from syncline to crest of folds is generally less than half the value found on the "G" unit surface. Preservation of thicker sections of Bass Islands rocks in the synclines, and similar structure on the eroded surface of the "Bois Blanc" formation suggests some degree of deformation or adjustment in Devonian time, and after the deposition and erosion of the "Bois Blanc" rocks. Repetition of similar structure on the "Bois Blanc" surface may, however, be largely due to further differential compaction over structure which is directly related to the rigid reef masses burled, at depth. Structure in formations younger than "Bois Blanc" may also be related, in part, to the same mechanism. The possibilities of structure repetition by differential compaction throughout a thick series of sediments is fully discussed by Athy (pp. 811-23), and McCoy (pp. 581-627).

Devonian and Mississippian Systems

"Bois Blanc" to top of Sunbury. Rocks from the top of the "Bois Blanc" to the top of the "Traverse limestone" are mainly carbonates. The structure on the top of the "Traverse limestone" of Devonian age is similar in character to that of the "Bois Blanc" surface several hundred feet lower in the section. The amount of relief is about the same in some areas and considerably less in other areas. The thickness intervals between the tops of these formations tend to be greater in the synclines and thinner over the anticlines.

Rocks above the "Traverse limestone" are principally shales. Structure on the top of the Sunbury shale of Mississippian age is similar in major aspects to that of the "Traverse limestone," and the amount of structural relief on the top of this formation is about the same as on

the "Traverse limestone." The thickness intervals between the tops of these formations are also greater in the synclines and thinner over the anticlines. Similarity of structure in Devonian and Mississippian rocks suggests a combination of continued differential compaction over older structures, and the continuation, or reoccurrences, of movement along the same zone of deformation at least through Sunbury time.

With the exceptions of the Canadian Colchester and Dover fields (J and K, Fig. 2), both of which have characteristics of synclines associated with faulting, the structural forms of trend fields are unlike those of other Ordovician fields In Michigan.

The Deerfield pool (A, Fig. 2) has been related to a part of the Bowling Green fault system which follows along the western edge of the Lucas monocline, a large regional flexure originating in Lucas County, Ohio, and extending northward into Michigan. Detailed mapping of the Trenton surface in the Deerfield pool discloses a series of small, low relief, en echelon anticlines plunging to the northwest. The pool occupies but a small part of the steeply dipping-west flank of the Lucas monocline. Oil production is associated with fracturing and dolomitization of the Trenton formation, and is limited mainly to a narrow zone along the edge of the flexure. Mississippian and some upper Devonian formations terminate abruptly against the west flank of the Lucas monocline (Fig. 2). Regional mapping indicates the Michigan part of the Lucas monocline to be related to other anomalous Trenton structural features in the counties to the north (Fig. 2).

The Northville pool (D, Fig. 2) produces oil and gas from a narrow, fractured and dolomitized zone in the Trenton-Black River formations. Detailed mapping of the Trenton surface discloses several narrow anticlines less than a mile wide and extending in a northwest-southeast direction through parts of Wayne, Washtenaw and Oakland counties. Some indication of en echelon arrangement is evident. The anticlines are asymetrical with the steeper flank to the north. At several places along the north flank, differences in datums on the Trenton surface amount to more than 380 feet in wells less than one-half mile apart. Gas is produced from wells relatively high on structure. Oil is produced from wells which, with few exceptions, are structurally low. Cores of the Trenton-Black River formation indicate the north flank to be fractured, brecciated, and dolomitized. The south flank appears to be unproductive of gas, oil, or water, since limestone rather than dolomite is found in the dry holes that outline this side of the structure. Data for the field warrants the conclusion that a faulted and fractured zone is associated with the north flank. The Northville anticline is sometimes referred to as the southern extension of the Howell anticline (2, Fig. 2). However, the Northville anticline appears to be but one of several narrow, en echelon, anticlinal noses which together constitute the Howell anticline system, or as termed by Newcombe, the Howell-Owosso anticline (1928, p. 215). Subsurface data indicate the west flank of the Howell structure to be faulted with vertical displacement amounting to as much as 1000 feet (Newcombe, 1933, pp. 208-11). Only a few Trenton-Black River tests have been made on the Livingston and Shiawassee County portions of the Howell anticlinal system. Neither oil nor gas production has been obtained from Ordovician rocks. Trenton datums indicate the persistence of steep dip on the west flank. Structure is reflected in nearly all formations of the Ordovician, Silurian, Devonian, and Mississippian systems encountered on the Howell and Northville anticlines. The regional structure of the Howell and Northville areas is well illustrated by the geologic map (Fig. 5).

