DEVELOPMENTAL HISTORY OF THE HOWELL ANTICLINE

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ABSTRACT

DEVELOPMENTAL HISTORY
OF THE
HOWELL ANTICLINE

By

Randy Max Paris

The Howell Anticline is the most prominent of Michigan's many northwest-southeast trending anticlines. Located along a major zone of basement weakness the Howell Anticline has responded to the regional tectonic forces which have affected the Michigan Basin. During late Salina time the northeast block of this fault zone subsided as tension and gravity acted as the dominant regional forces. Later as compressional forces began to be felt throughout the region accompanying the Appalachian Orogeny the Howell Fault zone reacted with uplift along the northeastern block resulting in a pattern of en echelon, faulted, asymmetrical anticlines that reflect simple shear wrench fault mechanics. Hydrocarbons accumulation occurred within fractured carbonates in linear trends associated with the fault zone. Projecting this model into the central Michigan Basin area opens up the possibility of deeper production beneath the many northwest trending anticlines which have been the heyday of Michigan oil and gas production.

DEVELOPMENTAL HISTORY

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HOWELL ANTICLINE

By

Randy Max Paris

A THESIS

Submitted to
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A note of gratitude is extended to those of the oil and gas industry of Michigan who provided information and materials that were used in the preparation of the thesis: the Michigan Geological Survey, Hunt Energy Corporation, and most especially my father and Panhandle Eastern Pipeline Company.

Special gratitude is given to my wife Nancy, whose love and patience made this effort worthwhile.

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INTRODUCTION

Lying nearly along the northwest diagonal of Livingston County in southeastern Michigan, the Howell Anticline is one of Michigan's most prominent linear features (Figs. 1, 1a). It is a part of a system of anticlines beginning with the Northville Anticline in Wayne and Washtenaw Counties which strike northwest through Livingston County, which Newcombe (1933) designated the Howell-Owosso Anticline. Additional drilling will most likely extend this feature through Shiawasse County and into Gratiot County, but current well control limits this extension to a much broader regional type of study rather than a local study such as this. The anticlines along this trend are northwesterly plunging and are roughly sub-parallel structures which Ells (1969) has termed the Washtenaw Anticlinorium.

Covered by a blanket of glacial till ranging between 40 and 350 feet in thickness, the Howell Anticline is not discernable from a surface study. The discovery of the anticline may have been in the 1920's when it was recognized that the Saginaw formation was not continuous across the area (in Kilbourne, 1947). Newcombe (1933) in an extensive study of Michigan geology defined the Howell-Owosso Anticline with a structure map on the Berea Sandstone. He suggested and presented evidence of an en echelon series of faults along the southwest flank of the structure with a total vertical displacement, throw, of as much as 1000 feet on the Berea Sandstone. Keck (1938) did some early

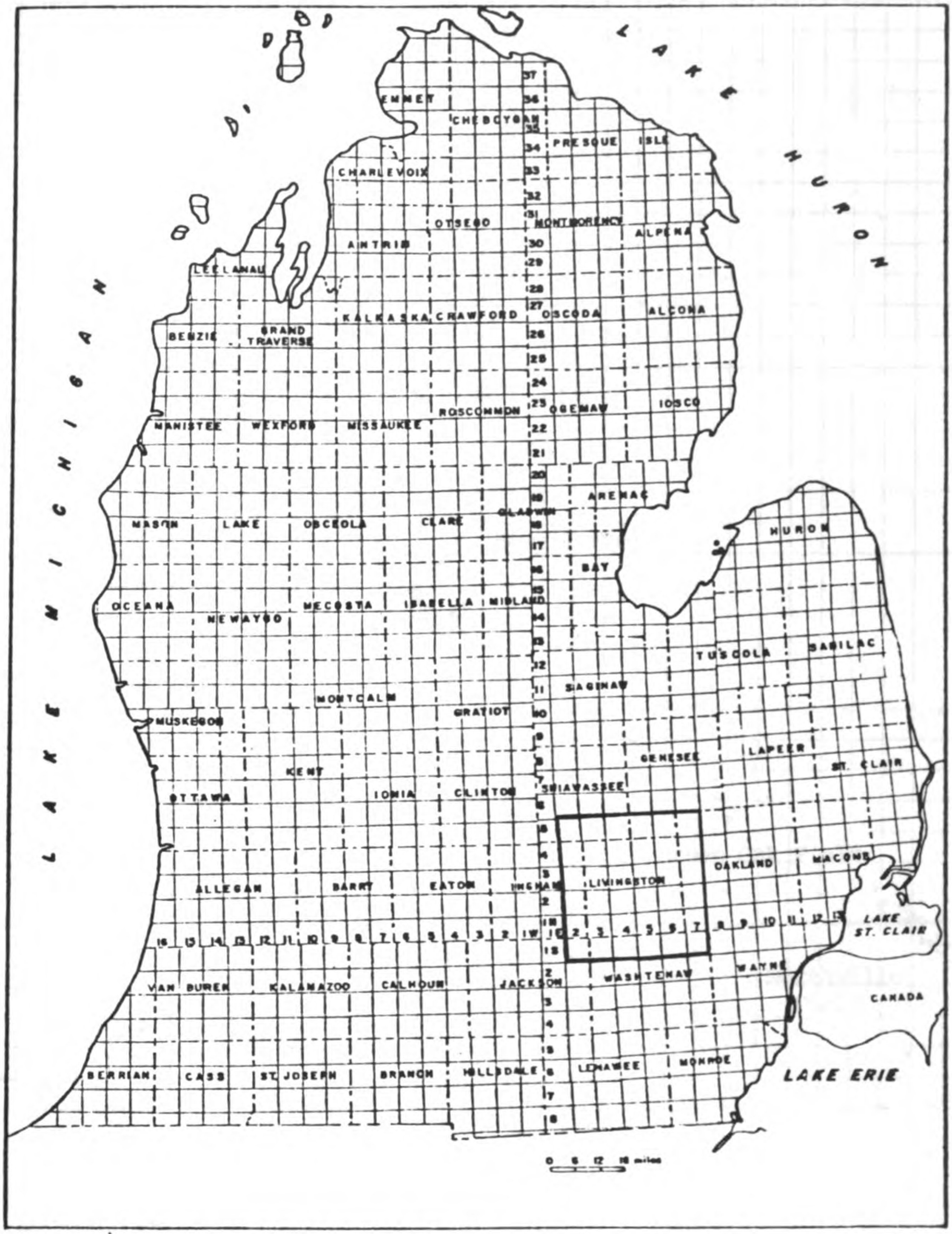


Figure 1. Location of Study Area Within Michigan

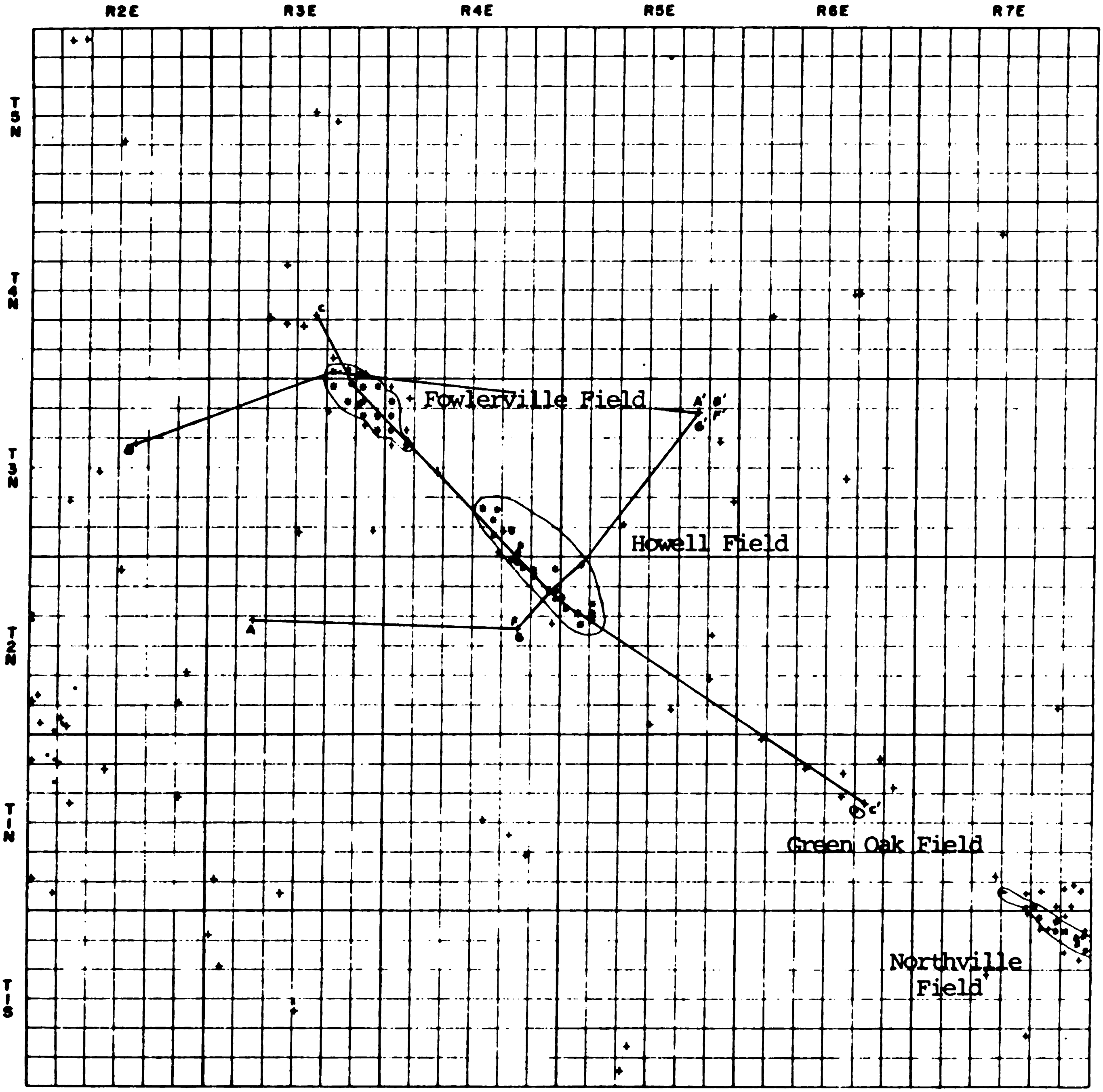


Figure la. Location Map
Location of fields and cross-section lines

geophysical work in the area by conducting a resistivity survey. His results showed the Saginaw was offlapped along the sides of the structure, with Coldwater shale exposed higher up on the anticline. Kilbourne, (1947), with more well control than was available to Newcombe, drew a structure map on the Dundee formation again showing faulting along the southwest flank. Cohee and Landes (1958) noted that the crest of the Dundee structure did not directly overlie the crest of the Niagara structure of the Howell Anticline. Hinze and Merritt (1969) noted that the Howell feature was on top of a Mid-Michigan gravity and magnetic high. Checkley (1968) conducted a field study of the Northville Field connected the Northville anticline with the Howell Anticline as being a part of the same structure. Ells (1969) used the control provided by the sixty-nine wells of the Howell Storage Field to yield good definition of the structure down to the Niagara formation in the region of Howell. Since Ells' work, there has been additional drilling near Fowlerville in Livingston County. The purpose of this study is to conduct a broader study of the Howell Anticline, extending the structure northward to include the Fowlerville Field and to the southeast to catch the northern terminus of the Northville Field. It is hoped that this study will illustrate the developmental history of the Howell Anticline from the late Ordovician (Cincinnatian) to Recent. It is further the purpose to construct a possible model, based on the Howell Anticline, to explain the many northwest-southeast striking anticlines of the central Michigan Basin area (Fig. 2).

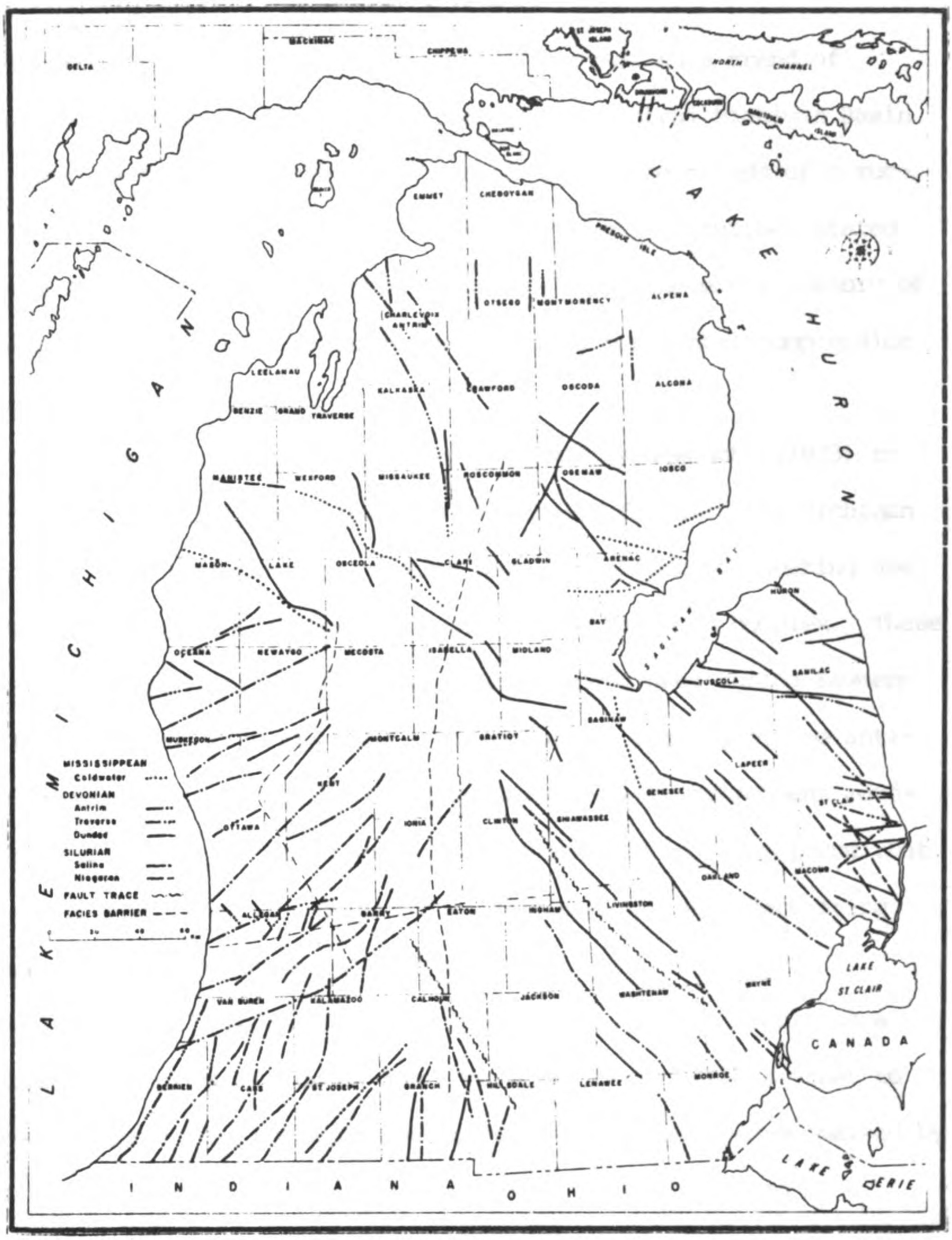


Figure 2. Major Structural Trends in the Michigan Basin (compiled by Prouty, 1971)

Previous Work

The Howell Anticline is the most prominent of this trend of northwest-southeast striking anticlines in the central Michigan Basin area. Pirtle (1932) attributed this fold pattern to trends of structural weakness in the Precambrian basement rocks. He further stated that the folds were due to vertical forces during the early history of the basin with continued deformation following horizontal compression during middle Mississippian time.

Deep seated basement faults were believed by Newcombe (1933) to control the localization of the many en echelon folds of the Michigan Basin. He felt that these structures were the effect of shearing due to movements along deeply buried faults in the basement complex. These faults were along lines of basement weakness developed during Keweenawan time, according to Newcombe. The principal folding of the anticlinal trends occurred during the late Devonian with subsequent movement during later periods accentuating the structures. The force that formed the anticlines is attributed to "growing stresses forcasting the Appalachian Revolution" (Newcombe, 1933).

Kirkham (1937) believed the Michigan Basin was the result of a shifting of large magma bodies from one area of the earth's crust to another. During this movement the Precambrian surface became marked by joint systems, faults, rifts, and shear zones creating zones of weakness along which vertical forces could later act. Step faults along these lines within the Michigan Basin resulted in the subparallel anticlinal trends.

The dominant positive structures are the cores of old Precambrian mountains according to Lockett (1947). The principal movement was subsidence of the basin. The weight of the sediments from these mountains provided the mechanism of subsidence. During the Paleozoic, three sides remained stable as the area of the Ontario Sag continued to subside resulting in a system of fractures in the basement. Continued sedimentation caused differential subsidence with preference on the basinward side of these lines of weakness. Lockett attributed the mid-basin anticlinal trends to this subsidence.

Kilbourne (1947) concluded that the area of the Howell Anticline was a local low until Coldwater time. At the beginning of Coldwater time normal faulting along old lines of weakness in the basement rocks resulted in uplift of the northeast side of the fault and the coming into existance of the Howell Anticline.

Cohee and Landes (1958) believed that the Michigan Basin underwent its greatest episode of subsidence during the late Silurian, with downwarping during Salina, Bass Islands, and Detroit River times. They further stated that the major structural deformation of the Basin occurred during late Mississippian and pre-Pennsylvania times. This episode of deformation formed the structural traps in Michigan.

Hinze and Merritt (1969) noted that the vertical magnetic intensity map (Fig. 3) and the Bouguer gravity anomaly (Fig. 4) map closely parallels the northwesterly trend of the mid-basin anticlines south of $40^{O}30'$N lattitude. Of particular interest is that the Howell Anticline is very closely associated with the Mid-Michigan gravity and magnetic High. They attributed this close allignment of trends of intrabasin structures and geophysical anomalies to lines of weakness in the basement complex that are associated with a rift zone filled with basalts delineated by the Mid-Michigan gravity and magnetic anomalies.

