MIDDLE ORDOVICIAN OF THE MICHIGAN BASIN

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ABSTRACT

MIDDLE ORDOVICIAN OF THE MICHIGAN BASIN

by

Douglas J. Seyler

The Michigan Basin in its present form began during the late Middle Ordovician time. During Glenwood time, the basin area experienced the initial transgression of the Middle Ordovician sea over the pre-Middle Ordovician unconformity surface. Basinal subsidence created an embayment of the Middle Ordovician sea in the area during Black River time. Increased subsidence created a closed basin centering in southern Lake Huron during Trenton time.

Basement block movement took place during Trenton time in the northern Lower Peninsula, creating wrench faulting in the overlying sediments. Due to the similarity of this structure to the structure in the Albion-Scipio trend of petroleum production, it is viewed as a prime area for future petroleum exploration. With this structural model in mind, several other possibly similar structures are suggested.

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by

Douglas J. Seyler

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INTRODUCTION

The Middle Ordovician carbonates of the Michigan Basin are in some localities a prolific producer of petroleum. However, little detailed work has been done on these important units on a regional scale. Total Ordovician isopach maps have shown a closed basin centered slightly south of Saginaw Bay, and previous work has placed the formation of the basin during Middle Ordovician time. As this is a critical period in the history of the basin, additional work is warranted. The Michigan Basin is considered in this study to be the closed depression which is now centered to the northwest of Saginaw Bay, and is bounded by stable, relatively positive areas in eastern Wisconsin, north-central Indiana, southwest Ontario, and the stable shield area in western Ontario.

PURPOSE

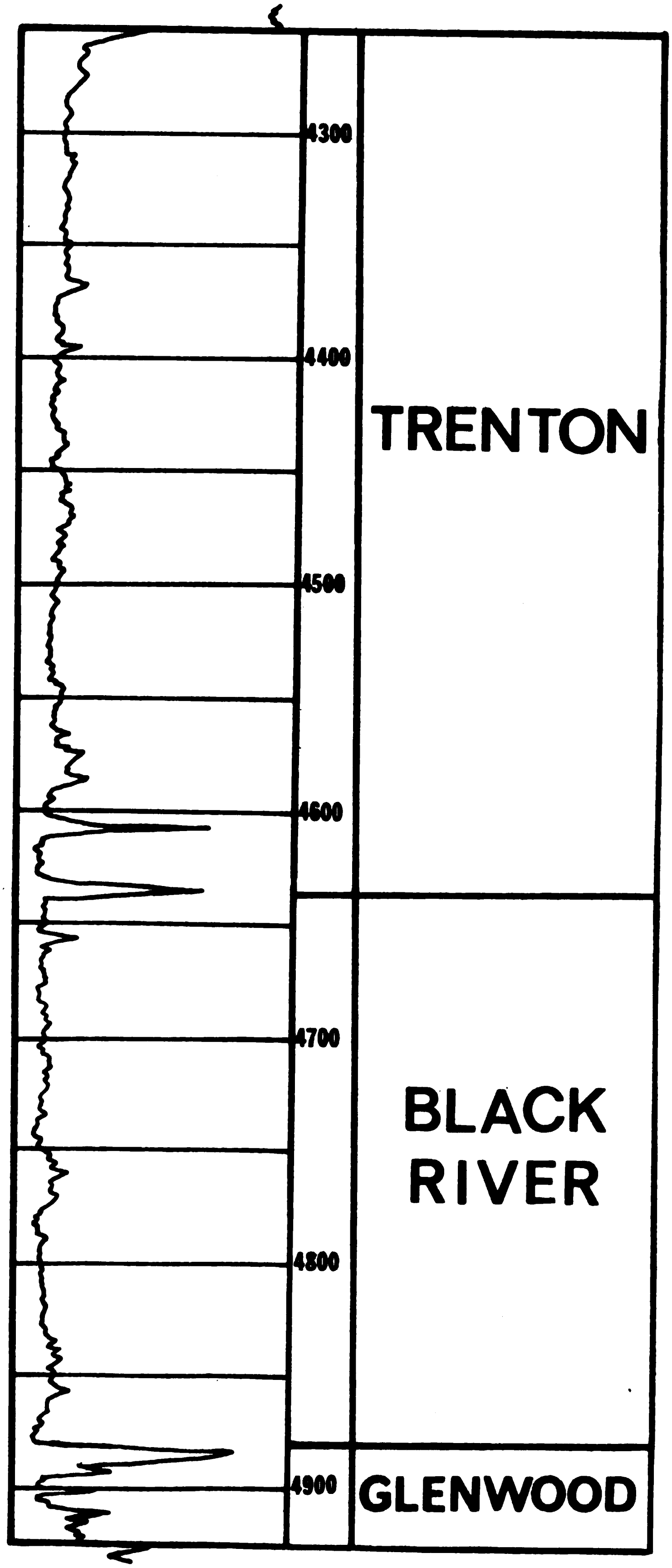
Recently several new wells in the upper half of the Southern Peninsula of Michigan have added vital correlation points for the study of the Middle Ordovician of the Michigan Basin. These data have facilitated a realistic evaluation of Middle Ordovician stratigraphy in the Michigan Basin, and have suggested new petroleum possibilities. The goals of this study, then, are: 1), to study the stratigraphy of the various units of the Middle Ordovician in the Michigan Basin; 2), to relate this stratigraphy to the evolution of the Michigan Basin; 3), to employ these studies in the prediction of future areas of petroleum potential in the Michigan Basin. Since Middle Ordovician rocks crop out in the Upper Peninsula, very few useful wells are available in that portion of the basin. As a result, this study utilizes only wells from the Lower Peninsula, which can be correlated to adjacent states and southwestern Ontario.

METHODS AND MATERIALS

This study was conducted primarily through the use of geophysical logs as these logs are often sensitive to physical variables that are not noticeable in samples. Since this was a regional study, characteristic patterns on the logs were selected for correlation which may not, in some cases, correspond to lithologic formation tops. This is particularly true of the Glenwood formation, where an interval was rather arbitrarily selected on the basis of a recognizeable pattern throughout the basin. The three intervals which were selected are shown in Figure 1. Further subdivision of the formations was attempted, but was found to be practical only in local areas.

The density of Middle Ordovician wells varies tremendously--from hundreds per county in Hillsdale, Calhoun, and Jackson counties, to less than one-half a well average per county in the northern half of the Lower Peninsula. As a result, in areas of high density only a sufficient number of wells was picked to delineate stratigraphy and structure in the area. In addition, well sample descriptions were examined in interesting areas.

Figure 1- A typical Gamma-ray well log



PREVIOUS WORK

Due to the lack of well control, few workers have looked at the Middle Ordovician of the Michigan Basin. Pirtle (1932) wrote a classic article on the Michigan Basin and its origin, without any well control into the Cambrian. Lockett (1947) did a similar broad form study of basins in the northeastern United States. Hussey (1950) examined the Middle Ordovician rocks in outcrop in the vacinity of Escanaba, Michigan in the Upper Peninsula. With better well control came more detailed studies, notably Cohee and Landes (1958), who utilized isopach maps together with current petroleum occurrences to characterize petroleum production in the Michigan Basin. Ordovician studies have been carried out in adjacent areas: Gutstadt (1958) in Indiana; Buschbach (1964) in northeastern Illinois; Calvert (1974) in Ohio; and Sanford (1961) in southwestern Ontario.

Hinze and Merritt (1969) have studied the Michigan Basin with respect to gravity and magnetics. Most recently, Harding (1974) has applied a wrench faulting model to the Albion-Scipio trend of oil production in the southern Lower Peninsula.

No work to date has dealt with the individual formations of the Middle Ordovician in the Michigan Basin on a regional basis, as in the present study.

STRATIGRAPHY

GLENWOOD UNIT

The "Glenwood" that was studied during this work does not necessarily coincide with that formation which has been correlated with the Glenwood Shale of Illinois and Wisconsin, but rather is an interval between the base of the Black River limestone and the underlying Lower Ordovician or Cambrian sediments which is recognizable regionally on geophysical logs. This interval is characterized in Michigan by green and gray sandy shale and limestone and dolomite. Since this interval rests on or near an eroded Cambrian-Lower Ordovician surface, one would expect the thickness to reflect an irregular, eroded topography. This, in fact, is shown by the Glenwood isopach map, Plate 1. Observed thickness ranges from less than 18 feet to 86 feet. Although well control is sparse for this map, one can readily notice similarities to present-day topography in areas marked by large drainage systems and karst topography. Similar features have been noted in northeastern Illinois (Buschbach, 1961) for the Glenwood-St. Peter interval.