The Freedom structure (E, Fig. 2) to the southwest of the Northville and Howell anticlines, appears to be a similar grouping of narrow, northwest-southeast trending anticlines, which are probably related to the Lucas monocline-Bowling Green fault system. The Freedom structure is not as well defined as the Howell anticline system, but enough well control is available to suggest at least two smalls narrow anticlines. Where enough Trenton well control is available, a dip on the Trenton surface of over 275 feet in a mile is encountered on the west flank. Dip on the north flank amounts to over 100 feet in about two miles. On the west flank, structural differences of nearly 600 feet are encountered in Devonian formations, and similar structural differences are evident in Mississippian formations. Oil and salt water were produced from one well completed in a dolomitized zone within a predominantly limestone section on the west flank of the Freedom anticline (Fugate, 1955, p. 872). Only one well was completed and it was abandoned in 1956. Data for this field suggest that faulting and fracturing, with subsequent dolomitization, has occurred on the west flank of the anticline.

The Albion-Scipio Trend has some characteristics common to other reasonably well defined Trenton-Black River structures in the Michigan basin. Apart from oil and gas production, the similarities may be briefly stated as follows: (1) The porous oil, gas, and water zones are associated with secondary dolomitization of limestone; (2) dolomitization is related to tight folding, fracturing, and faulting; (3) the width of the producing or dolomitized zone is narrow compared to the length; (4) the Trend has approximately the same northwest-southeast lineation as other well defined Trenton-Black River structures; (5) the Trend appears to be related to the same regional deformation that produced the Howell anticline system, Lucas monocline, and similar structures in the southeastern quadrant of the basin (see Figures 2 and 5).

DEVELOPMENT OF TRENTON STRUCTURE OR "SYNCLINE"

It has been suggested that the synclinal character of the Trenton surface along the Trend is caused by a dolomitization -- shrinkage process which superimposes 'a syncline over a normal fault zone of very minor vertical displacement (Burgess, 1960, pp. 128-30). According to this theory, the central depression or syncline is caused by an excess solution of limestone over dolomite deposition which results in a reduction in volume of Trenton-Black River rocks, and a shrinkage of section amounting to as much as 35 to 40 feet. Dolomitization of the limestone rock no doubt increased the porosity, and may be responsible for a small amount of reduction in volume of the dolomitized intervals, but it does not seem to account entirely for the formation of the synclinal features.

Thickness data from the top of the Trenton to the "Black River shale," and from the "Black River shale" to the top of the "Glenwood shale" are not abundant for the central part of the fields because wells are not drilled deep enough. Nearly all wells that have been drilled through the Trenton-"Glenwood shale" section are dry hole, edge wells which do not afford thickness information for the deeper part of the syncline, the area of supposed greatest volume reduction. Information assembled from different parts of the Trend do not, in general, tend to substantiate a significant volume reduction in Trenton-Black River rocks.

An analysis of the Trenton-"Black River shale" interval, as indicated by gamma ray-neutron logs for 24 wells in Section 1, T.4S., R.4W., Calhoun County, shows the following thickness variation: 343 feet, 1 well; 348 feet, 1 wells 350 to 352 feet, 3 wells; 354 feet, 2 wells; 355 feet, 2 wells; 356 feet, 3 wells; 358 feet, 3 wells; 361 feet, 2 wells; 367 feet, 2 wells; 368 to 369 feet, 2 wells; 370 feet, 2 wells; and 378 feet, 1 well. A dry hole adjacent to an oil well, but with a Trenton datum difference of 10 feet, may have the same thickness interval. A dry hole, with presumably an all limestone section, may be as much as 40 feet higher than an adjacent oil well, but the thickness interval in the oil well may be 15 feet less than in the dry hole. Adjacent oil wells may have essentially the same thickness interval, but datum differences of over 30 feet. When plotted on a map, the data do suggest a thinner interval coincident with the syncline, but the overall distribution pattern, when considered in relation to the amount of structural relief between wells, does not warrant the conclusion that the syncline results entirely from dolomitization. Almost all of the Trenton-Black River section has been cored in one well (type log, Albion field). The core description indicates the entire section as dolomite. No unusual concentrations of residual, insoluble materials are indicated; fossils have not been obliterated; and fracture and bedding planes are clearly visible. Carbonaceous partings which might be suggestive of solution activity are abundant in the dolomite section, but cores in limestone sections also show abundant carbonaceous partings. The amount of dolomitization of Trenton-Black River rocks along the Trend varies vertically and laterally within the sections, and is by no means consistent throughout, although some zones appear to have been more favorable to alteration than others. Dolomitization of limestone rock appears to have been chiefly a volume for volume exchange which, evidently, contributed but a small amount to the development of the "syncline."