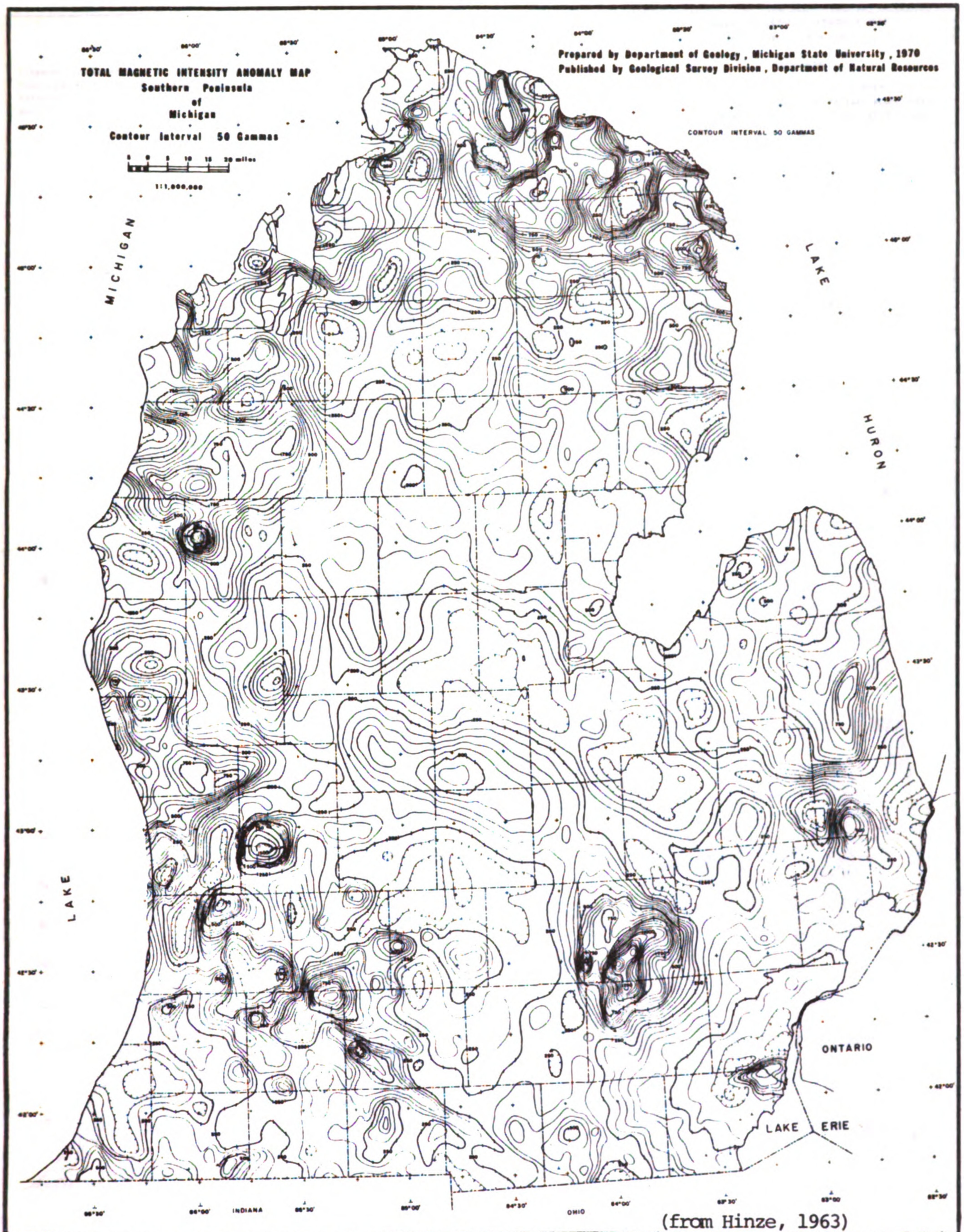


Figure 3. Aeromagnetic Map of the Southern Peninsula of Michigan

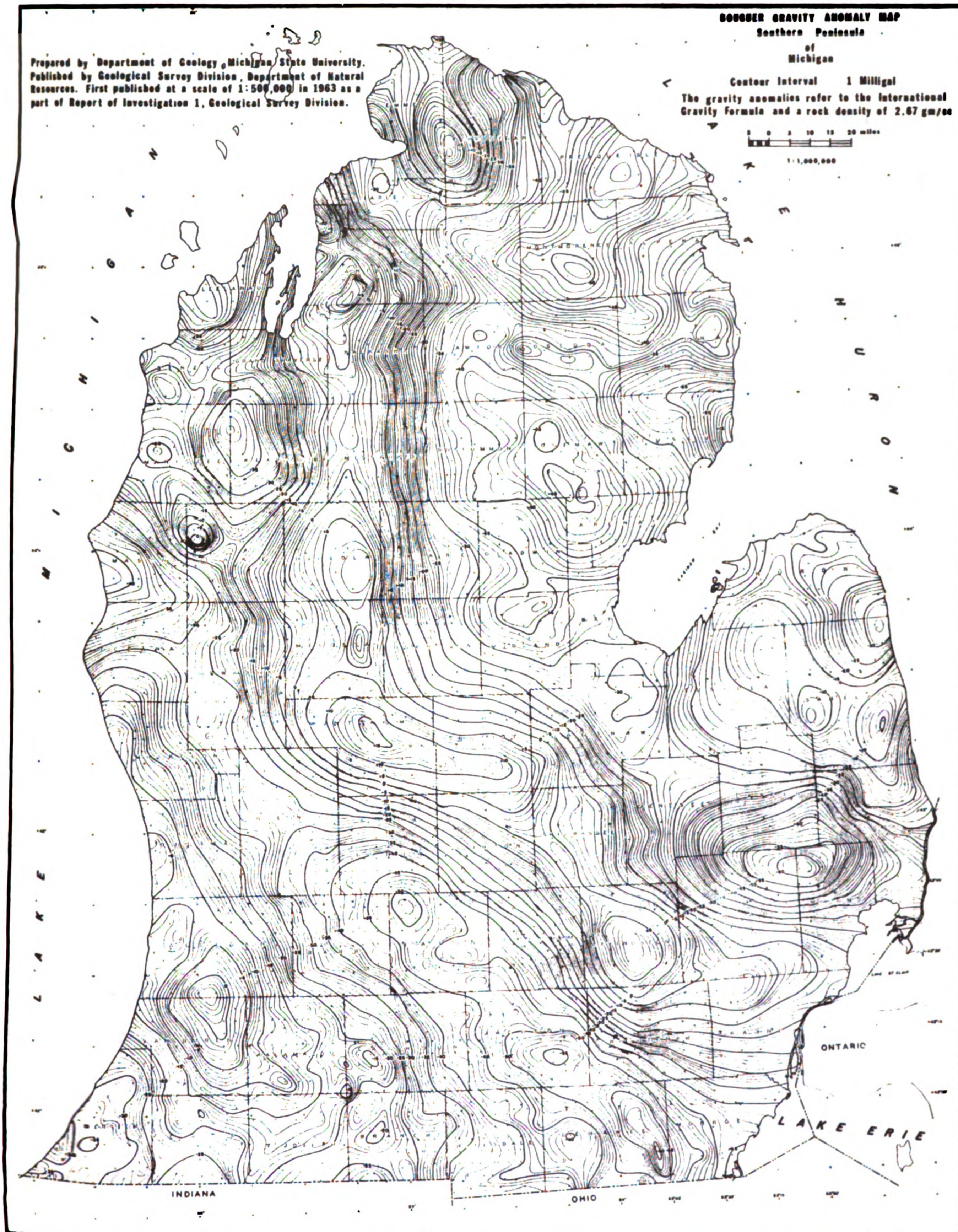


Figure 4. Bouguer Gravity Anomaly Map (from Hinze, 1963)

The structures are then due to rejuvination of these basement features during later episodes of the Basin history. Hinze's gravity and magnetic maps also reflect the slight change from dominately northwest-southeast to north-south in the northern area of Southern Michigan that Newcombe (1933) had noted earlier in the shallower Paleozoic rocks. Hinze and Merritt (1969) attributed the formation of the Michigan Basin to isostatic sinking as the crust readjusted to added mass of basic material in the basement complex. Their work is based on regional gravity and magnetic surveys of the lower penninsula of Michigan. They further associated the Michigan Basin with the Lake Superior Basin, the Michigan gravity and magnetic high being related to the Mid-Continent Gravity High along which the Lake Superior Graben formed.

Ells (1969) in a study of the Howell Anticline discounted the presence of a fault along the west side of the structure. Ells described the Howell Structure as a "series of linear, somewhat off-set anticlines". He attributed folding of the structure to minor faulting of deeper horizons, beneath the Trenton-Black River, along the west flank with possible accentuation of the structure on the Dundee formation by solution and removal of the thick Salina salts from the flank of the structure. Ells then described the Washtenaw Anticlinorium, of which the Howell Anticline is a part, as a structure controlled by master fault blocks in the basement rocks. Most of the movement occurred during late Mississippian (Meramecian) time though minor movement could have begun as early as late Ordovician. He further noted the similarity between the central basin Dundee structures and the Howell Anticline as being along the same dominant structural trend and probably controlled by basement rocks.

Fisher (1969) associated the Howell Anticline with faulting. According to Fisher the major period of basin subsidence occurred during Salina time. The major episode of folding in the central basin area is late Mississippian.

Methods and Procedures

Three structural cross-sections were constructed from gamma-ray neutron logs. There are two dip cross-sections and one strike cross-section. The cross-sections serve the dual purpose of introducing the log characteristics upon which the formation tops were picked and to present a quick visual picture of the Howell Anticline. Two restored stratigraphic cross-sections were also constructed, again to present a quick visual presentation of the paleo-structure at the time the uppermost units were deposited.

The interpretive study incorporated formation tops based on mechanical log picks. Where these mechanical logs were unavailable, State printed sample logs were used for tops. Formation tops used were Trenton, Utica, Cicinnatian, Rochester, Brown Niagara, Salina G, Dundee, Bell, Traverse Formation, Antrim, Berea, Sunbury, and Coldwater, as named on the Michigan Stratigraphic Chart (Fig. 5). The tops were based on lithologic characteristics of the gamma-ray and resistivity curves on the mechanical logs. Well cuttings were examined in several selected wells to check for concurrance of my sample interpretations and the interpretations of the State geologists. Two structure maps and six isopach maps were constructed from these data.

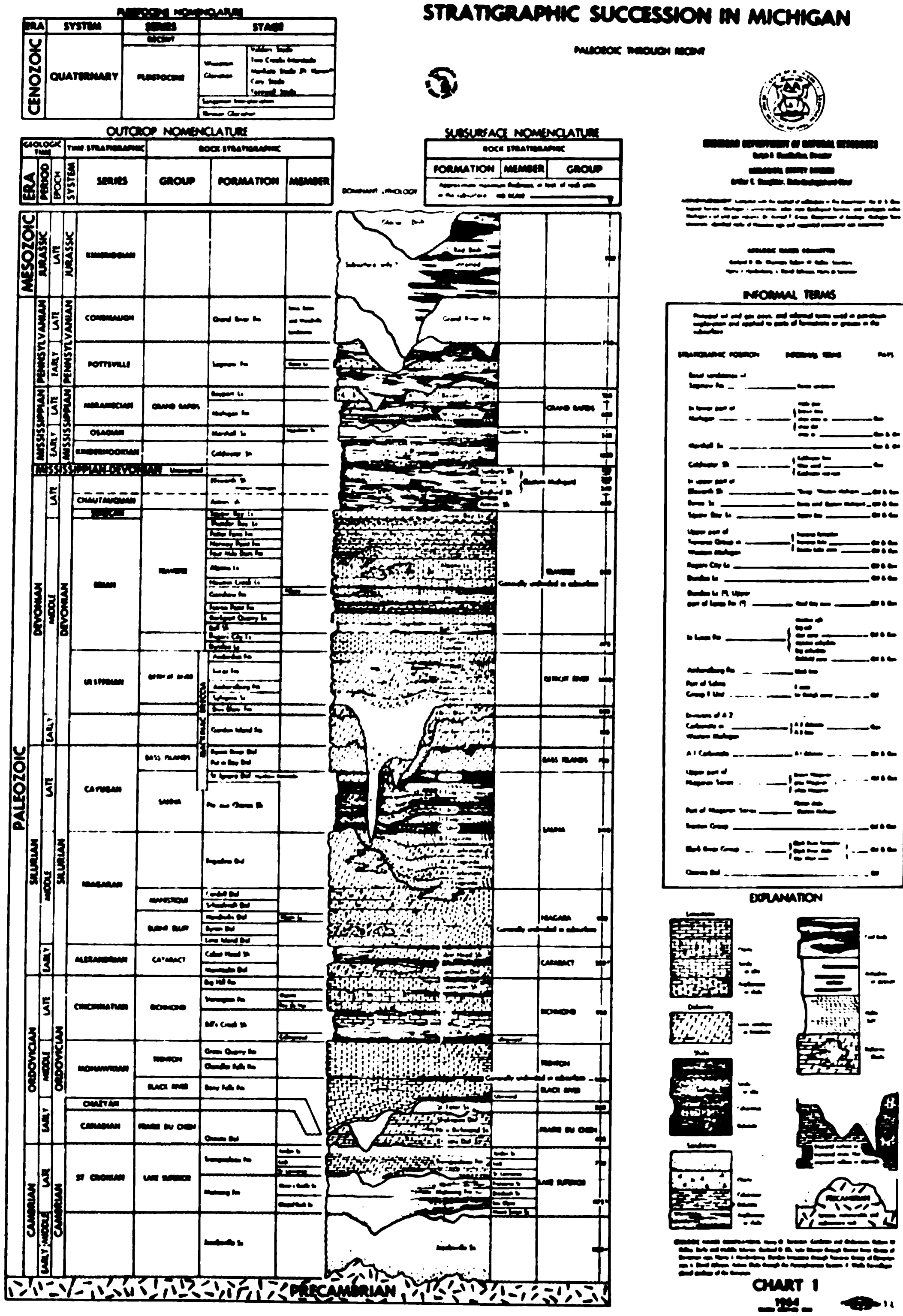


Figure 5. Michigan Stratigraphic Chart

STRATIGRAPHY

General Section

Group and formation names used in this study are based on the stratigraphic chart (Fig. 5). Formation contacts were based on work done by the Michigan Basin Geological Society (Fisher, et al, 1969). These publications were used to maintain consistancy with generally accepted nomenclature and formational boundaries. Previous work done by others as regional studies on the various units were also incorporated to observe changes in lithology, whether it would be a regional gradation or a local lithologic change in the proximity of the Howell Anticline.

Newhart (1976) described the Trenton as a brown fossiliferous limestone which grades into a dolomite in Western Michigan. The Trenton, in many places, is capped by a thin dolomite. In the eastern part of the Michigan Basin the Trenton limestone is dolomitized along linear trends associated with faults.

Nurmi (1972) described the Utica and the upper Cincinnatian shale unit, his Unit 5. Nurmi's Unit 6, the upper most Cincinnatian is absent in southeastern Michigan. The Utica is a dark colored shale, generally darkest near the base grading lighter towards the tip of the unit. Unit 5 consists of interbedded carbonates, which are argillaceous limestones near the central Basin area grading to dolomites near the Basin margins; and greenish grey shales near the center of the Basin which grade to green and red shales near the Basin margins.

Potter (1975) described the Clinton Group. The lower part is the Clinton restricted, a tan to gray dolomite which becomes split to the southwest by a thin grey dolomitic shale streak. The Clinton is overlain by the Rochester Shale, a thin grey dolomitic shale. In southern Michigan the Rochester is a good marker bed at the base of the Niagara.

Mesollela, et al, (1974) have described the Niagara and Salina Units. The Niagara is a light colored dolomite at the base. Throughout the Basin it is overlain by a thin brown dolomite often referred to as the Brown Niagaran. The Salina A-1 Evaporite is a salt near the center of the Basin which grades into an anhydrite near the Basin margins. The A-1 Carbonate is a dark brown, very carbonaceous, highly laminated carbonate. The algal laminations of this carbonate have led to it being termed a "poker-chip shale". The A-2 Evaporite is also an anhydrite near the Basin margins and a salt at the Basin center. The salt also grades upward to an anhydrite, which in turn grades into the overlying A-2 Carbonate. The A-2 Carbonate is a brown to grey carbonate which, in places is highly laminated by algal mounds. The C and G units are described by Fisher, et al, (1969). The C-shale is a green-grey shale, somewhat calcareous. The G-Unit is a thin, dark grey, generally anhydritic, dolomitic shale.

The Lucas, upper Detroit River, is an interbedded evaporite and dolomite sequence (Majedi, 1969), the dolomites being brown to tan and the evaporites being salt confined to the central Basin grading to anhydrites near the Basin Margins.

According to Bloomer (1969) the Dundee is a buff to brown to grey finely crystalline limestone, the central Basin, western, and

southwestern areas are a dolomite. He notes a breccia zone in the upper part of the Dundee. The Dundee is overlain by the dark grey to black calcareous Bell shale. The Bell is less argillaceous and more calcareous at the base.

Asseez (1967) described the lower Mississippian section. The Antrim is a black, pyritic, radioactive shale, though Asseez does note some color variations within the Antrim. The Bedford is a blue-grey shale, with sand and silt stringers. The Berea is an interbedded sandstone, shale sequence; both are grey in color. Overlying this is the black carbonaceous Sunbury Shale.

Howell Section

General descriptions of only those portions of the stratigraphic column covered by this study are given below. The rationale for differentiating the units is given along with the descriptions. Refer to the structure cross-sections (Figs. 6, 7, or 8) for log characteristics of the various units. The Brazos-Kizer well in section 14 T2N R4E was used as the standard section.

Descriptions are as follows:

Trenton: limestone, brown; finely crystalline to dense, grades to thin brown dolomite near top; sharp break away from shale marker on logs

Utica: grey-greenish grey, limey shale, occasionally becoming shaley limestone; top of Utica is fairly difficult to pick, as it grades into a calcareous shale above; the pick is made on this change to a more calcareous shale as the gamma-ray and neutron curve begin to move out from the shale line

Upper Cincinnatian: red and green silty shale; the upper Cincinnatian was picked as the first shale below the Manitoulin Dolomite; it is not a clean shale, getting many limestone stringers mixed in with it; this unit was relatively lighter colored ranging from red to green soft, silty shale; around