There is a sinuous thin which runs down the center of the state, which could have been a topographically high area. This corresponds to the "mid-Michigan high" which has been observed in gravity surveys of the state. To the west of this is a long, narrow thick which is reminiscent of a drainage valley. This thickening corresponds to a thickening which has been observed in the underlying St. Peter sandstone (M. Balombin, 1974, personal communication of thesis research material). To the east and northeast are local thickenings, interpreted as local basins. These are somewhat elongated and are roughly parallel to each other.

In adjacent states, the Glenwood is similar in character. In northwestern Ohio, the interval between the Black River limestone and the unconformity, called the Chazy, is characterized by green and greenish-gray argillaceous dolomite, with a thickness on the order of 10 feet (Gutstadt, 1958, p. 59). In northern Indiana, the equivalent section, again called the Chazy, varies from a St. Peter-type sandstone in the extreme west which is 95 to 135 feet thick, to a few feet of greenish dolomitic shale in the east (Gutstadt, 1958, p. 53). In northeastern Illinois the Glenwood consists of sandstone, dolomite, and shale, which varies in thickness from a few to 80 feet (Buschbach, 1964, p. 52). In southwest Ontario, an equivalent formation is called the Shadow Lake, which is placed as basal Black River, and is characterized by green shaly and sandy dolomite, dolomitic shale, and reddish arkose. It varies in thickness from 2 to 50 feet (Sanford, 1961, p. 5). These correlations are shown in Figure 2.

The Glenwood appears to represent deposits derived from the erosion of Upper Cambrian-Lower Ordovician sediments, and the marine transgression of the Middle Ordovician sea.

BLACK RIVER UNIT

The Black River is characterized in the Michigan Basin by 90 to 485 feet of light brown and gray, fossiliferous, dense to crystalline limestone and dolomite. There is locallized secondary dolomitization, and the unit becomes generally more dolomitic toward the west. It occurs

<table>
<tr><th>NE ILLINOIS</th><th>N INDIANA</th><th>NW OHIO</th><th>SW ONTARIO</th><th>MICHIGAN</th></tr>
<tr><td>GALENA</td><td>TRENTON</td><td>TRENTON</td><td>TRENTON</td><td>TRENTON</td></tr>
<tr><td rowspan="2">PLATTEVILLE</td><td rowspan="2">BLACK RIVER</td><td rowspan="2">BLACK RIVER</td><td>COBOCONK</td><td rowspan="2">BLACK RIVER</td></tr>
<tr><td>GULL RIVER</td></tr>
<tr><td>GLENWOOD</td><td>CHAZY</td><td>CHAZY</td><td>SHADOW LK</td><td>GLENWOOD</td></tr>
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Figure 2 – Correlation Chart

between a very argillaceous limestone and shale at the base of the Trenton, and the argillaceous limestone and shale at the top of the Glenwood. Although it has been suggested that an "extra section" is present at the base of the Black River in the eastern portion of the basin, the interval could not be reliably identified, and was not broken out. The isopach map of this unit, Plate 2, shows that during Black River time, the region was an embayment of the Middle Ordovician sea, open toward the southeast, and with a local thickening into the area of southern Lake Huron.

In northwestern Ohio, the Black River consists of light tan to dark tan lithographic argillaceous limestone ranging in thickness from 300 to 500 feet (Gutstadt, 1958, p. 71). In northern Indiana, Gutstadt (1958, p. 62), describes the Black River as light tan to dark tan, lithographic limestone, in part argillaceous and dolomitic, which is about 200 feet in thickness. Buschbach (1964, pp. 53-4) describes the equivalent Platteville group as consisting of gray to brown dolomite interbedded southward with very-fine-grained limestone, and having a thickness of from 100 to 150 feet. The equivalent Black River unit in southwestern Ontario consists of the Gull River and Coboconk formations, the former being characterized by brown to cream-colored, lithographic to pure limestone, which thickens toward the west to over 400 feet. The latter is described as consisting of buff to buff-brown and tan-colored limestone, which is finely crystalline to granular in texture, and which thickens to more than 100 feet toward the west. In the Upper Peninsula of Michigan, it is described (Cohee, 1948, p. 1432) as 67 to 86 feet of buff to brown, fine-grained, crystalline limestone and dolomite with small amounts of gray argillaceous limestone.

The Black River formation in the Michigan Basin represents a subsiding embayment of the Middle Ordovician sea. The embayment was open toward the southeast, and was probably rather shallow, as evidenced by the abundance of fossils and thick carbonates.

TRENTON UNIT

The Trenton of the Michigan Basin is lithologically very similar to the Black River; it consists of between 157 and 561 feet of brown and gray, fossiliferous, crystalline limestone and dolomite, occurring between the Utica shale above and a very argillaceous limestone and shale section at its base. The upper 10 to 40 feet of the unit is often dolomitic and argillaceous, and the shaly break at its base becomes more pure limestone and dolomite toward the extreme western part of the basin. It is generally more fossiliferous than the Black River, and tends to become more dolomitic toward the west. As with the Black River, the Trenton contains localized secondary dolomitization along fractures and unconformities. The isopach map of the Trenton formation, Plate 3, shows that in Trenton time the Michigan area became a closed basin, with a depositional center in the area of Sanilac County and the southern end of Lake Huron.

The Trenton in neighboring regions is also similar to the Black River in those regions. In the Upper Peninsula, the Trenton is characterized (Cohee, 1948, p. 1432) as 175 to 206 feet of buff-brown to brown crystalline limestone with some dolomite and gray to dark gray argillaceous limestone. The limestone is more argillaceous in the western part of the Upper Peninsula than in the eastern part. The Trenton of northwestern Ohio consists of light tan to medium tan crystalline limestone which is from 50 to 200 feet in thickness (Gutstadt, 1958, p. 71). In northern Indiana the Trenton consists of about 225 feet of light to medium tan fossiliferous dolomitic limestone. It becomes more dolomitic toward the west and consists entirely of dolomite in northwest Indiana (Gutstadt, 1958, pp. 62-4). In northeastern Illinois, the equivalent formation is called the Galena dolomite, and consists of about 200 feet of medium-grained, buff-colored dolomite (Buschbach, 1964, p. 56). The Trenton of southwestern Ontario consists of from 300 to 500 feet of gray to brown, finely crystalline to fragmental limestone, with abundant shale partings, grading into brown, finely crystalline limestone at the top. In the extreme southwest, the uppermost 5 to 30 feet consist of brown, medium crystalline dolomite with considerable amounts of bioclastic material (Sanford, 1961, pp. 9-11).

The Trenton formation in the Michigan Basin represents a locally closed basin. It was rather shallow, but steadily subsiding, as shown by the abundance of fossils and the thick carbonates.

STRUCTURE

The origin of the Michigan Basin has been a controversy for some time. Pirtle (1932) stated that the Michigan Basin probably originated as a long, broad geosyncline paralleling old mountains extending from central Wisconsin into northwestern Indiana. As such, he believed that the basin probably originated in the Precambrian. He felt that the principle folds which are found in later sediments are controlled by lines of structural weakness in the old basement rocks. In 1948, Cohee (p. 1432) stated that the basin was depressed in an area similar to its present form as early as Middle Ordovician time. Yet in 1958, he asserted (Cohee and Landes, 1958, p. 490) that a study of isopach maps had suggested that the Michigan Basin first became a depression in the earth's crust in Late Silurian time.

Green (1957, p. 637) also held this view, stating that the Michigan Basin began near the close of the Niagaran time; before that it was a part of the sea floor which sloped gently toward the southeast.

Fisher (1969, p. 92) returned to earlier interpretations that the basin was created during Middle Ordovician time, based on much more well control than was previously utilized.

Controversy also exists concerning features bordering the Michigan Basin. Pirtle's "Kankakee Arch" (1932) has been drawn in several locations, and Green (1957) has discounted its existance altogether. Although there is a positive feature in northeastern Illinois, Green states that it is a misinterpretation of the Sandwich Fault.

The Findlay Arch has had several origins ascribed to it. Lockett (1947) tied the Findlay Arch to the Algonquin Arch, saying that they are underlain by the cores of Precambrian mountains which extended from Canada through western Ohio and on south, the reflection of which remains in the sedimentary rocks as the Findlay Arch. Pirtle (1932) stated that the Findlay Arch developed largely during the Cincinnatian. Cohee (1948) infered the presence of a Findlay Arch in Upper Cambrian time by the apparent offlap of uppermost Cambrian units. Woodward (1961) showed a Findlay Arch existing as early as the Upper Cambrian. Sanford (1961), citing southwestern Ontario isopach and lithologic data, stated that the Findlay Arch, erroneously associated with the Algonquin Arch, was not prominent until Upper Ordovician time. However, he felt that the bioclastics which occur in the upper section of the Trenton in extreme southwestern Ontario could indicate that the Findlay Arch was emerging during late Trenton time. Most recently, Calvert (1974) has published isopach maps, constructed in 1965, showing that in northwestern Ohio there is no indication of a Findlay Arch during Black River time, and only a hint of thinning over a positive feature during Trenton time. Calvert states that previous interpretations of a prominent Findlay Arch during Trenton time had erroneously included within the Trenton theoverlying Cynthiana Formation, which consists of a series of reefs in northwestern Ohio.