It is difficult to demonstrate faulting as the major mechanism responsible for the development of the synclinal character of the Trend. There is little evidence of significant displacement of any type, no repetition of formations, no obvious scarp development, or other data might help to substantiate considerable displacement. Criteria which suggest faulting in Trenton-Black River rocks are as follows: (1) Excellent lineation, narrow width, and unusual length of the producing area. (2) Cores from producing wells show various degrees of fracturing, fracture orientation, and small amounts of displacement along fractures. Cores from all limestone edge wells show little or no fracturing. (3) Secondary dolomitization associated with the fracturing. In dry holes on the edge of the pools, and sometimes within the pool. Trenton-Black River rocks are all limestone or slightly dolomitized limestone with little porosity or permeability. Slight oil shows and some fracturing in limestone sections are noted on some core descriptions. Intense secondary dolomitization appears related to the areas of greatest fracturing. (4) The variable thickness of dolomitized limestone, oil and gas pay sections, oil-water contacts„ and static pressure build-up rates vary notably throughout the fields and within an individual area. This is characteristic of fracture type reservoirs where selective dolomitization and recementation of fractures and pore spaces has occurred.

The configuration of the Trenton surface along the Trend may perhaps be best described as an unusual lineation of ordinary deformational features. Structure contours on the Trenton throughout the densely drilled parts indicate numerous anticlinal folds and associated synclines in near en echelon arrangement, and similar to those shown on Figures 7, 16, and 37. The arrangement of the folds and synclines, and the small angle they make with the general northwest-southeast axis, suggests deformation by shearing forces and by some degree of movement along a pre-existing basement fault. Movement along the basement shear zone is manifest in the crumpling of formations and the fracturing of Trenton-Black River rocks. The interconnection of fractured zones along the synclines has resulted in a nearly continuous and dolomitized oil and gas trap that extends over a distance of many miles.

It is clear that the structural nature of the Trenton surface along the Trend is not related to a single, simple syncline; but is, from all indications, a complex association of numerous, low relief folds and shallow synclines. Minor fracturing and faulting, and

dolomitization, are confined to the synclines and flanks of the small folds or anticlines, and nearly all the oil and gas wells are similarly allied with the synclines. In this and in other respects, the oil fields of the Trend are similar to the zinc-lead mineral deposits of the upper Mississippi Valley where ore bodies are localized by fracture control often associated with folding.

The upper Mississippi Valley zinc-lead district includes the southwest part of Wisconsin, the northwest corner of Illinois, and a narrow fringe of Iowa just west of the Mississippi River. The total area of the region is about 4000 square miles. According to Heyl, at al (p. 26) the structural features of this district are of interest because of "(1) the excellence of the district as an example of an area that was never structurally developed beyond initial stages of deformation, (2) the unusual fault and cross-fold systems that are apparently related to similar larger structures in the surrounding region, and (3) the marked control that the gentle folds, minor faults, and joints had exercised on the localization of the ore deposits." The host rocks of the ore deposits are mainly those of the Prairie du Chien group and the overlying St. Peter, Platteville, Decorah, Galena sequences which correlates with the Prairie du Chien, St. Peter and Trenton-Black River units of Michigan.

The structural features of the zinc-lead district have been grouped into three orders of magnitude. The longest, first order folds are at least 40 miles long, and from 3 to 6 miles wide, with amplitudes as much as 200 feet. Second-order flexures between major folds, or superimposed upon them, have amplitudes from 40 to 100 feet. These folds tend to be linear in pattern, and average more than 10 miles in length. The third-order folds range from those having a linear extent of 1 to 2 miles and a vertical amplitude of 20 to 60 feet, down to very small crumples 100 feet long. The significant fracture systems, which are principally reverse and bedding-plane faults of small displacement along with Inclined joints, are on the flanks of the folds. The fracture systems often curve around the axial noses of the folds (Heyl, et alp 1959, pp. 26-66). Most of the folds, faults, and joints observed in the zinc-lead district are believed to have had their major development in post-middle Pennsylvanian time as a result of lateral compression related to the Appalachian-Quachita orogeny (Heyl, et al, 1959, pp. 52-63).