Figure 6. Structure Cross Section Across Howell Field

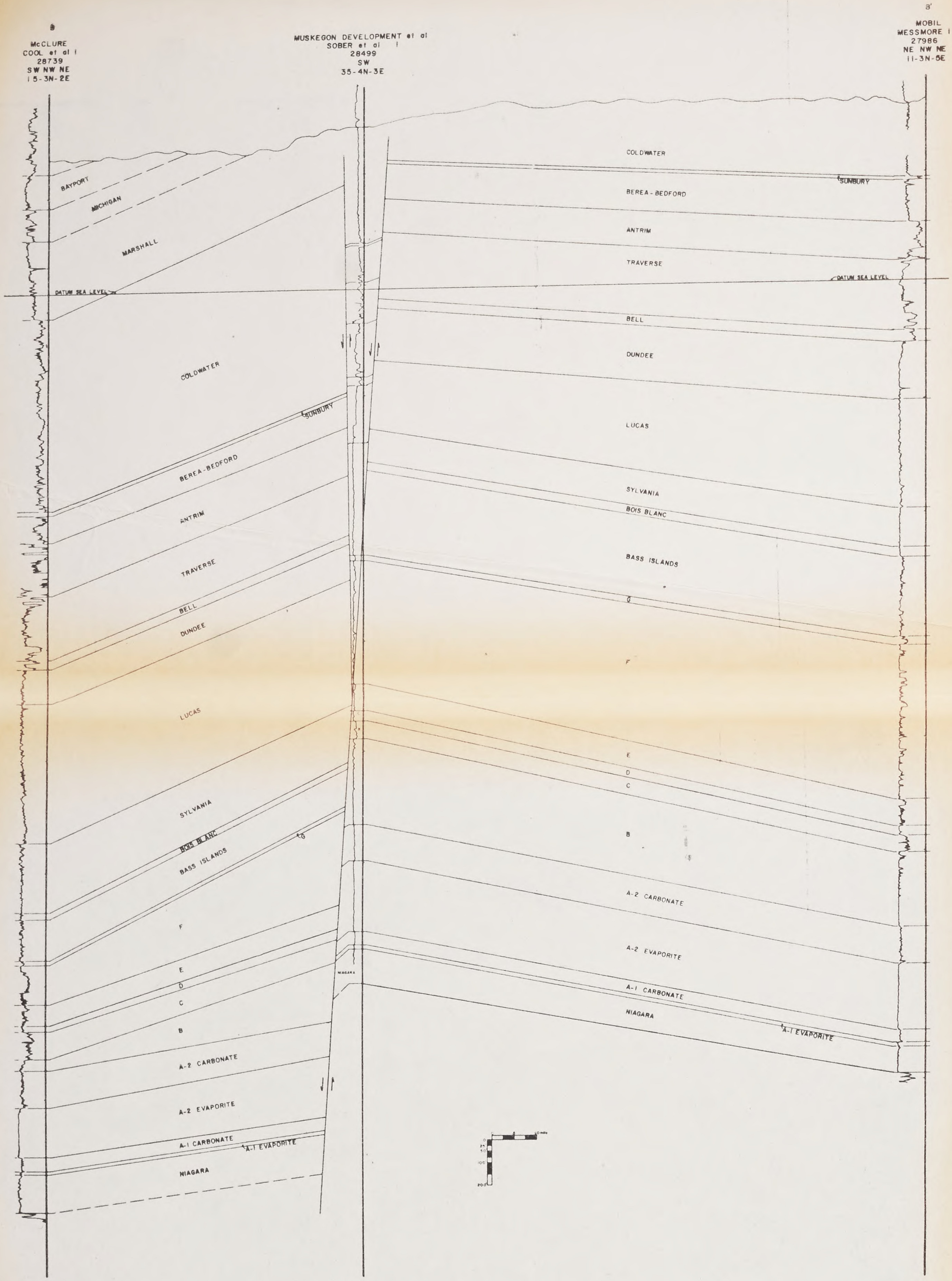


Figure 7. Structure Cross Section Across Fowlerville Field

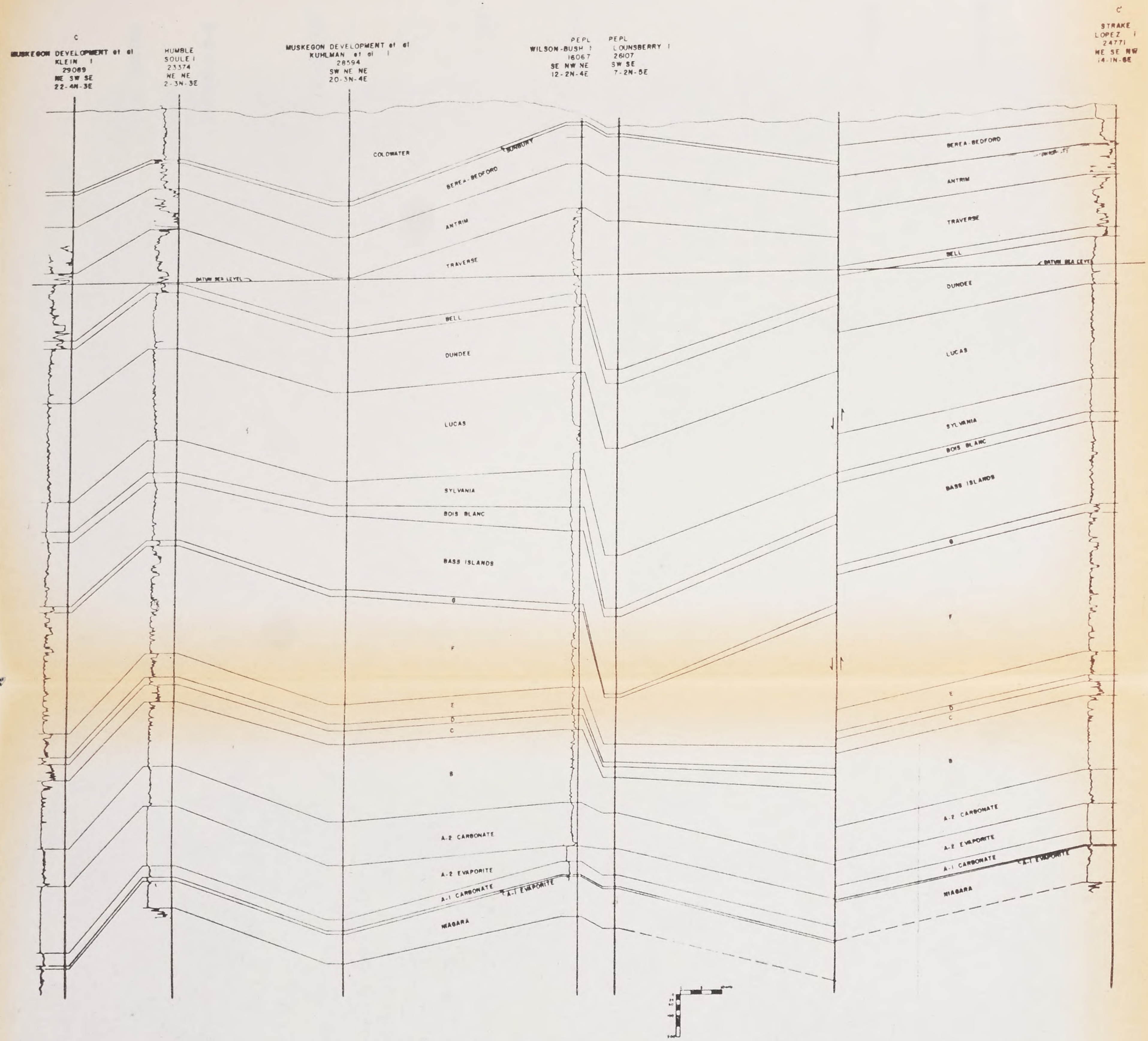


Figure 8. Structure Cross Section Along Strike of the Howell Fault System

Livingston County the base of this unit was picked as the return to the underlying carbonate; log picks are based on the increased gamma-ray response lying between the low gamma-ray curve of carbonates

Rochester: this unit was used primarily as the base of the Niagara; it is a very thin green to grey shale; it has a good shale break on the log both from the underlying Clinton Dolomite and the overlying Niagara; marked by an increased gamma-ray response

Niagara: white, light grey to blue-grey dolomite; finely crystalline with infrequent streaks of pink dolomite; in some wells it is very slightly shaley; it grades upward into the Brown Niagara (Guelph) which is brown and finely crystalline (the Brown Niagara is the reef facies of the Niagara); off the Howell structure it is generally dense and tight, over the structure the porosity is intercrystalline (a fresh break will absorb water almost like a sandstone) to vuggy-some being fairly large (1/2"), but more commonly pinhole porosity; the Niagara has good log definition being in contact with the overlying anhydrite; in the area of Ingham County this definition is lost where the A-1 Anhydrite is absent due to pinacle reef build up; in this situation the A-1 Carbonate and upper Brown Niagara were grouped together as undifferentiated Carbonate

A-1 Anhydrite: anhydrite, white to grey; absent over reef buildups, also pinches out southward as it does not cover the massive reef in Washtenaw County; sharp peak of low response on curves

A-1 Carbonate: brown dolomite, very carbonaceous; algal laminations give the unit a "poker-chip" characteristic which has led it to be described as "shaley"; porosity is again limited to the region of the fault zone and it also is characteristic as the sample appears finely crystalline when dry but disintegrates to a very sandy texture when acid is applied; log definition is a sharp increase in curve response from the overlying evaporite

A-2 Evaporite: good clean salt at base with many thin dolomite stringers; grades upward into an anhydrite; the whole unit becomes anhydrite as it thins southward, lapping onto the massive reef; log character is very distinquishable as a drop on neutron curves

A-2 Carbonate: brown, carbonaceous, finely crystalline dolomite; care must be taken to avoid a limestone stringer in the overlying B-unit, otherwise log definition is good

Salina "C-Unit": grey, dolomitic shale; good shale break on log curves, thin limestone streak near the center of the unit

Salina "G-Unit": thin grey to dark grey shale to shaley dolomite unit; in samples it is picked as the change from brown shale or dolomite in the overlying Bass Islands to grey in the Salina G; on the gamma-ray log it is more easily distinguished as a good shale break on the gamma-ray curve from the overlying Bass Island

Detroit River: picked as the first upward occurance of anhydrite in a light brown limestone; very easy pick of FDC logs as the curve kicks out demarking a very dense unit; neutron peaks follow a similar pattern as do resistivity peaks

Dundee: light brown to brown limestone, crystalline; the log characteristic is almost as good as the Utica-Trenton contact being a very sharp break away from the shale marker of the overlying Bell shale; low uniform gamma-ray curve, with associated high neutron readings

Bell: grey calcareous shale, develops a very limey streak in it which thickens westward toward Ingham County; toward the east the contact with the overlying Traverse is sharp on the log upon return to a carbonate; as the calcareous streak thickens care must be taken to maintain a consistant pick

Traverse: the Traverse Group is an alternating grey to brown limestone and grey to brown shale unit with much gradation between the two extremes; quite fossiliferous; the last strong radioactive kick of the overlying Antrim is used as the top of the Traverse on the logs

Antrim: black shale, pyritic; very high gamma-ray response on logs

Bedford: grey shale, somewhat silty; much lower gamma-ray response than Antrim

Berea: grey sandstone, contains shale stringers; contact with overlying Sunbury is very sharp on the logs

Sunbury: thin dark brown-black shale; very high radioactive peak on the gamma-ray log

STRUCTURE

Regional Framework

The Michigan Basin is a gravity sag basin of the Central Interior region on the North American Continent (Fig. 9). To the northwest, north, and northeast the Michigan Basin is bounded by the North American Shield consisting of an exposed Precambrian igneous and metamorphic complex. A ring of arches, the Algonquin Arch to the east, the Findlay and Kankakee limbs of the Cincinnati Arch to the southeast and southwest respectively, and the Wisconsin Arch to the west, complete the relatively low relief border of the Basin. The Chatham Sag and Logansport Sag provided inlets to the Basin during different epochs of the Basin's history.

Within the Michigan Basin there is a strong trend of northwest-southeast trending anticlines (Fig. 2). The most prominant of these is the Howell Anticline. The Northville Anticline is part of the same system as the Howell Anticline. Ells (1969) has termed this system the Washtenaw Anticlinorium. The Lucas-Monroe Anticline, a large faulted structure, terminates in Livingston County, strikes northwesterly through Washtenaw County, turns, and strikes south through Monroe County to join the Bowling Green fault system of Ohio. The Albion-Scipio Oil Field is a third northwesterly striking fault system in southern Michigan (Ells 1962, Merritt 1968).

The Howell Anticline has been mapped in several regional studies. Syrjamaki (1977) showed shear faults along the Howell Anticline and a

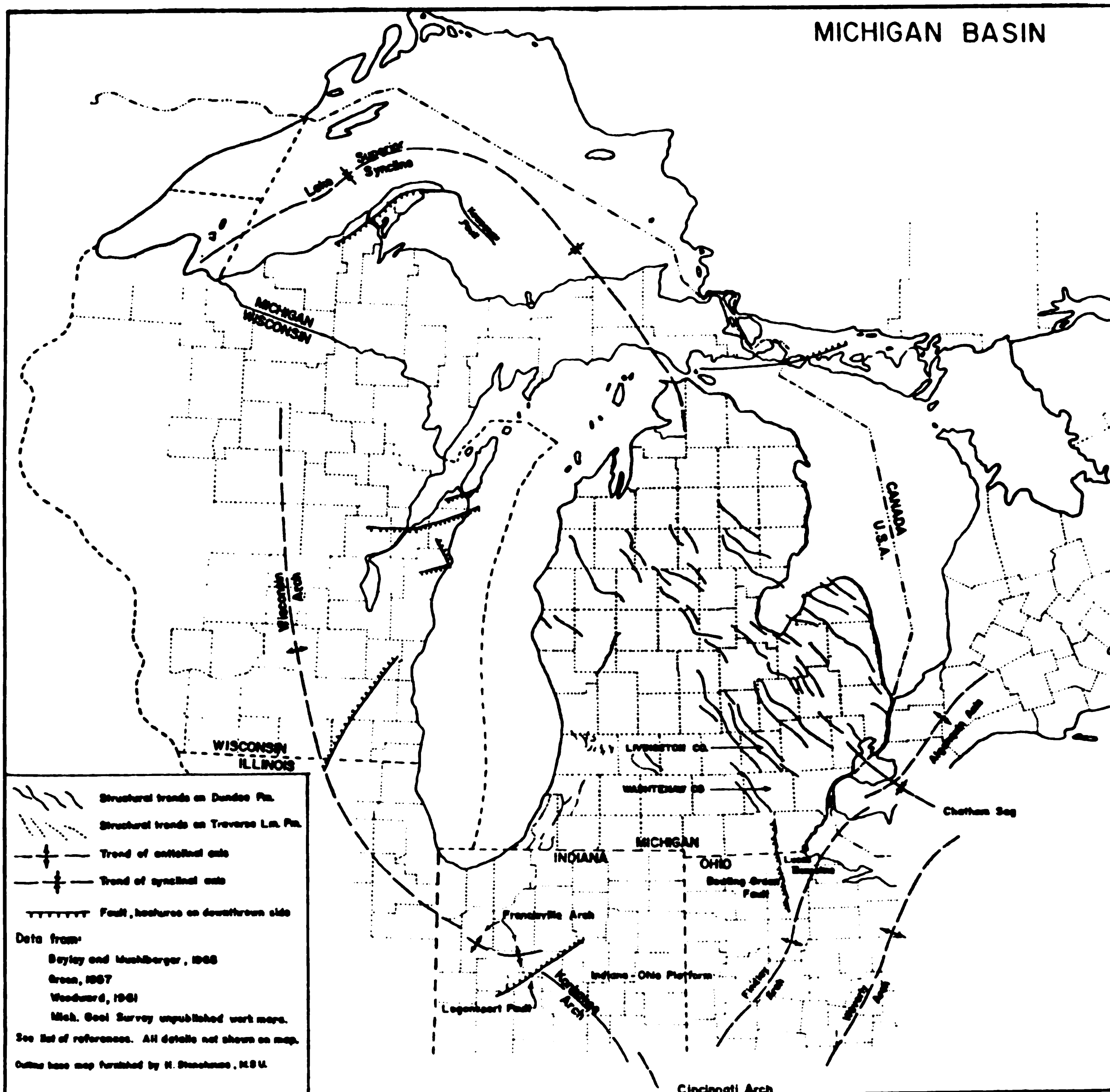
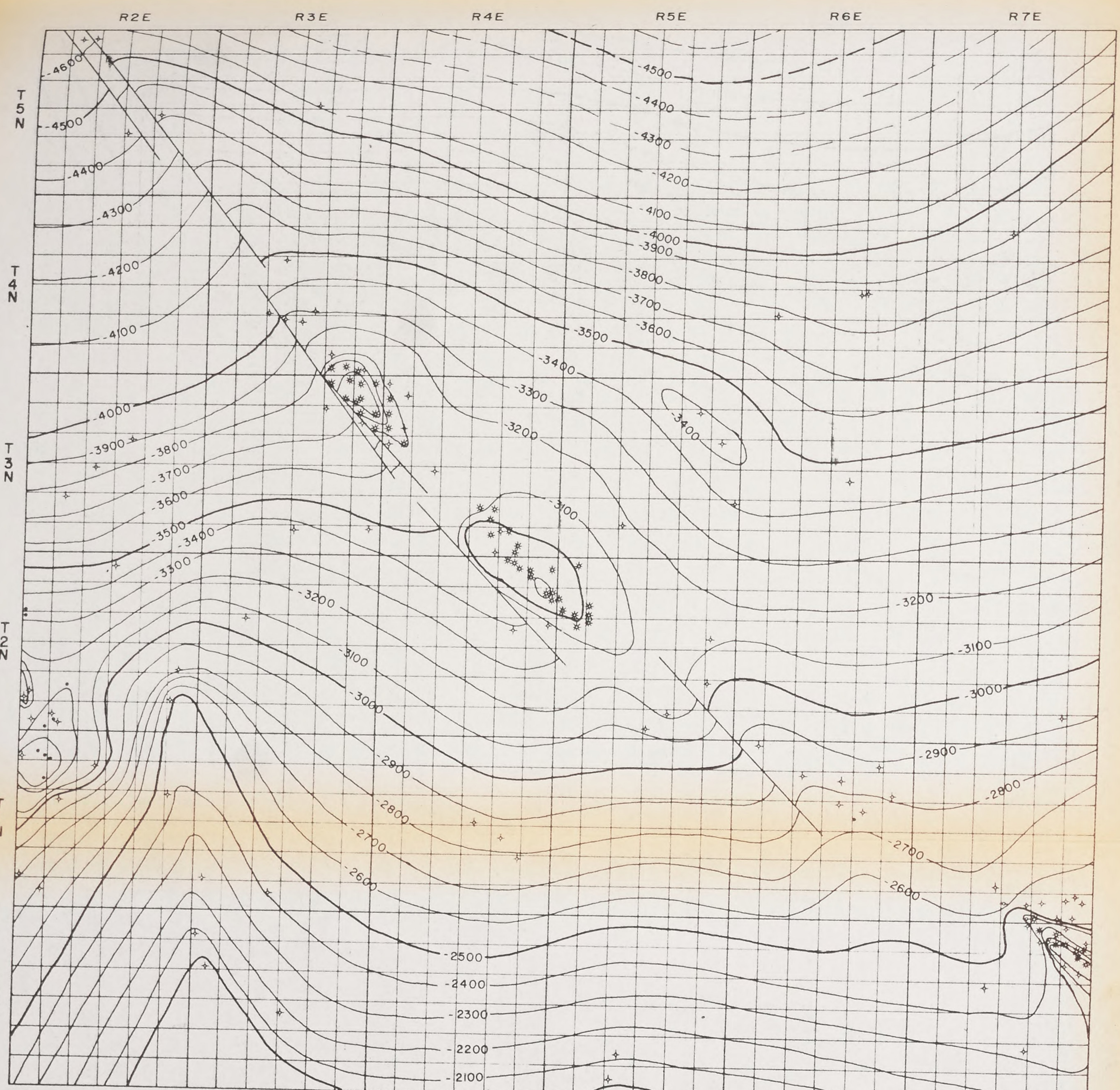


Figure 9. Regional Tectonic Setting of the Michigan Basin
(from Ells, 1969)

subparallel structure to the southwest in his Prairie Du Chein study. Seyler (1975) on his regional Trenton structure depicted the Howell Anticline as faulted along the southwest flank by a single continuous fault zone beginning in T5N R2E and dying out in the south of T2N R5E. He did not fault the area of Green Oak or Northville Fields. The fault was mapped by Fisher (personal communication, 1977) on his Niagara structure, while Ells (1969) believed the structure was not a faulted feature but rather an asymmetrical anticline with a steeply dipping southwest flank. Majedi (1969) concurred with a fault zone along the southwest flank on his Detroit River structure map. Bloomer (1969) chose not to draw the anticline as a faulted feature though he recognized that the Howell Anticline could well be faulted along the southwest flank. Asseez (1967) considered this a faulted system and depicts it as such on his Lower Mississippian structure maps. In order to show the Howell Anticline and the Northville Anticline as a continuous trend, the writer has included the northern terminus of the Northville Anticline. The Northville Field itself is not included in this study, therefore, reference to Checkley (1968) is made when referring to that structure.