There is general agreement that the Algonquin Arch has been a positive feature throughout the Paleozoic. Associated with this is the Chatham Sag which, although originally thought to be a breach in the old Findlay-Algonquin Arch formed by subsidence of the Michigan and Appalachian Basins adjacent to it (Lockett, 1947, and Fettke, 1948), is more likely a faulted basement block which acted as a fulcrum about which the Findlay Arch moved upward (Sanford, 1961).

MIDDLE ORDOVICIAN HISTORY OF THE MICHIGAN BASIN

The present study lends support to several of the previously stated ideas. A study of the isopach maps and of the general cross-sections, Figures 3 and 4, suggests embryonic basinal subsidence in the Lower Middle Ordovician. The Glenwood isopach, Plate 1, shows an elongate thickening in the area of the "thumb" of the Lower Peninsula. Interestingly, the elongation of this thickening is approximately parallel to the major northwest-southeast structural trend of folds and faults in the Michigan Basin. Another anomalous Glenwood thickening occurs in the extreme northern part of the Lower Peninsula. This is also elongated approximately parallel to the major structural trend in the basin. In both cases, the basins could be partially due to the vertical reflection of movement along basement faults. There is some evidence to justify the existance of basement fault patterns in the Michigan Basin. Through a gravity and magnetics study, Hinze and Merritt (1969) concluded that the dominent northwesterly structural trend in the basin reflects lines of weakness in the basement. These Glenwood anomalies, then, may be due to reactivation of these basement faults during Lower Ordovician time.

The concept of basement lines of weakness was first stated by Pirtle (1932). Figure 5 shows this lineation in features in the Paleozoic of the Michigan Basin. Thomas (1974) has recognized similar features in the Williston-Blood Creek Basin, and suggests that the basement is broken up by basement weakness zones into blocks. Regional horizontal compression would produce lateral adjustment in these basement weakness zones, resulting in a shear couple being applied to the sediments above. This basement block movement is illustrated in Figure 6.