A comparison of upper Mississippi Valley Ordovician structural features with known Ordovician structures in the Michigan basin reveals considerable similarity in relative size classification, deforrnational characteristics, and time of deformation. The structural character of Trenton-Black River rocks along the Trend appears to be similar to the third-order folds of the zinc-lead district. The accumulation of oil and gas in the fractured and faulted synclines, and on the flanks of the associated folds, is comparable to the localization of ore bodies by fracture control.

SUMMARY

The fields (or the Trend considered as a single unit) are examples of syncline porosity traps. The oil and gas reservoir rocks of the Trenton-Black River formations are closely related to shallow synclines where fracturing and some degree of faulting has occurred. Dolomitization of the limestone country rock, perhaps by magnesium bearing water ascending through fractures, resulted in Increased porosity and. permeability in the fractured zones and adjacent rocks. Migration of gas, oil, and water into the trap appears to have occurred sometime after the initial fracturing and development of secondary dolomite filling in the fissures. Hydrocarbon source rocks may be the Utica shale, the Trenton-Black River limestones, or the shaly transitional beds at the base of the Black River, although younger or older rocks cannot be eliminated as possible sources. Trenton-Black River rocks, which are rich in organic debris at many intervals throughout the section, are an adequate hydrocarbon source. Oil and gas formed from organic material during the deposition and compaction of Trenton-Black River rocks may have been localized in areas near the source, and where conditions were favorable for accumulation. The chance release of hydrocarbons from original reservoirs by various mechanisms and the further migration by devious paths to favorable traps which were barren of oil and gas, may account for the accumulations along the Trend. The migration routes may have been along master joint systems or some interconnecting combination of porous and permeable joints and fractures. One-well oil fields such as Hanover (F, Fig. 2) which produced nearly 63,000 barrels of oil in 1961 from a single well, do not appear to be related to any type of obvious structure. Such pools may be associated with joint systems in Trenton-Black River rocks.

The unusual similarity and coincidence of structural features in Ordovician, Silurian, Devonian, and Mississippian formations seem more than a chance association. The excellent lineation, continuity of Trenton-Black River oil pools, and similar or close continuity of structure throughout a large part of the Trend leads to the speculation that development was initially keyed to slight lateral and intermittent movement along a pre-existing basement fault by shearing forces. Recurrent, but slight, adjustment after Trenton times, development of Middle Silurian reefs coincident with the trace of the fault, and differential compaction of successive beds over the reefs, gave rise to similar structural features throughout the remainder of the Silurian. Recurrent adjustment along the same zones of weakness in Mississippian and Devonian time, or later. has helped to perpetuate the structural features.

The Trenton-Black River oil and gas fields of Michigan are related to the large regional structures that frame the southern margin of the Michigan Basin. Large folds or anticlines such as Howell and Freedom can be roughly outlined with minimum well control. But where to find the fractured and dolomitized, potential, oil and gas reservoirs is a problem which only the drill can solve.

Fields like those of the Trend impose even greater difficulties because of small structural definition. Similar accumulations probably exist but perhaps will only be found by extensive and costly drilling programs. These studies demonstrate a possible relationship between shallow structure and deeper deformational features on the shelf regions. Shallow Devonian structures on the shelf regions may be reflections of deeper Silurian reefs. The reefs may be instrumental in the development of oil and gas traps in the A-1 and A-2 carbonate units of the Salina group, as well as in younger overlying formations. In southern Michigan, the areas of abundant shallow well control often show excellent lineation of similar structural features which, except in those regions of thick easily deformed salt beds, may be clues to other Ordovician syncline pools such as those of the Trend.

FORMATION LITHOLOGIES

Sun Oil Company - H. H. Sundberg No. 1

SE NE NW section 26, T.1S., R.5W., Lee Township, Calhoun County

Well permit no. 22386

Schlumberger log measurements made from 948.0 feet above sea level.

Sample measurements made from 946.5 feet above sea level.

Sample description by Sun Oil Company. Certain formation tops and footages have been re-adjusted to agree with the gamma ray-neutron correlation points used in this report.