The Howell Structure

The present structural configuration of the Howell Anticline is shown by a set of three structural cross-sections (Figs. 6, 7, and 8) and two contoured structure maps, Niagara (Fig. 10) and Dundee (Fig. 11). The two structure maps show the offset of structure with progression upward through the sedimentary column. The Howell Anticline most likely underwent its major uplift during the Mississippian or early



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

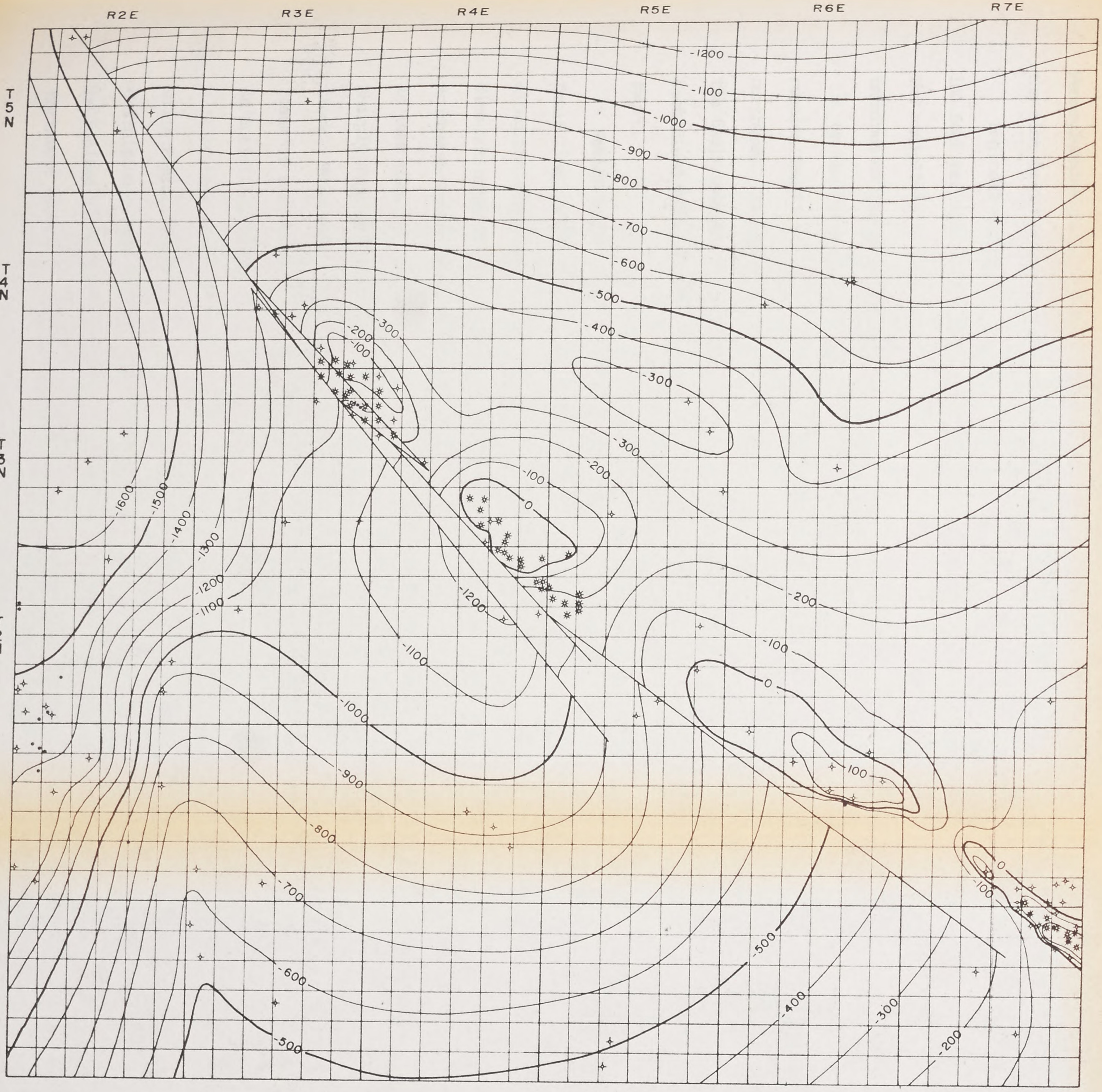
NIAGARA STRUCTURE

CONTOUR INTERVAL = 100'

SCALE: 1" = 4 MILES

APRIL 1977 R. PARIS

FIGURE 10



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

DUNDEE STRUCTURE

CONTOUR INTERVAL = 100'

SCALE: 1" = 4 MILES

APRIL 1977 R PARIS

FIGURE 11

Pennsylvanian as the basement responded to tectonic compression from the east as a harbinger of the oncoming Appalachian Orogeny.

Regional dip on the Niagara (Fig. 10) Formation is approximately 100 feet per mile, slightly more than 1 degree to the north-northeast. The anticlinal feature in the southwest corner of the map is the northern terminus of the Lucas-Monroe Anticline.

On the Niagara, the Howell Anticline is drawn as a series of en echelon faults striking roughly N45°W. The system plunges to the northwest. Increased control brings out the en echelon arrangement of the fault system. A regional study which uses only a few wells from each field will allow the fault to be drawn as a rather sinuous single fault.

Relief across the Fowlerville Field is nearly 900 feet across the fault line. This represents the greatest amount of structural relief along the length of the Howell Fault zone. Throw on the fault block dies out both to the northwest, into Shiawassee County, and to the southeast toward Green Oak field where relief across the fault line is less than 100 feet. Green Oak could easily have been drawn as a sharply dipping anticlinal nose with no faulting on its southwest flank. This area was interpreted to be faulted on the southwestern flank of the structure. The fault dies out to the southeast becoming an anticlinal nose.

As this study covers only the northwestern terminus of the Northville Field, Checkley's work of 1968 has been used for structural definition of the Northville Field. He shows the Northville Field to be faulted along the northeast flank. This faulting dies out to the northwest becoming a steeply dipping anticlinal nose along its terminus in this study area.

Evidence for interpreting this system as a faulted system of anticlines is primarily around the Fowlerville Field. Relief between the wells located in section 21 T4N R3E and 28 T4N R3E is 756 feet, where the wells are a little under one mile apart. Also between the wells located in section 11 T3N R3E and NE12 T3N R3E the structural relief is 714 feet. The relief between these wells accounts for nearly all of the structural relief on the Niagara across the Fowlerville Field.

Further evidence is found in the Helen Sober well located in SW35 T4N R3E. In this well from the lower portion of the Detroit River through the upper part of the Bass Islands (a sequence of 400 feet in nearby wells) is represented by 200 feet on the mechanical log. Thus, 200 feet are missing and the log of the interval present is severly jumbled. The well located in NW of 18 T3N R4E also has a missing section of rock units. The A-2 carbonate in this well is missing. A missing section of salt could be accounted for as removal by solution but removal of a carbonate perhaps is better explained as a result of faulting. Faulting along the southern flank of the Howell Field is a projection along the strike of this faulting.

The pattern of faulting seen along the fault zone from the northwestern limit of the map through the Northville Field area is representative of a scissor-type fault motion. A scissor pattern of fault motion would tend to indicate wrench fault mechanics operating within the basement complex beneath the Howell Fault zone. As the basement responds to regional tectonic forces, most likely this would be a compressive force from the east due to an early pulse of the Appalachian disturbance, stress will be relieved along ancient zones of weakness.

In Michigan the pattern of basement lines of weakness was probably set prior to the emplacement of the Keweenawan age basalts. These basalts were probably intruded along pre-existing lines of weakness (Hinze and Merritt, 1969; Kellogg, 1971).

The Dundee structure (Fig. 11), like the Niagara structure, shows an en echelon system of faulted anticlines that strike generally N45^{0}W and plunge basinward. The northern terminus of the Lucas-Monroe Anticline is again seen in the southwest corner of the map.

Structural relief over the fields is generally greater on the Dundee than on the Niagara. Across the Howell Field the relief is 1279 feet on the Dundee, measured between the well in section 14 T2N R4E and the well in section 35 T3N R3E while the greatest relief on the Niagara was only 509 feet between the well located in section 14 T2N R4E and that in the NE of section 12 T2N R4E. Another noticable feature near the Howell Field is the large depression along the south side of the field. (It is through this area that Ells (1969) chose to draw his cross section of the Howell Field).

The faulting near Fowlerville is considerably more complex on the Dundee horizon than on the Niagara horizon. Across the Fowlerville Field the difference in structural relief between the two horizons is not nearly as noticable as across the Howell Field, being about 1100 feet of relief across Fowlerville on the Dundee and 900 feet on the Niagara.

The Green Oak Field also exhibits greater structural relief on the Dundee, nearly 600 feet, than on the Niagara, less than 100 feet.

The two dip structure cross sections (Figs. 6 and 7) show that the offset of the crest of the Howell Anticline on the Dundee horizon to the northeast of the Niagara crest as noted by Cohee and Landes (1958), can be attributed to the fault dipping to the southwest. The result of the dipping fault plane is that the axial plane of the anticline also dips to the southwest. During uplift, drag along the fault resulted in the beds dipping toward the fault immediately along the fault zone. The crest, on both the Dundee and Niagara, is therefore not directly adjacent to the fault but is slightly to the northeast of the fault. This drag is also apparent on the Niagara and Dundee structure maps, where it yields the appearance of left lateral motion. On the down thrown side of the fault, drag can also be seen as the beds dip upward toward the fault.

A small anticline located in the northeast corner of T3N R5E also can be seen. This small anticline is probably a small wrinkle developed during uplift along the Howell Fault.

Further discordance of structures between the Niagara and Dundee horizons can be attributed to uneven response of the thick evaporite sections of the Salina and Detroit River Groups to the deformation of the Howell structure. The block along the south flank of the Fowlerville Field tilted, dropping down to the northwest. This block will be seen later to be acting independantly during deformation. Solution and removal of the Salina salts will also account for the depression of the south side of the Howell Field.

ISOPACHS

Regional

During Cambrian time, Fisher (1969) shows an embayment of the Illinois Cambrian depocenter in southwestern Michigan. A shallow depocenter of an early Michigan depression also occurs in the southeastern portion of Ogemaw County.

A Trenton depocenter located near southern Lake Huron is shown by Seyler (1974). Seyler's Trenton basin is elongated toward the east and west. The Utica shale (Nurmi, 1972) is thinnest in Western Michigan, becomes thicker toward the east, and reaches a maximum thickness in Lenawee County. Nurmi also notes that the Utica thickens and thins in a pattern reflecting structures which show on Trenton structure maps. This pattern holds true across the Howell Anticline. This would tend to indicate a topographic or structural high along the Howell Anticline during deposition of the Utica. Another possible reason could be that these shales responded more plastically during later uplift of the Howell Anticline and were "squeezed" or thinned by compaction across the crest of the structure. Nurmi's Unit 5 shows a gentle thickening toward the north with no reflection of the Howell Anticline.

The Clinton thickens considerably northward until it looses definition and grades into the overlying Niagara in the northern part of the southern peninsula according to Potter (1975). He also shows the Rochester shale to be thickest in St. Clair County thinning westward until it pinches out near Lake Michigan. This pattern repeats toward the central part of the Michigan Basin where the Rochester is absent.

Mesolella, et al, (1974) show a Barrier or Massive Reef complex of the Niagara surrounding the Michigan Basin margins. This Massive Reef attains a maximum thickness of just over 500 feet. Away from the Massive Reef the Niagara thins very quickly basinward to less than 100 feet thickness in the central Basin area. The A-1 Evaporite is thickest in the Basin interior and thins toward the Basin margins. The unit only partially fills in any topographic irregularities of the Niagara surface. The A-1 Evaporite wedges out against the flanks of barrier and pinnacle reefs. The A-1 Carbonate is also a "reefing" unit being thickest and dolomitized along the Basin margins becoming thinner limestones in the Basin interior. Where the A-1 Evaporite is absent the Niagara and A-1 Carbonate are grouped as an undifferentiated carbonate. The A-2 Evaporite is thinnest along the Basin margin, wedging out near the Massive Reef zone, and thickens to just over 1000 feet near the Basin center. The A-2 Carbonate is "non-reefing" being thinnest along the Massive Reef zone and thickest toward the Basin interior. Mesollela's, et al, work shows an interesting trend of deposition across the area of the Howell Anticline. The Massive Reef facies deposition of the Niagara is not continuous across Livingston County. The reef front turns west of Livingston County so that the reef front roughly parallels the strike of the Howell Anticline. The A-1 Carbonate also thins roughly along this same line. The A-2 Carbonate thickens parallel to the thinning Niagara and A-1 Carbonate and thickening A-2 Carbonate indicates a deeper water environment altered the depositional pattern of these units across the area of Livingston County.

Majedi (1969) shows a broad low entering from the north across Livingston County during Detroit River time. This low is shown by a general thickening of the Detroit River Group toward the northeast.

Isopachs of the Antrim, Bedford, Berea, and Sunbury by Asseez (1969) show no thickening or thinning of these units to reflect the existance of any structure in the area of the Howell Anticline during deposition of these units. The Antrim shale is thickest in the central Basin region and thins toward the west. The Bedford-Berea sequence is restricted to the eastern half of the Lower Peninsula. This sequence is thickest toward eastern Michigan and thins out toward a line running about north-south through the center of the state. Asseez terms the Bedford-Berea a prodelta sequence, with the sands of the Berea being bars and channel fills.

Chung (1973) shows the Coldwater Formation to be offlapped on the Howell Anticline. The Coldwater appears to thin gradually toward the Howell Anticline but it is very difficult to determine whether this offlap is due to erosion or non-deposition, however, the greater off-lap of the overlying Marshall formation suggests truncation erosion along the post-Marshall disconformity.

Howell Area

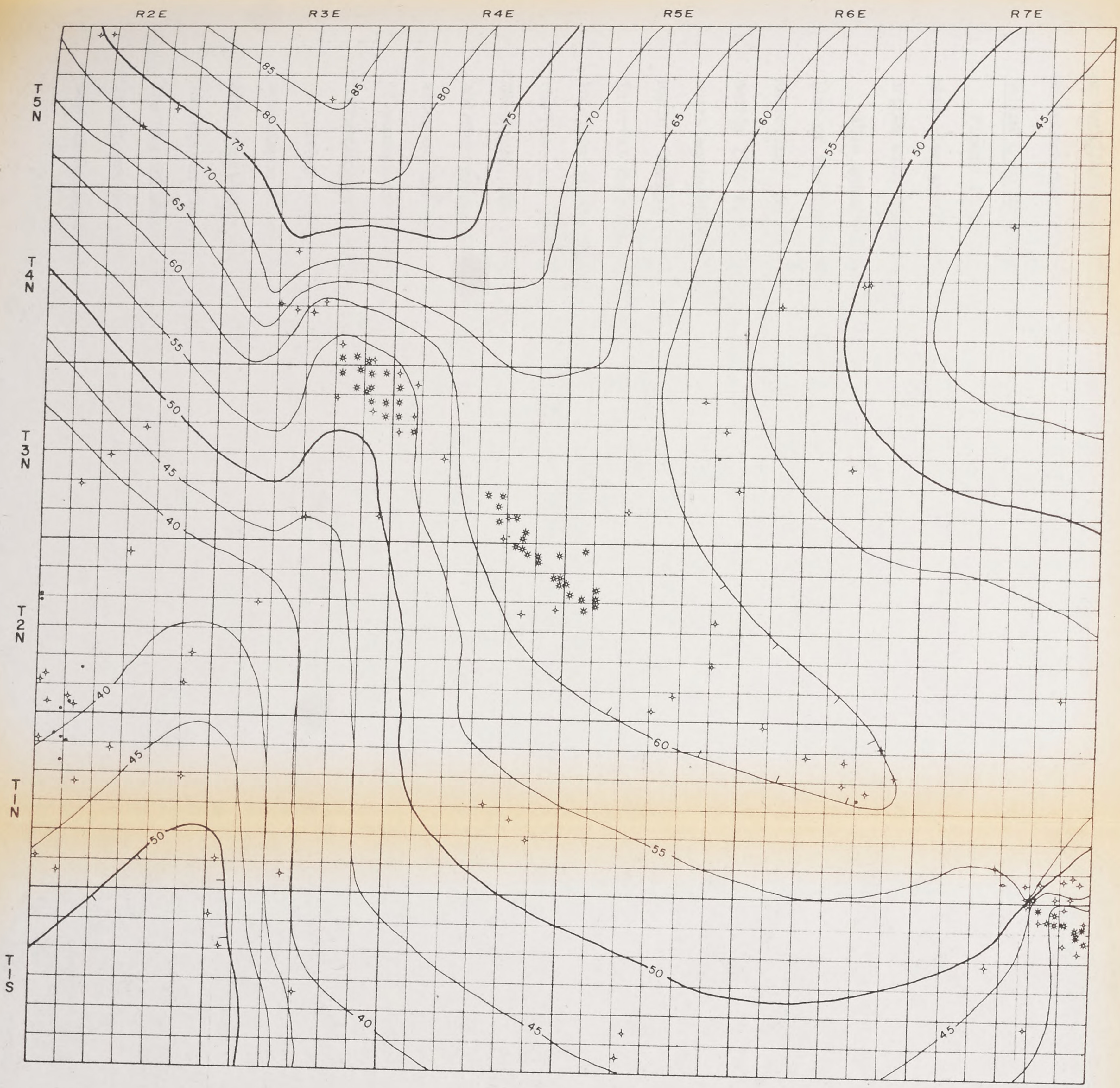
The previous section describing the Howell Structure depicted the present structural picture of the Howell Anticline. The Howell Anticline has not been a structural high throughout its past. Following is a set of isopach maps: Upper Cincinnatian or Unit 5; Salina G to Niagaran; Dundee to Salina G; Bell, Antrim, and Bedford-Berea. Two restored stratigraphic cross-sections, one on the Salina G unit and the second on the Bell Shale, also are used to develop an understanding of the developmental history of the Howell Anticline.

Upper Cincinnatian:

The Upper Cincinnatian (Fig. 12) has the least amount of control. As the picks were made on the basis of log characteristics only those wells which were logged were used.

The unit exhibits an uneven depositional pattern. Thickening toward the north and west reflects regional thickening into the basin interior. Nurmi (1972) suggests a period of erosion following deposition of the Upper Cincinnatian. The irregular thickening and thinning seen in areas of thighter control is reflecting an uneven surface which could be attributed to post-depositional erosion of this unit.