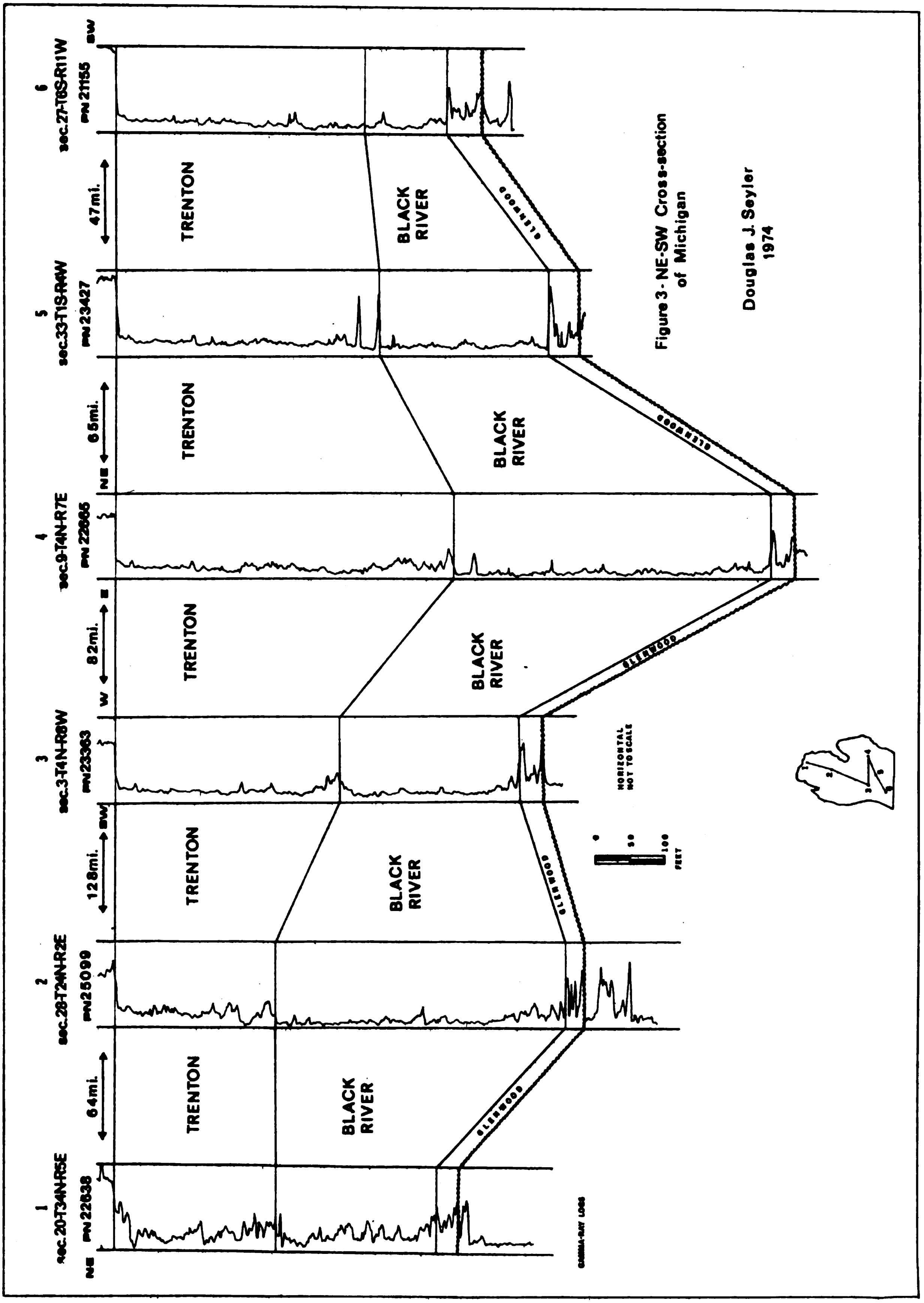

Figure 3 - NE-SW Cross-section of Michigan

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1974

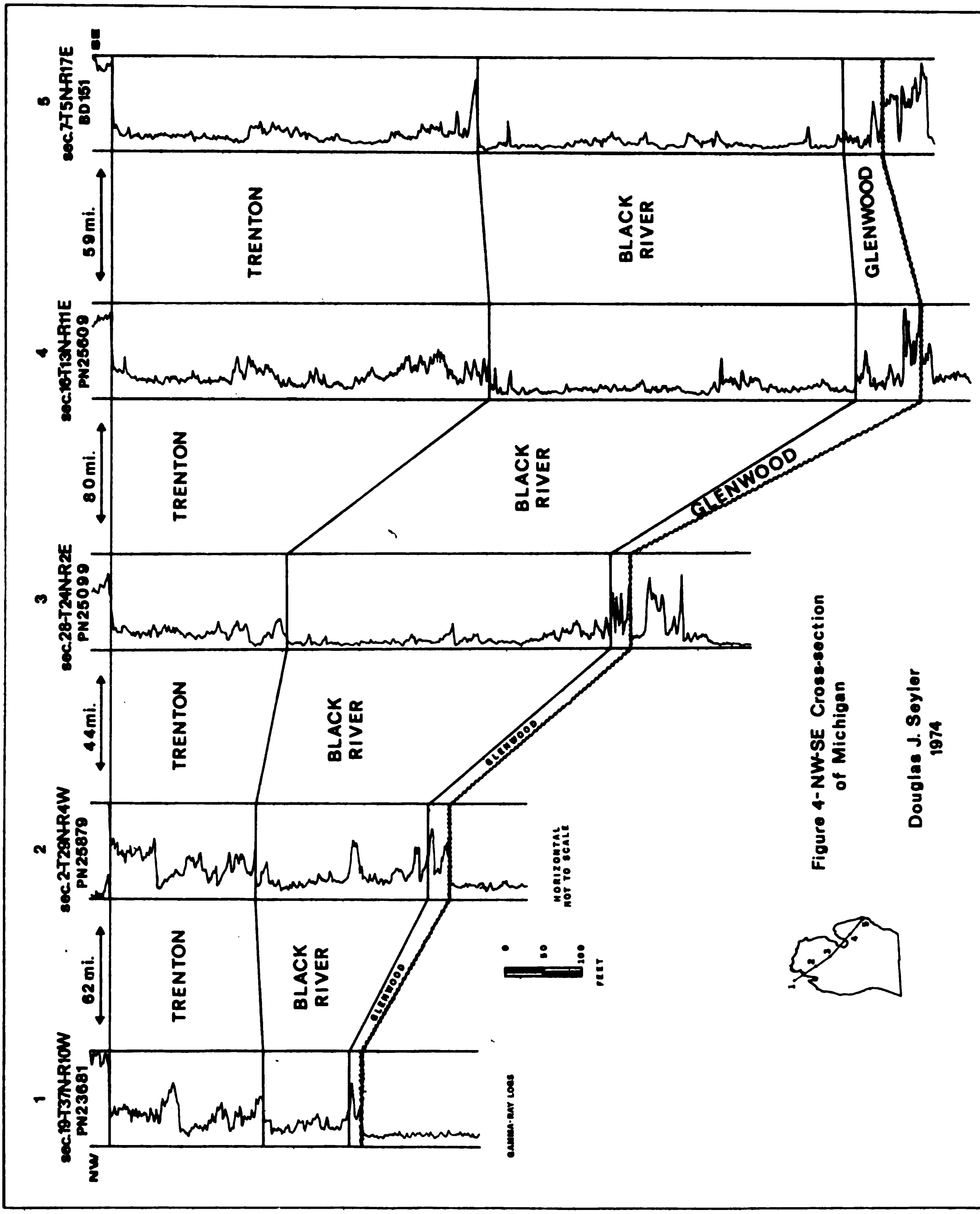

Figure 4-NW-SE Cross-section of Michigan

Douglas J. Seyler
1974

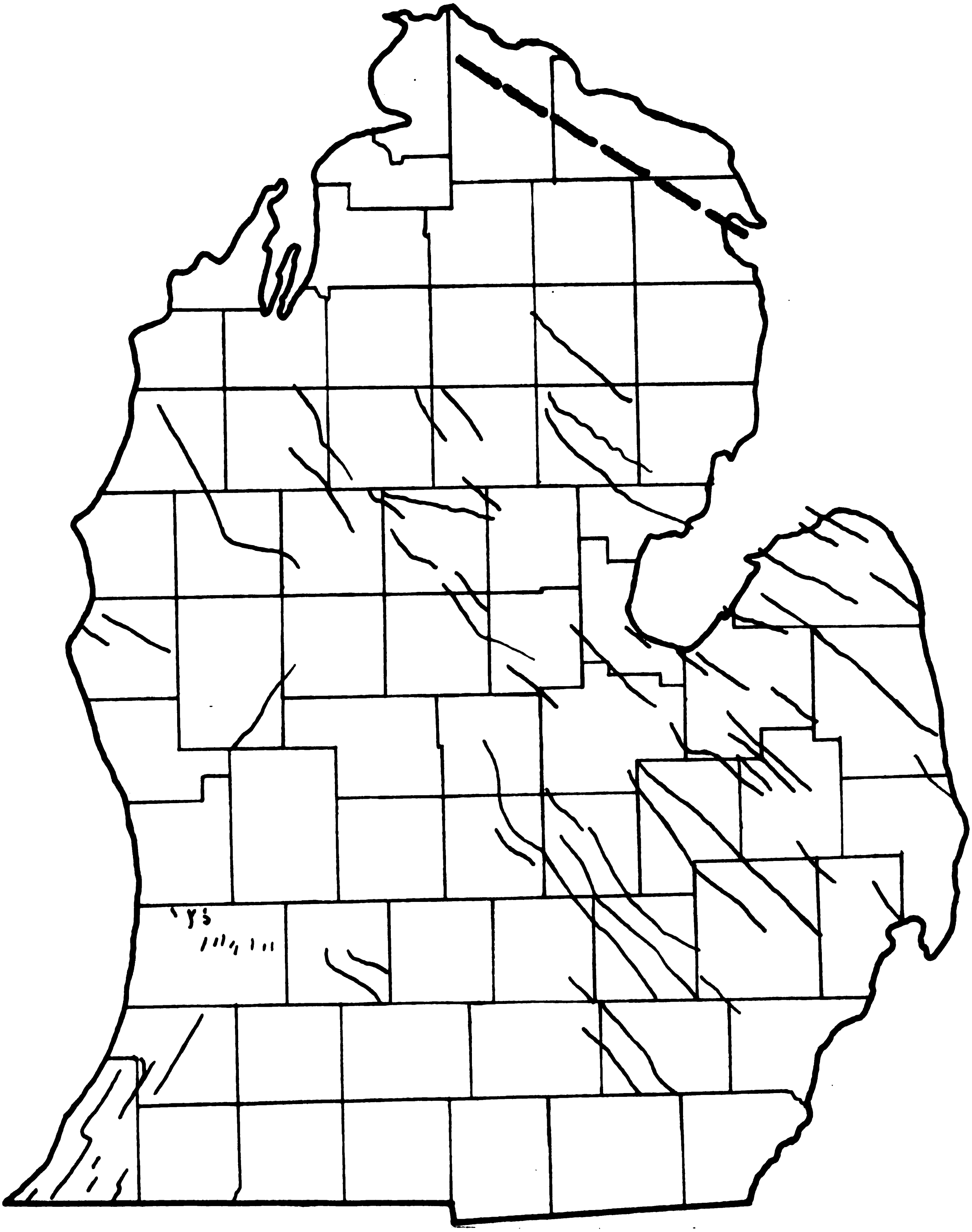

Figure 5. Major structural trends in the Michigan Basin (after Ells, 1969). The red dashed line represents the suggested fault area.

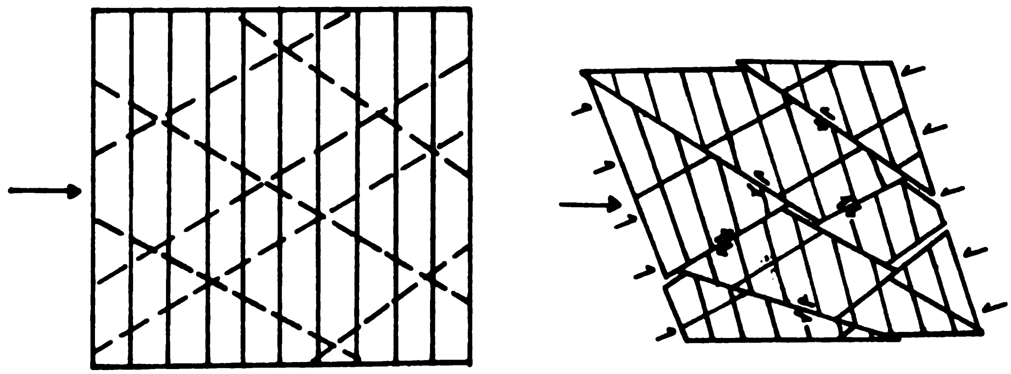

Figure 6.A. Initial cardboard model: dashed lines are precut weakness zones; solid lines are displacement indicators.

B. Representative experiment; compression from south of the bisectrix (after Thomas, 1974).

The Black River formation represents an embayment of the Middle Ordovician sea. It thickens locally into Lake Huron, but is open toward the southeast. In the southeast corner of the state there is an anomalous thin, which is open toward the area of the Chatham Sag. This type of thinning could be due to erosion of a subsequently positive area, or a lesser rate of subsidence of the area during deposition. Each explanation has support: there is some indication of an unconformity at the top of the Black River in this area; on the other hand, this area appears throughout the Middle Ordovician to have been somewhat more stable than surrounding parts of the basin. More well control is needed in order to resolve this problem.

It should be noted that the northern end of the Basin was quiet during this interval. Also, there is no indication of a Findlay Arch to the southeast during Black River time.

It is clear that during Trenton time a locally closed basin began to develop about a depositional center in southern Lake Huron. The Trenton isopach map, Plate 3, lends support to the statement by Green (1957) that the Michigan Basin was formed by basin subsidence, rather than by marginal uplift. There is no abrupt thickening off of a structure to the south, but rather a very gradual thickening, on the order of 25 feet per mile, into the basin. The Trenton basin is noticably elongate toward the east and west. This is particularly apparent when viewed in conjunction with isopach data from southwest Ontario, as shown in Figure 7. However, in view of the pattern and rate of thickening of the Trenton, the elongate shape of the basin is most likely due to stability, rather than uplift, of the marginal areas with respect to basinal subsidence.