	Thickness (feet)	Depth (feet)
PLEISTOCENE		
Glacial drift:	50	50
MISSISSIPPIAN SYSTEM		
Michigan formation: (undescribed)	50	100 Schj.
Marshall formation:		
Sandstone, white	340	440 Schj.
Coldwater formation:		
Shale, gray	1000	1440
Shele, red, with some gray (Coldwater redrock)	16	1456
Dolomite, light green; shale, brown, very very finely crystalline	4	1460 Schj.
	(1020)	
Sunbury shale:		
Shale, black, bituminous	10	1470
Berea-Bedford formations: (Undifferentiated)		
Shale, gray to green gray	15	1485 Schj.
MISSISSIPPIAN-DEVONIAN SYSTEM		
Antrim shale:		
Shale, black, bituminous, with occasional thin gray shale stringers	240	1725 Schj.
DEVONIAN SYSTEM		
Traverse group:		
"Traverse formation"		
Shale, gray, with limestone stringers, gray, dirty	40	1765
Shale, black, bituminous	11	1776 Schj.
	(51)	
"Traverse limestone"		
Dolomite, gray to brown, vuggy, medium crystalline, permeable	4	1780
Dolomite, gray, cherty, medium crystalline, dense (Water 1776-1785)	5	1785
Shale, gray (1790 DPM = 1795 SDP)	23	1808

DEVONIAN SYSTEM	Thickness (feet)	Depth (feet)
"Traverse limestone" (continued)		
Limestone, gray to brown, cherty	10	1818
Dolomite, buff, coarsely crystalline, vuggy (Water 1818-1825)	7	1825
Dolomite, gray to light gray, somewhat argillaceous, dense; a little shale	33	1858
Limestone, white, granular, fragmental, some permeability	12	1870
Limestone, gray to brown, argillaceous; a little shale, gray	46	1916
Shale, gray; with some lime, gray	24	1940
Limestone, gray, cherty	31	1971
Limestone, very light gray and brown to white	16	1987
Shale, gray	6	1993 Schj.
	(217)	
Dundee formation:		
Dolomite, very light gray to buff, finely granular, limy	4	1997
Limestone, very light gray to almost white, scattered pinhole porosity	55	2052 Schj.
	(59)	
Detroit River group: (undivided)		
Lucas formation		
Amherstberg formation		
Sylvania sandstone		
Dolomite, brown, granular, permeable (Water 1993-2059)	7	2059
Dolomite and anhydrite, thinly bedded; dolomite is light brown, and very finely crystalline (2094 DPM = 2098 SDP)	48	2107
Dolomite, light brown, very finely crystalline, some porosity and permeability	5	2112
Dolomite, light brown and anhydrite, thinly bedded	22	2134
Dolomite, light brown, very very finely crystalline, anhydritic; some anhydrite	10	2144
Anhydrite	14	2158
Dolomite, light brown to cream colored, anhydritic	14	2172
Dolomite, light brown, very very finely crystalline, interbedded, and anhydrite	43	2215
Anhydrite	15	2230
Dolomite, light brown, very very finely crystalline	11	2241
Anhydrite, with dolomite stringers, light brown	91	2332
Anhydrite and dolomite, light brown to buff, very finely crystalline, interbedded (Sylvania sandstone 2392-2403)	53	2385
Dolomite, buff, very finely crystalline, permeable	18	2403 Schj.
	(351)	
"Bois Blanc" formation (?):		
Dolomite, brown to gray brown, with stringers, black, bituminous, very finely crystalline	22	2425
SILURIAN SYSTEM		
CAYUGAN SERIES (Upper Silurian)		
Bass Islands dolomite: (H unit)		
Dolomite, buff to cream colored, very finely crystalline, permeable	103	2528 Schj.