The Michigan Basin was probably fairly shallow during deposition of the Upper Cincinnatian and the Howell area was quite near the shore line, possibly an intertidal zone. The deposition of red and green shales with thin limestones indicate this type of environment. The red shales were likely deposited in an oxidizing environment, indicating shallow, agitated waters with enough oxygen to oxidize the iron in the clay particles. The green shales may represent slightly deeper water and higher organic content. Deeper water would allow layers of mud to be covered before there is a chance to oxidize the iron. More organic material would rob the oxygen during decay of the organic material to produce a reducing environment. The inclusion of limestones in this sequence indicate a fluctuation of water level as determining whether the environment is oxygen rich (oxidizing) or oxygen poor (reducing). The limestone indicates a more stable slightly deeper warm water environment. The whole sequence taken together would indicate



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN
UNIT 5 ISOPACH

CONTOUR INTERVAL = 5'

SCALE: 1" = 4 MILES

APRIL 1977 R. PARIS

FIGURE 12

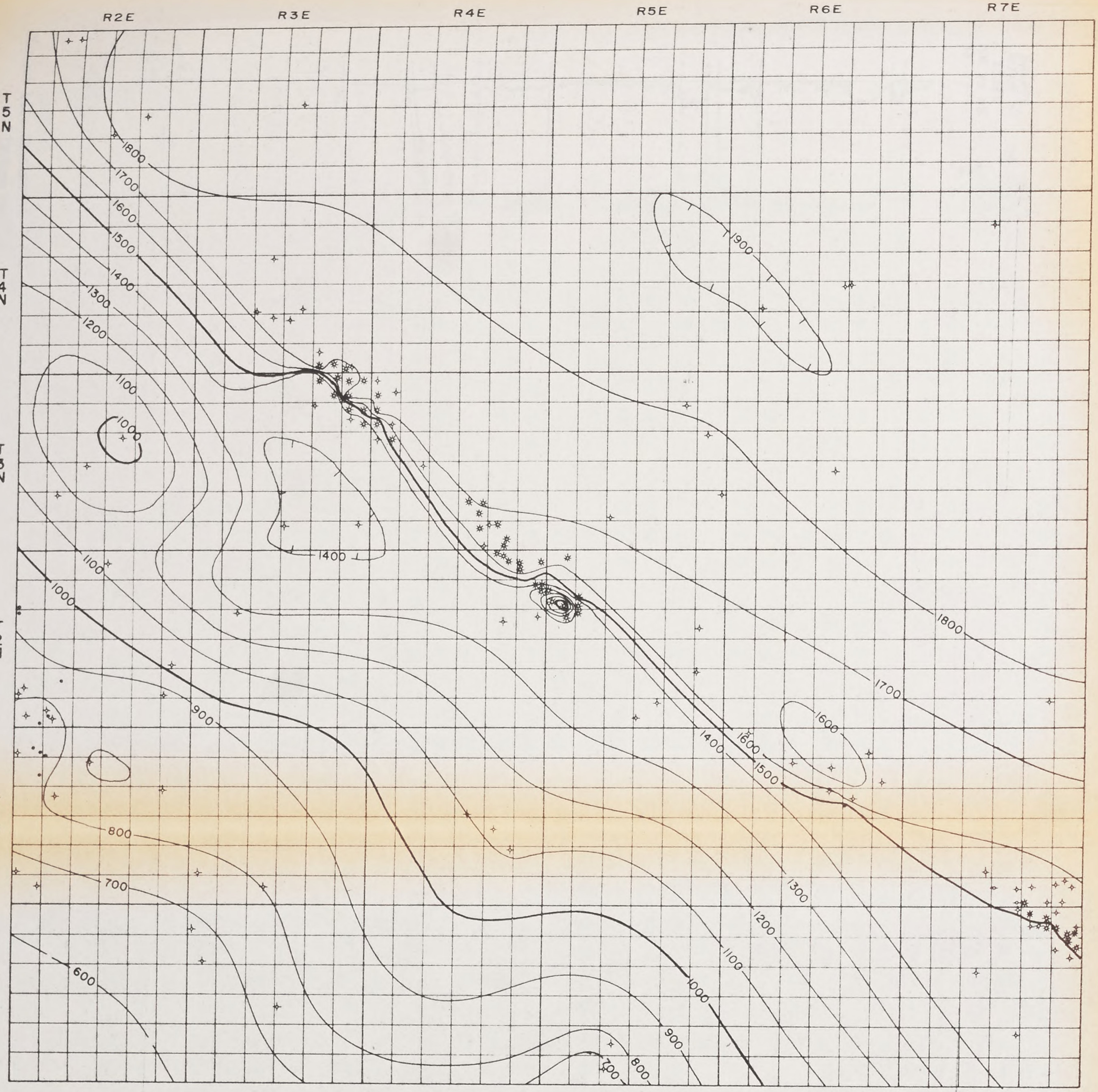
an oscillating water level such as would be expected of a tidal flat or intertidal zone.

Salina G to Niagara:

Figure 13 is an isopach of the Salina Group of Cayugan time. During this time the Michigan Basin was undergoing deposition of thick evaporites with interlayered carbonates and shales.

This interval thickens gradually toward the northeast until the line of the fault zone along the southwestern flank of the Howell Anticline. At this line the Salina units thicken from 1300 feet to nearly 1700 feet over a short distance. Beyond the fault zone the units again thicken gradually into the deeper portion of the Michigan Basin. Except for the abrupt thickening across the fault zone, this interval thickens gradually toward the Basin interior. This change in slope of the depositional surface can also be seen in figure 14, the restored stratigraphic cross-section on the Salina G. Going across the fault, the F-Salt Unit thickens most between the Brazos-Kizer well and the Panhandle Eastern-Wilson-Bush well, which are on opposite sides of the fault. This would indicate that the greatest episode of subsidence along the northeast flank of the Howell Fault was contemporaneous with F-Unit deposition.

Fisher (1969) indicates the Salina time to be the major period of subsidence of the Michigan Basin. Figures 13 and 14 would tend to concur that subsidence was greatest during upper Salina time in the area of Livingston County. Sudden thickening along the northwest diagonal of the map indicates that the fault zone along which the Howell Anticline interforms was active during Cayugan time also. The northeast block was subsiding during this time. This type of fault activity is termed



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

SALINA ISOPACH

CONTOUR INTERVAL = 100'

SCALE: 1" = 4 MILES

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FIGURE 13

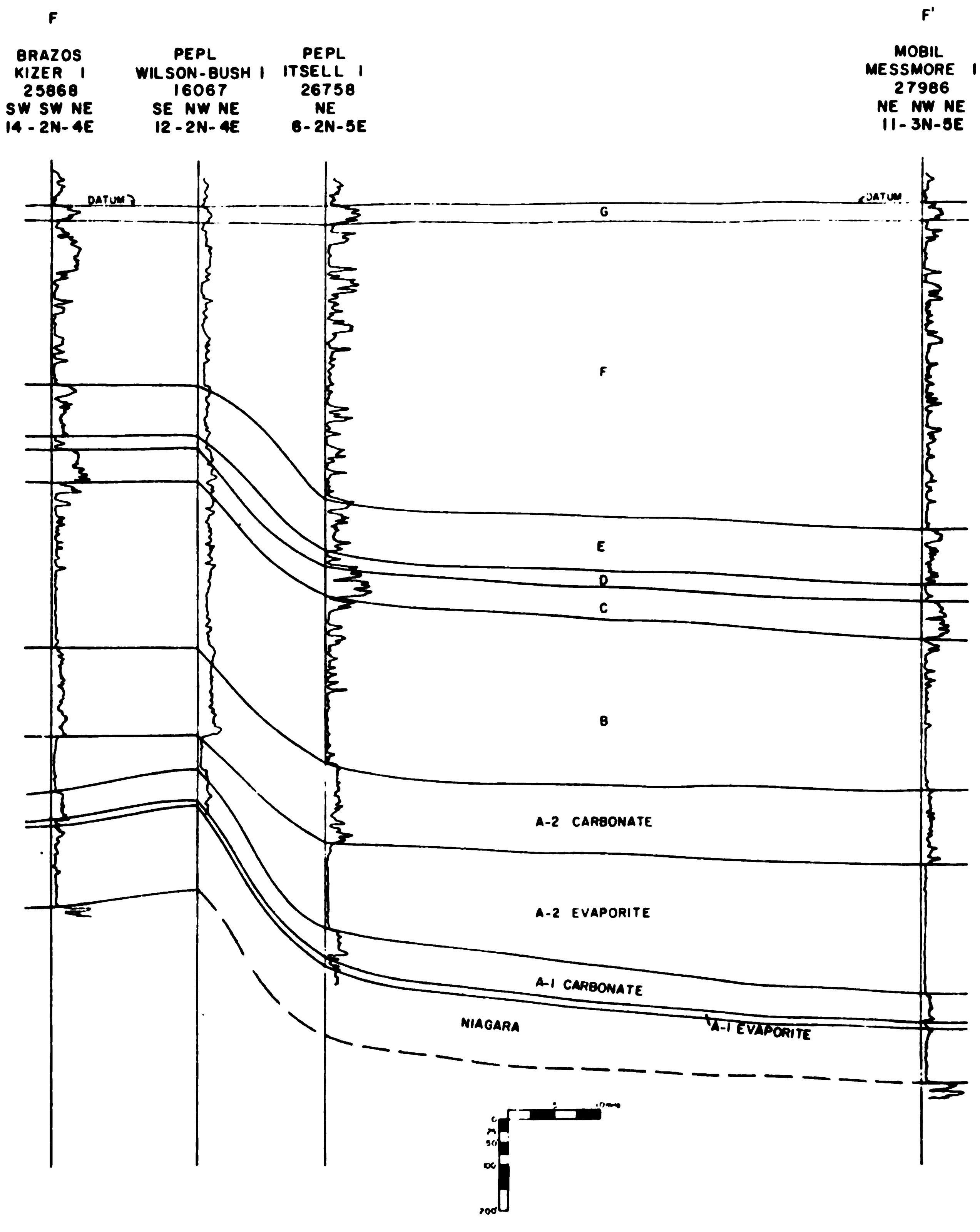


Figure 14. Restored Stratigraphic Cross Section Across Howell Field, Datum Salina G

growth faulting, when fault movement is contemporaneous with sedimentation, resulting in rapid thickening of the units along the fault line.

As tensional forces acted on the Basin during the Silurian the basement rocks would readjust themselves along pre-set fracture of fault patterns. The primary movement would be vertical readjustment as gravity became the dominant force acting on the basement blocks. The Salina G to Niagara map indicates that the northeastern block did respond during the Cayugan epoch by subsiding with the greatest amount of subsidence occurring during deposition of the F-Unit.

The anomalous thin area seen in section 7 T2N R5E is caused by solution and removal of the Salina salts during later uplift of the Howell Region, as suggested by Ells (1969). Collapse of the overlying beds would account for the depression on the Dundee surface. Landes (1945) describes collapse of Salina salt caverns near the Straits of Mackinac with resulting brecciation of pre-Dundee beds. He dates this as a pre-Dundee phenomenon.

Middle and Upper Silurian time is marked by deposition of alternating carbonates, evaporites, and shales within the Michigan Basin. A massive reef surrounding the Basin with patchy pinnacle reef growths on the basinward margin of this massive reef complex, followed by thin basinal limestones characterizes the Niagara. Following deposition of the Niagara, fluctuations in sea level are marked by cycles of evaporite and carbonate deposition through deposition of the A-2 Carbonate. Entrance of fresher waters is severely restricted during deposition of the B-Salt. The Michigan Basin remains generally restricted until deposition of the lower Bass Islands dolomites. This marks a respite from the cyclical deposition pattern and a general return to more normal marine conditions.

Dundee to Salina "G":

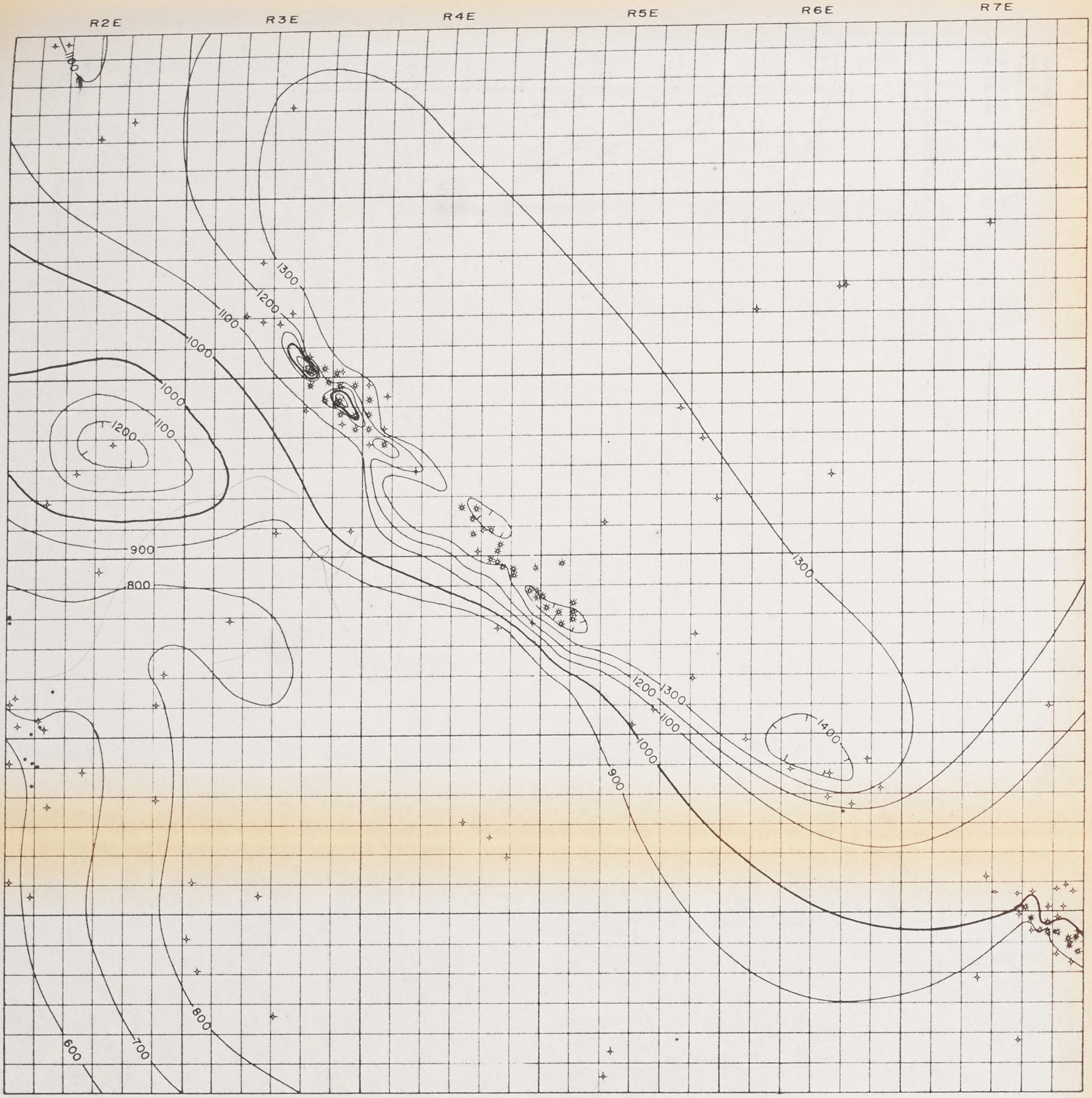
This map (Fig. 15) shows a general thickening toward the northeast. Again the sharp tightening of contour lines along the line of the Howell Fault zone indicates some subsidence of the northeast block during deposition of this interval. The restored stratigraphic cross-section (Fig. 16) on the Bell Shale datum shows that the majority of subsidence occurred during deposition of the Detroit River evaporite-carbonate cycle.

The general thinning along the Fowlerville Field is probably caused by flowage of the Detroit River evaporites during later uplift. This sliver coincides with the tilted block on the Dundee structure. This block seems to have acted somewhat independantly during deformation.

Deposition of the Bass Islands Group marks the end of the shallow restricted evaporite basin. The lower portion of Bass Islands is an anhydritic dolomite which represents a returning to more normal marine conditions of the Basin waters. It becomes more of a pure dolomite near the top. Normal marine water environments prevail until after deposition of the Sylvania. The interlayered evaporites and carbonates of the Detroit River indicate a return to an evaporite basin. Deposition of the Dundee limestone marks a return to a more open marine environment within the Basin. These conditions prevail until deposition of the Mississippian clastics begin to fill in the Basin.

Bell:

The Bell Shale isopach (Fig. 17) was drawn with a 2-foot contour interval. This smaller interval could lead to the interpretation of a complex depositional pattern, where in actuality the unit thickens very gently to the northeast with no sudden thickening across the fault



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

DUNDEE to SALINA G ISOPACH

CONTOUR INTERVAL = 100'

SCALE: 1" = 4 MILES

APRIL 1977 R. PARIS

FIGURE 15

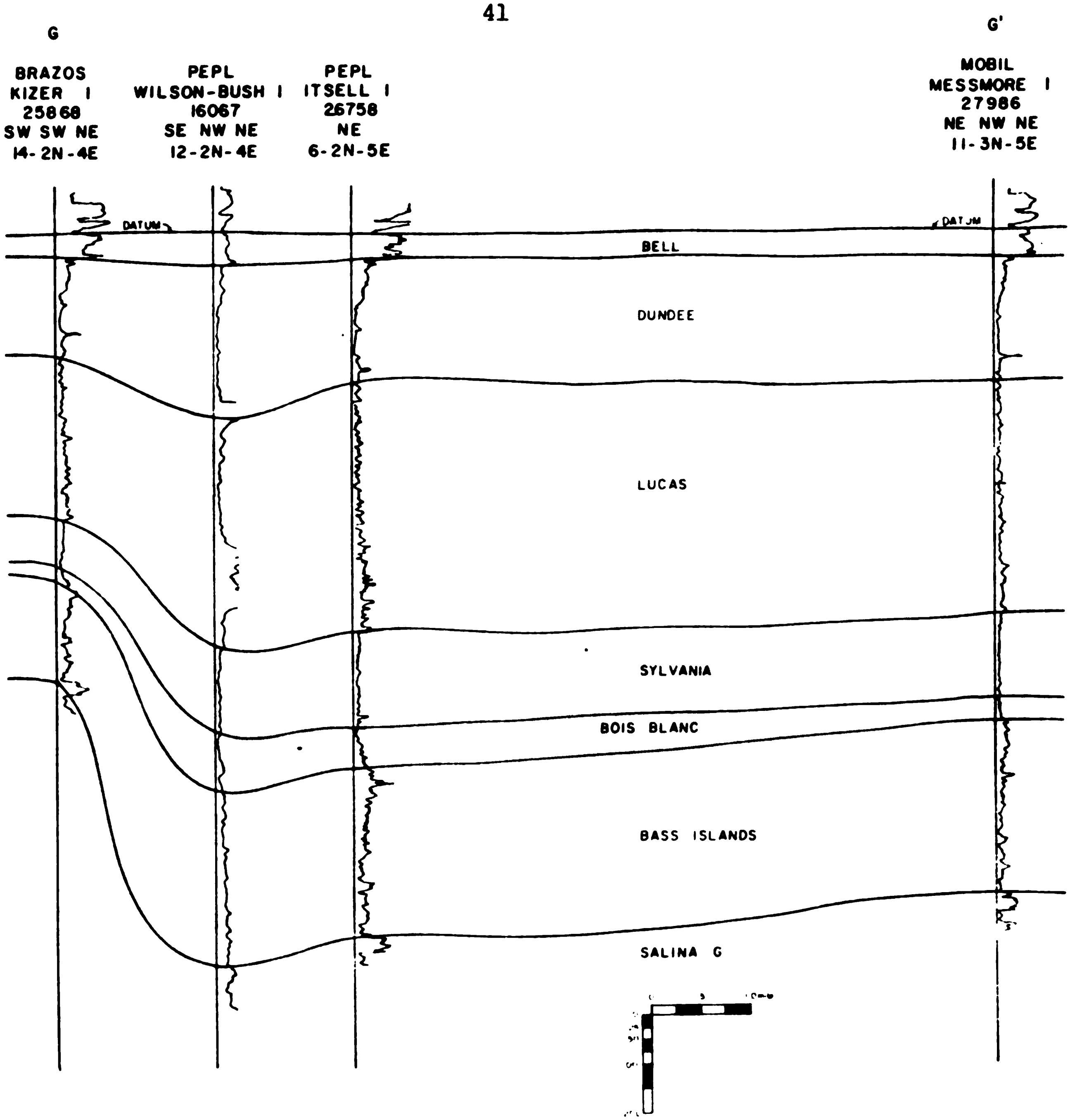
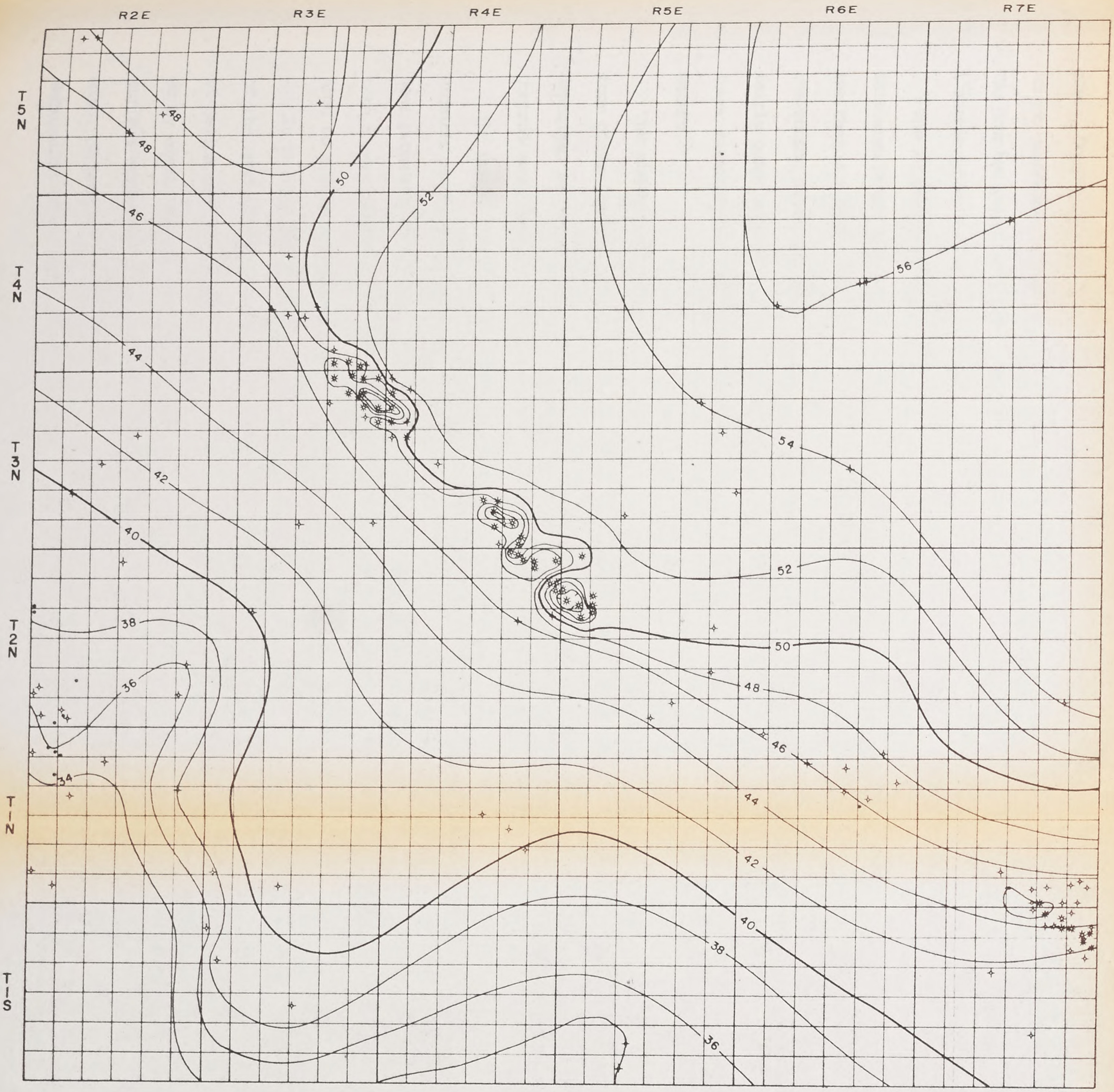