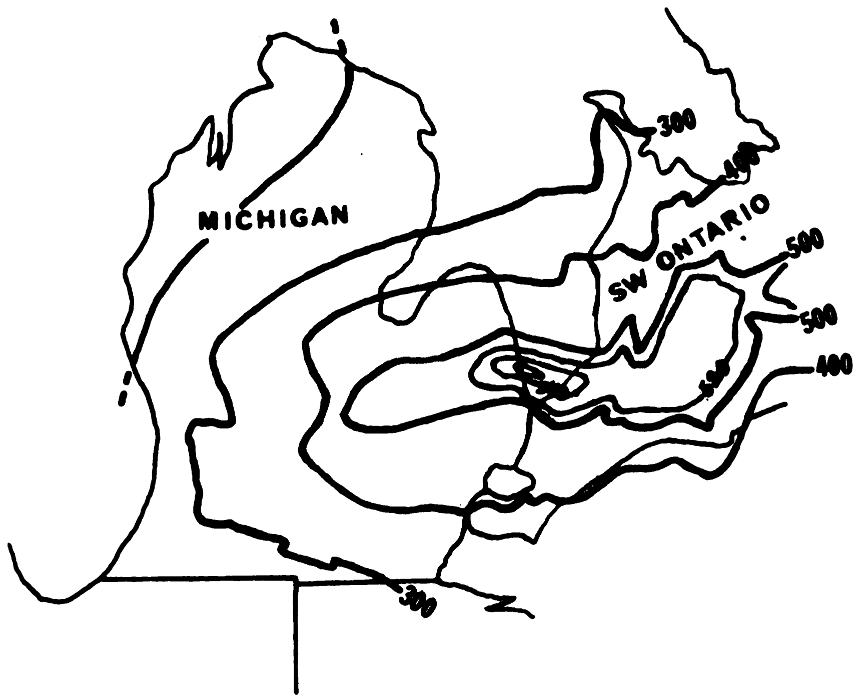

Figure 7. Trenton thickness in Michigan and Southwestern Ontario. Contour interval is 100 feet, except 20 feet where indicated (Southwestern Ontario after Sanford, 1961).

The northern part of the basin appears to have been active during the Trenton. During this period, there appears to have been wrench faulting, with the northeastern block moving right laterally. Figure 8 illuatrates the type of movement proposed; the general location of this fault is shown in red on Figure 5. Figure 9 is a cross-section of this area (note--the Trenton has been subdivided in this area, and the cross-section indicated that movement began during Middle Trenton time). If such movement did occur during deposition fo the Trenton sediments, there would be local thinning on the two truncated anticlines thus formed in the simplest case. This is, in fact, what is observed. Deposition concurrent with movement would produce thinning on the uplifted areas, and thickening in the troughs. Lateral movement need only have been on the order of a few hundred yards. It must be realized, however, that the structure is likely to be much more complex. Thus, en echelon folding and complex fracturing, as well as multiple lateral faulting is likely.

A similar origin has been proposed by Harding (1974) for the Albion-Scipio trend, in the southern Lower Peninsula. In the case of the Albion-Scipio trend, the wrenching was opposite to that proposed for the norhtern Michigan fault, being left lateral. In the Albion-Scipio trend, the wrenching was interpreted as being somewhat divergent, in order to produce the sag which occurs in the dolomitized zone of the trend. The movement was probably Upper Devonian (Fisher, personal comm., 1974); the proposed movement for the northern Michigan fault of this study was Middle Ordovician Trenton. Wilcox, Harding, and Seely (1973) present an excellent primer on basic wrench tectonics.

If this type of tectonic activity did take place in the Albion-Scipio trend, and in the norhtern Lower Peninsula, then it seems reason-

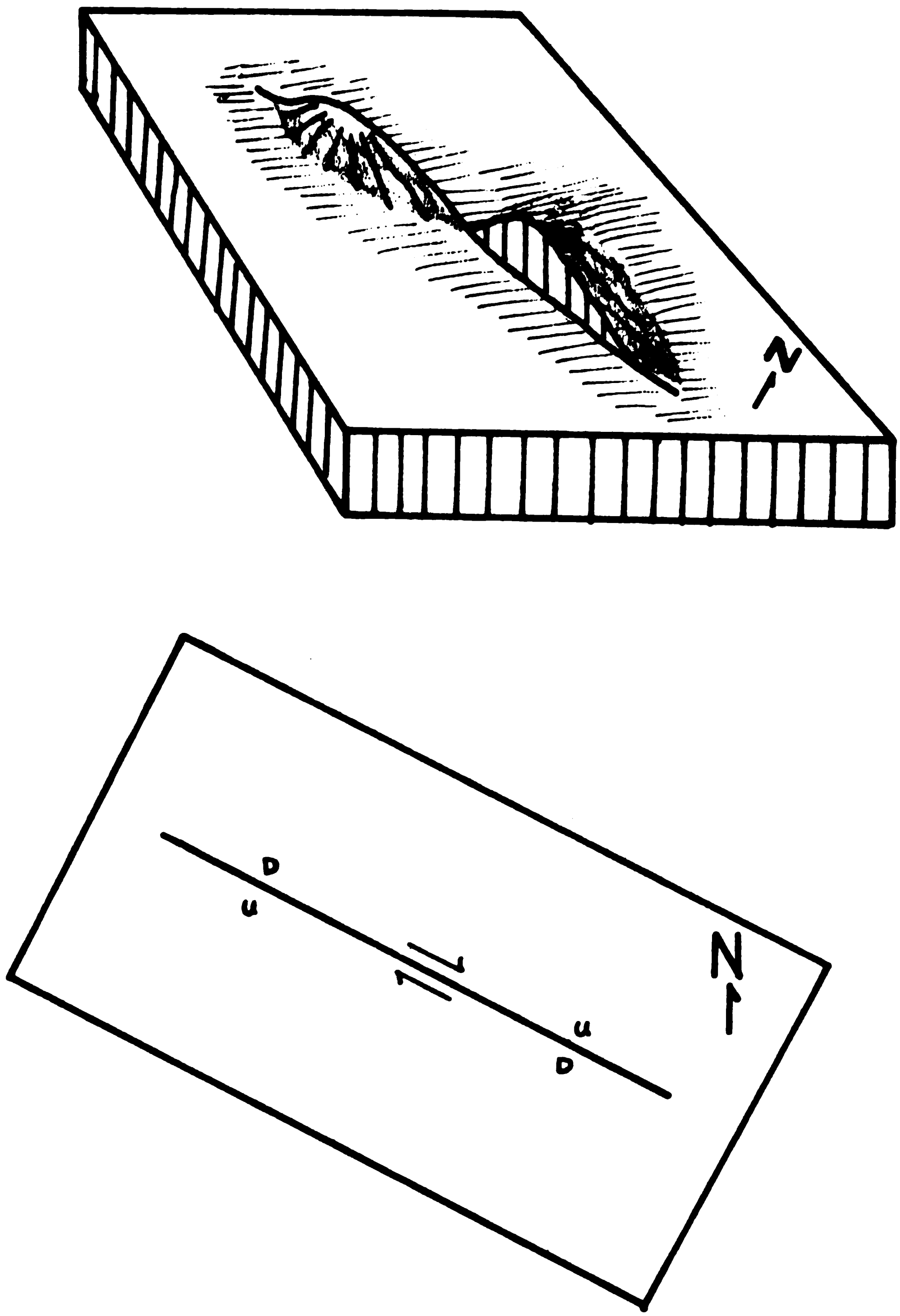

Figure 8. Diagram of the proposed type of wrench fault.