SILURIAN SYSTEM	Thickness (feet)	Depth (feet)
Salina formation:		
"G" unit (2528 to 2595)		
Shale, gray, grading to dolomitic and anhydritic shale	67	2595 Schj.
F unit (2595-2645) (F salts not present)		
Shale, gray, and dolomite, light brown, very very finely crystalline, interbedded	35	2630
Dolomite, light brown, very finely crystalline	8	2638
Shale, gray, dolomitic, with dolomite stringers, light brown, anhydritic	7	2645 Schj.
	(50)	
E unit (2645-2763)		
Shale, gray, anhydritic, dolomitic, with some dolomite stringers, brown; some anhydrite	61	2706
Dolomite, light brown, very finely crystalline, porous and permeable ("E" zone porosity at 2706 Schj.)	20	2726
Dolomite, light brown, very finely crystalline, interbedded	37	2763 Schj.
	(118)	
C unit (2763-2862)		
Shale, gray, grading to dolomitic and anhydritic with thin dolomite stringers, light brown, very finely crystalline	99	2862
B unit (Evaporite) (2862-2962) (no salt present)		
Anhydrite and shale, gray, dolomitic	10	2872
Shale, gray, dolomitic and dolomite, light brown, very finely crystalline, interbedded; some anhydrite	30	2902
Anhydrite, interbedded with shale, gray, dolomitic, anhydritic	23	2925
Dolomite, brown, anhydritic, grading to anhydrite	37	2962 Schj.
	(100)	
A-2 carbonate (or A-2 dolomite) (2962-3113) (includes A-2 "lime")		
Dolomite, light brown, very finely crystalline, tight	45	3007
Dolomite, light gray and light gray brown, very very finely crystalline, anhydritic, with thin, black, bituminous stringers (3034 DPM = 3042 SDP)	98	3105
Shale, gray to black, bituminous	8	3113 Schj.
	(151)	
A-2 evaporite		
Anhydrite (Salt not present)	36	3149 Schj.
A-1 carbonate (or A-1 dolomite)		
Dolomite, light brown, very finely crystalline, clean	37	3186
Dolomite, brown to gray brown, very finely crystalline, with black, bituminous stringers	27	3213
Dolomite, light brown to dark brown, carbonaceous, finely to medium crystalline; some porosity may contain a little anhydrite	7	3220
	(71)	
A-1 evaporite equivalent		
Dolomite, light brown, finely crystalline, clean, permeable; trace of anhydrite	27	3247 Schj.

	Thickness (feet)	Depth (feet)
MIDDLE SILURIAN		
Niagaran series (undifferentiated)		
Dolomite, light brown, finely crystalline, clean, permeable	36	3283
Dolomite, white, medium crystalline, permeable (Water 3213-3488)	206	3489 Schj.
	(242)	
LOWER SILURIAN		
"Clinton"-Cataract group:		
Cabot Head shale		
Shale, gray to green	9	3498
Dolomite, white, medium crystalline, dense	7	3505
Shale	5	3510
Shale, gray to green, with some red; with thin, dolomite stringers, brown	51	3561 Schj.
	(72)	
Manitoulin dolomite		
Dolomite, light gray to brown, cherty	41	3602 Schj.
ORDOVICIAN SYSTEM		
LATE ORDOVICIAN		
Cincinnatian series (undifferentiated):		
Shale, gray, with thin dolomite stringers, gray	92	3694
Limestone, gray, argillaceous; some shale, gray	21	3715
Shale, gray, calcareous; with limestone stringers, dirty, gray	25	3740
Shale, gray and red, with thin limestone and dolomite stringers, gray, dirty	40	3780
Shale, gray, with thin limestone stringers, dirty	170	3950 Schj.
Shale, gray to almost black (Utica at 3590 Schj.)(4036 DPM = 4034 SDP)	280	4230 Schj.
	(628)	
MIDDLE ORDOVICIAN		
Trenton formation:		
Dolomite, brown to gray, medium crystalline, tight; trace fluorescence	13	4243
Dolomite, brown to gray, medium crystalline, some granular porosity, with 50% limestone; trace fluorescence	12	4255
Limestone, gray to brown; with about 30% dolomite, gray to brown, medium crystalline; trace fluorescence	15	4270
Limestone, gray to brown, grading to dolomitic at points, medium to coarsely crystalline; trace fluorescence at points, with fair fluorescence 4315-4325; generally dense and non-permeable, increase in fluorescence 4424-4430, 4445-4450 (Drill Stem Test #1: failed; Drill Stem Test #2: 4235-4491, open 2 hours, 350' gas in drill pipe, recovered 10' mud, bottom hole pressure 275# in 30 minutes)	230	4500
Limestone, gray to brown, grading to quite dolomitic at points, with a few thin, limy dolomite stringers 4510-4515, fair fluorescence 4505-4520	20	4520
Limestone, gray to brown, with considerable white, fossil material; estimate little or no porosity	35	4555