Figure 16. Restored Stratigraphic Cross Section Across Howell Field, Datum Bell Shale



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

BELL ISOPACH

CONTOUR INTERVAL = 2'

SCALE 1" = 4 MILES

APRIL 1977 R PARIS

FIGURE 17.

zone. During deposition of the Bell the northeastern block is no longer subsiding though it could still be somewhat structurally lower. The complex pattern across the Howell and Fowlerville Fields is partly a matter of control in the field areas.

The increase in calcareousnous of the Bell toward the west across this area would imply the source of clastics for the Bell to be from the East. A shale unit will be more coarsely clastic and thicker nearer the source which provides the clastics, the fine clays settling out in fairly quiet waters. Going away from the source area one would expect fewer clastics and more carbonate material deposited in shallow warm waters.

The complex pattern of contours across the two gas fields results from closer control. The Dundee surface upon which the Bell has been deposited is undoubtably more irregular than shown by the scattered control away from these fields.

The Dundee surface should owe its irregularity to post-Dundee erosion, as suggested by Newcombe (1933) and Bloomer (1969). With the near proximity to the Michigan Basin edge of this area it would not take a very dramatic drop in water level or rise along the Findlay Arch to expose this area to erosion.

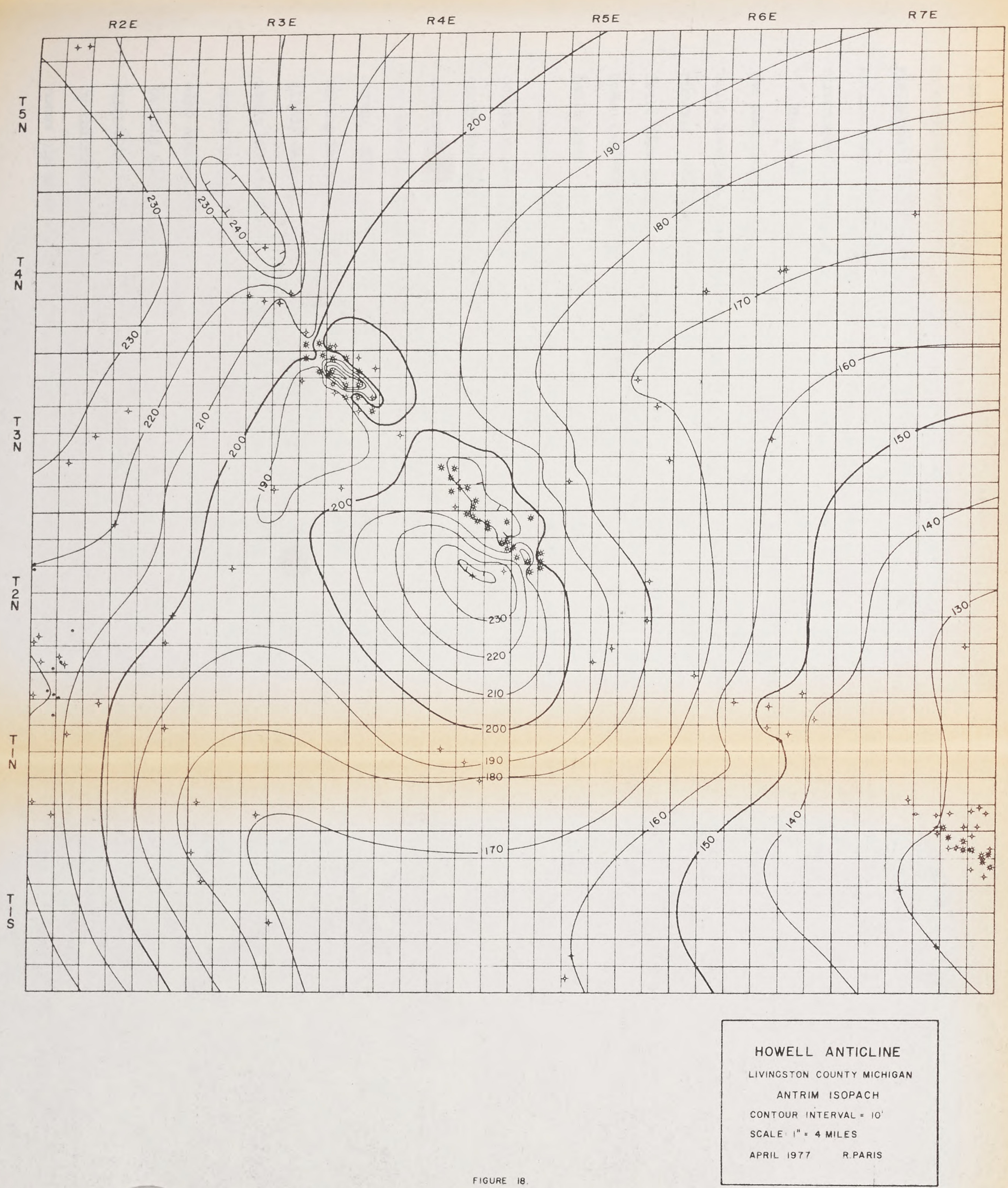
It is also possible, in the Howell area, that the irregularity of the Dundee surface is in part a reflection of flowage and removal of Salina and Detroit River evaporites. This suggestion is arrived at by examining the location and trend of irregularities on the Dundee surface across the separate fields. The thickest Bell in the Howell area, SE section 7 T2N R5E (Fig. 17), coincides with the large Dundee depression (Fig. 11), and the thin Salina interval (Fig. 13). That these should all coincide favors the thought that removal of the Salina salts is responsible for the relief of the Dundee surface in this area.

The thin area along the Fowlerville Field (Fig. 17) coincides with the thinning of the Dundee to Salina G interval, and with the tilted block on the Dundee structure. This could be a thin block or sliver which has responded independantly to a gentle compressive force which has halted the subsidence of the main northern block. The response of this sliver has been a gentle pre-Bell uplift with a subsequent thinning of the Bell along this block. The evaporites of the Detroit River Group could then have responded by flowing away from this zone of deformation with the resulting thin that is seen in this interval. Leaching and flowage of the evaporites of the Salina and Detroit River Groups can partially account for irregularities on the Dundee surface, which are in turn reflected on the Bell isopach map as irregular patterns of thick and thins.

Antrim:

The Antrim shale (Fig. 18) shows general thickening towards the northwest. This unit is a thick dark grey to black shale. It is very carbonaceous, heavily pyritized and radioactive. A shallow stagnent environment would produce the stagnent waters and reducing conditions which must have prevailed during deposition of the Antrim. Near the southeast corner of the map the Antrim subcrops beneath the glacial cover. Along the strike of the Howell fault the unit varies in thickness, again perhaps a matter of more well control.

If the fault zone was in motion as early as Dundee or Bell time it can be assumed that this motion was continued, though perhaps episodically, throughout deposition of the Traverse and Antrim. Cohee



R2E
R3E
R4E
R5E
R6E
R7E
T5N
T4N
T3N
T2N
T1N
T1S
200
190
180
170
160
150
140
130
230
240
220
210
HOWELL ANTICLINE
LIVINGSTON COUNTY MICHIGAN
ANTRIM ISOPACH
CONTOUR INTERVAL = 10'
SCALE 1" = 4 MILES
APRIL 1977 R.PARIS

FIGURE 18.

(1947) suggests that there was motion along the major structural trends as early as Traverse time. The thin along the crest of the Fowlerville Field could indicate that this portion of the fault was high during Antrim time. The area in Green Oak township was also slightly high, structurally, at this time.

The Howell Field is surrounded by a thicker deposit of Antrim than the surrounding area. It is quite likely that the early motions of the fault zone were not along a continuous line but were somewhat discontinuous. The Howell area would then have been a low or sag along the fault line which had not yet undergone uplift as the Fowlerville and Green Oak sections had, displaying differential movement along the fault zone.

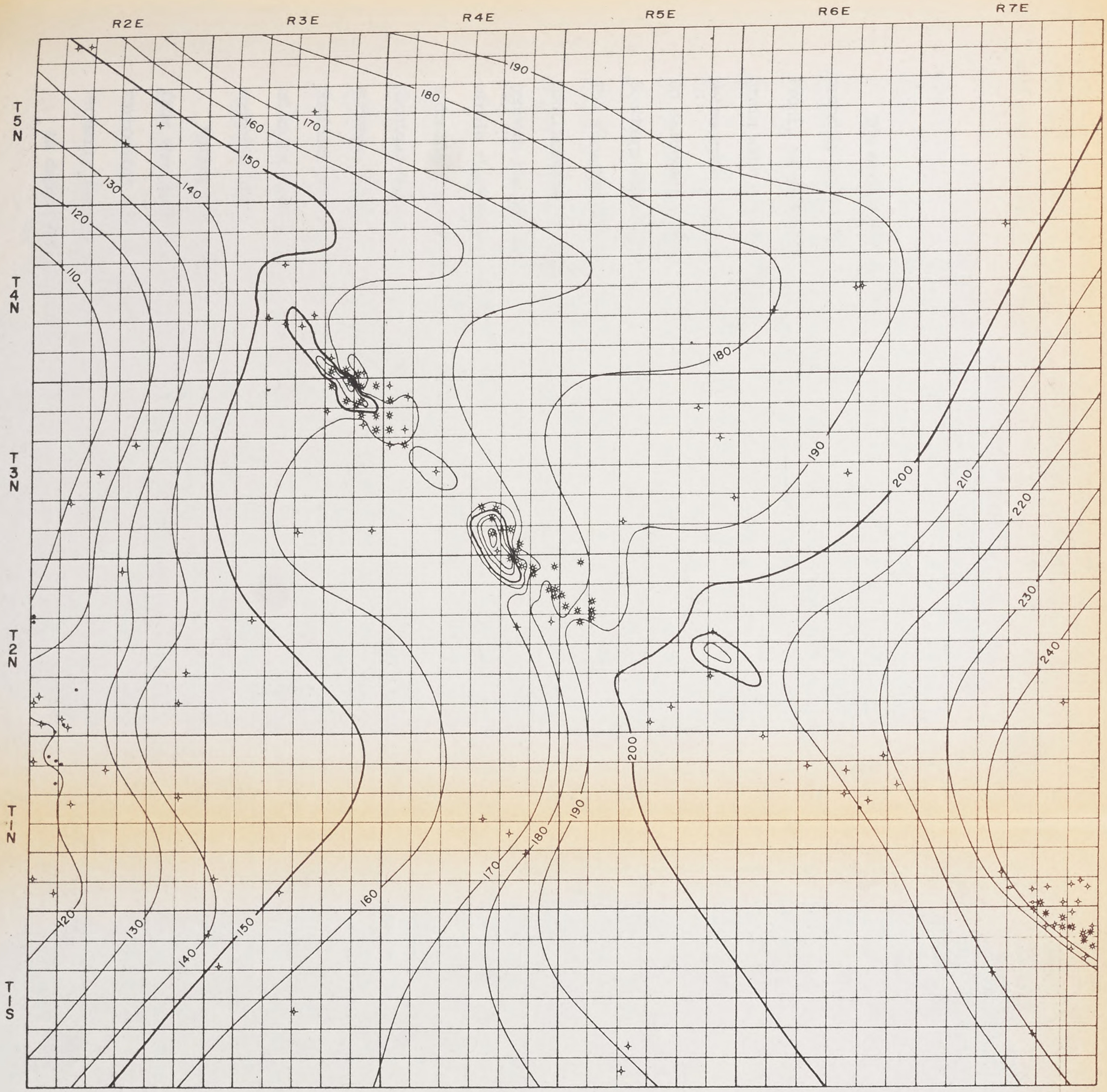
Asseez (1967) shows no strong thinning across the Howell Anticline on his regional Antrim isopach map. The minor relief created by these early movements would not show on a regional map contoured on a larger interval.

Another explanation would be karst development within the Traverse Group. Ells (1969) has suggested that a karst terrain was developed on the Traverse. This might account for the brecciation that Newcombe (1933) describes in the Traverse interval of the Tooley well (although fault brecciation can not be ruled out). Collapse into a cavern would result in brecciation of the overlying material. Karst terrain would also account for the irregular thickening and thinning of the Traverse in this area as noted by Runyan (1976). As the Antrim was deposited upon this irregular surface the karst topography would be reflected by thickening and thinning of the Antrim. Across the area that Runyan notes his most irregular Traverse interval, the overlying Antrim shows a poor matching of Antrim thicks with Traverse thins. As this irregularity of Traverse isopachs is most noticeable along the Howell Anticline, and the overlying deposition patter of the Antrim does not strongly suggest karst development of the Traverse, gentle irregular movement along the fault plane is suggested as the cause of both the Traverse and Antrim irregularities of thickening and thinning.

Berea-Bedford:

This unit (Fig. 19) shows a general thickening to the southeast, though there is a considerable degree of unevenness of deposition. The extreme irregularities across the Howell and Fowlerville Fields are in part the result of increased control. The uneven surface undoubtably extends beyond the field limits but is not observable, owing to sparser control. This unit subcrops in the southeast corner of the map, and is offlapped along the northeast block of the Howell Anticline. The subcropping of this unit introduces some anomalous thinning which was not contoured, as only control points of wells which contained the overlying Sunbury were utilized.

Asseez (1967) terms the Berea-Bedford a prodelta sequence in the Michigan Basin. He notes that this prodelta does not extend beyond the eastern half of the Lower Peninsula. The uneven pattern of deposition and the general lithologies of these units within the area of the Howell Anticline imply a progressive deltaic sequence during this time. The thinning across the Howell and Fowlerville Fields suggests that these areas were low-relief structural highs during deposition of the Berea-Bedford sequence.



HOWELL ANTICLINE

LIVINGSTON COUNTY MICHIGAN

BEREA - BEDFORD ISOPACH

CONTOUR INTERVAL = 10'

SCALE: 1" = 4 MILES

APRIL 1977 R. PARIS

FIGURE 19

SUMMARY OF DEVELOPMENTAL HISTORY

The structural grain of the basement beneath the Michigan Basin is probably quite complex. Western Ontario, in the region of the Grenville Front, is marked by a dominantly northeast-southwest structural grain with a northwest-southeast cross pattern within the igneous and metamorphic complex of the Canadian Shield. The Shield is marked by an east-west pattern east and north of the Upper Penninsula of Michigan. Southern Wisconsin also is marked by an east-west structural pattern. The structural grain in southern Western Ontario is also east-west. Continuation of these structural patterns of the surrounding areas beneath the Michigan Basin would result in a complex structural grain within the basement rocks. Hinze and Merritt (1969) have suggested a dominant northwest-southeast trend within the basement of the Michigan Basin, from interpretation of their gravity and magnetic surveys. They also suggest the Keweenawan age rifting would follow this dominant structural trend of basement weakness, allowing emplacement of thick basalts suggested as the source of the Mid-Michigan gravity and magnetic high.

During the Ordovician, deposition within the Michigan Basin changed from the predominant Cambrian sandstones to a more typical sequence of carbonates and shales. Nurmi (1972) and Seyler (1974), both describe an early form of the Michigan Basin during the Ordovician.

As deposition of the late Silurian Salina Evaporite cycle began, the zones of basement weakness responded to regional tensional forces and gravity by subsidence of fault blocks. Thickening of the Salina Group northeast across Livingston County shows that the Howell Fault was active at this time with the northeast block subsiding thereby responding to the tensional and gravitational forces.

The northeast block remained structurally low throughout the early Devonian with some continued subsidence during Detroit River time. By Bell time there was little or no relief across the Howell Fault marking the end of subsidence. Gentle compressive force is indicated by a small degree of thinning of the Bell Shale implying gentle uplift along the Fowlerville Field. Gentle compression continues to act on this area until at least Coldwater time. These movements which culminated in uplift of the Howell Anticline can be related to early stage or small displacement wrench fault tectonics acting on the basement complex.

The present configuration of the Howell Anticline, as depicted on figures 10 and 11, reflects a pattern of structural features (Fig. 20) which can be attributed to wrench fault mechanics. Release of stress along the Howell Fault has resulted in vertical uplift of the northeast block along the fault zone with little lateral offset.