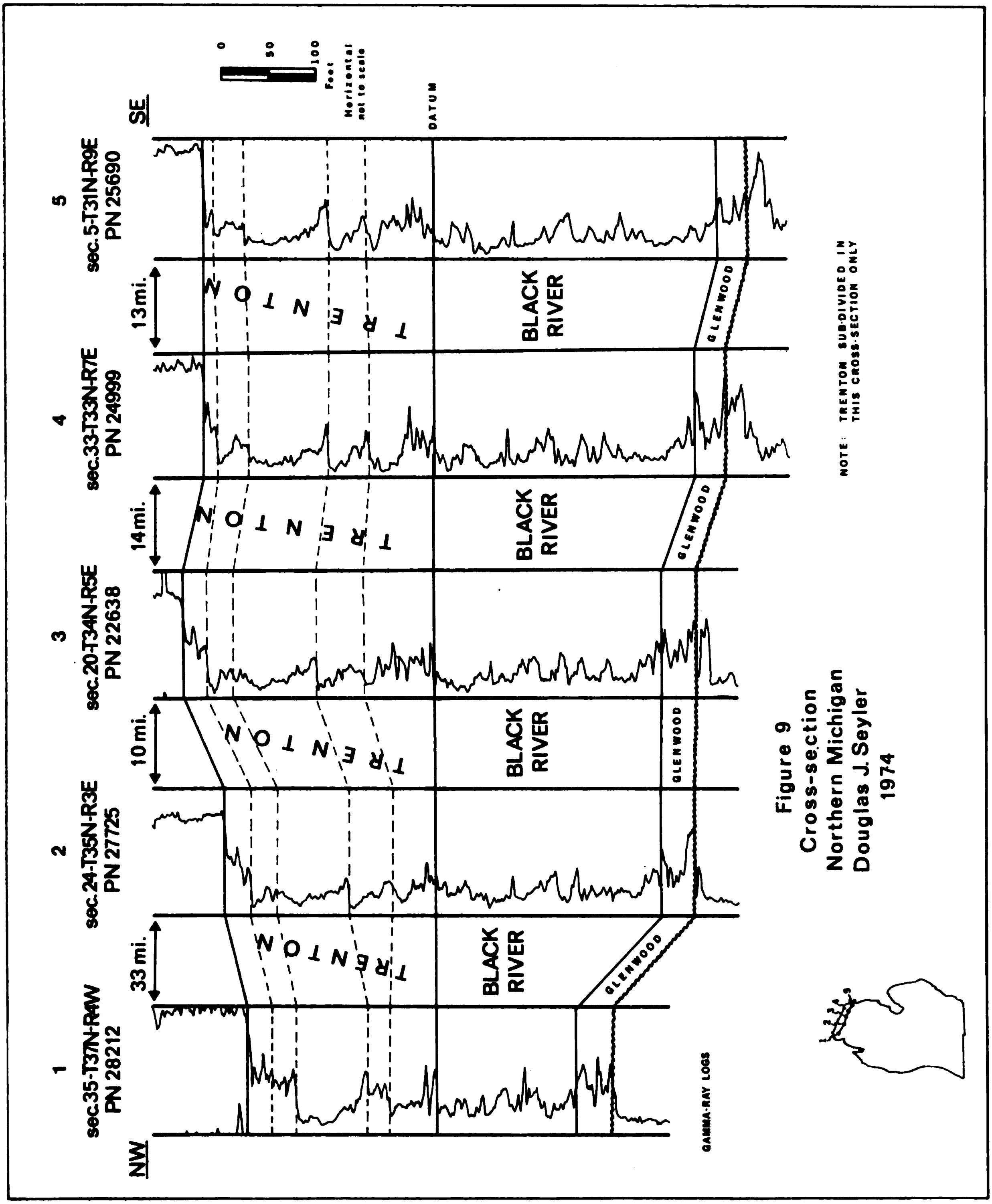

Figure 9
Cross-section
Northern Michigan
Douglas J. Seyler
1974

able to expect other examples to exist in the Paleozoic. Wrench faults, along with associated en echelon folds, truncated folds, and fractured zones along which dolomitizing solutions might travel, are viewed as a most attractive possibility for petroleum traps.

PETROLEUM POSSIBILITIES

The limestone and dolomite of the Black River and Trenton formations is essentially tight throughout the basin. Significant Trenton-Black River production has been essentially confined to porosity developed in localized secondary dolomitization of the limestone. The inferred source of dolomitizing solutions is the salt-water-bearing porous sandstones and dolomites of the Lower Ordovician and Upper Cambrian. Hydrocarbons may have been derived from the Middle Ordovician formations, from the shales and limestones below the Black River, or perhaps most likely, from up-dip migration of the hydrocarbons from the structurally lower portions of the overlying Utica shale.

In any case, the Trenton and, to a lesser degree, the Black River, have yielded petroleum in many parts of the basin. The most prolific field is the Albion-Scipio trend, which is classed as a giant oil field. The Trenton of southwestern Ontario also yields oil from locally dolomitized zones along small folds or faults. Trenton oil was produced in small quantities on Manitoulin Island, at the northern end of Lake Huron, during the 19th century. Continued Trenton discoveries are considered likely.

Since much of the Trenton production to date has been from porosity developed in locally dolomitized zones along fractures, the best future potential in other parts of the basin will probably come from similar structures.

SUGGESTIONS FOR EXPLORATION

The most significant result of this study has been the isolation of the anomalous structure in the northern part of the Lower Peninsula. If the interpretation of the structure as a wrench fault is correct, it is probable that this structure would develop local dolomitization similar to that in the Albion-Scipio trend. At the present time it is difficult to suggest specific localities for concentrated study due to the lack of well control; however, two observations can be made. The wells show that the Trenton and Black River in the area are essentially limestone, but the formations generally contain some dolomite, especially near the top of the Trenton. In addition, most drilling to date in the area has been at least several miles to the northeast of the proposed location of the fault, which is indicated in red on Figure 5. Further exploration is recommended toward the southwest, nearer the proposed structure.

The Trenton structure map, Plate 4, suggests several other possible faults that warrant more study. The locations of these are:

1) between T2S-R12W-sec. 31 and T2S-R13W-s-c. 36, a possible fault trending northwest;

2) between T6N-R8W-sec. 4 and T7N-R8W-sec. 34, a possible fold or fault trending northwest;

3) between T16N-R16W-sec. 11 and T16N-R16W-sec. 15, a probable fault trending northwest;

4) a possible fault trending northwest diagonally across the centers of Ingham and Washtenaw counties.

These features could develop similarly to the Albion-Scipio trend, and warrant closer examination with the present structural model in mind.

Finally, the Deep River field in Arenac county, T19N-R4E, should be studied with deeper objectives in mind. The present field is in the

Devonian Rogers City limestone, capped by the Bell shale. The petroleum accumulation is in a porous, locally dolomitized zone, and the feature bears a remarkable resemblence to Trenton accumulation in the Albion-Scipio trend. Not one well in this field, however, has been drilled into the Trenton (Mike Bricker, Michigan Geological Survey, personal comm., 1974). The linearity of the field, and its orientation parallel to the major structural trend of the basin suggest that this field could also be the result of wrench faulting. If this is true, then similar petroleum accumulation may occur in this field in the Trenton below.

Although the present fad in Michigan Basin exploration is Silurian reefing, the Middle Ordovician must not be overlooked as a potential source for significant new discoveries. The history of petroleum exploration in the Michigan Basin has all too often been marked by sporadic exploration, rather than by careful, thorough geologic study.

CONCLUSIONS

A closed, embrionic Michigan Basin began to form during the Middle Ordovician Trenton time, about a depositional center in the southern Lake Huron area. Prior to this, the area which is now the Lower Peninsula of Michigan, and southwestern Ontario, was an embayment of the Middle Ordovician sea, opening toward the southeast. The Glenwood rocks consist of eroded Cambrian and Lower Ordovician sediments, and transgressive marine sediments of the Middle Ordovician sea.

Isopach maps of the separate formations indicate a sizeable anomaly in the northern part of the Lower Peninsula. This anomaly is interpreted as a result of wrench faulting occurring concurrently with Trenton sedimentation, and to a lesser degree, during or prior to Glenwood deposition. Utilizing this model, several other possible faults have been identified. Petroleum accumulation is proposed in locally secondarily dolomitized zones along these faults, as in the Albion-Scipio trend.

The principal limitation encountered in a detailed study of the Middle Ordovician of the Michigan Basin is the lack of well control in the northern two-thirds of the Lower Peninsula. More study is clearly required in order to better determine the effect of basement faulting on the overlying sediments in the basin. A detailed study of the mechanisms and occurances of secondary dolomitization throughout the basin is also necessary for the prediction of the most favorable locations for exploration.

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APPENDIX-

WELL LOG DATA

LIST OF ABBREVIATIONS

PN = Permit Number

EL = Log Datum Elevation

T = Trenton depth (top)

BR = Black River Depth (top)

GW = Glenwood Depth (top)

BGW = Base of Glenwood Depth

LOCATION	PN	EL	T	BR	GW	BGW
T1N-R1W-sec. 11	28794	991.3	5189	5588	---	---
T1N-R2E-sec. 13	22607	972	4578	5018	5430	5463
sec. 31	24470	944.2	5020	5430	5770	5794
T1N-R5W-sec. 18		901	4470	4821	---	---
sec. 30	22487	885	4399	4772	5006	---
T1N-R6E-sec. 14	24771	929.1	4633	5072	5488	5524
T1N-R6W-sec. 2	22497	947.7	4554	4927	5161	---
sec. 17	22541	953.6	4408	4767	5003	---
T1N-R7W-sec. 19	22170	950	4208	4561	4780	---
T1N-R8E-sec. 32	18962	962	4386	---	---	---
T1N-R8W-sec. 14	BD153	942	4195	4552	4756	---
T2N-R1W-sec. 29	28607	939.1	5213	5611	---	---
T2N-R2W-sec. 33	28929	937	5022	5407	5706	---
T2N-R3E-sec. 17	28752	960	5053	5487	5891	5928
T2N-R4E-sec. 14	25868	939	5342	5807	6222	6258
T2N-R5W-sec. 18	22672	924.7	4755	5131	5365	---
sec. 22		913.6	4820	5200	---	---
T2N-R7W-sec. 22	21999	979	4567	4933	5152	---
T2N-R9W-sec. 34	20732	925	4197	4546	4747	---
T2N-R11W-sec. 18	21865	822.8	3761	4090	4266	---
sec. 30	23361	835.6	3688	4016	4190	---
T2N-R12W-sec. 10	23685	827	3755	4083	4257	---
sec. 25	21684	849	3717	4047	4216	---
T2N-R16E-sec. 17	25780	581	3050	3493	3937	3996
T3N-R3E-sec. 1	29051	920.2	4798	5280	5655	5678
sec. 2	23374	939	4744	5231	5600	5634
T3N-R4E-sec. 20	28594	970	5117	5595	---	---
T3N-R5E-sec. 11	27986	980.2	5289	5765	6201	6229
T3N-R7W-sec. 22	21987	907.8	4843	5211	5440	5455
sec. 24	23589	949.5	4917	5290	5518	---
T3N-R11W-sec. 17		789.8	3996	4332	---	---