	Thickness (feet)	Depth (feet)
MIDDLE ORDOVICIAN		
Trenton formation: (continued)		
Limestone, gray to brown, with white, medium crystalline; considerable black, bituminous material, dense	13	4568
Limestone, light brown to gray to white, very very finely crystalline to lithographic, grades to somewhat dolomitic	9	4577 Schj.
	(347)	
Black River formation:		
Shale, gray to greenish gray ("Black River shale" at 4606 Schj.)	3	4580
Limestone, shades of light gray and brown to white, very very finely crystalline to lithographic; considerable brown to black chert; grades to somewhat dolomitic; estimate very low porosity and permeability	24	4604
Shale, shades of gray to greenish gray (Second Black River shale at 4604)	3	4607
Limestone, shades of light brown and light gray to almost white, very very finely crystalline to lithographic; samples from 4610-4625 grades to limy dolomite with fair to good fluorescence from 4610-4625; estimate very low porosity and permeability	18	4625
Limestone, shades of very light gray and very light brown to light cream colored and white, very very finely crystalline to lithographic; trace fluorescence here and there (Drill Stem Test #3: 4491-4710, open 2 hours, recovered 5' mud, bottom hole pressure 52# in 30 minutes)	211	4836
Dolomite, brown to gray, medium to very finely crystalline, oil stains, fair fluorescence; estimate very low permeability and porosity.	8	4844
Limestone, gray to brown, medium crystalline, dense	5	4849 Schj.
	(272)	
"Glenwood" shale-St. Peter sandstone:		
Shale, gray to black, bituminous, sandy (Drill Stem Test #4: 4709-4850, open 1½ hours, recovered 5' mud, bottom hole pressure 35# in 30 minutes)	6	4855
Dolomite, cream colored to white, sandy; some shale, green, glauconitic	6	4861
Sandstone, grading to dolomitic; sandstone, with white to cream colored dolomite; sand grains are rounded, frosted, ill-sorted; some sand, green, glauconitic; trace yellow fluorescence, permeable (Water 4861)	10	4871
	(22)	
EARLY ORDOVICIAN:		
Prairie du Chien group:		
Oneota dolomite ?		
Dolomite, very light brown to white, sandy with shale, gray	19	4890
Dolomite, white to buff, pink, sandy, finely crystalline, permeable (Drill Stem Test #5: 4835-4906, open 2 hours, recovered 4175' salt water, bottom hole pressure 2105# in 30 minutes)	11	4901
	(30+)	
TOTAL DEPTH		4901

Completed as dry and abandoned

Table 2

Wells Used in Figure 6

Well No.	Company and Well Name	State Permit	County	Township	Range	Section
1	The Ohio Oil Co. Rossman #1	22503	Jackson	T.4S.	R.3W.	33
2	The Ohio Oil Co. Rockwell Unit #A-1	22456	Calhoun	T.3S.	R.4W.	36
3	Perry Fulk etal Farley #1	22040	Calhoun	T.3S.	R.4W.	15
4	McClure Oil Co. Hartung #2	22000	Calhoun	T.2S.	R.4W.	32
5	McClure Oil Co. etal Young #1	22415	Calhoun	T.2S.	R.5W.	13
6	Fulk Oil Co. Scott Unit #1	22723	Calhoun	T.2S.	R.5W.	1
7	C. J. Simpson G. Walter #1	22578	Calhoun	T.1S.	R.5W.	15
8	C. J. Simpson Murphy & Altenhein #1	22489	Calhoun	T.1S.	R.5W.	6
9	Athens & Ryan Hickok #1	22487	Eaton	T.1N.	R.5W.	30
10	The Petrolia Corp. LaMonte #1	22672	Eaton	T.2N.	R.5W.	18

Table 3

Oil and Gas Production - Michigan Trenton-Black River Pools

		1961 Production Oil (Bbls.)	1961 Production Gas (MCF)	Accumulative Production Oil (Bbls.)	Accumulative Production Gas (MCF)
1	Albion-Scipio Trend	11,159,338	8,227,397	21,740,881	11,065,204
2	Deerfield	12,509	-	639,836	-
3	Freedom (Aband. 1956)	-	-	7,217	-
4	Hanover	62,874	67,494	70,746	127,047
5	Macon Creek	91	-	91	-
6	Medina	972	-	972	-
7	New Boston (Aband. 1949)	-	-	2,349	-
8	Northville	69,438	1,533,484	680,231	9,068,531
9	Ridgeway	-	-	47	-
10	Summerfield	369	-	1,646	-
11	Sumpter (Aband. 1942)	-	-	221	-
12	Tekonsha	1,170	-	2,630	-

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