Harding (1974) describes the Albion-Scipio oil field trend as a pattern which represents a stage of wrench faulting during which slight left-lateral displacement of the basement complex beneath the area has occurred. Prouty (1976a, 1976b) has extended the concept of wrench fault tectonics to apply throughout the Michigan Basin and shows a close correlation between the azimuths of linear oil fields and shear patterns related to compression from a general eastward direction. Thomas (1974)

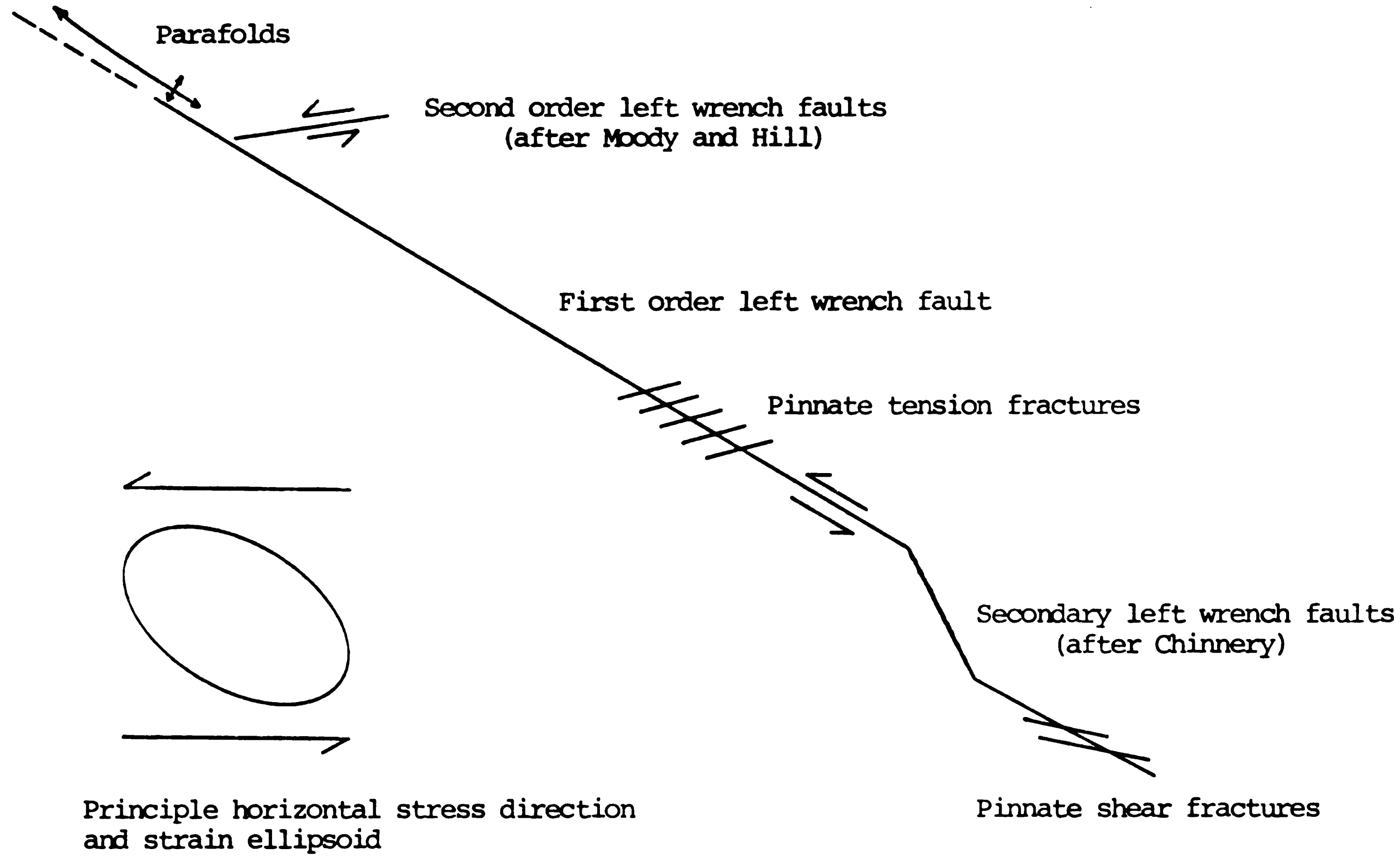


Figure 20. Structural Features Resulting From Simple Shear Wrench Fault Mechanics

in a study of the structural features of the Williston-Blood Creek Basin suggests that this area has been subjected to compressional simple shear mechanics. According to Thomas the basement beneath the Williston-Blood Creek Basin is not an unbroken competant medium, but rather a fairly complexly fractured basement which would divert any applied stress along these basement lines of weakness allowing compressional simple shear block coupling mechanics to predominate.
The Michigan Basin basement also can be expected to have a fairly complex structural pattern as suggested by Stockwell (1965) and Hinze and Merritt (1969). Stockwell describes the structural grain of the Canadian Shield. Hinze and Merritt suggest the structural grain beneath the Michigan Basin.

During the incipient stages (Thomas 1974; Wilcox, et al, 1973) of a left lateral couple, para-folds would develop (Fig. 21a). As the compression continues, the axes will be rotated counterclockwise (clockwise in a right lateral shear couple), toward the direction of the shear couple (Fig. 21b).

With the Albion-Scipio trend to be generally agreed upon as lateral strike-slip movement (Harding, 1974; Fisher, 1969; Ells, 1962), this trend is probably a reflection of deep seated wrench fault tectonics as suggested by Harding. This model, with the modification of being a less intense stage of deformation, can be assumed to apply to the features associated with the Howell Fault system. The offset en echelon anticlines of the Howell, Fowlerville, Northville, and Green Oak Fields have axes which are rotated to nearly parallel the general strike of the basement fracture patterns along which the lateral motion of the wrench zone would occur. Faulting along the southwest side may

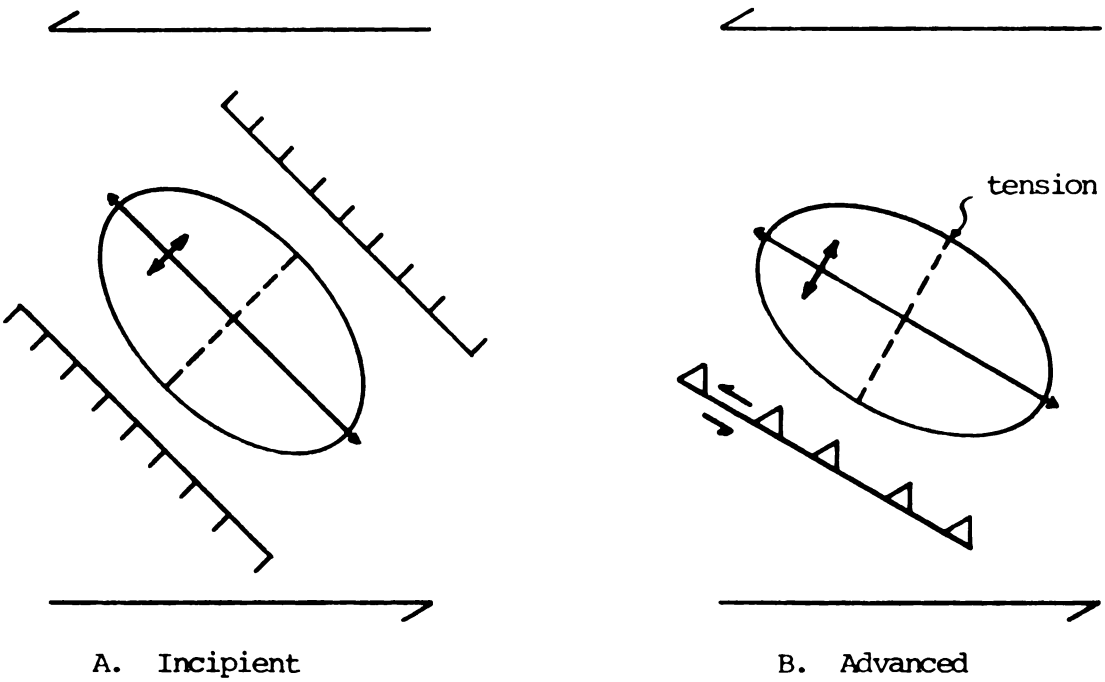


Figure 21. Progression of Axial Plane Rotation During Simple Shear Deformation (after Thomas, 1974)

Lineament simple shear produces block coupling resulting in parafolds with the associated flank faults and cross-fold tension. Incipient and advanced stages apply to degrees of axis rotation, not degree of wrench motion.

have begun as normal faulting with dips to the southwest and continued with eventual uplift of the northeast block during later stages of this deformation. Cross faults, possibly the shear couples, or pinnate tension fractures, would develop at nearly right angles to the fold axis. Ells (1969) drew such a cross fault on his Niagaran structure. This type of feature would provide channel ways for the solution and removal of the Salina salts on the south side of the Howell Field which resulted in the large depression on the Dundee structure. The small anticline located directly northeast of the Howell Field would then be a smaller para-fold along the en echelon trend, without the attendant faulting.

Additional evidence of this being a wrench fault-related system lies with the faulting of the Northville Anticline. Checkley (1968) interprets the Northville as faulted along its northeast flank on both his Niagaran and Trenton structures. With the die out or loss of throw on the Niagara in Green Oak Township being near the location of the pivot point of the fault system, the entire system from Northville Field to Fowlerville Field can be interpreted as a scissor fault.

The wrench fault system has not progressed to the stage of lateral offset of facies in this area. (Harding, 1974, suggested left-lateral offset along the Albion-Scipio wrench fault system.) Kilbourne (1947) does indicate some offset of Coldwater facies but this is based on relatively few wells. Evidence of considerable left-lateral movement is lacking along the Howell Fault. Mesolella, et al, (1974) have an extension of basinward facies of the Salina and Niagaran units into Livingston county near the Howell Fault system. This extension is opposite that which would be expected of any significant left-lateral motion, that is, the marginal facies should be extended basinward as you cross the fault zone to reflect left-lateral motion. The extensive offset as suggested by the Bedrock of Michigan geological map would be better explained as erosional offset along regional dip of the north-eastern uplifted block of the Howell Anticline.

OIL AND GAS PRODUCTION*

Earliest indications of oil and gas associated with the Howell Anticline were reported by Smith in 1834, (in Newcombe, 1933) northwest of the city of Howell. Later in 1893, Lane mentions considerable shows east of Howell. Shows of oil and gas in shallow water wells have been reported since that time to the present. By the early 1930's many Berea and several Dundee tests had been drilled. Only shows were recorded with no commercial quantities of oil or gas. Most of the Berea wells were deep water wells. One well, the Robb, drilled by Norris and Smith in 1928, had gone into the upper Salina beds. This well was drilled in section 26 of Cohoctah Township.

First discovery of significant quantities of gas was in 1935. The Duck Lake Oil Company commenced drilling, on the McPherson farm, NW35 T3N R4E, in September 1934, and completed the well in March 1935. The well was completed open hole with initial production of 478 MCF of gas. The 1930's had a very limited market for natural gas, the primary use being to reinject the gas into oil reservoirs for pressure maintainance, resulting in plugging and abandonment of this well. In October 1946, Panhandle Eastern Pipeline Company completed the McPherson #1 SE35 T3N R4E for 8,000 MCF of gas from the Guelph or Brown Niagara dolomite.

*Production figures are from Annual Statistical Summary 24, Michigan Oil and Gas Fields 1975, published by the DNR Geology Division, November 1976.

Development proceeded rapidly thereafter until 1950 when 16 wells were producing gas and light condensate from the Guelph. Commulative production from the field was 23,678,129 MCF of gas before the field was switched to a gas storage reservoir in 1962.

Production is from the Guelph, the brown dolomite associated with the reef buildups in the northern and southern Niagaran reef play. Ells (1969) suggests the dolomite reservoir might be a low relief reef buildup of Brown Niagara along the crest of the Anticline. This is doubtful as the maximum thickness of Brown Niagara over the Howell Field is 12 feet while the minimum might be 11 feet. Both of these values are within the regional "inter-reef" thickness of Brown Niagara for this area.

Gas and oil have been produced in Northville Field. Production comes from the Dundee, Salina-Niagara, and Trenton-Black River. Discovery of Northville was in November 1947 when the Heath #1 Dugan was completed as a Dundee gas well. Taggart completed the Kehrl in December 1954 to open production of the Salina-Niagara. Earlier, in January, 1954, Taggart had completed the LeMaster well beginning production of the Trenton-Black River reservoir.

Production from the Dundee was not significant enough to tabulate but came from 4 wells offset from the deeper production. The Salina-Niagara produces 3,794,518 MCF of gas with small amounts of oil from 10 wells. Trenton-Black River production has been the most prolific in Northville yielding 1,075,702 barrels of oil and 14,332,358 MCF of gas from 50 wells.

In 1945 Shell drilled the Wilkinson, SW36 T4N R3E, as a Niagaran test hole. This well was plugged after shows of gas from the

Salina-Niagara and test flows of 280 MCF and 179 MCF of gas and shows of oil from the Dundee. It is interesting to note that this well was drilled on the Dundee crest and just off of the Niagara crest. Humble then drilled the Soule Unit #1, NE2 T3N R3E, to record the discovery of the Fowlerville Field in August, 1961. Fowlerville produces from the Salina A-1 Carbonate and the Brown Niagara. A total of 18 wells have produced 1,419 barrels of oil and 1,848,503 MCF of gas. The majority, 1,360,565 MCF of gas and all oil being produced in 1975 after Michigan Consolidated Gas Company acquired the field as a shut-in gas reservoir awaiting commercial line tie-ins.

Texaco is credited with discovery of the Green Oak Field after completing the Kish #1, SW14 T1N R6E, in November, 1967, for 15 barrels of oil per day from the Trenton-Black River dolomites. Shows of gas were reported from the Dundee and Niagara, and a show of oil were reported from the Dundee. This one well field produced 2,836 barrels of oil before being abandoned in 1970.

Checkley (1968) notes that the Dundee production in the Northville Field is offset to the production from the deeper zones. It is possible that this production is from the crest of the Dundee structure which is offset to the deeper structures. This pattern of structural offset is not inconsistant, as over both the Fowlerville and Howell Fields the Dundee anticlinal crest is to the northeast of the Niagaran anticlinal crest. It is from this pattern of structural offset that the writer has interpreted the dip of the Howell Fault system to be to the southwest near Howell and Fowlerville (Figs. 6 and 7).

Hydrocarbon reservoir potential of the Howell Anticline was greatly enhanced by the faulting which accompanied the folding of the Anticline.

Porosity and permeability of the Trenton and Niagaran production horizons is rather well limited to the fault zone. Away from the fault zone both Trenton and Niagaran reservoir rocks grade to a dense, tight carbonate. Toward the fault zone porosity and permeability increase becoming intercrystalline to pinhole porosity to occasional vuggy porosity. Intercrystalline and interconnections of porosity give rise to good permeabilities. This reservoir quality, good porosity and permeability, probably developed in response to stress applied during faulting. Pressures associated with the faulting most likely crushed or fractured the normally dense carbonates, formational waters, or artesian waters as suggested by Newhart (1976) and Runyon (1976), could then enhance porosity while percolating along these fractures developing pinhole and vuggy porosity.

Source material for the Trenton-Black River production could be the Utica shale. While this shale is stratigraphically higher than the Trenton reservoir, it is structurally lower near the fault zone. Migration of hydrocarbons could take place along the fault zone to become entrapped in the Trenton reservoir (Fig. 22).

Another source could well be the Trenton itself or the Black-River Shale zone. The Trenton-Black River sequence has several organic rich intervals which could act as source for the hydrocarbons (Ells, 1962).

A source for the Niagara production is somewhat harder to locate. The upper Cincinnatian is a good candidate being a thick shale sequence. Migration upward of hydrocarbons along the fault zone would be halted by the A-1 Evaporite which would be less likely to fracture and more likely to flow during deformation. A closer and more likely source is the structurally low A-1 Carbonate on the down thrown block

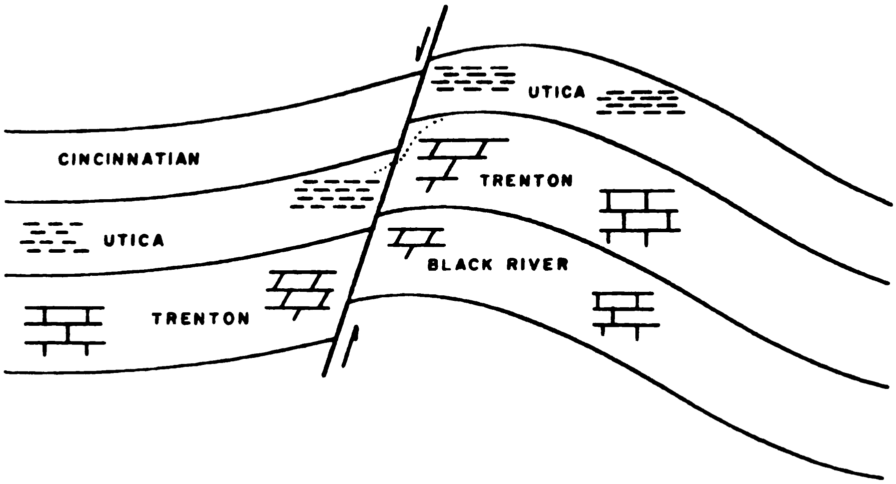


Figure 22: Possible migration of hydrocarbons from stratigraphically lower Utica to structurally higher Trenton along a fault plane.

of the fault. The A-1 Carbonate is a very organically rich unit, so much so that the algal laminations of this unit have led it to be termed the "poker chip shale". During compaction the associated heat and pressures would undoubtably be sufficient to generate hydrocarbons. Gas and light condensate could migrate upward along the fault zone and become entrapped in the Niagara dolomite along the upthrown side. The B-Salt of the down thrown block against the A-2 Evaporite (Fig. 6) would act as a barrier to further upward migration and eventual loss of the hydrocarbons from the Niagara horizon.

The production of light condensate in the Niagaran and Salina A-1 Carbonate in the Howell area indicates that the maturation of hydrocarbons has not progressed to the dry gas stage. In fact it indicates that the shallow basin rim production is of early stage development of hydrocarbons. The central basin region should have potential for deeper production of Silurian age hydrocarbons. The association of high pressure gas, the Gulf-Bateson well drilled in Kawkawlin Field, Bay County, and the deeper development of Akron Field, Tuscola County, with Salina A-1 or Niagaran reservoirs within the central Michigan Basin region demonstrate this potential for deeper hydrocarbon production in this region. The development of central Basin reservoirs should follow a pattern of wrench fault mechanics responding to simple shear stresses acting upon the basement as modeled after development of the Howell Anticline.

CONCLUSIONS

Since Newcombe first described the Howell-Owosso Anticline as a faulted structure there has been debate as to whether this feature is a faulted anticline or a steeply dipping asymmetrical anticline. The evidence available to this study indicated that the Howell Anticline is a series of en echelon anticlines faulted along the southwest flank. This fault zone is part of the same system as the Northville Anticline which is faulted along its northeast flank. Together the Howell Fault zone and the Northville Anticline are a system of faulted parafolds developed in relation to compressional simple shear wrench fault mechanics acting on basement lines of weakness beneath this area as stress is applied from the east during the oncoming Appalachian Orogeny of Mississippian time.

This same compressional stress is responsible for developing the reservoir qualities of the Howell Anticline. Fracturing along the fault zone of the normally dense tight carbonates during compression developed the porosity and permeability necessary for the accumulation and subsequent economic removal of stored hydrocarbons.

It seems reasonable to extend this model of wrench fault mechanics into the central Michigan Basin Area. The many northwest-southeast trending anticlines would occur along minor zones of basement weakness whereas the Howell Fault zone developed along a major zone of basement weakness.

The Howell Anticline has not always been a structural high. During the late Silurian the northeast block was downfaulted in response to regional tensional forces and gravity. This area remained structurally low until it underwent uplift during the Mississippian.