LOCATION	PN	EL	T	BR	GW	BGW
T4N-R3E-sec. 28	22642	899.5	5118	5592	5955	5987
T4N-R7E-sec. 9	22665	1004	5865	6352	6809	6842
T4N-R7W-sec. 20	23572	882.2	5048	5412	5637	5672
T4N-R8E-sec. 35	28258	1046.5	5400	5870	6320	---
T4N-R8W-sec. 3	23363	882.4	5038	5359	5618	5651
sec. 20	23573	863.8	4822	5143	5393	5428
T4N-R13E-sec. 1	26214	692	4219	4681	5120	5179
sec. 29	29024	663	4104	4554	5062	---
T4N-R13W-sec. 3		731	3910	---	---	---
T4N-R15E-sec. 31	BD139	615.5	3546	3988	4434	4486
T5N-R2E-sec. 5	22379	856.1	5885	6340	6719	6756
sec. 22	23376	906	6336	6849	---	---
T5N-R3E-sec. 15		885	5986	6495	---	---
T5N-R7W-sec. 15	23574	870.2	5394	5763	5994	---
T5N-R8W-sec. 28	23482	816.4	5055	5392	5633	5673
T5N-R13E-sec. 7	22439	785.3	4728	5200	5630	---
T5N-R13W-sec. 30		685	3884	4197	---	---
T5N-R15W-sec. 11	21529	649	3767	4046	4202	---
T5N-R17E-sec. 7	BD151	633	3584	4057	4532	4579
T6N-R8W-sec. 4	27021	685	5439	5760	6018	---
	25025	718	5496	5830	6073	6089
	27441	705	5472	5806	6048	6072
T6N-R12E-sec. 18		908	5431	5923	---	---
T7N-R1W-sec. 6	27811	772.5	6811	7218	7579	---
T7N-R8W-sec. 34	24619	775.1	5551	5886	6132	6157
sec. 35	26990	820	5659	5998	6242	---
T7N-R13E-sec. 28	25632	813	5310	5794	6231	6306
T7N-R13W-sec. 34	25800	653.5	4372	4661	4838	---
T7N-R15W-sec. 19	20147	639	3898	---	---	---
T7N-R16W-sec. 27	25813	617	3744	---	---	---

LOCATION	PN	EL	T	BR	GW	BGW
T8N-R4W-sec. 27	22399	754	6755	---	---	---
T8N-R9W-sec. 6	24826	867	5914	6244	6479	6512
sec. 35	24627	872.2	5829	6183	6398	6428
T8N-R13E-sec. 34	25786	801	5609	6097	---	---
T9N-R8E-sec. 4	24079	836.5	7473	7986	8450	---
T9N-R10W-sec. 26	26908	911	5994	6323	6564	6596
T9N-R13W-sec. 6	537	704	5048	---	5490	---
T9N-R15E-sec. 27	26480	759	5183	5717	6187	6263
T10N-R9E-sec. 5	20209	873.1	7860	---	---	---
T10N-R15E-sec. 9	25939	775	5562	6123	6599	6683
T10N-R16E-sec. 27	24441	770.2	5204	5755	6240	6304
T11N-R12W-sec. 10	23149	811.8	6044	6321	6503	---
T11N-R13W-sec. 15	22918	817	5687	5958	6138	6180
T12N-R17W-sec. 20	18666	666	4389	---	---	---
T12N-R18W-sec. 36	BD 1	656	4259	4474	4592	4625
T13N-R1W-sec. 10	22782	676.7	3384	---	---	---
sec. 21	23849	694.7	8980	9470	---	---
T13N-R9E-sec. 8	23890	678	8885	9381	9914	9992
T13N-R11E-sec. 16	25609	737.5	8119	8606	9078	9164
T13N-R18W-sec. 13	28182	699.2	4516	4720	4837	---
T14N-R4E-sec. 2	5441	599	9400	---	---	---
T15N-R14W-sec. 20	26662	829	6044	6268	6432	6486
T15N-R17W-sec. 36	24087	733	5120	5323	5451	5500
T16N-R16W-sec. 11	22801		5685	5879	6028	---
sec. 15		945	5674	5869	---	---
T16N-R17W-sec. 6	17549	651.3	4945	5121	5233	---

LOCATION	PN	EL	T	BR	GW	BGW
T17N-R16W-sec. 25	18905	726.2	5605	5797	5940	5999
sec. 18	29503	718	5494	5671	5799	5836
T18N-R10W-sec. 29	12802	1133.3	8319	---	---	---
T19N-R18W-sec. 27	17789	647	5077	5234	5325	5345
T20N-R17W-sec. 3	27155	686	5194	5355	---	---
T22N-R2E-sec. 35	12898	903.4	9779	10036	10394	---
T23N-R3E-sec. 28		877.5	9408	---	---	---
T24N-R2E-sec. 28	25099	1477	9767	9995	10412	10440
T24N-R13W-sec. 8	24557	907.5	6779	6951	---	---
T25N-R4W-sec. 21	28110	1240.5	9379	9594	9912	9933
T29N-R4W-sec. 2	25873	1412.5	7696	7885	8108	8136
T30N-R11W-sec. 6	22627	925.4	5378	5549	5705	5723
T31N-R9E-sec. 5	25690	684	4802	5023	5296	5322
T32N-R1W-sec. 30	27448	981	6133	6315	6530	---
T32N-R5E-sec. 34	29571	740.6	4616	4846	5108	5162
T32N-R8W-sec. 19	22639	878.3	5390	5578	5737	5755
T33N-R5E-sec. 13	29372	776	4743	4966	5206	---
T33N-R7E-sec. 33	24999	816	4836	5059	5310	5340
T34N-R5E-sec. 20	22638	844.2	4576	4811	5043	5076
T34N-R7W-sec. 14	29119	716.5	4600	4784	4962	---

LOCATION	PN	EL	T	BR	GW	BGW
T35N-R2E-sec. 29	27199	808.5	4254	4482	4700	4743
T35N-R3E-sec. 24	27725	730.1	4159	4365	4589	4617
T35N-R6E-sec. 31	20194	668	3888		4380	4427
T37N-R4W-sec. 35	28212	715	3528	3709	3845	3880
T37N-R10W-sec. 6	23478	743	3007	3201	3310	3322
sec. 19	23681	660.6	3054	3253	3364	3380
T38N-R10W-sec. 27	23435	679.5	2876	3073	3185	3195
T1S-R3E-sec. 7	19384	939.3	4222	4650	5045	5100
sec. 22	24161		4269	4686	5088	---
T1S-R3W-sec. 14	22719	944.5	4513	4907	5171	---
T1S-R4W-sec. 33	23427	985.8	4256	4637	4883	4926
T1S-R5W-sec. 12		193.3	4395	4800	---	---
sec. 16	23637	969	4302	4680	4918	---
sec. 26	23020	948.3	4208	4588	4830	4870
T1S-R7E-sec. 1		987.6	4274	---	---	---
T1S-R8E-sec. 25		717.7	3656	4097	---	---
sec. 26		683	3625	4047	---	---
T1S-R9E-sec. 30		705.9	3596	4036	---	---
sec. 32			3525	3962	---	---
T1S-R10W-sec. 27	20972	913	3564	3906	4085	---
T1S-R12W-sec. 10	23035	789.5	3302	3626	3792	3797
T1S-R14W-sec. 16	28590	764	2963	3259	3404	---
T1S-R15W-sec. 13	10550	694.8	2857	---	---	---
T1S-R16W-sec. 28	21900	641	2551	2815	---	---
T2S-R4W-sec. 7	23553	931.8	4118	4498	4739	4786
sec. 19	23757	985	4091	4468	4710	---
sec. 20	25096	979	4110	4462	---	---
sec. 33	23001	951	3989	---	---	---
sec. 33	22748	976	4212	4591	---	---

LOCATION	PN	EL	T	BR	GW	BGW
T2S-R5W-sec. 6		963.2	4056	4434	---	---
sec. 11	22723	970	4120	4498	---	---
sec. 12	23746	962	4137	4515	4755	---
sec. 13	22415	954.4	4070	4446	4686	---
T2S-R11E-sec. 19	25560	587.7	2990	3427	3868	3906
T2S-R12W-sec. 31	13483	857.3	3117	---	---	---
T2S-R13W-sec. 36	21370	824.8	2995	---	---	---
T3S-R4E-sec. 6		967.7	3784	4232	---	---
sec. 8	19231	945.1	3810	4227	---	---
T3S-R4W-sec. 3		966	3972	---	---	---
sec. 4	22873	992.6	3966	4340	---	---
sec. 10	21502	997.7	3937	4302	---	---
sec. 15		1029.2	3950	4309	---	---
sec. 16	22882	952.7	3866	4237	---	---
sec. 18	28596	946.5	4128	4553	---	---
sec. 22	22657	999.5	3849	4220	---	---
sec. 36	23560	1017.3	3827	4190	---	---
T3S-R3W-sec. 14	22107	995	3995	4377	4635	---
sec. 30	22351	999.3	3833	4207	4458	4502
T3S-R8W-sec. 13	22352	951.6	3497	3850	4048	4104
T3S-R14W-sec. 2	24624	752	2709	---	---	---
T3S-R18W-sec. 36	24368	731.5	2167	2429	2556	2573
T4S-R1E-sec. 30	26016	705.9	3596	4035	---	---
T4S-R2E-sec. 24	23656	1051.1	3892	4283	4595	4625
T4S-R2W-sec. 8	23446	1055.6	3847	4218	---	---
sec. 17	23013	1071.5	3848	4217	4478	---
T4S-R3W-sec. 6	23115	1073	3842	4210	---	---
sec. 8	22731	1033.8	3774	4115	---	---
sec. 8	22955	1033	3830	4198	4454	---
sec. 17	22934	1017	3704	4070	---	---
sec. 18	23828	1008	3713	4078	4325	4343
sec. 20	25950		3846	4243	4562	4582
sec. 28	24031	1104.9	3730	4092	4342	---
sec. 33	22503	1092.7	3682	---	---	---
sec. 34	23197	1114.5	3692	4053	4324	---

LOCATION	PN	EL	T	BR	GW	BGW
T4S-R4W-sec. 1	23608	1037.6	3800	4168	4414	---
sec. 22	23551	1025.6	3642	4004	4249	4271
T4S-R5E-sec. 14	23921	794.5	2944	3351	---	---
T4S-R6E-sec. 28	22292		2757	3154	3579	---
T4S-R6W-sec. 17	23753	1004.1	3475	3825	4036	4081
T4S-R7W-sec. 5	19591	943	3420	3771	3969	---
T4S-R8E-sec. 22	5830	642	2490	---	---	---
T4S-R9E-sec. 18	10099	635	2564	---	---	---
T4S-R10E-sec. 22	BD146	609.4	2361	2783	3231	3252
T4S-R10W-sec. 11	23004		3079	3409	3588	---
T4S-R13W-sec. 5	18559	810	2667	---	---	---
T4S-R14W-sec. 34	23524	921.5	2614	2894	3040	3064
T5S-R1E-sec. 18	22010	1091.7	3703	4050	4355	4402
sec. 33	22044	1079.6	3552	3892	---	---
T5S-R2W-sec. 23	22877	1115.7	3636	3994	4261	4295
sec. 24	22183	1135.5	3634	3995	---	---
sec. 31	22876	1158	3488	3837	4102	4156
T5S-R3W-sec. 3	22403	1097.3	3680	4021	---	---
sec. 4	23422	1029.6	3588	3949	4200	4222
sec. 4	22201	1087.8	3662	4007	---	---
sec. 8		1017.4	3517	3875	---	---
sec. 10	22268	1041.2	3526	3885	4135	4165
sec. 11	21946	1067	3577	3935	4190	---
sec. 14	23810	1147	3620	3976	4227	---
sec. 23	22381	1175	3634	3981	---	---
sec. 25	22257	1173.5	3576	3931	4191	---
sec. 26	24535	1147	3558	3906	---	---
T5S-R4E-sec. 14	22886	872.3	3150	3533	3949	3989
T5S-R4W-sec. 11	21373	1057	3531	3886	4126	---
sec. 19	23193	1041	3390	3736	3969	---
T5S-R5W-sec. 5	21862	966	3382	3730	3947	3990
T5S-R5E-sec. 23	24645	720	2518	2905	3272	---
T5S-R6E-sec. 13	22092		2452	2829	3279	3321
sec. 15	23659	685.5	2488	2868	---	---

LOCATION	PN	EL	T	BR	GW	BGW
T5S-R7E-sec. 22	23532		2420	2771	3224	---
T5S-R7W-sec. 17	21968	940	3144	3439	3671	3708
sec. 20		925.4	3102	3424	---	---
T5S-R13W-sec. 31	23668	921.7	2528	2818	---	---
T6S-R1E-sec. 20	23838		3258	3574	3889	3922
T6S-R2E-sec. 25	23751	864	3002	3332	3707	3740
T6S-R2W-sec. 4	24312	1215	3577	3940	---	---
sec. 6	25761	1122.8	3444	3797	---	---
sec. 7	23018	1162.8	3495	3846	4111	4163
sec. 7	21834	1124.5	3438	3784	4045	---
sec. 22	23590	1161	3424	3764	4031	---
sec. 32	21771	1178.5	3387	3719	---	---
T6S-R3W-sec. 32	20220	1137	3255	3584	3836	---
T6S-R4W-sec. 7	20357	1024	3225	3531	3798	3824
sec. 7	23817	1082	3104	3436	3655	3690
sec. 35	23677	1163.3	3289	3588	3892	---
T6S-R5W-sec. 36	26478	1075	3125	3414	3680	3718
T6S-R6E-sec. 30	20986	678.4	2043	2392	---	---
T6S-R6W-sec. 36	23639	1004.7	3012	3300	3553	3585
T6S-R8W-sec. 29	21519	865.4	2732	3036	3228	---
T6S-R9W-sec. 29	24183	861.7	2642	2917	3127	3168
T6S-R11W-sec. 14		837.5	2547	2807	3026	3077
sec. 27	21155	823	2490	2750	2961	2978
T6S-R14W-sec. 14	23698	919.8	2418	2696	2843	2869
T6S-R17W-sec. 10	26112	804.2	2021	2284	2413	2469
T6S-R19W-sec. 1	24369	654	1762	2009	---	---
T7S-R1E-sec. 29	22716	911.8	2931	3246	3525	3562
sec. 34	23723		2782	3097	---	---
T7S-R1W-sec. 2	21951	1088	3283	3620	3907	3942
sec. 35	23058	915.2	2912	3220	3495	3534
T7S-R2E-sec. 12	28533	827	2880	3198	3537	---
sec. 27	23737		2752	3058	3425	---

LOCATION	PN	EL	T	BR	GW	BGW
T7S-R2W-sec. 10	21770	1097.7	3213	3508	3803	---
sec. 24	22304	1061.5	3140	3429	3725	3758
T7S-R4W-sec. 29	21856	1080.5	3053	3349	3577	---
T7S-R5W-sec. 25	25758	1101.7	3034	3301	3568	3605
sec. 32	23860	1017	2911	3164	3424	3460
T7S-R6W-sec. 2	21433	1027	3011	3293	3530	3569
sec. 15	23564	1022	2944	3221	3473	3485
T7S-R7E-sec. 12	23024		1833	2181	---	---
T7S-R7W-sec. 10	21893	955.5	2833	3099	3347	3397
T7S-R8W-sec. 7	22867	886	2677	2947	3176	---
sec. 15	20685	910	2695	2967	3196	3270
T7S-R9W-sec. 15	23839	875.5	2587	2848	3078	3087
T7S-R14W-sec. 8	23289	864.8	2220	2491	2641	---
T7S-R15W-sec. 26	23290	846	2028	2309	2451	2477
T8S-R1E-sec. 3	23276	853	2809	3120	3465	---
T8S-R1W-sec. 5	22147	938.7	2932	3237	3510	3545
sec. 11	23997	924	2877	3183	3456	3486
T8S-R2E-sec. 20	23718	790	2583	2874	3240	---
T8S-R3E-sec. 26	28531	746	2496	2783	3124	---
T8S-R4E-sec. 18	16693		2508	2808	3156	3187
T8S-R4W-sec. 10	23973	1081	2914	3171	3445	3488
sec. 34	23101	979.3	2711	2959	3238	3247
T8S-R6E-sec. 31	23373	695.6	1809	2132	2534	2558
T8S-R6W-sec. 9	23686	1007.6	2781	3049	3291	3328
T8S-R14W-sec. 3	22047	846.7	2092	2348	2498	2506