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APPENDIX

APPENDIX

LIST OF WELLS USED FOR ISOPACH AND STRUCTURE CONTOUR MAPS

<u>Legend</u>

PN	Permit Number
S	Sunbury
B-B	Berea-Bedford
A	Antrim
T	Traverse
B	Bell
D	Dundee
G	Salina G
N	Niagara - in area of Pinnacle Reef A-1 Carbonate and Niagara are grouped together as an undifferentiated carbonate
CL	Clinton
5-T	Upper Cincinnatian - Unit 5 - top
5-B	Upper Cincinnatian - Unit 5 - base
*	Well not logged

LOCATION	PN	DATUM	S	B-B	A	T	B	D	G	N	CL	5-T	5-B
NE SW SW 6-1S-3E	28620	960 KB	922	935	1075	1254	1492	1527	2370	2992	3486	3646	3700
SW SW SE 7-1S-3E	19384	939 RT	883	892	1046	1228	1452	1491	2329	2163	3408	----	----
SW SW NW 22-1S-3E	24161	961 KB	930	944	1108	1280	1501	1540	2397	3156	3454	3598	3637
NE NE SW 28-1S-5E	29964	959 KB	863	873	1064	1224	1435	1469	2294	3079	----	----	----
SE SW NW 33-1S-5E	19371	952 KB	825	838	1022	1184	1388	1422	2320	2975	3387	3533	3579
*NW SE SE 1-1S-7E	18796	963 RB	----	----	350	440	----	707	1715	3326	----	----	----
NW SE SW 1-1S-7E	18912	969 GL	----	250	396	450	661	709	1647	3110	3264	----	----
NW NW SW 1-1S-7E	18968	973 GL	----	----	412	455	678	721	1683	3176	3327	----	----
NE NW SW 1-1S-7E	19240	974 GL	----	----	396	452	671	715	1713	3253	3405	3539	3571
SE SW SE 1-1S-7E	25536	970 KB	----	----	358	430	650	693	1688	3238	3393	3548	3587
SE NE NW 1-1S-7E	25622	985 KB	----	----	381	457	677	720	1738	3329	3485	----	----
SW NE NW 2-1S-7E	19200	994 GL	----	----	466	590	808	852	1785	3243	3377	----	----
NE SE NE 2-1S-7E	19235	984 GL	----	----	354	458	691	735	1767	3361	3517	----	----
NE NW SE 2-1S-7E	19274	983	----	----	----	----	744	788	1692	3125	3279	----	----
SE NE SE 2-1S-7E	25650	982 KB	----	----	436	510	716	759	1655	3082	3231	----	----
NE NW SW 2-1S-7E	25759	996 KB	429	446	676	802	1006	1050	1930	3421	3581	----	----
NE NE NE 3-1S-7E	23743	1040 KB	400	416	653	778	995	1038	1956	3464	3610	3768	3816
W½ NW NE 12-1S-7E	18841	935 GL	----	309	352	415	622	662	1581	2999	----	----	----
NW SE NE 12-1S-7E	19061	935 GL	----	188	342	415	622	664	1562	2992	----	----	----
NE SE NE 12-1S-7E	19166	936 GL	----	----	340	397	610	652	1575	3009	3148	----	----
*SW NW NE 16-1S-7E	10141	915	----	596	775	905	----	1143	1941	3379	----	----	----
*NE SE NE 27-1S-7E	10792	886	420	440	660	790	----	1009	1795	3200	3354	----	----
SW SW SW 5-1N-2E	29973	964 KB	1727	1739	1861	2088	2334	2369	3157	3911	----	----	----
SE NW SE 6-1N-2E	28858	971 KB	1751	1763	1885	2114	2365	2401	3178	3958	4422	----	----
NE SE SE 6-1N-2E	29747	976 KB	1744	1756	1877	2093	2352	2387	3175	3920	----	----	----
NE SW SW 6-1N-2E	30592	956 KB	1740	1752	1871	2089	2349	2384	3162	3951	----	----	----
NE NE SE 7-1N-2E	29748	967 KB	1720	1735	1853	2067	2320	2361	3104	3897	4362	----	----
NW NE 9-1N-2E	28913	967 KB	1714	1730	1856	2075	----	2366	3153	4075	4412	----	----
NW NW NW 13-1N-2E	22607	971 RB	1082	1095	1239	1428	1678	1716	2494	3376	3759	----	----
NE SE NW 17-1N-2E	29415	966 KB	1710	1721	1845	2054	2313	2349	3092	3953	4329	----	----
*N½ SW SW 30-1N-2E	30091	952 KB	1692	1704	1817	2029	----	2314	----	3753	4205	----	----
SE NE 31-1N-2E	24470	944 KB	1672	1684	1798	2014	2261	2295	3065	3711	4167	----	----
*SW SE SW 30-1N-3E	22273	939 RF	945	956	1087	1303	----	1558	----	3148	3573	----	----

LOCATION	PN	DATUM	S	B-B	A	T	B	D	G	N	CL	5-T	5-B
*NW SW NE 33-1N-3E	16636	910	983	994	1146	1330	----	1604	2716	3212	3622	----	----
*SE SE SW 15-1N-4E	23074	915 RF	1236	1246	1425	1617	----	1871	----	3798	4022	----	----
*SW SE NW 23-1N-4E	23073	907 RF	1186	1197	1362	1556	----	1817	2650	3768	----	----	----
*NE NE NE 26-1N-4E	23624	888 RF	1130	1143	1323	1499	----	1764	2576	3683	----	----	----
*NE SE SE 2-1N-6E	19793	930 RB	----	----	472	618	926	948	2980	3823	3987	----	----
*SW NE NE 6-1N-6E	15875	928 RB	190	215	400	550	----	875	2205	3798	----	----	----
*SW NE NW 9-1N-6E	17719	908 RB	----	----	477	520	770	823	2115	3760	----	----	----
NE SW NE 10-1N-6E	25801	916 KB	----	268	328	472	749	796	2228	3766	3934	----	----
*NW SE SW 12-1N-6E	19052	928	----	250	352	491	----	814	2218	3755	3938	----	----
NE SE NW 14-1N-6E	24771	929 KB	----	----	344	491	735	782	2056	3676	3852	4014	4075
SW NW SW 14-1N-6E	26999	936 KB	370	390	600	750	995	1048	2172	3646	3800	----	----
NW NE 15-1N-6E	27720	910 KB	----	203	362	505	748	794	2046	3686	3797	3962	4023
*NW SE SE 28-1N-7E	19506	973	----	303	410	546	----	832	1938	3610	3708	----	----
NW SW NW 34-1N-7E	22681	963 GL	385	401	640	776	1003	1047	2024	3573	3717	----	----
SE SE 34-1N-7E	19411	1043 GL	422	438	590	718	947	991	1944	3428	3545	3545	3600
SW NE SE 34-1N-7E	23278	1006 KB	----	----	----	----	870	918	1923	3457	3598	----	----
*NW SE SE 35-1N-7E	19055	1020	----	----	433	524	----	791	----	3541	3670	----	----
*NW SE NW 35-1N-7E	19114	1015 RF	----	----	385	574	----	802	----	3585	3733	----	----
SW SW 35-1N-7E	20274	1029 GL	----	----	474	598	828	872	1847	3399	3536	3677	3720
*NE NE NW 36-1N-7E	19139	994 RB	----	----	365	475	----	760	----	3550	3710	----	----
*SW NW NW 36-1N-7E	19140	996 RB	----	----	350	490	----	762	----	3575	----	----	----
*NE SW NE 36-1N-7E	19236	983 RF	----	----	----	490	----	755	----	3595	----	----	----
*NE SW NW 36-1N-7E	19437	990 RB	----	----	380	460	----	730	----	3570	----	----	----
S½ SW NW 3-2N-2E	30134	944 KB	1827	1839	1968	2188	2470	2501	3319	4434	4471	----	----
SW SW SW 7-2N-2E	29338	935 KB	1818	1839	1946	2170	2446	2485	----	4172	----	----	----
*NW NW NW 18-2N-2E	29334	965 KB	1850	1863	1977	2214	----	2520	----	4251	----	----	----
SE SW 24-2N-2E	30247	945 KB	1268	1280	1427	1627	1892	1928	2745	3750	----	----	----
SW SW SW 25-2N-2E	30288	970 KB	1173	1186	1332	1528	1787	1825	2609	3487	3920	----	----
S½ SW NE 29-2N-2E	29554	943 KB	1768	1782	1908	2122	2390	2427	3191	4068	4545	----	----
*SW SE SW 30-2N-2E	29721	972 KB	1797	1810	1928	2146	----	2450	----	----	----	----	----
*W½ NE SW 30-2N-2E	30006	960 KB	1786	1792	1919	2132	----	2438	----	4045	----	----	----
*N½ SE SE 31-2N-2E	29727	970 KB	1754	1767	1887	2104	----	2403	----	3979	----	----	----
NE NE SW 31-2N-2E	30737	970 KB	1779	1792	1814	2143	----	2433	3204	4120	----	----	----
E½ NW SW 32-2N-2E	29158	963 KB	1748	1761	1885	2100	----	2407	----	3959	4475	----	----

LOCATION	PN	DATUM	S	B-B	A	T	B	D	G	N	CL	5-T	5-B
SW SW NW 32-2N-2E	29297	975 KB	1773	1787	1911	2128	——	2430	——	3991	——	——	——
SW NE SW 32-2N-2E	29306	969 KB	1157	1769	1893	2111	——	2412	——	4006	——	——	——
NW NW NE 17-2N-3E	28752	960 KB	1319	1331	1480	1676	1939	1979	2759	4052	4251	4414	4451
SW SW NW 1-2N-4E	26101	901 GL	134	147	308	522	792	836	2167	3806	——	——	——
NW SW 1-2N-4E	26099	930 GL	156	169	344	543	819	859	2195	3838	——	——	——
N SE NE 1-2N-4E	26819	916 GL	113	122	300	510	796	842	2237	3872	——	——	——
SW SE NE 1-2N-4E	26820	913 GL	125	134	315	530	816	862	2225	3859	——	——	——
S½ NE 2-2N-4E	26817	103 GL	254	264	415	611	838	885	2178	3809	——	——	——
SW NW NE 2-2N-4E	26096	900 GL	230	244	403	622	831	864	2183	3809	——	——	——
NW NE NW 2-2N-4E	26116	941 GL	258	271	400	597	857	906	2253	3867	——	——	——
NE NE 12-2N-4E	26102	916 GL	168	175	353	557	983	1037	2423	3823	——	——	——
SE NE 12-2N-4E	26109	919 GL	183	196	373	578	1095	1152	2590	3824	——	——	——
SE NW NE 12-2N-4E	16067	935	197	208	395	614	1025	1085	2513	3825	4013	——	——
* NE 13-2N-4E	18974	970 RF	870	883	1066	1304	——	1758	——	4104	4418	——	——
SW SW NE 14-2N-4E	25868	938 KB	1374	1390	1560	1774	2092	2139	2998	4337	4519	4682	4743
SE SW NE 6-2N-5E	26758	978 GL	229	241	419	623	911	960	2337	3989	——	——	——
NW SW NW 7-2N-5E	26807	913 GL	166	179	353	572	1020	1076	2458	3843	——	——	——
SE NW SW 7-2N-5E	13287	924 DF	210	223	398	614	1255	1314	2808	3855	——	——	——
SW SE 7-2N-5E	26107	918 GL	236	250	435	656	1374	1443	2937	3879	——	——	——
NW SW 8-2N-5E	26111	960 GL	295	307	492	684	1056	1106	2472	3992	——	——	——
SW SW 8-2N-5E	26095	941 GL	242	255	444	636	1102	1152	2563	3953	——	——	——
*SE NW SW 13-2N-5E	15389	1000	340	350	550	733	——	1082	——	4134	——	——	——
NW NW 17-2N-5E	26108	926 GL	225	238	426	630	1131	1135	2612	3927	——	——	——
NE 18-2N-5E	26106	924 GL	232	245	439	644	1233	1288	2716	3928	——	——	——
*W½ NW NW 25-2N-5E	11818	968	223	235	440	621	907	954	2255	3989	4168	——	——
*SW NW SW 34-2N-5E	1344	940	1088	1105	1285	1430	1705	1750	——	4060	4231	——	——
*SW NE NE 34-2N-5E	14120	1015	1040	1055	1240	1425	1640	1750	——	4294	——	——	——
NE NE NE 35-2N-7E	21298	978 KB	364	384	630	756	1010	1064	2192	3898	——	——	——
SW NW NE 15-3N-2E	28739	905 KB	1894	1908	2030	2256	2552	2595	3888	4831	5002	——	——
NE NE NW 21-3N-2E	27910	928 KB	1893	1906	2022	2246	2543	2584	3713	4766	4954	——	——
N½ NE NW 29-3N-2E	28145	931 KB	1885	1897	2008	2236	2523	2563	3584	4699	4903	——	——
NW 1-3N-3E	23727	936 KB	250	263	435	632	929	977	2173	3833	——	——	——
SW 1-3N-3E	28117	926 KB	616	630	766	922	1190	1232	2032	3783	3912	——	——

LOCATION	PN	DATUM	S	B-B	A	T	B	D	G	N	CL	5-T	5-B
NW SW SW 1-3N-3E	29051	920 KB	610	622	765	936	1196	1243	2270	3807	3955	4140	4193
NE NE 2-3N-3E	23374	939 KB	334	348	475	675	942	988	2188	3823	3954	4108	4157
SE 2-3N-3E	28283	928 KB	577	589	729	918	1214	1263	2359	3736	----	----	----
NW 2-3N-3E	28524	929 KB	642	652	811	1011	1301	1346	2498	3867	----	----	----
*W½ NW NW 11-3N-3E	10990	920	1343	1356	1518	1730	2012	2060	2980	4632	4770	----	----
NE 12-3N-3E	28209	924 KB	606	619	772	939	1234	1274	2267	3803	----	----	----
*NW NE SW 12-3N-3E	29339	921 KB	903	924	1086	1269	----	1632	----	4323	4460	----	----
NW 12-3N-3E	28308	931 KB	639	652	810	1012	1307	1354	2485	3929	----	----	----
SE 12-3N-3E	28405	921 KB	701	716	871	1070	1369	1418	2558	3947	----	----	----
NW NW 34-3N-3E	29675	922 KB	1308	1321	1485	1673	1944	1987	2841	4272	4430	----	----
*SE NW NE 36-3N-3E	19063	904	1480	1502	1648	1845	----	2160	----	4471	4642	----	----
SW NE SE 6-3N-4E	15561	941 KB	292	309	465	695	866	1044	----	----	----	----	----
SW 6-3N-4E	28949	912 GL	240	255	418	622	936	985	2259	4007	----	----	----
NW 6-3N-4E	28950	932 KB	274	286	451	660	970	1022	2305	4073	----	----	----
SW 7-3N-4E	28440	921 KB	698	712	812	1018	1310	1358	2469	3948	----	----	----
NW 7-3N-4E	28461	923 KB	477	489	559	724	1029	1071	2286	3993	----	----	----
SE 7-3N-4E	29296	928 KB	460	472	601	786	1009	1057	2376	4050	4185	----	----
NE 18-3N-4E	28482	928 KB	660	676	837	1043	1333	1383	2436	4027	----	----	----
NW 18-3N-4E	28556	921 KB	890	910	1071	1269	1564	1611	2270	4100	----	----	----
*SW NE NE 20-3N-4E	28594	970 KB	583	605	760	957	1206	1243	2472	4132	4274	----	----
SE NE 27-3N-4E	26816	895 GL	----	----	290	508	798	846	2249	3955	----	----	----
NW SE SE 27-3N-4E	26759	882 GL	76	88	268	478	778	820	2219	3888	----	----	----
NW SE NW 27-3N-4E	26815	881 GL	104	118	284	490	788	835	2231	4042	----	----	----
NE NW NE 34-3N-4E	26775	884 GL	262	285	403	539	810	856	2241	3865	----	----	----
*NE SE SE 34-3N-4E	13877	912	289	302	478	650	----	988	1985	3883	----	----	----
NW SW SE 35-3N-4E	12603	948 KB	----	----	287	495	796	843	2244	3895	----	----	----
NE NE NW 35-3N-4E	2179	915 GL	119	135	290	506	799	842	2250	3931	----	----	----
*SW NW NW 35-3N-5E	14846	921	110	135	295	505	----	840	----	3891	----	----	----
NE NW SE 35-3N-4E	26760	937 GL	127	140	313	528	812	859	2243	3887	----	----	----
NE NW NE 11-3N-5E	27986	980 KB	523	536	724	892	1199	1253	2554	4361	4483	4647	4705
E½ NE NW 13-3N-5E	30033	957 KB	486	499	683	855	1160	1213	2514	4296	4420	----	----
NE NE 25-3N-5E	27034	1003 KB	579	593	779	953	1271	1324	2680	4407	4547	----	----
SW SW 28-3N-5E	22853	974 KB	343	356	545	726	1042	1095	2438	4158	4296	----	----
SW NE 22-3N-6E	24029	951 KB	628	643	836	996	1305	1359	2574	4407	4541	----	----

LOCATION	PN	DATUM	S	B-B	A	T	B	D	G	N	CL	5-T	5-B
*SE NW NE 16-4N-3E	19848	912 RB	635	648	801	1047	1352	1406	----	4386	4509	----	----
SW SW SW 21-4N-3E	26623	915 KB	1360	1374	1527	1741	2057	2103	3215	4935	5079	5278	5346
NE SW SW 22-4N-3E	29089	940 KB	490	504	660	881	1208	1258	2512	4247	----	----	----
N½ S½ NW 27-4N-3E	28255	932 KB	645	660	805	1014	1264	1296	2448	4152	----	----	----
NE NW NE 28-4N-3E	22642	900 KB	860	875	1030	1207	1519	1564	2759	4164	4294	4467	4527
SW 35-4N-3E	28499	921 GL	710	726	873	1072	1313	1351	2120	3889	----	----	----
NW 35-3N-3E	24324	906 KB	345	358	513	729	1045	1094	2329	4059	4184	----	----
SE 35-4N-3E	28128	937 KB	267	280	448	642	937	983	2221	3887	----	----	----
NE SW SW 36-4N-3E	29021	945 KB	239	252	426	629	931	978	2217	3907	----	----	----
*NW SE SW 36-4N-3E	11737	937	235	245	420	647	928	1004	2230	3919	4060	----	----
SE SW SW 20-4N-6E	22995	945 KB	779	794	974	1146	1474	1530	2812	4722	4818	----	----
SE NE NE 22-4N-6E	23426	1062 KB	1005	1023	1206	1377	1698	1754	2994	4876	----	----	----
NW NW NW 23-4N-6E	23169	1045 KB	1009	1027	1214	1385	1707	1763	3003	4893	5005	----	----
NE NE 9-4N-7E	22665	1004 KB	1113	1129	1326	1498	1802	1858	3073	4905	5023	5194	5236
SE NE 5-5N-2E	22379	856 KB	1322	1336	1492	1718	2050	2098	3155	4945	5037	5227	5304
SE SE NW 5-5N-2E	27907	843 KB	1525	1539	1686	1912	2259	2308	3454	5167	5260	5456	5530
SW SW 22-5N-2E	23376	906 KB	1597	1610	1753	1978	2318	2366	3536	5336	5455	5648	5718
*SW NE NW 23-5N-2E	16738	913 RB	1060	1080	1225	1475	1777	1830	3000	4719	----	----	----
SW SE 15-5N-3E	23375	885 KB	1055	1070	1244	1457	1798	1845	3162	5019	5128	5298	5384